Together or apart: Modelling the inter-agency workings of emergency response multiteam systems

Jane Madeline Stoate

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Abstract

This thesis is concerned with the sub-optimized performance of emergency response systems in the UK. These emergency response systems come together during large scale civil emergencies to try and minimize the consequences of such events, with specific attention paid to protecting human welfare, the environment and the security of the UK. Such systems are comprised of individuals (referred to as agents throughout this thesis) from multiple agencies (i.e. fire service, health services, local authorities, private organizations, science advisors etc.) organized into multiple levels of command (i.e. operational at bronze level, tactical at silver level and strategic at gold level). In numerous past major incidents the emergency response system sub-optimized and did not perform as effectively or efficiently as it could. Inquests into these events have revealed that sub-optimization typically results from breakdowns in communication, collective understanding, coordination and decision making between the different agencies involved in the response. The aim of this thesis was thus to gain a greater understanding into why such sub-optimization occurs in emergency response systems – an organizational design I conceptualize as a multilevel multiteam system. Multiteam systems are a relatively novel concept to the organizational and management literatures, and thus our understanding of the functioning of such designs are currently still limited and worthy of further study.

Computer simulation techniques were utilized within this thesis, specifically a relatively novel simulation technique known as agent-based modelling, in which agents with specific behavioural rules for acting and interacting are modelled with a view to determining the effect on aggregate level outcomes. I empirically tested the effects of theoretically derived generative mechanisms that could explain this system sub-optimization: social identity processes. These processes were isolated from the social identity approach (comprised of both social identity theory and self-categorization theory), which explains how people come to see themselves through their group membership, and interact with others on the basis of these memberships. The approach suggests that individuals have a bias towards favouring people within the same group, whilst treating those from 'out-groups' in a more derogatory fashion, and thus helps explain antagonism in intergroup contexts such as emergency response. Specifically, I considered how the level of commitment agents have to specific categorizations in conjunction with intergroup biases influence system-level communicative outcomes (specifically time taken, propagation and accuracy).

The multilevel multiteam system design adopted in emergency response provides two salient groupings with which agents can categorize themselves that have not been considered in previous research: their originating organizational agencies (e.g. fire service, police service, local authority) and their level of command (e.g. bronze, silver or gold command), referred to in this thesis as horizontal categorizations and vertical categorizations respectively. It was found that high levels of commitment to horizontal categorizations and intergroup biases, both in isolation and in interaction, explain system sub-optimization in terms of communicative outcomes. Counterintuitively, it was also found that if agents had high commitment to their vertical categorization, then this could protect the system from sub-optimizing. The theoretical and practical implications of these findings are discussed including implications for designing interventions to prevent future communication breakdowns.

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Chapter 1: Introduction

The effective response and recovery to large-scale civil emergencies is a clear issue of public concern because of the potential for catastrophic losses to human life and infrastructure (Schaaftal, Johnston and Oser, 2001). The emergency response systems utilized in response come together in an ad-hoc fashion to try and minimize the consequences of such events, with specific attention paid to protecting human welfare, the environment and the security of the UK. Effective response requires the collaborative effort of individuals from multiple agencies (i.e. fire service, health services, local authorities, private organizations, science advisors etc.) organized into multiple levels of command (i.e. operational at bronze level, tactical at silver level and strategic at gold level). These multiple organizational groups must combine and act as a coherent multi-agency group; consulting, agreeing and deciding on key issues as a unit (HM Government, 2010). However, developing inter-agency understanding and coordination is notoriously difficult and is a major challenge to effective emergency response (Auf der Heide, 2006; Kozlowski and Ilgen, 2006; Salmon, Stanton, Jenkins and Walker, 2011). Sub-optimization of the emergency response system caused by issues of cognition, coordination and decision making have all been previously noted as occurring during large-scale incidents, such as the 1987 King's Cross Underground fire (Fennell, 1987), the 1995 Ais Gill Railway incident (Smith and Dowell, 2000), the Fort Worth Tornado in 2000 (McEntire, 2002) and Hurricane Katrina in 2005 (Faruzmand, 2007; Thévenaz and Resodihardjo, 2010).

I argue that system sub-optimization in terms of cognition, coordination and decision making is a result of communication failures throughout the system. Failures in communication between the numerous responding government agencies, volunteers, businesses and humanitarian organizations are repeatedly highlighted as contributing to the escalation of incidents in case study reports and public inquests. For example, in the 2012 inquest into the emergency response to the 1989 Hillsborough incident in which overcrowding of the football stadium led to the deaths of 96 people, it was found that: *"communications between all emergency services were imprecise and inappropriately worded, leading to delay, misunderstanding, and a failure to deploy officers to take control and coordinate the emergency response"* (Hillsborough Independent Panel, 2012, p.12).

Another example is the 7/7 London bombings, in which the 7th July 2005 Review Committee concluded that *"communications within and between the emergency services did not stand up on 7 July"* (Barnes *et al.*, 2006, p.120) and stated that *"we believe that more effective communications between the emergency services in relation to each scene, and overall, could have reduced the duration of the period of uncertainty... and enabled the emergency services more rapidly to put in place a co-ordinated emergency response"* (p.127). From these examples it is clear that communication, both within and between the agencies that comprise the response, is an on-going issue that needs addressing. However, as noted by Bharosa, Lee and Janssen (2010), little empirical research regarding information flows and communication in emergency response settings has been conducted to date, and scholars still lack understanding as to why it is so difficult for emergency response agencies to share and coordinate information.

The aim of this thesis is to offer a new perspective on the generative mechanisms that might contribute to breakdowns in communication within and between the different responding agencies in order to gain insights into why this problem occurs and thus make suggestions as to how it might be resolved. To this end, I specifically focus on a behavioural mechanism found in the literature concerning work groups and teams that I theorise will influence multiteam system functioning, namely, social identity processes. The social identity approach explains how people categorize themselves and others into groups, simplifying the social world into a dichotomy of 'us' and 'them'. These categorizations then influence the way in which an individual thinks and behaves, and significantly, how they interact with those they consider to be 'them'. It has been found that even the smallest degree of identification can lead to intergroup bias (i.e. in-group favouritism and out-group derogation), resulting in reduced communication with individuals outside of the in-group (e.g. Billig, 1973; Billig and Tajfel, 1973; Diehl, 1990; Ellemers, Wilke and van Knippenberg, 1993; Mulling and Hogg, 1998; Tajfel, Billig, Bundy and Flament, 1971; Turner, 1975). Social identity theory and the attendant processes of categorization and bias can therefore help explain some of the system sub-optimization that has been found to occur. However, the multiple overlapping identities available within UK emergency response create further complexities that the current literature on social identity does not encompass and it is therefore unknown exactly how social identity might manifest and influence the functioning of such systems. This presents a gap in the literature that requires exploration.

It is only by studying the complex structures of tightly-coupled teams from multiple agencies as holistic entities (rather than extrapolating from research of its parts) that one can uncover the points of breakdown and fracture that exist within them, and thus the emergency response arrangement is conceptualised as a 'multiteam system' (Mathieu, Marks and Zaccaro, 2001). Multiteam systems are defined by Mathieu *et al.,* (2001) as "two or more teams that interface directly and interdependently in response to environmental contingencies towards the accomplishment of collective goals" (p.290), and the emergency response system in the UK, with its composition of agents from multiple different organizational agencies (e.g. fire service, police, local authority etc.) is a perfect example of this organizational design. For this reason, conceptualizing the emergency response system in this manner can help provide additional traction in trying to understand why the emergency response system sub-optimizes. Empirical work on multiteam systems undertaken outside the confines of the laboratory is infrequent and sparse, and thus this thesis aims to rectify this gap through the study of real-world multiteam systems (i.e. emergency response multiteam systems). However, genuine civil emergencies would present an extremely hazardous setting for field work, posing potential dangers to both the researcher and researched. Given this obvious constraint, I employed a novel alternative method - agent-based modelling and simulation - with a view to gaining insights into how the processual aspects of social identity, specifically categorization and bias, variously facilitate and impede effective system functioning in emergency response settings.

Through the use of computer simulation methods, I have been able to systematically test the relative influences of a multitude of different social identity manifestations that can arise within the unique structure adopted by the UK response to major incidents (conceptualized as a multilevel multiteam system due to the additional breakdown of the response into multiple levels of command) and their influence on system-level communicative outcomes (time taken, propagation and accuracy). I have found that specific component processes of social identity within the emergency response structure can explain significant communicative breakdowns between the different agencies, thus resulting in system sub-optimization. Specifically, if agents categorize themselves as part of their response agency and/or there are strong intergroup biases, system-level communicative outcomes are significantly impaired. Counterintuitively, I also found that one of the other processes of social identity can have a protective quality, in that if agents have high commitment to their level of command categorization (i.e. bronze, silver or gold) then the negative influences of high commitment to one's agency categorization and intergroup biases are prevented.

This work contributes to theory and practice in a number of ways. First, this thesis furthers understanding of system sub-optimization in emergency response. My findings highlight that taking a social identity perspective can indeed help explain breakdowns in communication that have been found to occur in emergency response multiteam systems. This provides a new perspective to the emergency response literature that has not previously been considered, thus augmenting the current debates taking place within this literature stream. Moreover, this suggests emergency response practitioners and practitioners in other organizations adopting similar multiteam system designs should place greater focus on the role social identity plays in restricting their ability to be communicatively efficient and effective.

Second, I contribute to the literature of social identity in general and within multiteam systems specifically in proposing a viable alternative mechanism through which to manage identity. Specifically, I propose that increasing agents' commitment to the vertical grouping with which they categorize themselves can protect the system from sub-optimization. Predominantly, scholars contend that a superordinate or dual identity is required for effective system functioning. However, I argue that such an initiative is likely to be restricted in emergency response systems and have instead shown how the benefits believed to be achieved through these overarching identities can alternatively be achieved through the careful management of team identities. In systems in which a dual or superordinate identity may be too challenging to develop, this thus might present a viable alternative option. The concept that a team-based identity can protect the system from sub-optimization in multi-group settings is novel to the social identity literature. This therefore contributes to the literature in providing further understanding of how it might be possible to prevent social identities from causing sub-optimization and warrants further study.

Third, this thesis highlights the need for scholars to distinguish between different forms of multiteam systems, and to make these design characteristics explicit. In theorising why high commitment to vertical categorizations is found to be beneficial within this thesis, I suggested this could be due to the composition of the system in terms of whether it is comprised of integrative or representative teams. Moreover, I have argued that the reason for divergent findings regarding the influence of social identity in multiteam systems thus far is likely due to the size and compositional complexity of the multiteam systems under study. This suggests that divergent forms of multiteam systems are indeed likely to result in divergent outcomes, and thus might limit the generalizability of multiteam systems studies to only systems comprising similar designs. Additionally, I have developed the concept of a multilevel multiteam system. This design, comprised of a multiteam system with more than one overlapping team network structure, has never previously been considered in multiteam systems research before, and thus presents a contribution to the literature that merits further exploration.

Fourth, this work demonstrates the need to nuance our conception of social identity in future research. I have coined new terms to be used in social identity research in complex multiteam systems; namely, horizontal and vertical categorization. In nuancing social identity in this manner and studying these categorizations as separate concepts, my research has shown how categorization with these different groupings affects system-level outcomes in divergent ways. This illustrates how it is not just the processes of categorization and intergroup biases alone that cause communication issues within systems, but that this is specifically related to the grouping on which these processes are focused and the composition of these groups within the wider system. The breakdown of social identity within this context into such formulations has allowed me to show that even when mechanistically similar, social identity processes do not affect system-level outcomes in uniform ways, and thus taking such a nuanced and more complex view of social identity is important when considering identification research in complex multiteam systems.

Finally, I have utilized a novel methodology for this research, and in so doing, shown its utility for both multiteam systems research generally and emergency response research specifically. In using this methodology, I have been able to consider a contextually-based multiteam system that differs in design from those predominantly studied in multiteam systems research thus far. Most research in multiteam systems to date is conducted using 'scaled world' designs, in which the multieam system is reduced to only two or three teams composed of two members in each. In contrast, agent-based modelling allowed me to consider a system of thirty six agents organised across nine possible component teams. In so doing, I have been able to provide an explanation for some of the conflicting findings that currently exist within the literature and generated further insights into how social identity may manifest in emergency response.

Chapter 2: Literature Review

2.1: Introduction

The effective functioning of emergency response systems is critical to ensuring an efficient and timely response. If the systems set up to help during large-scale civil emergencies sub-optimize, the response can be delayed or even escalate the emergency, leading to increased risks to infrastructure, security and human lives. Understanding what therefore leads to system optimization or sub-optimization in such situations is thus a matter of public interest. Whilst the emergency response literature to date has provided some explanations as to how emergency response systems sub-optimize, normally framed around issues of coordination, collective cognition and decision making, it so far has failed to understand *why* these processes become ineffective, nor provided satisfactory suggestions regarding how we might prevent these issues recurring in future emergency situations. The aim of this research is thus to understand the mechanisms that lead to emergency response system sub-optimization.

I propose that the social identity approach provides a theoretical explanation of how and why sub-optimization might occur within emergency response systems through its influence on between-team communication. However, whilst the social identity approach does provide a likely explanation for the sub-optimization of such systems, it is unclear exactly how social identity might manifest throughout a system of this design, one which I define as a multilevel multiteam system, and exactly what influence this will have on system-level outcomes. This thus requires further study and provides the rationale for this research project.

Within this chapter, I shall first outline case study examples and the current debates in the emergency response literature regarding system sub-optimization. Through this discussion, I shall display how common a problem ineffectual response is during real-world emergencies and touch on how scholars within this field currently understand the problem in terms of issues with cognition, coordination and decision making, which they attribute to structural problems and the level of centralization. It will be argued that this existing debate still fails to provide appropriate explanation of system sub-optimization. I shall then explain how I conceive of the emergency response system as a multilevel multiteam system and outline some of the research conducted in this area into what drives system effectiveness, evidencing how I believe communication to be the process that underpins whether or not a system optimizes. Finally, I shall propose social identity processes as the generative mechanisms that lead to communication breakdown in emergency response settings, but show that little is currently known as to how this might manifest in an emergency response system. This thus provides the rationale for further exploration into how social identity can influence system outcomes, and that in order to do so, one must consider the categorization and intergroup bias processes that generate social identity phenomenon.

Figure 1 has been included to help summarize the variables of interest within this thesis and their relationships to one another. It is presented as a causal path diagram. Only the first two variables (social identity and communication) are explicitly taken forward throughout the rest of the thesis, and the justification for this tighter focus is explained in more detail throughout the literature review.

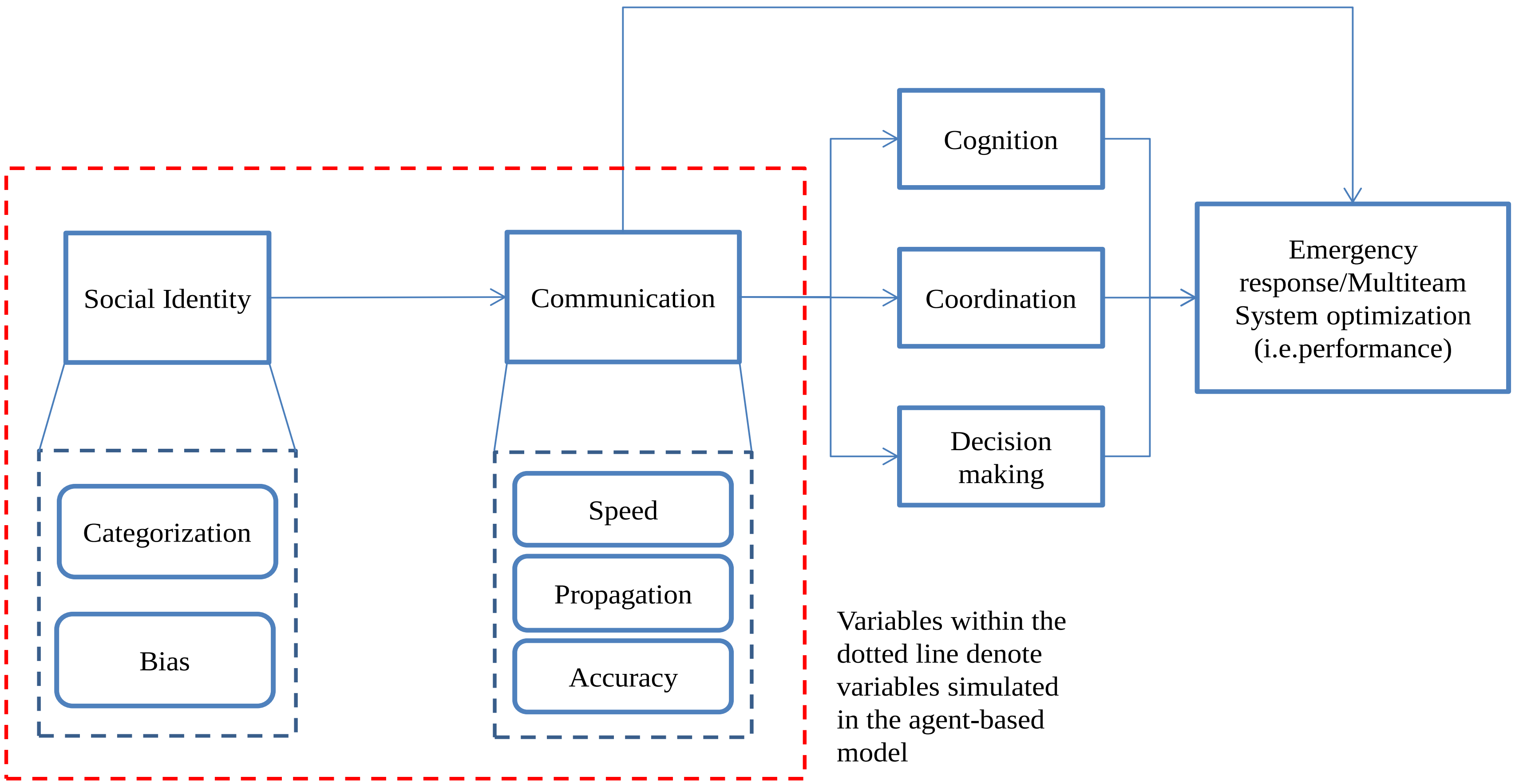


Figure 1: Variables of interest within this thesis and their causal relationship chain

2.2: Emergency Response

The literature on emergency response is characterised by discussions of system sub-optimization caused by breakdowns in inter-agency interoperability. Interoperability is defined by the National Policing Improvement Agency as "the capability of organizations or discrete parts of the same organization to exchange operational information and to use it to inform their decision making" (2009, p.14) and has been deemed to be the key to successful coordination of the multiple responding agencies involved in emergency response (House, Power and Alison, 2014). However, at numerous major incidents the systems responding seem to fail at interoperability, with both case study academic papers (e.g. de Brujin, 2006; Faruzmand, 2007; Fennell, 1987; Jenkins, Salmon, Stanton and Walker, 2010; Jenkins, Salmon, Stanton, Walker and Rafferty, 2011; McEntire, 2002; Smith and Dowell, 2000; Thévenaz and Resodihardjo, 2010) and public inquests (e.g. Barnes, Hamwee, McCartney, Cross and Johnson, 2006; Hillsborough Independent Panel, 2012; HM Coroner, 2011) repeatedly highlighting failures in inter-agency coordination, shared understanding and collaboration between agencies, usually brought about through poor communication. System sub-optimization within emergency response can lead to not only to a delay in the response, but can actually lead to escalation of the incident, and yet it is still a problem that continues to resurface despite the significant amount of research conducted on the topic.

In this section, I shall firstly describe the emergency response structure adopted within the United Kingdom (UK). Following this, I shall explicate some of the issues that have thus far been found within the emergency response literature as preventing interoperability, including a discussion on the main debate within the literature on whether a command and control or coordination model of response is the best format to adopt. It will be demonstrated that our current understanding of emergency response failings still does not fully explain why system sub-optimization occurs. Finally, I shall discuss how the nature of the system means that in order to gain understanding of the issues that are found, the system must be considered as a holistic entity and not collapsed and reduced to an investigation of its individual component parts, thus necessitating the consideration of emergency response as a multiteam system.

2.2.1: The UK Emergency Response Structure

According to the Civil Contingencies Act (2004), an event or situation is termed an ‘emergency’ within the UK when its consequences threaten serious damage to human welfare, the environment, or security (such as in war or terrorist attacks). To constitute an emergency (or what most emergency services term a ‘major incident’), the situation must also pose a considerable challenge for the organizations’ ability to perform normally, such as when the impact of the incident is large in scale or requires exceptional deployment of resources beyond the scope of normal operations. A civil emergency can therefore refer to events such as natural disasters, man-made accidents or acts of terrorism if they pose a threat to life or infrastructure.

Civil protection in the UK is based on the concept of integrated emergency management (IEM); a holistic approach for preparing for and responding to emergencies in a manner that is flexible and adaptable to enable the effective multi-agency response to any incident confronted (HM Government, 2005). ‘Response’ is just one of the 6 key steps that encapsulate the IEM approach (which also includes anticipation, assessment, prevention, preparation and recovery), and yet as it encompasses the decisions and actions taken in the immediate aftermath of an emergency (typically lasting between a matter of hours or days), it is often the most critical aspect to prevent escalation of the incident and minimize the negative consequences. The various agencies involved in the response must manage both the direct effects of the emergency (such as fighting fires or rescuing individuals) and the indirect effects (such as dealing with the media). The responding agencies therefore have a number of common goals that they must work together to achieve. These goals include: saving and protecting human life, relieving suffering, providing advice and information to the public, maintaining or restoring critical activities, protecting property and facilitating investigations and inquiries (HM Government, 2010).

When responding to a civil emergency, coordination between the various responding agencies is critical for ensuring the coherent and integrated response necessary for maximising effectiveness. As each agency retains its own command authority in an emergency, the agencies therefore have a collective responsibility for decision making and implementation. To successfully achieve this, the agencies must rely on a process of discussion and consensus to reach joint decisions and thus enhance coordination. Recognising this, the government has produced a generic national framework that governs the command and control of the situation in a manner that encourages inter-agency liaison and collaboration (HM Government, 2010). In a multi-agency response, the system is structured into at least one of three ascending tiers depending on the scale and nature of the emergency. These tiers consist of the operational level (the 'lowest' tier – known as bronze command), the tactical coordinating group (known as silver command) and the strategic coordinating group (the 'highest' tier – known as gold command) (Pearce and Fortune, 1995).

Bronze command is implemented in any emergency situation and is expected to assess the nature of the problem (to determine whether the circumstances warrant a tactical level of management) and carry out the 'hands-on' work directly at the incident site. If events require greater planning, coordination, or resources than the bronze level is able to provide, then the silver level of management may be evoked to take responsibility and ensure that the bronze commanders have the means, direction and coordination necessary to produce successful outcomes. Silver command's main responsibility is to ensure that the bronze level actions are coordinated to achieve maximum effectiveness and efficiency, and so they will determine priorities for allocating resources, obtain additional resources (if required), plan and coordinate tasks, assess risks and ensure health and safety needs are met. Finally, if the emergency event has an especially significant impact, substantial resource implications, or lasts for an extended duration, it becomes necessary to convene the gold command. The purpose of gold command is twofold: (1) to take overall responsibility for the multi-agency response management, and (2) to consider the emergency in its wider context, providing information, warnings and advice to the public and media, attending to the longer term implications for communities, economies and the environment and planning the recovery operations.

However, even though this structure is explicitly designed to encourage multi-agency communication and a coordinated response, it has been repeatedly suggested that inter-agency coordination does not always occur to a satisfactory level. Instead, the response often suffers from breakdown in communications, misunderstandings, duplication of effort and a fractured response. In the next section, I shall explicate further some of the literature regarding these instances of sub-optimization and the proposed causes of this.

2.2.2: Failures within emergency response

2.2.2.1: Interoperability

Considering the above outlined system, ineffective responses are surprisingly common. As mentioned previously, interoperability between agencies is seen as critical for an effective response, as the inherent scale and trans-boundary nature of response requires the coordination of a number of disparate agencies (Rosenthal, Boin and Comfort, 2001). This is even more critical in emergency response than elsewhere due to the fact that the systems are ‘hastily formed networks’ (Denning, 2006) that are created in the moment and yet must be able to quickly set up shared communication networks in order to mobilize and respond within a high risk environment (House, Power and Alison, 2014). House, Power and Alison (2014) characterised the successful interoperable command system as one that establishes “common operational pictures, clear superordinate goals, a hierarchical organizational structure, task interdependence, collective accountability, trust, and an overall ability to communicate useful and appropriate information across the multi-team network" (p.326). However, they noted that this need for collaboration is especially troublesome during major incidents, especially given the need to communicate and share disparate ideas of the situation as it unfolds and gain a collective understanding of the expertise within the system that can be utilized to produce a coherent and collaborative response.

Many examples of system sub-optimization during emergency response can be found within the literature and they generally all link the issues back to problems of coordination, cognition, decision making and communication. For example, in their analysis of the Stockwell shooting, in which Jean Charles de Menezes, an innocent man, was mistaken for a suicide bomber and shot dead by police just after boarding an underground train at Stockwell Station in July 2005, Jenkins *et al*. (2010) highlighted that a lack of flexibility within the demand structure, mixed with ineffective communications that resulted in disparate understanding between the multiple teams involved in the operation, led to poor decision making and the tragic death of an innocent man. Similarly, in their analysis of the response to the 1995 Ais Gill Railway crash, Smith and Dowell (2000) identified that poor coordination caused by poorly developed and shared mental models (a collective cognitive construct that shall be elucidated in more detail in section *2.3.2.2: Cognition*) and an innate conflict between the distributed decision making (between multiple individuals) expected in emergency response compared to the nature of individual expert decision making (see section *2.3.2.4: Decision making* for further explanation) resulted in significant resource redundancy and a less effective response. Other researchers have also raised these same issues of organization, decision making, communication and cognition as resulting in the ineffective American response to Hurricane Katrina in 2005 (e.g. Comfort, 2007; Farazmand, 2007; Thévenaz and Resodihardjo, 2010) and even for the lack of action on the basis of intelligence regarding the 9/11 terrorist attack in New York in 2001 in which the agencies were "over-fragmented and guilty of not sharing enough information" (de Brujin, 2006, p267).

For some, the endemic nature of these issues within emergency response have led to them to question whether interoperability is even a possibility within the current structure, suggesting instead that it may just be an unrealistic ideal (Groenendaal, Helsloot and Scholtens, 2013; House, Power and Alison, 2014). Such perspectives have led to a major debate within the emergency response literature regarding the organizational nature of the response itself, suggesting that "the barriers to coordination may lie more in the structure of organizations seeking a common approach to action than in any misconstruction of the goal itself" (Comfort, Dunn, Johnson, Skertich and Zagorecki, 2004, p.64). Those involved in the debate question whether the current structure, essentially defined as following the 'command and control' model, is sufficient, or whether a new, more decentralised version of emergency response is required, which some have termed the 'coordination models' (e.g. Comfort *et al*., 2004; Dynes, 1994; Groenendaal, Helsloot and Scholtens, 2013).

2.2.2.2: Command and Control versus Coordination Models

Command and control is defined by the US Department of Defence (2005) as "the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission" (p.40). The current bronze-silver-gold command model, which is reflective of the 'command and control' models utilized in military operations, was adopted in the UK following the urban riots in the 1980's, as it allowed for the easy organization of a large number of responders and centralization of decision making (Pearce and Fortune, 1995). Since then, it has become the standard operating procedure for any civil emergency in the UK, and is used across jurisdictions and response agencies.

Pearce and Fortune (1995) noted a number of benefits to using this standardized response, as it allows for the quick deployment and set up of agencies after an incident without the necessity of pre-planning how the structure should form. The standardization also allows for easy recognition of who the relevant authority and decision making members are, thus reducing possible confusion. Moreover, the centralized structure of decision making authority allows for only a few members to require a full understanding of the response in order to effectively coordinate actions.

The benefits of having a standard operating structure were illustrated during a flight simulation experiment of a command and control environment, as Cooke, Goreman, Duran and Taylor (2007) found that teams with previous experience at command and control performed better, with fewer errors on process-related training knowledge, superior team process ratings, and communications containing fewer coordination-related utterances than teams without such experience. They suggested that having a standard procedure that individuals become familiar with allows for improved cognition of expected interactions, and that this could then be transferred across different tasks. A similar structure is also adopted in the US in terms of their Incident Command System for the same reasons (Bigley and Roberts, 2001; Buck, Trainor and Aguirre, 2006). However, whilst this approach is the preferred structure for practitioners, numerous academics have criticized this mode of working for (a) being inflexible and not dynamic enough, (b) for the heavy information sharing requirements between levels of command and (c) for the fact that it prevents those on the frontline who are likely to have the most accurate understanding of what is occurring from making decisions (e.g. Bain, 1999; Comfort *et al.*, 2004; Comfort, 2007; Groenendaal *et al*., 2013; Helsloot, 2008).

Instead, academics promoting a ‘coordination model’ for response suggest that the system should be self-organized with decentralised decision making capabilities in order to respond more effectively in light of the dynamism and uniqueness of emergency response events (Comfort *et al*., 2004, Jenkins *et al*., 2011; House, Power and Alison, 2014;

Quarantelli, 1988; ‘t Hart, Rosenthal, and Kouzmin, 1993). This decentralization provides greater autonomy to individuals and groups, allowing more flexibility for agents to break away from standard operating procedures and to act in innovative and creative ways; an activity that has been repeatedly reported as necessary for effective functioning in emergency response environments (e.g. Comfort, 2007; Stochowski, Kaplan and Waller, 2009; Turner, 1994; Weick, 1993).

However, whilst the coordination models of organizing might provide more flexibility, it causes issues for coordination (which is central to this model working effectively) as the decentralised nature of decision making makes it difficult to develop a common idea of what is occurring and who is doing what, which can lead to coordination failures (Alonso, Dessein and Matouschek, 2008; Thévenaz and Resodihardjo, 2010). Comfort *et al*. (2004) suggested that agencies would coordinate effectively through a process of mutual adjustment in which participants adjust their actions as they gain understanding of what the other participants are doing through communication. However, in their research on multiteam systems (a subject that shall be revisited in more detail in section *2.3: Multiteam Systems*), Davison, Hollenbeck, Barnes, Sleesman and Ilgen (2012) found that such systems were too large to support mutual adjustment as a viable option, with mutual adjustment between agents at lower levels of the system actually being detrimental for system-level performance.

As has been suggested by Thévenaz and Resodihardjo (2010) and Wise (2006), neither model is exclusively appropriate for all forms of emergency. In essence, the UK system is actually a combination of the two, with a bureaucratic structure that resembles command and control, whilst retaining some flexibility in the way the components are constructed and a certain degree of allowance and ability for improvisation and decision making by agents lower in the system. Bigley and Roberts (2001), in their discussion of the incident command system in the United States of America (a structure that is significantly similar to the bronze-silver-gold structure adopted in the UK), suggested that the system had ‘surprising flexibility’ as long as those individuals within the structure were able to “build and maintain viable understandings of the activity system to which they belong” and attention was given to “developing, communicating and connecting individuals understanding” (p.1290).

Both the command and control and coordination modes of organizing have high requirements for accurate and timely information sharing between groups, whether this is vertically along the hierarchy (i.e. in command and control designs) or horizontally across the different responding teams (i.e. in coordination designs). Although proponents of the coordination model suggest that the communication issues likely to arise within the command and control model will be between the levels of command, causing distorted images of the event to those in charge of decision making (e.g. Jenkins *et al*, 2011), the communication issue often cited within incident reports is actually of breakdowns in communication and coordination between the numerous agencies involved (such as those pronounced in the review of the response to the 7/7 London bombings; see *Chapter 1: Introduction*). This therefore shows that this debate is still failing to suitably explain how and why communication breakdown can occur within emergency response systems.

Whilst the debate regarding the emergency response structure and degree of centralization has instigated much discussion and consideration regarding the nature and cause of system sub-optimization, I argue that the debate misses the central point of considering the between-team processes that manifest through these structures. Arguing along the same lines as Harrald (2006), so long as the system balances the control and clarity gained from hierarchical organization with the ability to improvise and adapt in flight to changing situational characteristics, it will benefit from both order and flexibility. Instead of focusing on the structure utilized itself, I believe a consideration of how such structures influence the social and cognitive processes critical to effective responding is a more pressing issue. As stated by Leonard and Howitt (2010), “it probably makes more sense to harmonize on and practice making this system work that it would to redesign it significantly or adopt a completely new approach" (p.383).Communication breakdowns in either organizational model would lead to dire consequences for system performance due to the inability of agents to generate an accurate and full operating picture of the situation and actions being taken, thus debilitating decision making and coordination. The command and control versus coordination model of organizing debate however fails to present answers as to why such breakdowns are repeatedly found within emergency response, nor ways in which these issues can be prevented.

I believe that there is currently a lack of understanding as to the underlying causal mechanisms that create the latent conditions for disruptions and failures in cognition, coordination, decision making and communication repeatedly identified as pervasively problematic within emergency response. This therefore raises the question: what are the generative mechanisms that facilitate or inhibit between-team processes critical for effective system functioning in emergency response? Within this body of work, I aim to begin to illuminate one such generative mechanism that could explain the system sub-optimization that characterises emergency response: social identity. This mechanism will be explained in more detail in section *2.4: Social identity.* However, in order to understand how any proposed generative mechanism might influence the response structure, it is first important to consider the system holistically.

2.2.3: Considering emergency response as a non-reducible system

When considering behaviour in collaborative environments such as emergency response, it is important to consider the system as a holistic entity itself, rather than focusing on individual components as the unit of analysis. Researchers contend that if such systems are reduced to only a consideration of the parts, rather than as a whole, then emergent properties that arise from the interactions of the levels below will be ignored, and thus much of the complexity would be missed (DeChurch and Zaccaro, 2010; Hutchins, 1995a; Jenkins *et al.*, 2010; Jenkins *et al.*, 2011; Pearce and Fortune, 1995). This is especially important if the emergent states and structures emerge through compilation, in which the higher-level constructs are non-isomorphic with the constructs that created them at the level below (Kozlowski and Klein, 2000). DeChurch and Zaccaro (2010) specifically contend that when systems are made up of multiple interacting teams, such as in the emergency response context, that they should be considered as non-reducible units of analysis. If the teams that comprise the system are considered in isolation, this will result in an overly reductionist approach that overlooks important between-team and across boundary dynamics. They argue that due to the high levels of interdependence, complex motive structures, large size and distributed nature, systems comprised as ‘teams of teams’ should instead be treated as a ‘multiteam system’.

In order to understand why failures in cognition, coordination, decision making and communication are repeatedly found to occur in emergency response, thus resulting in system sub-optimization, I have therefore chosen to consider the UK emergency response system as a ‘multiteam system’. In the next section, I shall firstly explicate what a multiteam system is and how it relates to the emergency response structure. Following this, I shall use the lens of multiteam systems to discuss in more detail the research regarding cognition, coordination, decision making and communication specifically in order to gain a better understanding of how these processes occur and enact within such complex systems.

2.3: Multiteam Systems

Multiteam systems are an increasingly important area for study, with public, private and military organizations progressively employing more team-based work designs to cope with the dynamic, time-pressured, non-routine and multifaceted task domains many organizations now face (DeChurch, Burke, Shuffler, Lyons, Doty and Salas, 2011). The multiteam system is just one of these team-based designs, with their ‘teams of teams’ structure making them particularly suitable for complex environments such as emergency response as it permits both the collaboration of specialists from multiple domains and requisite variety (i.e. holding a repertoire of possible responses that are at least as nuanced as the diverse problems the system faces; Ashby, 1968) (Mathieu, Marks and Zaccaro, 2001). In order to gain a comprehensive understanding of these unique and complex entities, this section aims to integrate and critically examine the sparse multiteam systems publications in relation to two questions: (a) what are multiteam systems? and (b) what factors are thought to impact on their functioning, specifically in terms of cognition, coordination, decision making and communication?

2.3.1: What are Multiteam Systems?

In their seminal piece, Mathieu *et al.* (2001) defined multiteam systems as "two or more teams that interface directly and interdependently in response to environmental contingencies towards the accomplishment of collective goals" (p.290). They are usually temporary systems made up of multiple specialist teams that come together to collectively tackle challenges too complex for a single team or organization to manage. Healey, Hodgkinson and Teo (2009) state that multiteam systems are formed for two main purposes: (1) to enable individuals within teams with complementary skills and knowledge to focus on specific aspects of their proximal task, and (2) to enable them to do this within a wider network of specialised component teams who focus on proximal goals but collaborate to achieve collective, more distal superordinate goals. This makes them especially suitable as the organizational structure for emergency responders, who come from numerous distinct organizations, each serving particular functions, but which must work together to achieve common overarching goals.

There are five distinguishing characteristics of multiteam systems that separate them from other similar entities (Mathieu *et al.*, 2001): (1) they are composed of two or more teams, (2) they are unique entities larger than teams but typically smaller than the larger organization(s) within which they are embedded, and may even, as in the present context of application, cross organizational boundaries, (3) all component teams must exhibit input, process and outcome interdependence with at least one other team in the system , (4) they are open systems whose configuration stems from their environment and the technologies they adopt, and (5) the component teams may not share proximal goals, but must share at least one common distal goal and a superordinate goal for which all component teams have a vested interest. These characteristics, explicated in more detail below, distinguish both the design of multiteam systems and the factors that define their attendant processes.

2.3.1.1: Multiteam system structural characteristics

As already stated, multiteam systems consist of multiple teams which combine to form a single system. They can therefore become quite large in scale, made up of members from various backgrounds and specialties who are often geographically distributed (Zaccaro, Marks and DeChurch, 2012). As open systems, the environment has significant importance for the configuration of multiteam systems as it becomes a primary system component and essential to their functioning. Multiteam systems are shaped by two types of environments (Mathieu *et al*, 2001), (a) their embedding organizations, and (b) the external environment. Regarding their embedding organizations, multiteam systems can originate either from a single organization (known as internal multiteam systems), or present additional complexities (in terms of different hierarchical structures, cultures and working practices) by crossing numerous organizational boundaries (known as cross-boundary multiteam systems).

The multiteam system structure is also influenced by the external environment with which it interfaces directly, as the nature of the task establishes which specialist teams are required to successfully accomplish it and their relative interdependencies, requiring the teams to be sensitive to how the task evolves over time in order to synchronize their actions accordingly. For example, in DeChurch *et al.'s* (2011) historiometric analysis of leadership functions, they found that even though they did not share common goals, alignment of the multiteam system with external entities was a critical function and contributed directly to multiteam system-level performance. The external environment therefore imposes temporal constraints on multiteam system goal hierarchies as component teams must entrain their actions to the tempo of the dynamic task environment.

Emergency response systems fit the definition of a cross-boundary multiteam system. They are composed of teams of specialists that span numerous organizational boundaries. Such members are defined by the civil contingencies act (2004) as either category 1 or category 2 responders, and the exact agencies to be involved in an incident is contingent on the nature and location of the emergency. Category 1 responders are those from organizations at the core of the emergency response (such as the emergency services, local authorities, health bodies and government agencies), whereas category 2 responders refers to those from organizations that act as “cooperating bodies” who are expected to cooperate and share information when an event is related to their sector (including members from the utilities or transport sectors, affected private sector firms, health bodies such as the health and safety executive and science and technical advisors).

However, there is an implicit problem within the original conception of multiteam systems in that Mathieu, Marks and Zaccaro (2001) do not distinguish any further than the concept of internal and cross-boundary multiteam systems the notion of different types of multiteam systems. It is assumed in the multiteam systems literature thus far that only one level of networked teams exists to comprise the system, yet within the UK emergency response context, it is possible to distinguish a second, overlapping team network structure. The ‘team of teams’ structure exists both at each level of hierarchy in isolation (i.e. multiple organizational agencies), and also between them (i.e. the bronze-silver-gold command structure). The system could thus be considered a ‘multilevel multiteam system’. This therefore adds even greater complexity for such systems, as it highlights a need to consider not only the horizontal integration of agencies, but also the vertical integration of levels of command. It is therefore important to acknowledge this additional complexity that a multilevel multiteam system has, as the factors that lead to effective functioning are likely to diverge compared to standard multiteam systems that only have a single level to contend with.

As can be seen in Table 1 below, other distinctions of multiteam systems have also been proposed in the more recent literature on multiteam systems, such as the discernment of ‘distributed’ multiteam systems by Zajac, Shuffler, Darling and Salas (2013), ‘ad hoc’ multiteam systems by Bienefeld and Grote (2014), and the distinction between multiteam systems comprised of integrative or representative teams by Keyton, Ford and Smith (2012). All three of these are of import for this research, as the UK emergency response multiteam systems (i.e. a multilevel multiteam system) is deliberately spread across at least three different locations (hence distributed), is formed in response to an incident at short notice and constructed of teams who have not likely worked together previously (hence ad hoc), and is constructed of component teams who are both wholly from a single organization and enter the multiteam system complete (i.e. the originating organizational agencies; an integrative team) whilst concurrently being constructed of teams made up of individuals who broker for their organizations (i.e. the hierarchical command levels; a representative team). The authors making these distinctions contend that each will have different ramifications for multiteam systems performance requirements and thus must be distinguished when considering the study of multiteam systems.

Table 1: Multiteam system types distinguished within the literature

Type	Definition	Reference
Multiteam System (MTS)	Two or more teams that interface directly and interdependently in response to environmental contingencies toward the accomplishment of collective goals.	Mathieu, Marks and Zaccaro (2001)
Internal MTS	Multiteam systems that are fully embedded within a single organization.	Mathieu, Marks and Zaccaro (2001)
Cross-Boundary MTS	Multiteam systems that contain teams from multiple organizations.	Mathieu, Marks and Zaccaro (2001)
Distributed MTS	Multiteam systems in which members are geographically dispersed but work together interdependently to achieve a common goal.	Zajac, Shuffler, Darling and Salas (2013)
Ad Hoc MTS	Multiteam systems composed of teams whose members come together for a specific time or purpose, as opposed to multiteam systems composed of traditional, stable teams who have worked together previously.	Bienefeld and Grote (2014)
MTSs composed of integrative teams	Multiteam systems comprised of teams that join the system ‘intact’ as they would exist outside of the multiteam system context.	Keyton, Ford and Smith (2012)
MTSs composed of Representative teams	Multiteam systems comprised of teams that are formed by individuals from different organizations to solve specific problems (i.e. the members each represent their organization within the team).	Keyton, Ford and Smith (2012)
Multilevel MTS	A multiteam system with more than one overlapping team network structure.	

An example of a multilevel emergency response multiteam system can be seen in Figure 2 below.

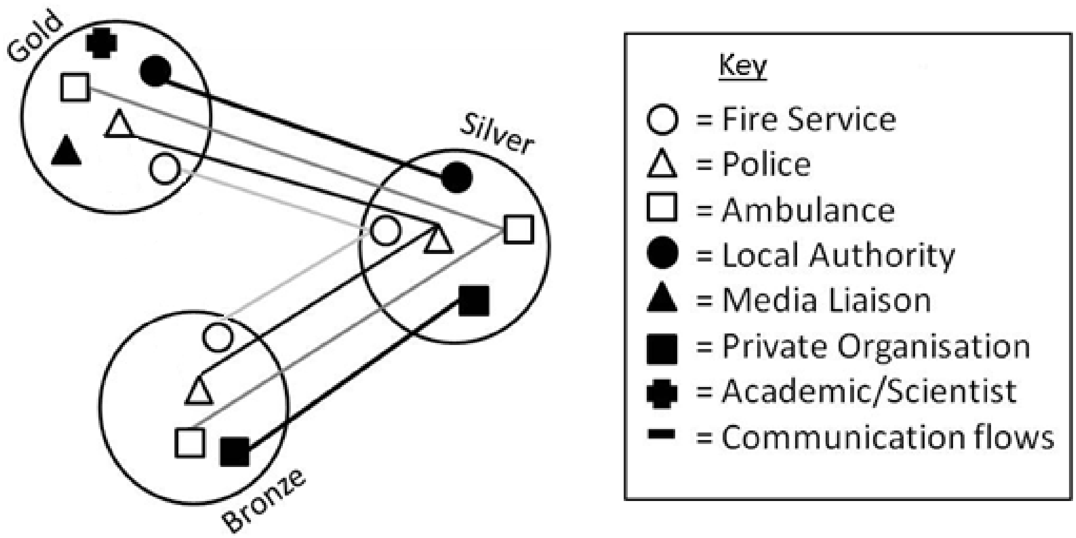


Figure 2: An example of the structure of emergency response multiteam systems

2.3.1.2: Factors that define the processes of multiteam systems

The core elements of multiteam systems functioning as delineated by Mathieu *et al.,* (2001) are epitomized in the complex interdependencies embedded in multiteam system goal hierarchies and their respective performance episodes. The level of interdependence, governed by the goal hierarchy, determines the degree to which teams must work together for success. It shall be shown that in emergency response, there are high levels of interdependence between both the levels of command and the agencies within each group, and thus, according to multiteam systems theory, effective and timely cross-team processes will be critical for system optimization. This thus becomes one of the most critical challenges for emergency response multiteam systems performance, and a failure to synchronize cross-team actions appropriately is what likely leads to system sub-optimization.

According to Mathieu *et al* (2001), goal hierarchies are determined by the task requirements and environmental constraints, and set the team direction. In multiteam systems, goal hierarchies are especially complex, as component teams will often have to simultaneously accomplish multiple distal (long term) and proximal (short term) goals that change in relative importance over time. This means that individual members must allocate effort and resources to at least three distinctive sets of goals (individual goals, team goals and multiteam goals) which are not always in accordance with one another (DeChurch and Zaccaro, 2010). To successfully accomplish superordinate system goals, the completion of proximal and distal goals will also need to be completed in a complex sequence of actions aligned both within and between component teams and across multiteam system boundaries with the external environment. This results in an intricate web of input, process and output interdependencies between teams.

DeChurch and Zaccaro (2010) highlighted that interdependence in multiteam systems should be thought of as a four dimensional construct, with different orientations in terms of type, form, level and phase. First, the 'type' of interdependence is the manner in which contributions are combined (dictated by task requirements) which can be pooled, sequential, reciprocal or intensive in nature (Saavedra, Earley and Van Dyne, 1993). Pooled interdependency is when the collective output is made up of the additive sum of outputs from its component parts, with the output of one group therefore not dependent on the output of the others and thus no synchronization is necessary. Sequential and reciprocal interdependencies both require one team to complete a task before the other is able to contribute, with sequential indicating unidirectional workflows, and reciprocal indicating cyclical workflows. Finally, intensive workflows require simultaneous and collective collaboration for successful task accomplishment as team functions are intertwined. Second, there are two possible 'forms' of inputs that can be combined by interdependent components: information or behavioural inputs (Mesmer-Magnus and DeChurch, 2009). Third, the 'level' of interdependence refers to the abstraction level at which the interdependence exists, which can be at the team, unit, multiteam system or external constituent level. Finally, the 'phase' dimension refers to how interdependencies change over time as component teams pursue different goals over numerous performance episodes.

These fundamental interdependencies for multiteam systems mean that teams might have to share key resources (such as information, strategies or equipment), interact on tasks, or rely on other component teams completion of distal goals in order to achieve their own goals, and in turn the collective goal of the multiteam system. Marks, DeChurch, Mathieu, Panzer and Alonzo (2005) found that as the level of goal hierarchy interdependence increased (from sequential to intensive types), cross-team processes (such as monitoring and coordination) became increasingly important, with multiteam system-level behaviours having a significant influence on performance supplementary to that at team-level. Therefore, for the multiteam system to be successful the component teams need to be able to orchestrate multiple episode interfaces, with synchronised actions and temporal alignment thus becoming one of the most critical challenges for multiteam systems (DeChurch and Marks, 2006).

When responding to the immediate aftermath of an incident, emergency response agencies come together and split into the three multi-agency tiers of bronze, silver and gold (outlined in section 2.1.1) that are dispersed across a number of locations (typically three – the incident site, incident control point, and strategic coordination centre). Viewed from the perspective of multiteam systems, all members of the system share the same superordinate goal of resolving the situation, which they must work interdependently to achieve through the accomplishment of lower level distal and proximal goals. These lower level goals may be specific to the individual teams, such as the police goal of setting up cordons or the fire brigade putting out a fire, or they may require collaboration to be successfully completed (especially for distal goals) such as the generic aims to protect lives and property, which require the integrated efforts of multiple responding agencies.

In seeing to render the situation safe, preserve life, and rescue victims from danger, the various agencies that come together to deal with major incidents are clearly highly interdependent with one another, and therefore integration and the coordination of effort are critical to the overall functioning and effectiveness of the emergency system as a whole. Responders may be interdependent on each other for action, as for instance when firemen are required to rescue a victim from wreckage before the ambulance service can treat them (a form of sequential interdependence). Such sequential interdependence is especially prevalent at the level of bronze command, the level responsible for the 'hands on' work at the incident site. More prevalent in emergency response multiteam system however are informational interdependencies between the various agencies, which are more likely to be of reciprocal type or intensive type interdependencies. Informational interdependency refers to the need to share relevant and accurate information in a timely manner between agencies, which is necessary for decision making. Decision making in emergency response is a critical activity, as decisions must be made under time pressure in ambiguous and often novel situations, where the consequences of decisions can be severe. Effective communication flows are therefore essential for reducing ambiguity and ensuring decisions are well informed.

The high levels of interdependence (and specifically, informational interdependence) that exist within emergency response systems thus engender an elevated requirement for between-team interactions and coordination for system optimization compared to systems with less complex goal hierarchies. When communication breaks down between the various teams and agencies involved in a civil emergency, the response becomes fractured and the agencies are less able to coordinate their efforts into an integrated whole. This can then lead to problems such as misunderstandings, duplications of effort or important situational factors being overlooked, thus reducing the effectiveness of the overall response and putting more lives and property in danger than is necessary. It is this sub-optimization of response that is of interest within this thesis, and will therefore be analysed through the concept of multiteam systems.

As was hinted to within the review of the emergency response literature, sub-optimization of emergency response systems has typically been attributed to failures in developing a collective understanding of the incident and the response system in which the individuals reside, in coordinating effectively, in decision making, and effective communication. In order to gain insight into the potential causes of breakdown between and within the different agencies involved in emergency response, I now turn to a discussion of these critical processes informed by the multiteam systems and related literatures.

2.3.2: Communication, cognition, coordination and decision making in emergency response multiteam systems

As was outlined in section *2.1.2: Failures within emergency response,* the main causes of system sub-optimization proposed in the emergency response literature are breakdowns and inefficiencies in cognition, coordination, decision making and communication. Within this section I shall argue that effective communication flows between system members underpin the ability of the system to engender the effective collective cognition, coordination and decision making also required for optimal performance, and thus remains the focus of this research.

2.3.2.1: Communication

Emergency response multiteam system functioning is likely to be significantly impeded without adequate communication. Communication and information sharing have been shown to be critical for teams through enhancing team performance directly, but also through improved cohesion, decision satisfaction and knowledge integration, especially when unique information is shared (Mesmer-Magnus and DeChurch, 2009). As interdependence in multiteam systems leads to increases in between-team working requirements (Marks *et al.*, 2005), it is likely even more critical for effective functioning for multilevel multiteam systems. This contention has also been made in regards to similar groupings, such as Rentsch, Mello and Delise (2009) noting that knowledge must be externalised and transferred to others for it to become interoperable in ‘intense problem solving teams’ such as those utilized in emergency response, Roberts and O’Reilly (1976) finding that communication frequency was related to increased performance of aircraft crews across a number of divergent tasks, and Kanki and Foushee (1989) attributing enhanced performance in the aircrews they studied to improved communications between team members. Effective communications are thus likely also imperative in emergency response multiteam systems.

The emergency response literature has begun to place greater focus on the role of effective communication for successful systems functioning. Van de Walle and Turoff (2007) note that “the faster emergency responders are able to collect, analyse, disseminate and act on key information, the more effective and timely will be their response, the better needs will be met and the greater the benefit to the affected populations” (p.30), and Hale (1997) states that “the key obstacle to effective crisis response is the communication needed to access relevant data or expertise and to piece together an accurate understandable picture of reality” (p.241). Emergencies are always unique, and as stated by Turoff, Chumer, Van de Walle and Yao (2004) “almost everything in a crisis is an exception to the norm” (p.8). Responding agencies therefore need to communicate to effectively understand the unfolding situation and act in a manner that is responsive and flexible, and without this communication, responders revert back to known routines that can actually be detrimental for the specific incident at hand. For example, Turoff *et al*. (2004) suggest that high level of deaths of first responders during the 9/11 terrorist attack is at least partly due to coordination errors following a lack of effective communication, resulting in individuals resorting to known patterns without re-evaluation in light of the specific situation they faced. As stated by Manoj and Baker (2007), in emergency response contexts, “sharing and disseminating information is both critical and problematic” (p.52).

However, whilst communication is repeatedly highlighted by authors as a primary challenge in emergency response (e.g. Bharosa, Lee and Janssen, 2010; Dawes, Cresswell and Cahan, 2004; Manoj and Baker, 2007), and Bharosa *et al*. (2010) and Van de Walle and Turoff (2007) both note that similar sentiments are echoed within the practitioner community, academics have tended to focus on the development and utilization of interoperable communication technology rather than considering other barriers or facilitators of inter-agency communication, or communication itself more directly (Turoff *et al*., 2004; Van de Walle and Turoff, 2007).

Whilst the underlying technologies for effective communication is a valuable area of study, as without interoperable systems communication between the diverse agencies is significantly inhibited, researchers have recently started to suggest that this is not the only factor of interest in emergency response communications research. Technological problems are now only seen as part of the reason for communication issues, with researchers increasingly pushing for research regarding the inter-relationships of individuals in the response (Dawes *et al*., 2004) or focusing on sociological or organizational problems (e.g. Bharosa *et al.,* 2010; Manoj and Baker, 2007). For example, Dawes *et al.,* (2004) suggest that conflicts of interest, proprietary worries and fragmentation issues can all have significant influence on communication flows during emergency response. However, as noted by Bharosa *et al.* (2010), whilst research into such communication issues is still high on the research agenda, we are still currently lacking direct empirical evidence on communication in emergency response contexts, which they suggest is due to the difficulty in studying the emergency response context using conventional methods.

Not only is communication likely critical in its own right, but, as will be explicated below, communication plays a critical role in the development and utilization of different cognitive architectures, for explicit coordination (and the development of cognition required for implicit coordination), and for providing the information required for decision making, three processes already noted in section *2.1.2: Failures within emergency response* as critical for effective responding according to the emergency response literature.

The emergency response literature has also started to focus on the notion that communication is critical for cognition, coordination and decision making. For example, Chen, Sharman, Rao and Upadhaya (2008) acknowledged that “efficient communication is an essential ingredient to the development and spread of common understanding and buy-in” (p.72). Turoff *et al.* (2004) also touched on similar concepts when discussing the requirements needed to be met to create an effective ICT system for use in emergency response contexts. They repeatedly refer to how important accurate and timely information is for coordination and decision making in emergency contexts, due to the fact that “the exact actions and responsibilities of the individuals cannot be pre-determined” (p.10) and thus flexibility and innovation is required in the moment, requiring communication and discussion. Decisions can thus only be established with confidence “by supplying the best possible up-to-date information” (p.9), as lacking this risks delays in making decisions or irreversible incorrect decisions that may exacerbate the emergency or hinder the response. In terms of coordination, Dynes and Quarantelli (1977) state that coordination by feedback is required in emergency response, and yet often “the increase in communication is usually taken as a failure of coordination, not a necessary condition for it” in post incident reports (p.26) and that for this reason we have failed to promote this within emergency planning and training. Increases in communication are required for agencies to adjust to the actions of one another in the moment and for achieving collective mindfulness (Bharosa, Lee and

Janssen, 2010; Weick and Sutcliffe, 2001) and thus without such communication, authors note that coordination is likely to fail.

Whilst cognition, coordination and decision making in their own right have proved important for consideration in emergency response multiteam systems, I will not be focusing on any of them directly within this research project, but instead will explicitly target the communication required for the above to be created and used. There are a number of reasons for this choice of focus compared to taking a direct view of cognition, coordination or decision making which are explicated below.

2.3.2.2: Cognition

Having a good understanding of the event as it unfolds and of a persons' place within the system responding to it is repeatedly highlighted as critical for emergency response. Smith and Dowell (2000), Comfort (2007) and Jenkins *et al*. (2011) all attributed the failures in response during the incidents they studied (the Ais Gil railway crash, hurricane Katrina and the stockwell shooting respectively) to issues of understanding and collective cognition. The discussions of cognition in emergency response tend to focus on the need for a 'common operating picture'; the notion that individuals within the system must have an accurate idea of what is happening in the event (i.e. an accurate and shared assessment of the situation; Comfort, 2007; House, Power and Alison, 2014; Seppänen, Mäkelä, Luokkala and Virrantaus, 2013) and of the actions being taken by other elements of the system to tackle this situation (Bigley and Roberts, 2001; Comfort *et al*., 2004; Smith and Dowell, 2000). Without a common operating picture, these researchers contend that the teams within the system will make inaccurate decisions that are not based on accurate and timely information (i.e. Jenkins *et al.*, 2010; Jenkins *et al.*, 2011), and will struggle to cooperate and coordinate their actions (Seppänen *et al*., 2013).

Whilst it is undeniable that having a good understanding of the emergency and system is important for effective functioning of emergency response multiteam systems, the actual constructs of import to this are not clear. Numerous constructs have been proposed in the emergency response literature, the multiteam systems literature, and the general collective cognition literature itself; so many that the conceptual space of collective cognition has become saturated and fraught with overlapping and contradictory constructs that make the area abstruse. A table of some of these concepts and their possible relation to the emergency response multiteam system context is presented below (see Table 2).

Table 2: Cognitive constructs that might have an influence in emergency response multiteam system functioning

Construct	Definition	How it might influence in an emergency response multiteam system	Main benefit	Key References	Examples of the constructs mention in emergency response or multiteam systems research
Shared mental models	"knowledge structures held by members of a team that enable them to form accurate explanations and expectations for the task, and in turn, to coordinate their actions and adapt their behavior to demands of the task and other team members" (Cannon-Bowers, Salas and Converse, 1993, p.221)	If members share a task mental model, they should interpret new information similarly and develop similar expectations for future system states, and if they share a team-mental model, they hold a common understanding regarding the expected behaviour patterns of other members of the system. This should lead to compatible expectations and thus allow individuals to better anticipate the behaviours and needs of others and adjust their actions accordingly. This in turn makes it possible to coordinate actions without the need to communicate (i.e. implicit coordination).	Implicit coordination	Cannon-Bowers and Salas (2001), Cannon-Bowers, Salas and Converse (1993), Healey, Vuori and Hodgkinson (2015), Klimoski and Mohammed (1994) Mohammed and Dumville, (2001), Mohammed, Ferzandi and Hamilton (2010), Salas, Sims and Burke, (2005)	Mathieu *et al.* (2001) proposed shared mental models as one of the four 'critical levers' of multiteam system functioning. Smith and Dowell (2000) suggested that the response system in the 1995 Ais Gil Railway Crash was ineffective due to a lack of a 'reflexive shared mental models'.
Transactive memory systems	"A combination of the knowledge possessed by each individual and a collective awareness of who knows what" (Austin, 2003, p.866)	The division of cognitive labour provided by a transactive memory system allows access to a large stock of task-relevant information whilst reducing the cognitive load on each individual team member. As individuals know where to go for specific information this should result in improved explicit coordination and planning, assigning tasks to the individual with the correct knowledge.	Explicit coordination	Austin (2003), Brandon and Hollingshead (2004), Choi and Robertson (2008), Moreland, Argote and Krishnan (1996), Wegner (1987)	Healey, Hodgkinson and Teo (2009) conducted an empirical study regarding the degree of transactive memory that was fostered during alternative forms of training exercises in multiteam systems. They found that increased levels of transactive memory enhanced communication quality between members and prevented the misallocation and duplication of effort, resulting in improved multiteam system performance.
Cross-understanding	"the extent to which the group's members possess an accurate understanding of the mental models of other members" (Huber and Lewis, 2010, p.7)	The degree to which individuals holds an accurate understanding regarding the factual knowledge, beliefs, sensitivities and preferences of other group members is proposed to influence group processes through improving communication quality, elaboration of non-shared mental models, and enhancing the ability of the team to collaborate and coordinate through anticipating their behaviours and needs.	Implicit/ explicit coordination	Huber and Lewis (2010; 2011)	Oțoiu, Andrei and Băban (2012) have found early empirical evidence of cross-understanding in their qualitative study of emergency intervention teams, and found associations between the degree of this cross-understanding and the efficiency of actions and ability to coordinate behaviours without the need to communicate. Whilst they refer to it as 'organizational awareness', Goodwin, Essens and Smith (2012) contended that having a good understanding of the perspectives of other parties enabled the multiteam system to collaborate effectively.

Table 2 Continued:

Construct	Definition	How it might influence in an emergency response multiteam system	Main benefit	Key References	Examples of the constructs mention in emergency response or multiteam systems research
Situation awareness/ Team situation awareness/ Distributed situation awareness	"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley 1988, p. 97)	The ability to correctly perceive, comprehend and project elements of the situation and environment both provides the information required to make effective decisions, and determines whether the individual adopts the most appropriate problem solving strategy. This therefore enhances the decisions that are made, especially if using recognition-primed decision making (Klein, 1993) generally utilized by experts.	Effective decision making	Durso and Sethumadhaven (2008), Endsley (1995a; 1995b; 1997; 2001), Gorman, Cooke, and Winner (2006), Lundberg (2015), Stanton *et al*., (2006)	Goodwin *et al*. (2012) argued that situation awareness is an important aspect for the collaboration of multiteam system teams, and suggested that it was through effective situation awareness that the operational control centre for the Netherlands Railway they described maintained effective functioning. Seppänen Mäkelä, Luokkala and Virrantaus (2013) have also suggested that situation awareness is integral to the effective functioning of search and rescue teams, and highlighted that communication issues that result in information gaps are often the reason that shared situation awareness cannot be developed.
Sensemaking	"the process through which individuals work to understand novel, unexpected, or confusing events" (Maitlis and Christianson, 2014)	Sensemaking can be thought of as the process by which situation awareness is developed (Durso and Sethumadhaven, 2008). Without an accurate interpretation of what has occurred during moments of ambiguity or uncertainty, individuals cannot effectively comprehend or project elements of the situation they are confronted with, and thus are unable to make effective decisions. It is clear that without the ability to understand what is occurring, any attempts to control or manage the situation will be limited and ineffectual or perhaps even escalate the incident further.	Effective decision making	Maitlis (2005), Maitlis and Christianson, (2014), Weick (1988; 1993; 1995), Weick, Sutcliffe and Obstfeld (2005)	In Weick's two seminal articles on the topic of sensemaking, he asserted that disintegration in sensemaking led to the escalation of incidents, both in terms of the 1984 Bhopal disaster (Weick, 1988) in which individuals failed to enact enough to effectively understand what was occurring and prevent the spread of leaking gas that resulted in the deaths of thousands of people, and in terms of the 1949 Mann Gulch disaster (Weick 1993) in which 13 firemen were killed when they failed to effectively sensemake and thus utilize creative responses required for survival.
Macrocognition	"how teams move between internalization and externalization of cognition and build knowledge in service of problem solving" (Fiore, Rosen, Smith-Jentsch, Salas, Letsky and Warner, 2010,	Macrocognition was conceptualized to explain how experts use a combination of cognitive processes (e.g. problem solving, planning, decision making) when they are in un-stable and novel environments rather than 'rule-based performance' environments (Rasmussen 1983) to re-interpret knowledge to produce novel solutions to problems. As large-scale civil emergencies are generally unique one-off	Problem solving and creation of novel ideas	Fiore, Rosen, Smith-Jentsch, Salas, Letsky and Warner (2010), Keyton and Beck (2010), Letsky, Warner, Fiore and Smith (2008), Rosen, Fiore, Salas, Letsky	Whilst aiding individuals in building new knowledge and adapting rules is something that would be incredibly useful in emergency response settings, especially considering that working outside of the 'standard operating procedure' has been found to be of import in emergency response in novel situations (Comfort, 2007; Stochowski, Kaplan and Waller, 2009), very little mention of this cognitive construct has yet been made in either the multiteam system or

Table 2 Continued:

Construct	Definition	How it might influence in an emergency response multiteam system	Main benefit	Key References	Examples of the constructs mention in emergency response or multiteam systems research
Macrocognition (Continued)	p. 203-204)	events, it is likely that emergency responders will face novel problems not seen before, and thus being able to create new interpretations of knowledge for problem solving is likely critical.		and Warner (2008)	emergency response literature. The macrocognition literature itself has however related this concept to being required in complex collaborative environments (e.g. Fiore *et al.*, 2010) and having utility for intense problem solving teams (e.g. Rentsch, Mello and Delise, 2010).
Distributed-cognition	"The theory of distributed cognition, like any cognitive theory, seeks to understand the organization of cognitive systems. Unlike traditional theories, however, it extends the reach of what is considered *cognitive* beyond the individual to encompass interactions between people and with resources and materials in the environment" (Hollan, Hutchins and Kirsh, 2000 p.175)	Distributed cognition theory makes clear how important it is to consider cognition from the system-level of analysis, and to understand that cognition occurs both internally within the individual but also through externalizations in interactions and through the use of cognitive artefacts. Similarly to macrocognition, it encompasses a number of cognitive elements and assumes that cognitive understanding and processing occur in a distributed manner across an entire sociotechnical system, rather than just within the head of individuals. As emergency response systems are sociotechnical systems distributed across locations, it is likely that distributed cognition is utilized.	Coordination, decision making and problem solving.	Hollan, Hutchins and Kirsch (2000), Hutchins (1995a; 1995b), Hutchins and Klausen (1996), Salomon, (1997)	Hutchins original conception of distributed cognition came to the fore from his ethnographic study of sociotechnical systems such as the bridge of a ship (Hutchins, 1995a) or an airline cockpit (Hutchins 1995b; Hutchins and Klausen, 1996) that are similar to the high-reliability organization of emergency response. More recently, examination of distributed cognition in emergency medical service professionals found that such cognition helped reduce cognitive workload during emergency response (i.e. 999 response), thus aiding effective working for such teams (Angeli, 2015).

Significant focus has been placed on the cognitive mechanisms driving group processes and performance in recent years, and it is clear from this research that effective collective cognition significantly contributes to the effectiveness of groups (DeChurch and Mesmer-Magnus, 2010; Hinsz, Tindale and Vollrath, 1997; Hodgkinson and Healey, 2008; Kozlowski and Ilgen, 2006; Salas and Fiore, 2004). However, the literature on collective cognition has become significantly fractured, as evinced by the different constructs and streams mentioned in Table 2. Cognitive researchers differ in perspective with regards to the focus of cognition (i.e. whether the focus should be on understanding the situation such as in task shared mental models, sensemaking and situation awareness or the system in which an individual resides such as in team shared mental models, transactive memory systems and cross-understanding), the level at which this cognition resides (i.e. within the individual, the group or the entire sociotechnical system), and the degree to which such cognitions should be 'shared' (see Canon-Bowers and Salas, 2001 and Mohammed, Ferzandi and Hamilton, 2010 for discussions relating to the meaning of 'shared') or distributed across group members. Moreover, Healey, Vuori and Hodgkinson (2015) have recently highlighted that cognition can also differ *within* the individual to the extent that it is reflexive or reflective, adding additional complexity to the conceptualization and study of collective cognition.

The fact that the literature on group cognition is so saturated with constructs that purport to be important for the effective functioning of emergency response multiteam systems makes it challenging to choose a specific construct to study. It is currently unclear as to whether any one of the constructs already identified, or any that have not been mentioned within this body of work, would be most important within the emergency response multiteam system context, and it would thus be premature at this stage to suggest that one is more appropriate and worthy of study than any other. In reality, no one construct in isolation is entirely able to explain and help address emergency response functioning. Instead, a mixture of aspects from each of these concepts will be influential in emergency response multiteam system functioning, as effective coordination, decision making and knowledge building will all be required. Moreover, the content of collective cognition in emergency response context is liable to be as ephemeral and dynamic as the contexts and systems themselves are. It is therefore not likely to be fruitful to attempt to study these cognitive concepts directly, as inappropriate cognitive architecture may be chosen for explicit study, or the insights found might prove not to be generalizable to any other system other than the exact system in the exact moment of study.

Rather that considering any of the collective cognition constructs explicitly therefore, I instead consider communication flows. Each of the cognitive constructs mentioned above requires explicit communication between individuals to be developed or effectively utilized (e.g. Bolman, 1979; Bolstad, Cuevas, Gonzalez and Schneider, 2005; Brandon and Hollingshead, 2004; Denzau and North, 1994; Hollingshead and Brandon, 2003; Huber and Lewis, 2010; Keyton and Beck, 2010; Mathieu, Heffner, Goodwin, Salas and Cannon-Bowers, 2000; Murphy, 2001; Prince and Salas, 1993; Wellens, 1993; Wright, Taekman and Endsley, 2004). It is only through such interactions that members can learn what others know, share specialist cognitive resources, and update the accuracy of their understanding of other members and the situation as a whole. This could be visualized as oxygenated blood flow to the brain. If the brain receives an adequate supply of oxygenated blood, it will perform effectively. However, if there is a lack of oxygen in the blood, or not enough blood reaching the brain, then the brain will die. It will not matter which brain systems are trying to function, as the brain will be unable to carry out any activity. In this instance, the brain represents the collective cognitive architecture, and oxygenated blood represents appropriate information flows through communication. Through explicitly considering communication flows therefore, I am considering the precursor to effective use of cognition in emergency response multiteam systems. Moreover, an explicit focus on communication will provide insights that can be attributed to any of the cognitive concepts suggested and utilized in any system adopting a multiteam system design, and therefore hold additional benefits of generalizability.

Considering communication instead of cognition directly is especially poignant for research on emergency response. Many of the cognitive constructs themselves require communication in order to be properly utilized, but even those that do not, such as shared mental models which are purported to aid coordination *without the need for communication*, need to be fully developed before such benefits can be realised. However, the nature of emergency response, in which the system is formed in an ad-hoc, transient fashion, in conjunction with the types of environments they face (i.e. unique and time pressured problem solving environments) prevents the development of such architecture pre-incident. They must therefore be developed 'in flight' once the situation has begun to unfold. Communication is required for such architectures to be developed, and thus, is likely even more critical in emergency response than other environments as the system attempts to build the cognitive architectures required to effectively respond.

Furthermore, taking an explicit consideration of communication instead of directly studying cognition aligns with the increasing recognition that emergent collective phenomena (such as collective cognition) must be understood through a consideration of the interactions of individuals, rather than just aggregating the data of the individual elements that compose the system. The traditional cognitive perspective, which focused solely on what has been internalized by individuals, therefore no longer accords with this view. Instead, collective cognition must be viewed as an emergent property of the interactions of those within the system, and thus studied in a more holistic manner through the explicit consideration of the *interactions* between the individuals that compose the system (Cooke, Salas, Cannon-Bowers and Stout, 2000). This is an approach promulgated by academics interested in collective cognition (e.g. Hutchins, 1995a; Stahl, 2006).

2.3.2.3: Coordination

The demands encountered when responding to large-scale civil emergencies transcend the capabilities of any one individual or team, and thus requires the collective and coordinated response of several acting agencies to effectively manage (House, Power and Alison, 2014). Failures in effective emergency response have repeatedly been attributed to a lack of coordination between the agencies participating in the response, to the extent that in reading the emergency response literature, one would assume this to be the main cause of system sub-optimization (e.g. Helsloot, 2008; Kettl, 2003; McEntire, 2002; Portsea, 1992; Quarantelli, 1988; Roberts, 2011; Smith and Dowell, 2000; Thévenaz and Resodihardjo, 2010). Similarly, coordination errors are repeatedly highlighted as causing significant issue during government inquests and reports into responses, such as was highlighted in the Government Accountability Office (2006) report into the coordination issues between FEMA and the Red Cross organizations during Hurricane Katrina and Hurricane Rita. A lack of coordination results in efforts being duplicated, responders not knowing what actions they should take, resources being wasted and victims' needs being wrongly assessed (United Nations Disaster Assessment and Coordination, 2006), and can thus lead to not only sub-optimization but a complete disintegration of response. Yet whilst coordination has been highlighted as a key goal, it is still found to plague responses during emergency response, leading Comfort *et al*. (2004) to query "why is coordination so admired in theory, but so difficult to achieve in practice?" (p.63).

Despite much discussion of coordination requirements and failures in the emergency response literature, we still lack much insight into why coordination failures tend to occur or how coordination can be properly implemented during emergency response. Whilst the practitioner literature in emergency response does repeatedly highlight that coordination between the different practicing agencies is required, it generally fails to give any explanation as to how this can be achieved (e.g. Civil

Contingencies Act, 2004; HM Government, 2010; National Policing Improvement Agency, 2009). This therefore makes it difficult for practitioners to enact, especially considering that the preconditions known to facilitate expertise coordination (such as known group membership and time to share who knows what) are limited or non-existent in emergency response settings (Majchrzak, Jarvenpaa and Hollingshead, 2007). Exacerbating this issue, Ödlund (2010), Comfort and colleagues (Comfort, 2007; Comfort *et al.,* 2004) have noted that coordination within emergency response is fundamentally a voluntary activity, as the command and control structure of the system (i.e. the bronze, silver and gold design adopted in the UK) prevents authoritative jurisdiction over any agency outside of their own. This therefore means that agencies can choose to be non-participative, and that if this arises there is little that can be done to resolve it.

Research in multiteam systems has also highlighted the importance of coordination, especially in regards to the alignment of activities between component teams. The successfully coordinated timing and sequencing of interdependent actions has been found to have substantial influence on the performance of both the individual teams that make up the system (Hoegl and Weinkauf, 2005; Hoegl, Weinkauf and Gemuenden, 2004) and for the multiteam system as a whole, with effective coordination actually displaying performance improvements that were incremental to the additive performance of the teams involved (DeChurch and Marks, 2006; Healey, Hodgkinson and Teo, 2009; Marks *et al.,* 2005).

However, as in emergency response, multiteam systems researchers looking at real-world multiteam systems in action have found that coordination can be hard to enact. For example, in their study of cabin and cockpit multiteam system crews in the simulation of a real flight incident, Bienefeld and Grote (2014) found numerously that the cockpit crew could succeed and yet the multiteam system as a whole still fail in the safe landing of the plane with no casualties on board, which they attributed to a lack of coordination between the cockpit and cabin crew component teams. Between-team coordination may pose additional complexities, as members must overcome language, goal and thought-world differences that are not found in traditional teams (de Vries, Walter, van der Vegt and Essens, 2014; Dougherty, 1992), and may hold incompatible perspectives and goals (Maltz and Kohli, 2000). Dietrich, Kujala and Artto (2013) suggest that in multiteam environments, and especially when the system is transient such as in emergency response, “the coordination mechanisms used in routine production environments may not suffice” (p.7). Instead they suggest that high levels of information exchange and a greater focus on horizontal alignment between teams are likely required. Similarly, the United Nations Foundation (2011) has noted that in emergency response environments, “good communication is essential to effective coordination” (p.10).

Rico, Sánchez-Manzanares, Gil and Gibson (2008) stated that mechanisms for coordination should be considered as either explicit or implicit. Explicit coordination, they argue, is actualized through planning and communication. It requires significant information exchange between the coordinating parties, with members continually feeding back information regarding their activities to allow others to adjust and work alongside them. Alternatively, implicit coordination mechanisms include cognitive structures and architectures (such as shared mental models outlined in section *2.3.2.2: Cognition*) that allow individuals to “anticipate the needs of their colleagues and task demands and dynamically adjust their own behaviour accordingly” (Rico *et al.*, 2008, p.164) without the need to communicate (Cannon-Bowers and Salas, 2001).

Both forms of coordination have been suggested to be required in emergency response. For example, communication as a necessary pre-requisite for coordination is mentioned by Comfort *et al*. (2004), who explain that timely and accurate information exchange is required to allow participating organizations to adapt their responses. They state that this is especially important at critical junctures of change to the situation or the actions taken by others, as these may necessitate adjustments in performance to accommodate the shifting priorities that accompany such variations. In terms of implicit coordination, Bigley and Roberts (2001) stated that the degree to which the fire department they studied were able to coordinate behaviours that emanated from the command and control form of organizing in which they operated (i.e. the US incident command system) "depends largely on the extent to which organizational members are able to build and maintain viable understandings of the activity system to which they belong" (p.1290). Similarly, in their command and control flight simulation experiment, Cooke *et al.* (2007) found that teams with experience at command and control (thus enabling enhanced cognition of the expected procedures and interaction patterns that pertain to this arrangement) performed better, and that they accomplished this with fewer 'coordination-related utterances' in their communications than lower performing teams.

Whilst coordination is thus clearly critical for optimized performance of emergency response multiteam systems, I shall not be considering coordination explicitly within this thesis. Instead, I shall be focusing on the critical pre-cursor to coordination: communication. Explicit coordination is directly enacted through communication between agents or groups within the system as they provide feedback to one another regarding their actions to allow for mutual adjustment. Whilst implicit coordination is meant to occur without the need to communicate, it requires the existence of a fully functioning cognitive architecture (such as shared mental models) to be able to be utilized. As was already mentioned, the transient and ad-hoc nature of emergencies make the development of a collect cognitive architecture pre-incident intractable, and thus this must be developed in flight as the incident unfolds. Communication is therefore essential for both forms of coordination during emergency response, at least in the initial stages as the system develops collective cognition. Thus, if communication between the different agents or groups within the system breaks down, then it is unlikely that the component teams will be able to coordinate effectively, and hence it is suitable to consider communication directly within this thesis.

2.3.2.4: Decision Making

Effective decision making is obviously critical for emergency response multiteam systems. As prior research shows (e.g. Jenkins *et al*., 2010), poor decisions can have disastrous consequences in such high risk settings. The main factor that determines whether a decision will be effectively made is whether or not the decision maker in question holds an accurate understanding of the decision's problem-space (i.e. the exact specifications of the incident that relates to the decisions they must make), both in terms of the situation specific information and the necessary expertise and knowledge regarding possible courses of action (Kapucu and Garyev, 2011). This is especially true for expert decision making, which Klein (1993) suggested was enacted through rapid recognition of patterns in the environment, allowing an individual to link the current event back to experiences they have had previously and intuitively decide on the most appropriate course of action. In order to have an accurate conceptualization of the decisions problem-space, an individual must thus have a strong situational awareness, either from seeing the situation in front of them or through having this effectively communicated to them through others. This leads to the current debate occurring in relation to decision making in emergency response and/or multiteam systems as to whether decision making should be centralized or decentralized.

Scholars contending that emergency response should adopt the more coordinative modes of structuring believe that decision making should be decentralized down to the agents responding to the incident who are closest to the task at hand, as their understanding of what is actually occurring is likely to be the most accurate (e.g. Bain, 1999; Comfort *et al.,* 2004; Groenendaal *et al*., 2013; Helsloot, 2008; Scholtens, 2008). They argue that this is especially true within the first minutes or hours of a response, as it would take time for the higher levels of command (i.e. the centralized decision makers) to acquire sufficient information to form an accurate interpretation of what is occurring, and yet immediate action and decision making is required for an effective response (Groenendaal *et al*., 2013; Quarantelli, 1985).

However, if decision making is decentralized, this provides less incentive to share information with others and can lead to significant coordination problems due to a lack of awareness of the actions and decisions being made by other groups. As Comfort *et al*., 2004 stated, “lacking relevant information to form a system-wide perspective, individual units make separate decisions that, while appropriate for the individual unit, may counter or conflict with the system-wide goal and prove averse to other units within the system” (p.67). Some researchers thus contend that centralization is critical as then decisions can be made by a few key people who are kept abreast of the decisions and actions of the other key decision makers within the system (Alexander, 2008). By having fewer agents who need to have an entire overview of the system, there is less chance of individuals making decisions that might negatively impact on the workings of other groups. Such coordination errors due to decentralization have also been found in the Multiteam systems research by Lanaj, Hollenbeck, Ilgen, Barnes and Harmon (2013) in their study of 14 person multiteam systems comprised of air force personnel conducting a simulation task. They did find that decentralization had some positive effects for performance, but that these were significantly outweighed by the negative influence of enhanced risk seeking and coordination failures.

In either the centralized or decentralized form of decision making, communication is critical, whether this is to build up an accurate image of the situation before decision making, or to effectively communicate the decisions made to other responding bodies to allow for coordinated decisions elsewhere throughout the system. Kapucu and Garyev (2011) go so far as to say that “communication, thus, is the basis of collaborative decision-making during emergencies” (p.369) and suggest that it would be even more critical for decision making in emergency response than elsewhere due to the inherently stressful, time pressured, uncertain and complex environments in which they operate. If communication is lacking under such conditions, authority figures might approve or reject certain decisions without adequate understanding of the consequences of these decisions, which House, Power and Alison (2014) contend could undermine the entire collaborative response. Improved communication flows would thus enable a more optimal response regardless of the form of decision making utilized within the system, but a breakdown of communication in either a centralized or decentralized system would cause fracture, ineffectiveness and potentially cause greater harm. Therefore, instead of directly considering decision making within this thesis, which would limit the inferences made to systems utilizing the same degree of centralization, I instead choose to directly consider the communication flows that enact throughout the system and would optimize the decisions made and ability to coordinate around those decisions regardless of the structure of the system in place.

2.3.2.5: Summary

In the above sections, I have explained how effective cognitive architecture, coordination and appropriate decisions can influence the degree to which an emergency response system is able to optimize during response. However, I have also outlined that effective communications are a critical pre-cursor to each of these processes. Without effective communication, collective cognition cannot be developed or utilized effectively, teams and individuals are unable to sequentially align and coordinate their actions, and decisions may be made on the basis of inaccurate or incomplete understandings of the situation or the activities of other system components, resulting in sub-optimal response and possibly even exacerbating the situation further. Ineffective communication (through miscommunication or withholding information) is therefore at the heart of everything that goes wrong in such systems. Research thus focusing on these issues whilst ignoring communication is in essence considering the symptoms rather than the cause of system sub-optimization in emergency response. Instead, communication is the predominant focus of this thesis.

Kanfer and Kerry (2012) outlined how difficult between-team communication is in multiteam systems however, stating that there is little motivation for between-team working. This is because there are few rewards associated with between-team working and such activity might divert critical time and resources away from the individual team. Instead, team members are motivated to communicate within their own teams as this can offer members intrinsic rewards such as pride in team performance and a sense of competency. Compounding this issue, between-team communication needs are often only implied implicitly, and thus Kanfer and Kerry argue that such communication will only occur on a problem-based mandate (i.e. if the team runs out of the resources it needs). In their conclusion, they stated that whilst it is known that communication between teams enhances multiteam system performance, "what is less well known are the factors and interventions that may be effective in mitigating these trends [for within-team communication instead of between-team communication] and promoting sustained allocation of resources toward [between-team] and cross-team member interactions and cooperation" (p.104-105).

Similarly to Kanfer and Kerry (2012), I contend that the key to understanding breakdowns and failures in emergency response multiteam systems is to understand the generative mechanisms that lead to communication breakdown during the incident and that in understanding these, scholars and practitioners can move one step closer to preventing such issues in the future. In the next section I will therefore discuss in more detail the behavioural mechanism that I believe to be the most significant contributor to communication breakdown in emergency response multiteam systems: social identity processes.

2.4: Social Identity

Social identity processes can explain why members of different agencies and groupings might have impeded communication and cooperation by creating a systematic tendency for in-group favouritism and bias towards relevant out-groups, and thus might be the root cause of communication errors leading to sub-optimal response in emergency response multiteam systems. In this section, I shall briefly outline what social identity is and how it can influence between-team communication, followed by a review of the relevant literature in multiteam systems research. Finally, I shall explicate how and why social identity is likely to be influential in emergency response contexts. This discussion shall explicate how our current understanding of social identity in multiteam systems is insufficient for explaining exactly how social identity related processes can manifest within the emergency response organizational design, nor how such processes might influence whether a system optimizes or sub-optimizes, and thus provides the rationale for conducting this exploratory research.

2.4.1: What is social identity?

Social identity is defined as "that part of an individual's self-concept which derives from his [or her] knowledge of his [or her] membership of a social group (or groups) together with the value and emotional significance attached to that membership" (Tajfel, 1978a, p.63). Social identity theory (Tajfel, 1972, 1974, 1975, 1978a 1978b; 1982; Tajfel and Turner, 1979) was conceived to understand collective level phenomenon that could not be explained through individual motivations, specifically why antagonistic intergroup behaviour became apparent once individuals were placed into groups[1]. Tajfel thus conceived of social identity theory to explain how individuals define themselves as members of certain groupings and how this in turn affects their individual and collective

[1] See Wildschut, Pinter, Vevea, Insko and Schopler's (2003) review into research on the interindividual-intergroup discontinuity effect, in which groups are systematically found to compete even in situations in which individuals would cooperate.

behaviour. Social identity theory takes a top down perspective from the collective level, suggesting that societal structures – groups that exist with historical, cultural and social backgrounds and that an individual can feel a sense of "oneness with or belongingness to" (Ashforth and Mael, 1989, p.21) - influence collective and individual level behaviour.

Through the process of social identification, individuals internalize certain identities into their self-concept, attaching emotional and evaluative components to this identity (Tajfel, 1982). This sense of belonging to certain groups is theorised to influence individuals' self-esteem (Tajfel, 1975). Individuals thus strive to enhance the self-esteem they are able to achieve from their groups, principally through categorizing the world into 'us' and 'them' and seeking to differentiate their group from others in ways that promote the negative aspects of out-groups and positive aspects of their in-group along valued dimensions of comparison. The differentiation between groups and need for enhanced self-esteem leads to certain degrees of favouritism with members perceived to be part of the in-group and bias against out-group members, and can encourage competition between groups even when an individual receives no direct rewards from this behaviour.

The theorised in-group favouritism and bias towards out-group members has been numerously replicated in the laboratory in the minimal group paradigm experiments (e.g. Billig, 1973; Billig and Tajfel, 1973; Diehl. 1990; Ellemers, Wilke and van Knippenberg, 1993; Mullin and Hogg, 1998; Tajfel, Billig, Bundy and Flament, 1971; Turner, 1975). Through these experiments, it has been shown that intergroup bias is prevalent even under conditions in which the group allocation is random and abstract, when the individual has no interaction with other members of their group and when the individual had nothing to gain or lose from making their decisions. This research thus suggests that the mere act of dividing people into groups can be sufficient to cause bias and antagonism between them[2].

[2] Although Reicher, Spears and Haslam (2010) do note that we should be careful in our interpretation of the minimal group paradigm findings due to potential conflation of 'differentiation' and 'discrimination'.

Researchers have extended social identity theory to try and understand the mechanisms at the individual level that lead to identification with specific groupings and to further explain the relationship between social identification and intergroup antagonism. Ellemers, Kortekaas and Ouwerkerk (1999) suggested social identities are comprised of three components, that while related, operate relatively independently of each other: "a *cognitive* component (a cognitive awareness of one's membership in a social group – self-categorization), an *evaluative* component (a positive or negative value connotation attached to this group membership – group self-esteem), and an *emotional* component (a sense of emotional involvement with the group – affective commitment)" (p. 372), and showed the elements to be empirically distinct from one another (see also Bergami and Bagozzi, 2000).

Furthermore, other researchers have considered when and why intergroup biases come to the fore. Growing evidence suggests that, in contrast to Tajfel's original assumption that bias was the inevitable consequence of categorization with a group, intergroup bias and categorization are essentially distinct facets, with intergroup biases only truly galvanized when an individual's identity is threatened or challenged (Brewer, 1999; Brewer and Brown, 1998; Brown and Gaertner, 2001; van Knippenberg, 2003). This is not to say that intergroup biases are never evident in situations without such threat, as has been evidenced in the minimal group paradigm experiments mentioned previously, but that the correlation between identification and intergroup bias is reduced in situations where no challenge or competition exists compared to when an identity is threatened (Brewer, 1999). Thus intergroup biases may, but also may not, be engendered by categorizations.

To make sense of the above extensions to social identity theory and how these influence group processes and performance, van Knippenberg, De Dreu and Homan (2004) integrated divergent literature streams into the categorization-elaboration model. They suggested that identity related phenomenon should be considered through the overarching concepts of categorization and intergroup bias, and that these two facets are independent of one another. They then use this distinction to explain when diversity in groups will have positive or negative outcomes for group performance. Specifically, van Knippenberg *et al.* (2004) argue that categorizing oneself and identifying with certain groups does not necessarily lead to negative outcomes for groups, but that if an identity is then threatened in terms of its value or distinctiveness then this will lead to intergroup biases which disrupt the elaboration of task-related information (i.e. effective communication and in-depth processing) between members of different categorized groups, resulting in reduced performance. For the purposes of this thesis, I perceive their 'categorization' concept to include both the cognitive and emotional components proposed by Ellemers *et al*. (1999), whereas the 'intergroup bias' concept incorporates a mixture of the evaluative component and intergroup bias research in general.

Social identities and social identification (i.e. the act of identifying with a group) can thus help explain why communication breaks down between groups in intergroup contexts, such as that found in the emergency response multiteam system under study. In order to understand how social identity processes might impact on the functioning of an emergency response system, it is important to make a similar distinction to that of van Knippenberg *et al* (2004), splitting social identity phenomenon into categorization and intergroup bias.

2.4.1.1: Categorization

Self-categorization theory (Oakes, Haslam and Turner, 1994; Turner, 1982, 1985; Turner, Hogg, Oaks, Reicher and Wetherell, 1987) is an integral part of the social identity approach and was developed to extend the cognitive components of social identity theory and explain how individuals gain their sense of belonging with a specific grouping. Self-categorization theory explains the individual level socio-cognitive phenomenon (categorizing, prototyping, depersonalization and self- and other- stereotyping) that aggregate at a collective level to create the phenomenon of social identities (Hogg and Terry, 2000).

Specifically, self-categorization theory asserts that individuals categorize the world into groupings within a nested hierarchy of possible identities at different levels of abstraction that can be activated or switched on. At the lowest level, an individual can see themselves as an individual in relation to other individuals, or at the highest level, can view themselves as a human being in relation to non-humans. Between these levels of abstraction, individuals can align themselves with groupings at other alternative levels, and this is where the focus of self-categorization theory has been placed. Thus individuals hold a myriad of possible identities at alternate levels of abstraction that can be activated. Individuals align with one of these identities on the basis of salient aspects brought to the fore by the situation and context in which they find themselves.

A central feature of self-categorization theory is that the categories used to organize the social world at any one time are contingent upon which properties are made most salient within a given context (Hogg and Terry, 2000). Which categories are made most salient at any one time depends largely upon the interaction of cognitive accessibility and fit within that specific situation (Oakes, 1987; Oakes, Haslam and Turner, 1994; Turner, 1999; Turner *et al.*, 1987). A category becomes cognitively accessible if it is valued, perceptually salient or if it is a frequently employed aspect of the self-concept and thus refers to the readiness with which that category can be brought to mind (Hogg and Terry, 2000). A category has fit to the extent to which it reflects social reality (Hornsey, 2008) and this can be in terms of normative or comparative fit. Normative fit refers to whether the category specifications account for context-specific behaviours and matches prior expectations, thus referring to the degree to which a category is useful in regards to the current environment and task at hand. Comparative fit refers to the extent to which a category maximises the similarities of individuals within that grouping whilst concurrently accentuating the differences to individuals outside of that category, and thus creates large distinctions among alternative categories. As Oakes (1987) explains, “the salient level of abstraction determines the content of self-perception, which in turn determines the form of social behaviour” (p.117), and thus the categories made salient in a specific context can influence the values and goals on which an individual will make decisions.

Self-categorization theory further proposes that categories are cognitively viewed in terms of their prototypes; the characteristics of that grouping abstracted from its members to become a representative exemplar of that category. As individuals identify with a specific grouping, they move through processes of depersonalization and self-stereotyping to align their thoughts and actions with the activated identity prototype. As explained by Hornsey (2008), “they come to see themselves and other category members less as individuals and more as interchangeable exemplars of the group prototype” (p.208). This prototype is therefore internalized and acts as a socio-cognitive schema, causing individuals to adopt distinctive group norms as guidelines for his or her behaviour and attitudes (Ellemers, De Gilder and Haslam, 2004; Hogg, Terry and White, 1995; Korte, 2007; Reicher, 1987, 1996; Terry and Hogg, 1996). It is therefore through this process of prototype based depersonalization that individuals begin to adopt the norms and values of the groups as their own and integrate the identity of that category membership into their self-concept.

Moreover, as noted by Ashforth and Mael (1989), “social identification is *not* an all-or-none phenomenon” (p.21). The extent to which individuals identify with a specific grouping is instead a matter of degree, or what Ellemers, Spears and Doosje (2002) refer to as ‘commitment’. This aligns with the emotional component proposed by Ellemers *et al*. (1999). Whilst the content of the identity remains the same, the strength of peoples association or emotional tie with that grouping can differ, and Ellemers *et al*. (2002) argue that this will influence the degree to which the individual aligns with the prototype of that categorization and acts in accordance with the group norms. If an individual holds only a low degree of commitment to a specific categorization, their affective, behavioural and perceptual responses are less likely to be influenced by the characteristics, norms and outcomes of that specific grouping. If commitment is high however, this suggests that the individual derives a substantial portion of their self-esteem from that group membership and invests in the outcomes and status of that group, and thus is more likely to use such membership as the basis for perceiving and acting in the world.

2.4.1.2: Intergroup bias

In their annual review, Hewstone, Rubin and Willis (2002) refer to intergroup bias as “the systematic tendency to evaluate one’s own membership group (the in-group) or its members more favourably than a nonmembership group (the out-group) or its members” (p.576), resulting in more positive perceptions, attitudes and behaviour towards in-group members than out-group members (Brewer, 1979). Such favouritism can influence a number of outcomes, including reward allocation, conflict, and communication, each in ways that benefits the in-group whilst having negative repercussions for out-group members.

As stated previously, van Knippenberg *et al*. (2004) state that categorization and intergroup bias are distinct constructs, as categorization merely refers to the perceptual grouping of people and thus does not necessarily infer that intergroup biases will accrue from this. However, intergroup bias does stem from the categorizations in the sense that without categorizing people into ‘them’ and ‘us’, intergroup bias cannot exist. Researchers have thus tried to explain the conditions in which categorizations result in intergroup bias, and when they do not.

The original conception of social identity theory (Tajfel 1975; Tajfel and Turner, 1979) suggests that intergroup biases stem from social identification as a means to enhance an individuals’ self-esteem, and empirical evidence has been found for this suggestion in a meta-analysis (Aberson, Healy and Romero, 2000). However, researchers have extended this notion to suggest that intergroup biases are more significantly triggered when an identity is threatened in terms of its value or distinctiveness, and that without such threats it is less likely that intergroup biases will develop (Branscombe, Ellemers, Spears and Doosje, 1999; Brewer, 1999; Hagendoorn, 1995; van Knippenberg *et al*., 2004)[3].

van Knippenberg *et al*. (2004) suggest that the key underlying mechanism through which intergroup biases impact on group outcomes is through its influence on communication. This assumption is predominantly based on the literature into the effects of diversity[4] on group outcomes that van Knippenberg *et al*., integrated with the social categorization perspective to explain when diversity has beneficial or detrimental effects to group processes and outcomes. The diversity literature generally argues that certain forms of diversity (i.e. information diversity) are beneficial for group outcomes in as much as they beget divergent perspectives, cognitive resources and skills that can be beneficial for problem solving (Bantel and Jackson, 1989; Baron, 1991; De Dreu and West, 2001; Hoffman and Maier, 1961; Mannix and Neale, 2005; Milliken and Martins, 1996) but that other forms of diversity (i.e. social-category and/or value diversity) can prevent the benefits of diversity from manifesting due to increasing conflict within groups and thus disrupting group processes such as communication (Jehn, Northcraft and Neale, 1999; Lau and Murninghan, 2005; Pelled, 1996a, 1996b; Pelled, Eisenhardt and Xin, 1999; Smith, Smith, Olian and Sims, 1994). Moreover, teams with little diversity in terms of social-categories or values are thought to have increased group cohesion which is thought to aid the open discussion of ideas and result in greater participation in decision making (Aldag and Fuller, 1993; Lichtenstein, Alexander, Jinnett and Ullman, 1997). Evidence for this perspective has been found, with Earley and Mosakowski (2000) finding that team communication mediated the relationship between group diversity and performance, and Dahlin, Weingart and Hinds (2005) finding that moderate levels of diversity were

[3] See also Petriglieri (2011) for a review on the multitude of alternative responses that may be adopted to identity threat.
[4] See van Knippenberg and Schippers (2007) for a review on work group diversity research.

associated with the greatest information use. van Knippenberg *et al*. (2004) suggested that the way in which diversity influences group outcomes is dependent on how the individuals categorize themselves, and whether intergroup biases stemming from these categorizations manifest throughout the system which negatively impact on task-related elaboration of information.

van Knippenberg *et al*. (2004) suggest that biases disrupt the elaboration of task relevant information between members categorized as belonging to different groups as members become “less willing to invest in outgroup others and to keep them fully informed and up-to-date in matters” (p. 1017). Members are thus “more likely to communicate and share information within rather than across their subgroups” (Lau and Murninghan, 2005, p.657), which is likely especially deleterious in groups in which sharing information is vital (e.g. emergency response multiteam systems; see section *2.2.2: Cognition, coordination, decision making and communication in emergency response multiteam systems*). I argue that intergroup biases stemming from categorizations are thus at the heart of everything that goes wrong in emergency response multiteam systems; miscommunication, withholding information, misdiagnosis, failure to cooperate and failure to share resources. The information gaps also in turn lead to coordination and decision making failures as individuals fail to develop an accurate common operating picture. Empirical support for the proposition that intergroup bias, stemming from social identities, causes disruption to communication and elaboration, and that this in turn negatively influences performance outcomes in intergroup contexts is beginning to grow, supporting these suggestions (e.g. Greenaway, Wright, Willingham, Reynolds and Haslam, 2015; Meyer, Shemla and Schermuly, 2011).

2.4.1.3: Summary

Social identity theory thus provides a likely explanation for communication breakdown in emergency response multiteam systems. Through the activation and internalization of specific identities, individuals begin to show preference for in-group others, reducing their willingness to communicate with those they deem to be members of the out-group. If communication is impeded in emergency response, this will also detriment the system in terms of cognition, coordination and decision making, and thus lead to system sub-optimization. Understanding how social identity processes such as categorization, commitment and intergroup bias, manifest throughout the emergency response multiteam system and influence system-level communicative outcomes is therefore of critical importance.

Whilst it is possible that social identity related processes could be the root cause of system sub-optimization, the system does not always sub-optimize. It is therefore imperative to understand how social identity processes may negatively influence performance in emergency response, and how they can sometimes be ‘cut through’ in order to accomplish an effective coherent response. The multiteam systems literature has recently started to consider the role of social identity within such systems, and I shall now turn to discuss the theory and research conducted in this area.

2.4.2: Social identity in multiteam systems

Although social identity was not posited as one of the original critical levers of multiteam system success in the seminal article by Mathieu *et al.* (2001), recent multiteam system theorising has begun to bring this topic to the fore. The potential role of social identity in multiteam systems was initially hinted at by DeChurch and Mathieu (2009), who proposed that the heterogeneity implicit in multiteam system design can create challenges for multiteam system functioning, and that such heterogeneity of members and teams was a potential theme for future multiteam system theorising. DeChurch and Zaccaro (2010) advanced this further, explicitly stating that the role of affective emergent states (of which they propose social identity to be one of) on multiteam system functioning is an area in need of research going forward. They stated that the systems research community has privileged behavioural and cognitive processes at the expense of issues such as trust, systems level cohesion and competitive between-team dynamics that are of interest to practitioners (who opine that if the system can be brought together through an appropriate patterning of affective states then this will culminate in the desired levels of behavioural synchronization).

Connaughton, Williams and Shuffler (2012) explicitly theorised on the role of social identity on multiteam systems functioning and outcomes, advancing twenty four research questions and sixteen propositions related to facets of the multiteam system definition of particular relevance to social identity concerns. They generally contended that issues of culture, goal alignment and role-based heterogeneity would create difficulties for multiteam system functioning through their ability to create conflict among individual's identities. To resolve such identity tensions, Connaughton *et al.* proposed that multiteam system members should strive to create a superordinate or dual identity to help align team members with the overall goals of the multiteam system.

A superordinate identity refers to a category that transcends the overall system and thus unifies members together in an overarching category of 'multiteam system member'. Superordinate identities have been discussed in the general social identity literature and found to reduce the degree of intergroup bias found against out-group members to whom the individual shares a salient superordinate identification (e.g. Gomez, Dovidio, Huici, Gaertner, and Cuadrado, 2008; Greenaway *et al.*, 2015). However, Connaughton *et al*., (2012) also proposed that only identifying at the level of the superordinate identity would have negative repercussions for the multiteam system if members fail to focus on team-level goal accomplishment as well, as if the teams that comprise the multiteam system fail, the system as a whole will also falter. They therefore proposed that a dual identity in which the individuals categorized themselves as both part of the multiteam system collective as a whole but equally as a component team member might be more suitable in order to encourage the successful alignment and accomplishment of both team-level and multi-team level goals.

The notion that a dual identity, highlighting both the superordinate and team identities concurrently, would be beneficial for multiteam systems has also been suggested by Hinsz and Betts (2012). In their theoretical consideration of conflict in multiteam systems, Hinz and Betts suggest that conflict is inherently more likely in multiteam systems, and that part of the reason for this might be intergroup biases that stem from individuals within the system categorizing themselves into separate identities. They suggest that promoting a dual identity through bringing attention to the shared superordinate goal of the multiteam system whilst concurrently valuing component team functions, would help reduce the chance of conflict between teams in such settings. Thus, the theoretical literature on social identity in multiteam systems generally extols the virtues of a dual identity in multiteam systems.

Williams (2011) was the first to explicitly consider the role of social identity empirically in multiteam systems in her PhD thesis. She took a communicative, interpretive perspective to uncover how identity influences individuals within an emergency response system in the USA, predominantly comprising of a police and fire department for two large cities. Within this work, she failed to find the identities proposed by Connaughton *et al*. (2012) as influential, instead finding that individuals seemed to accomplish successful system performance whilst only identifying with their professional body. She thus suggested that the system worked not through a transcendent ‘we’ as expected, but instead as a “collection of us’s” (p.155). Williams also explained how the system itself appeared an abstract concept for many of the participants, querying what she even meant by ‘system’. This therefore raises questions as to the legitimacy and possibility of even creating a superordinate category within such systems, which would also preclude the ability to develop a dual identity. However, as Williams contends, the system was still effective even without the development of an overarching shared identity. This thus leads to questions of how emergency response systems could achieve this success without an overarching identity, a question that unfortunately Williams was unable to answer.

More recently, another empirical study has been conducted on the influence of social identity in multiteam systems. Cuijpers, Uitewilligen and Guenter (2015) used a simulated fire-fighting command and control experiment with a multiteam system comprised of two two-person teams of students to investigate the influence of a dual identity on multiteam system performance. In accordance with the theory proposed by Connaughton *et al*., (2012), but in contrast to the findings of Williams (2011) real world multiteam systems study, Cuijpers *et al*. found evidence that holding a superordinate multiteam systems identity tempered between-team task and relationship conflict, and enhanced multiteam system performance. Surprisingly however, no evidence of a beneficial effect of dual identification was found, finding that multiteam systems level identification was more important for reducing between-team conflict when component team identification was low rather than high.

The Cuijpers *et al*. (2015) study therefore neither agrees fully with the previous theoretical work on social identity in multiteam systems, in which a dual identity is proposed to be beneficial, nor the previous empirical work, in which no evidence of a superordinate identity was found at all. However, this study utilized a small scale version of a multiteam system within the study, having only two teams with two members in each to represent the system. Davison, Hollenbeck, Barnes, Sleesman and Ilgen (2012) criticised multiteam systems research utilizing small scale designs such as this, arguing that research using small multiteam systems with little unique specialization are unlikely to trigger the important within- and between-team dynamics that occur in multiteam systems and separate them from other organizational designs, thus arguing that these designs are testing multiteam systems that are indistinguishable from traditional teams. It is therefore possible that the results from the Cuijpers *et al*. (2015) study might not be generalizable to large-scale real-world multiteam systems such as that utilized in emergency response.

Moreover, not only was a superordinate identity not found within the Williams (2011) study, but other theoretical and empirical work in the social identity stream of literature has questioned whether fostering a superordinate identity is always the most appropriate course of action. Research has shown that individuals favour identities that are highly distinctive (Brewer, 1991), and thus sole identification at a high level of abstraction (i.e. the superordinate identity) can leave individuals feeling over-included and indistinctive. Accordingly, even if leaders try to forge identification at this more inclusive level, individuals might resist such efforts to change their identities (Ellemers, 2003), and intergroup bias might be triggered as a result of identity distinctiveness threats (one of the two forms of identity threat suggested to inspire intergroup bias by van Knippenberg *et al.*, 2004). Hogg and Terry (2000) noted the externally imposed assimilation of identities is particularly likely to lead to identity threat in situations to which "the superordinate group is very large, amorphous and impersonal" (p.131), an assertion that was furthered more recently by Peker, Crisp and Hogg (2010) who showed that superordinate identification was significantly reduced when a superordinate identity was perceived to have complexity (i.e. a large number of defining prototypes). Such issues of distinctiveness are thus less likely to arise or be as significant when a multiteam system is as small as that studied by Cuijpers *et al.* (2015), but in real-world multiteam system contexts such as the emergency response context studied here and by Williams (2011), the risk of individuals feeling that their identity is being denied or suppressed by leaders highlighting a superordinate identity is much exaggerated and thus might not provide an appropriate course of action.

It is clear from the above outlining of the multiteam systems literature on social identity that the theory and findings are sparse and contradictory. From this, it is thus difficult to clearly ascertain how identity will likely impact on the functioning of emergency response multiteam systems (conceptualized as multilevel multiteam systems), nor how individuals can 'cut through' strong identification and intergroup biases in order to engender an effective response in a timely and coordinated manner. Further research on this is thus required, which is the reasoning for this research project.

2.4.3: Social identity within emergency response

To the best of the author's knowledge, there are no studies currently in circulation that consider the role of social identity within the emergency response system other than the study conducted by Williams (2011) discussed above. The multiteam system literature on this topic does little to provide a coherent and agreed upon idea as to how identity can influence the functioning and performance of such systems, especially in emergency response. Whilst the virtues of a superordinate or dual identity is generally extolled by the theoretical work in this area and in a single laboratory-based empirical study, the research on a real world multiteam system similar to that considered in this thesis found no evidence of a superordinate identity at all. Instead, Williams (2011) found that the system was able to function effectively through amalgamating groups with distinct identities.

As stated above, fostering a superordinate identity (also required for a dual identity) within a large system such as those used in emergency response could ironically risk entrenching negative identities and intergroup biases further due to the lack of distinctiveness proffered at this level. Moreover, the process of fostering a superordinate identity in emergency response systems is even more challenging due to the transient nature of such systems, as this would need to be developed in flight as the response was underway. Literature that currently pertains to developing superordinate or dual identities in organizational settings, such as Haslam, Eggins and Reynolds (2003) ASPIRe model and Fiol, Pratt and O'Connor's (2009) intractable identity conflict resolution model, generally suggests that such a process takes significant time and a multitude of phases or stages to be appropriately achieved. Such attempts would thus not be possible in the transient and fast paced environment of emergency response. This thus raises the question; how was the emergency response system in Williams (2011) study able to remain effective if a superordinate or dual identity were not fostered, considering the inherent way in which individuals aligning with disparate social identities is assumed to disrupt intergroup functioning?

Within the context of UK emergency response, the potential effects of social identity processes are even more complex due to the multilevel multiteam system design adopted, a design not previously considered in multiteam systems research. Agents within the system have two possible categories with which they can align; their originating organizational agency (i.e. police, fire service, local authority etc.) and their level of command (i.e. bronze, silver or gold). For clarity, I shall refer to agents categorizing themselves in accordance with the originating organizational agency as '*horizontal categorization'* (as this categorization creates distinctions at a single level of the hierarchy), and agents categorizing oneself in accordance with their level of command *'vertical categorization'* (as this categorization creates distinctions between groups at different levels of the hierarchy). Figure 3 below provides an example of these distinctions.

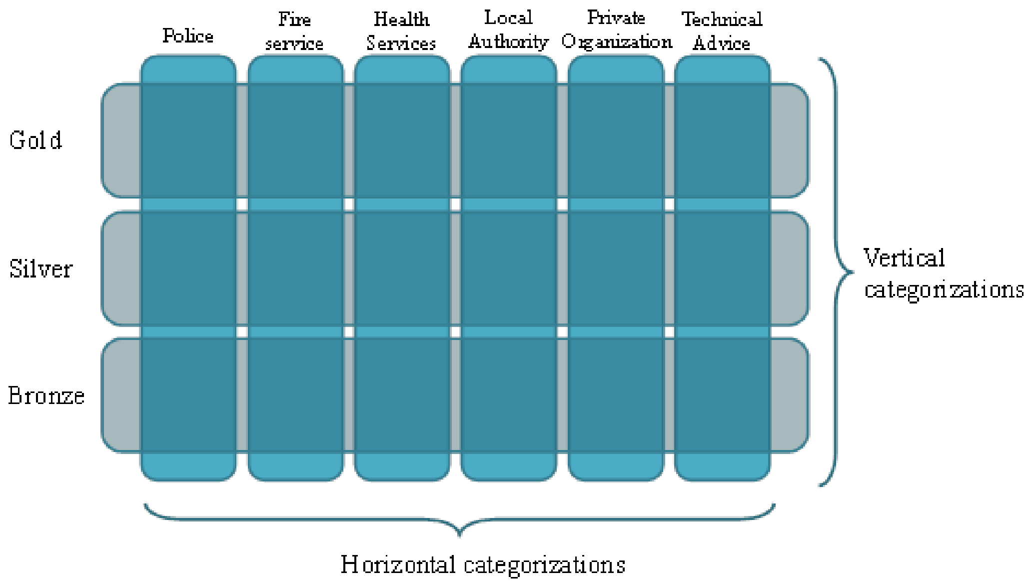


Figure 3: Example of the possible categorizations in emergency response

For the system to function effectively, integration between groups both horizontally and vertically is required, and thus this multilevel multiteam system design creates additional complexities. This is especially true in terms of communication, as effective communications are required both vertically and horizontally across the system. For example, Preece, Shaw and Hayashi (2015) found that breakdowns in communication and information sharing in the emergency response to the Great Hanshin-Awaji Earthquake in Japan in 1995 were both horizontal and vertical in nature, and that these breakdowns resulted in the response being less efficient and effective. Specifically, they found the breakdowns in communication along the vertical axis (i.e. within a single agency up and down the command system) led to increased confusion and delays in deploying critical resources. Breakdowns in communication along the horizontal axis (i.e. between the different agencies within a single command level) led to duplications of effort and silo-based thinking. This shows that effective functioning both horizontally and vertically is required for the emergency response to be effective.

The social identity literature suggests that identifying with any group that cuts across the system might be detrimental to performance through its influence on communication, and thus it is likely that having a high level of commitment to either one's vertical or horizontal categorization will have deleterious effects on system performance if intergroup biases also develop. However, social identity processes are extremely likely to occur in emergency response settings as the saliency of certain categorizations are high (especially one's horizontal categorization with their agency) and due to ambiguous, time pressured and politically charged nature of the emergency environment providing optimal circumstances for intergroup biases to form.

Whilst there are two grouping options with which agents may categorize themselves in emergency response, there is likely elevated salience of agency categories (i.e. the agents' horizontal categorization). Agency categories have high comparative fit as the different agencies provide a high meta-contrast ratio, with high similarities between agents from the same originating organization in terms of the organizational culture that have been socialised into, training experiences, uniforms and language that exacerbate the salience of difference with those whom do not share these properties (e.g. agents from other organizations). Agency categories also have a high subjective meaningfulness, thus increasing normative fit, as members within a single category will have similar job roles and responsibilities, whilst those external to the organization will have different roles based on the agency from which they originate (e.g. firemen will focus on fire-related factors whilst paramedics focus on looking after injured individuals). This categorization thus allows individuals to use identity cues as a simple basis for knowing who to turn to for successful completion of the task at hand. Finally, agency categories are also highly cognitively accessible, due to having been socialized into these categories during normal operating conditions and having past experience working with members within one's own agency, uniforms and numerous other identity symbols (such as on equipment and operating territories) that act as contextual cues that prime that category in the minds of those involved in emergency response. All of this suggests that agency categories are likely to be highly salient in emergency response situations, and thus provide a likely source of identification.

Moreover, not only are categorizations made salient within emergency response, but identification (i.e. a strong commitment to a categorization with a grouping that gets internalized into the individual's self-concept and governs their behaviour) is likely further compounded due to the high levels of uncertainty engendered in emergency response. Mullin and Hogg (1998) found that situations of uncertainty led to increased identification with the in-group as an uncertainty-avoidance mechanism. They empirically showed that in identifying more strongly, individuals then felt reduced uncertainty, as the identity provides guidelines in how an individual should think and behave. Thus in emergency response situations, in which uncertainty is an innate quality, individuals have increased desire to identify with the most salient category in order to reduce this negative emotional state.

Having categorised as part of their horizontal or vertical grouping, this is in turn likely to result in each agency attempting to portray the best possible image of themselves as professional and effective, and anything that could cause damage to this image will be avoided. Therefore, if these agency identities are subjectively threatened or challenged (in terms of either distinctiveness or value), intergroup biases will likely emerge that are disruptive to between-team functioning through their influence on individuals' willingness to elaborate task relevant information (van Knippenberg *et al*., 2004). Due to the politically sensitive nature of emergency response, and the high visibility to the public through public inquiries and media interest, emergency responders might be afraid to act in any way that may make their organization look bad. In addition, the environments they work in are highly changeable and ambiguous and so the probability of making mistakes is higher, and this notion is likely salient in the minds of the agents. This can therefore make the chances of feeling threats to the value of their identities higher, and thus emergency response situations are likely to be prime environments in which intergroup biases might manifest.

2.4.4: Summary

Within the above discussion, it is clear to see that social identity processes likely explain sub-optimization in emergency response systems. Emergency response systems are environments susceptible to identity related processes, due to the multiple groupings with which an agent can categorize themselves (i.e. both horizontally and/or vertically), the high salience of these categorizations (specifically their horizontal agency categorization), and the nature of the system making it impractical to develop an overarching superordinate or dual identity that might have alleviated some of the problems associated with agents identifying with groups that cut across the system. Moreover, the politically charged nature of the emergency response environment, and the fact that the situations they face are ambiguous, might make it more likely that identity threat is triggered, generating intergroup biases that disrupt communication between agents in different groupings.

However, very little is known about how identity related processes could manifest throughout the system and effect system optimization (through their influence on communication) within the multilevel multiteam system design adopted in emergency response contexts, especially in regards to how a system can remain effective without developing a superordinate or dual identity. The key question that needs to be answered in this research project is thus:

> ***How do social identity related processes, such as the grouping with which an agent categorizes, the level of commitment to this grouping, and intergroup biases, manifest throughout a multilevel multiteam system, and how does this impact on system-level communicative outcomes?***

This research is therefore explorative in nature, both attempting to test whether this theorised generative mechanism does indeed explain system-level communicative breakdown whilst concurrently creating further theory as to how the mechanisms of social identity may enact within the multilevel multiteam system.

Chapter 3: Method

3.1: Introduction

As outlined in the previous chapters, the aim of this research is to better understand why emergency response systems sub-optimize, increasing the risk to infrastructure, security and human lives. Within the literature review, I proposed that phenomenon associated with the social identity approach such as self-categorization, commitment and bias, likely cause communication issues across the system, and thus lead to the sub-optimization of response in emergencies. After raising social identity as a likely generative mechanism that leads to fracture and sub-optimization within the emergency response multilevel multiteam system, the key question of this research becomes:

> ***"How do social identity related processes (i.e. categorization, commitment and bias) manifest throughout a multilevel multiteam system, and how does this impact on system-level communicative outcomes?"***

To address this question effectively, agent-based modelling and simulation techniques are utilized, underpinned by the philosophy of critical realism. Agent-based modelling is especially suitable for this research as it specifically focuses on multi-level and emergent phenomenon, allows for a consideration of dynamic processes, and can make it possible to conduct extensive experimentation in contexts that would be difficult to access or understand through traditional methodological techniques.

Within this chapter, I shall first briefly explicate the alternative methods considered for this research project and why these were rejected before explaining what agent-based modelling is and how it is used within organizational research to expand or provide clarity to theory or even help develop new theory. In the second section of this chapter, I shall discuss how research on multiteam systems and emergency response is typically conducted, displaying how such techniques are limited in the extent to which they can uncover the phenomena of interest in this thesis, and highlighting how agent-based modelling can help circumvent these issues. Following this, I shall explicate the underpinning philosophy of critical realism, explaining its implications for the study of generative mechanisms of interest in this programme of work and providing a critical examination of how agent-based modelling can help uncover such phenomenon. Finally, I shall specify the software being used to create and simulate my agent-based models.

3.2: Alternative methods considered for this research

In attempting to answer the research question of interest in this research, a number of possible methodologies were considered before deciding to use agent-based modelling and simulation techniques. It was important that the correct method was selected for answering this question, as such design choices can influence the types of conclusions that can be drawn from research (Sackett and Larson, 1990). In this section, it shall be shown that whilst these alternative methods may have provided some answers to the question, they were not suitable within this research project, and that agent-based modelling can provide answers that other methods would struggle to uncover. These arguments are then further compounded when we look at the types of research conducted in multiteam systems and emergency response contexts specifically (see below section *3.4: Difficulties in researching Emergency response multiteam systems through traditional methods*).

The first option considered was observation research within naturalistic emergency response settings. Conducting observational research in applied, naturalistic settings enables one to see the “evolution and unfolding of social action through time and across situations” (Denzin, 2009, p.185). It therefore allows a more holistic understanding of the concept (Tedlock, 2000) as researchers are simultaneously able to capture both contextual information and detect the behavioural stream that initiated that behaviour (Gittelsohn, Shankar, West, Ram and Gnywali, 1997). Participant observation is also one of the least inferential methodologies (Goldfried and Kent, 1972), as the sampled data is actual behaviour in natural settings, and it therefore benefits from a high ecological validity.

However, observing emergency response MTSs in genuine civil emergencies obviously presents potential dangers to both the researcher and researched, and is therefore too hazardous for direct field study. Moreover, the fact that such emergencies are unpredictable and unexpected prevents the researcher from being able to plan and arrange access beforehand, an issue that is discussed in more detail below, as well as presenting additional ethical issues (see section *3.4.2: Challenges faced when researching emergency response*). This therefore did not present a viable option for this research project.

An alternative to studying such systems in their natural environment of real emergencies could involve observation or field experiments of emergency response training exercises. This would allow the researcher to study response patterns without the potential ethical issues, and is much easier to plan for beforehand. However, as discussed in more detail in section *3.4.2,* access to such contexts is still difficult to gain and the events are too large for a single researcher to fully comprehend or study, making it difficult to gain access to enough useful data required for making robust inferences regarding the explanatory power of the proposed causal mechanism(s). Even if a single researcher were able to gain access to enough training events and had the resources necessary to oversee the entire event, using observation techniques would preclude the ability to directly assess the internally based psychological constructs of interest within this research. The social identities of individuals and how this affects their interactions with others would have to be inferred by proxy measures rather than through direct measurement.

Field experiments could be conducted instead, where social identities are measured (or manipulated) at multiple different training exercises to more directly see how identification influences communication between agents of multiple groupings. Such a strategy would help gain realism of context due to being conducted in the field itself (although even this is questionable, due to the potential lack of generalizability between training events and real-world emergency scenarios), however, also leads to a reduction in the control of variables and precision of measurement afforded (Scandura and Williams, 2000). There are many possible confounding variables that could also influence the communication patterns of interest as dependent variables within this thesis, meaning that it would be impossible to isolate the influence of the factors of interest to make robust conclusions regarding the singular role of identity related processes. Moreover, stopping the training exercises to take measurements would risk disrupting the dynamics of the unfolding situation of interest in this research. For example, Rentsch and Small (2007) have noted that repetitive interruption for data collection can interfere with the development process of team mental models, creating measurement artifacts. Even if one could collect data at multiple points without disturbing the flow of the incident, the discrete nature of the measurements means the data would not be granular enough to fully understand non-linear effects that may occur.

To improve precision and control over the variables of interest and prevent confounding variables from influencing the study, laboratory experiments were considered. This would have allowed a specific consideration of how social identity related processes influences communication between participants. Laboratory experiments allow the researcher to isolate mechanisms and processes of interest through closed-system designs, and manipulate them to see how this influences the dependent variable(s). They also afford strict control over extraneous variables, thus ensuring high internal validity. For these reasons, laboratory experiments have been utilized by most MTS research to date (e.g. Cobb, Mathieu and Marks, 2003; DeChurch and Marks, 2006; Marks *et al.*, 2005).

However, as noted by McGrath (1982) and Scandura and Williams (2000), the precision afforded by laboratory experiments must be traded-off against the low generalizability and realism of context of such artificial environments. The role of context is completely disregarded (or controlled) in laboratory experiments, and the tasks and samples used are often unrepresentative of the population of ultimate interest, thus limiting the degree to which one can make inferences that can generalize to conditions outside of the narrow confines of the laboratory in which they have been generated. One of the main arguments within this thesis is that large-scale and multilevel multiteam systems utilized within emergency response contexts are likely to engender and require different dynamics to smaller, less complex systems, and thus it would be necessary to create very large experiments with numerous individuals participating to recreate the dynamics of the system of interest. It would therefore require an incredibly large number of participants, and likely result in student populations being utilized which would not be likely to be generalizable to the emergency response contexts of interest.

Moreover, there is much debate regarding how social identities can be manipulated within experiments (e.g. see the discussions regarding whether the minimal group paradigm experiments are actually maximal group studies by Reicher, Spears and Haslam, 2010 and the difficulties faced by Cuijpers *et al*., 2015 in attempting to manipulate identities in multiteam system contexts). Social identities (and their attendant processes of categorization and bias) are so inherently personal and suffused with historical and contextual information, that it is virtually impossible to replicate within a laboratory. Instead, identities and categorizations created within the laboratory tend to be arbitrary and temporary (Doosje, Spears and Ellemers, 2002) and thus not similarly meaningful as those used by individuals within the real world.

Finally, retrospective case-study based research was considered. This is typically used within emergency response research due to the inherent difficulties of gaining access to the context of interest mentioned above (e.g. Majchrzak *et al.*, 2007; Smith and Dowell, 2000; Weick, 1993, 2010). The use of retrospective reports allows the researcher to gain access to the contexts and populations of direct interest (i.e. emergency response collectives functioning in real emergency situations) without the risks associated with researching such populations and contexts as the incident unfolds (Buchanan and Denyer, 2013). However, as mentioned in more detail below (section *3.4.2: Challenges faced when researching emergency response*), these retrospective studies also face significant limitations, especially in regards to the quantity of data available and the whether the inferences made from such research are generalizable outside of the idiosyncratic cases considered.

Data availability, practical and ethical issues, and the inherently internal and unconscious nature of the concepts in question therefore create challenges for the study of emergency response multiteam systems using these more traditional methods. I therefore chose instead to utilize a relatively novel methodology that would provide a large data pool, maintain the precision and rigour over variables and measurement, and yet maintain the multilevel multiteam system structure of such contextual importance to this research: agent-based modelling.

3.3: What is agent-based modelling?

Agent-Based modelling is a relatively novel method that can be used to simulate human social interaction. Harrison, Lin, Carroll and Carley (2007) define simulation as "a computational model of system behaviour coupled with experimental design" (p.1234). Simulation is starting to become recognised as a 'third way' to do social science (Axelrod, 1997; Hulin and Ilgen, 2000; Waldrop 1994) as it is neither purely deductive nor inductive in nature (as opposed to traditional methods that generally fall under only one of these polarized logics). Simulation can therefore focus on the "sweet spot" between theory-creating and theory-testing (Davis, Eisenhardt and Bingham, 2007, p.481), with Holland (1999) suggesting that "it provides a halfway house between theory and experiment" (p.119). Agent-based modelling is one of the major paradigms that exists in simulation modelling, along with discrete event modelling and system dynamics modelling (Borschev and Filipov, 2004). It is a bottom-up technique in which researchers can 'grow' macro-level social structures and global patterns from their microspecifications; a distinct approach to social science that is termed 'generative' (Epstein, 2006; Epstein and Axtell, 1996).

Generative social science researchers are interested in the question “how could the decentralized local interactions of heterogeneous autonomous agents generate the given regularity” (Epstein, 2006, p.5). Generative social science is therefore focused on explaining *how* macro structures emerge from their micro-level constituents, rather than just demonstrating that the relationship between factors exists (Smith and Conrey, 2007). Agent-based modelling is the perfect instrument for permitting this distinctive approach to social science, as it provides computational demonstrations that a given microspecification is sufficient to generate a macrostructure of interest (a demonstration that is “taken as a necessary condition for explanation itself”: Epstein, 2006, p.8). Specifically, an agent-based model incorporates theoretically specified properties of individual agents (usually depicted as individuals, but can be conceptualised at lower- or higher-level specification, such as psychological model variables or as organizations respectively), their connections, and their interactions. The model is then run in a simulation to allow the observation of the complex collective patterns that emerge over time as a result of the agents’ behaviours and their interactions.

Agent-based modelling has been receiving revived interest in recent years as a methodology suitable for organizational problems. A number of recent papers in top organizational science journals have propounded the benefits of its use and urged organizational scholars to understand and utilize this methodology (e.g. Burton and Obel, 2011; Davis *et al.*, 2007; Fioretti, 2013; Harrison *et al.*, 2007; Hughes, Clegg, Robinson and Crowder, 2012; Vancouver and Weinhardt, 2012). Whilst they do not propose this methodology should be undertaken at the expense of other research designs, they argue that through its use we are able to understand problems intractable by other methodologies, and can offer insights that complement those found through traditional means. Whilst modeling has often been considered the ‘redheaded stepchild’ of organizational research methods (Hulin and Ilgen, 2000, p.7) a number of scholarly works utilizing computer modelling and simulations have made pioneering advances in certain organizational fields.

Examples include Cohen, March and Olsen's (1972) garbage can model, March (1991) and followers research on exploration and exploitation (e.g. Lazer and Friedman, 2007; Levinthal, 1997; Rivkin and Siggelkow, 2003; Siggelkow and Levinthal, 2003; Siggelkow and Rivkin, 2006), research on organizational imitation (e.g. Chang and Harrigton, 2007; Rivkin, 2001) and leadership (see Hazy, 2007 for a review).

The main strength of agent-based modelling is in its ability to enable discovery through conducting virtual conceptual experiments, allowing for the construction of new theory and/or further articulation and development of existing theories (Bonabeau, 2002; Burton and Obel, 2011; Epstein, 1999, 2006; Gross & Strand, 2000; Kozlowski, Chao, Grand, Braun and Kuljanin, 2013). The precision afforded by the method allows the identification, articulation and testing of underlying logic for theories (Ren, Carley and Argote, 2006), and can reveal variables omitted in prior theory (Davis *et al.* 2013). This is especially true when theories are dynamic in nature and thus difficult to study through conventional methods (Davis *et al.*, 2007; Hughes *et al*. 2012). As noted by Vancouver and Weinhardt (2012), "organizational scholars often develop verbal dynamic theories, but there is little discussion of how the dynamic relationships play out over time" (p.603). Agent-based modelling is especially useful for uncovering such dynamic processes, as time is explicitly modelled within the simulation (Gilbert and Troitzsch, 2005) and one can therefore plainly see how things change or occur over time as the simulation unfolds. This allows for an in depth inspection of how the proposed mechanisms shape and change system-level dynamics over time, and thus provides a clearer understanding of exactly how the generative mechanisms proposed create the phenomena of interest.

Not only are there advantages to using agent-based modelling simulation in general, but it is also a suitable alternative tool to use when an area would be unfeasibly studied using traditional methodological techniques, or when these techniques would be incapable of fully or even representatively capturing the full dynamics of the situation (Dionne and Dionne, 2008; Eidelson and Lustick, 2004; Heinke, Carslaw and Christian, 2013; Kozlowski *et al*., 2013). Due to the inherent complexity within both the areas of multiteam systems and emergency response, methodological problems are rife, and make the study of such systems difficult. In the following sections, I shall illuminate some of the issues faced in studying both multiteam systems in general, and emergency response systems specifically, and display how agent-based modelling is a useful tool for circumventing these issues.

3.4: Difficulties in researching emergency response multiteam systems through traditional methods

3.4.1: Issues with previous research on multiteam systems

As highlighted by Davison *et al.* (2012), multiteam systems exist in a performance environment that is difficult to study through traditional means. Multiteam systems are often dynamically formed and are large-scale by nature, making them relatively intractable for study via traditional methods. Whilst a number of scholars have surmounted this problem through the utilization of 'scaled world designs' (Mathieu, Cobb, Marks, Zaccaro and Marsh; 2004) in which they simulate flight or fire-fighting in laboratory experiments, the systems studied in these contexts are often small in scale, comprised of only two or three two-person teams with limited unique specialization (e.g. Cuijpers *et al.,* 2015; DeChurch and Marks, 2006; Lanaj *et al.,* 2013; Marks *et al.*, 2005). Davison *et al.* (2012) notes that such designs are unlikely to trigger the important within- and between-team dynamics that occur in multiteam systems and separate them from other organizational designs, thus arguing that these designs are testing multiteam systems that are indistinguishable from traditional teams. Davison *et al*. (2012) then showed that in considering a more realistic multiteam systems design, they found results that, whilst theoretically expected, conflicted with previous multiteam systems research.

This work by Davison *et al*. (2012) thus suggests the need to study more 'life like' multiteam systems that are representative of the multiteam systems found in practicing organizations. This view is also implied by the fact that other multiteam systems research conducted out of the laboratory has also seemingly produced findings that contradict studies conducted using small scale methods utilized in early multiteam systems research. For examples, in her consideration of a real-world emergency response system, Williams (2011) did not find that a shared superordinate identity was required for the system to function effectively. However, when similar research was conducted on only a small multiteam system (comprised of only two teams with only two members in each), Cuijpers *et al.* (2015) found that an overarching superordinate identity was essential. It is highly likely that the difference between the findings of these studies is influenced by the size and unique specialization of the multiteam system in question. Healey *et al.* (2009) further affirm this view, stating that studies conducted in "demanding naturalistic contexts will potentially yield a far richer understanding of the operation of multiteam systems than studies conducted in the sparse confines of the laboratory" (p.3).

The need to study more complex and realistic forms of multiteam systems therefore suggests the need to study such systems within the context of real world multiteam systems designs, such as within the context of emergency response. However, there are a number of difficulties in using traditional methods for this, such as the requirement for research to consider the multi-level nature of multiteam systems, and the intractability of studying real-world emergency response systems. However, whilst these issues, discussed in more detail below, do make studying the dynamics of emergency response multiteam systems intractable through traditional methods, I shall show how these issues can be alleviated through the utilization of a specific non-traditional methodology – agent-based modelling computer simulation. A similar argument was proposed by DeChurch and Mathieu (2009), who suggested that non-traditional designs such as modelling may be required to enhance our understanding of these complex systems and to circumvent the issues of modest sample sizes and cumbersome data collection that plague multiteam systems research.

3.4.1.1: Multi-level focus in multiteam systems

Multiteam systems are complex organizations for study. As Davison *et al.* (2012) highlighted, they are a 'hybrid' organizational form, taking aspects from traditional teams and traditional organizations concurrently. The multiteam systems concept thus simultaneously emphasises both the system as a whole and its component teams (Mathieu *et al.*, 2001). Consequently, the levels of analysis important for multiteam systems concurrently resides at the level of the individuals that compose the system, the component teams to which they belong, and the system as a whole. Prior multiteam systems research has shown that these systems function as more than just the sum of their parts with additional variance in multiteam systems performance found that cannot be accounted for through the additive performance of the teams that construct the system (e.g. Marks *et al.*,2005; DeChurch and Marks, 2006; Healey, Hodgkinson and Teo, 2009). This research highlights emergence from different levels of analysis, with new properties of the system emanating from the interactions of the parts at the level below. Any research on multiteam systems thus has to take account of these multiple levels of analysis and the emergent properties that arise between the levels that comprise the system, and that researchers cannot just assume that facets true at the team-level of analysis will also aggregate isomorphically at the system level of analysis (DeChurch and Mathieu, 2009; DeChurch and Zaccaro, 2010).

In order to understand when and how the system optimizes or sub-optimizes – the phenomena on which this research is based – it is therefore important to consider these emergent properties in existence within multiteam systems. Kozlowski and Klein (2000) define a phenomenon as emergent when "it originates in the cognition, affect, behaviours, or other characteristics of individuals, is amplified in their interactions, and manifests as a higher-level collective phenomenon" (p.53). In order to therefore gain understanding of why a system may sub-optimize in the context of emergency response multiteam systems, it is imperative to consider the process mechanisms inherent in the micro-interaction dynamics of the system (i.e. the agents and teams that comprise the system) that culminate into the system-level collective phenomenon. Scholars must ask; what parsimonious ‘rules’ drive agent interactions and processes in a way that leads to the manifestations of a collective macrostructure of interest (Epstein, 1999)?

Whilst multi-level research has grown in popularity recently, highlighted in the development of the ‘meso paradigm’ in which scholars note that any phenomena of interest is the result of an amalgamation of influences emanating from the levels surrounding it (House, Rousseau and Thomas-Hunt, 1995; Rousseau, 1985), true multi-level research is still limited. Mathieu and Chen (2011) and Kozlowski *et al*. (2013) both note that multi-level research thus far has predominantly focused on the ‘top down’ influence of structures on agent behaviour rather than a consideration of emergent processes from the ‘bottom up’, and suggest that this is due to the inability of current traditional quantitative methods to directly capture the dynamics of emergence. Kozlowski *et al*. (2013) attribute these difficulties to the fact that emergent phenomena are intrinsically multi-level, process oriented and temporally sensitive in nature, three aspects that are difficult to concurrently capture using traditional quantitative designs. Despite this, Mathieu and Chen (2011) note that such upward influences “can still be prominent in instances where higher-level phenomenon have yet to fully crystalize or form” (p.616), such as in settings where individuals have not worked together previously. In emergency response multiteam systems, the individuals amalgamate dynamically on the basis of the situation, and thus are prime contexts in which emergent properties will arise from the interactions among lower level entities to yield phenomena manifesting at higher, collective levels.

In order to circumvent the issues traditional quantitative methods face in considering multi-level or emergent phenomena, factors that are both critical for understanding multiteam systems, Kozlowski *et al*. (2013) present agent-based modelling as a viable methodological option. As agent-based modelling involves the specification and implementation of micro-level rules which govern the behaviour and interactions of agents and allows these process dynamics to occur over time to form patterns of effects at the macro-level, it inherently includes the aspects proposed by Kozlowski *et al*. (2013) as important for considering emergence; that it is multi-level, process oriented and temporally sensitive. They thus suggest that “although conventional correlational and experimental research methods are challenged with respect to studying emergence, computational modelling and agent-based simulation offer distinct theoretical and methodological advantages for direct investigation of the dynamic processes that yield emergent macrostructures” (p. 601). Moreover, agent-based models are multi-level by nature. The phenomenon of interest originates from the lower level of the system, in this instance the agents that comprise the system, as this is where the logical ‘if-then’ rules are implanted. Measures are then taken at the higher-level, the system, in order to identify the way in which the collective phenomenon manifests. Agent-based modelling therefore considers both macro and micro levels concurrently (Saam, 1999). Agent-based modelling is thus suitable for the study of phenomena that are multi-level and that emerge from the dynamic interaction of lower level constructs, such as collective communication patterns in emergency response multiteam systems.

3.4.2: Challenges faced when researching emergency response

Not only does agent-based modelling provide significant opportunity to study the multi-level and emergent properties important in multiteam systems research, but it also offers an opportunity to study an area that is often problematic with other traditional methods: emergency response. Emergency response environments are inherently difficult to study for a number of reasons. Firstly, emergencies are by nature unexpected events, and thus research conducted on the response could not easily be pre-planned. This makes access to required data incredibly difficult, as the researcher would either have to spend significant time in the right context awaiting a suitable emergency, or happen to be there by chance in order to get direct access to the emergency response environment. Secondly, observing the response to genuine civil emergencies raises questions of safety for both the researcher and researched as the environments are often hazardous and any diversion of attention of the responders away from their activities for study purposes could increase the potential risks to everyone involved. Finally, it would be ethically questionable to study a live emergency; those involved in the event may not wish to partake in any research and may possibly be shocked or traumatized further by researchers in the field, confidentiality and anonymity might be jeopardized, and the potential to cause more harm to participants substantially outweighs the benefits of conducting such research.

Some researchers have thus chosen to study emergency response through the observation of their training exercises, such as the research conducted by Healey, Hodgkinson and Teo (2009). This allows researchers to garner an understanding of the dynamics of emergency response whilst avoiding the practical and ethical issues associated with studying real world emergencies. However, time and resource constraints, in addition to the difficulties inherent in gaining access to such politically sensitive contexts, can make it problematic to gain access to enough data to make robust inferences about the relationships between the concepts in question. Moreover, because of the large size and distributed nature of emergency response multiteam systems (often located across at least 3 different locations in accordance with their gold/silver/bronze architecture), it would be unmanageable for a single researcher to fully comprehend everything that occurs and isolate the effects of specific plausible mechanisms. A consideration of the emergency response training environment thus does not present a viable option for the study of system sub-optimization of interest for this research project.

As noted by Buchanan and Denyer (2013), the issues inherent in studying emergency response directly have meant that “researchers have been required to adopt designs and methods considered unconventional in other areas, and to use data from sources normally considered unreliable or biased” (p.206). In general, research in this area is forced to retrospectively study idiosyncratic case study events qualitatively, using sources such as government inquest reports or information provided by the media. However, such sources are often considered ‘impression managed’ versions of reality as authorities attempt to allay public concern (Brown, 2000; Brown, 2003). Even direct access to participants involved in the event is unlikely to garner unbiased accounts due to the highly political nature of emergency response. Participants are unlikely to have accurate retrospective accounts of exactly what occurred or how they acted and might actively change their accounts in an attempt to avoid blame.

Moreover, the findings of most emergency response research are typically focused on ‘lessons learnt’ and practitioner focused outputs, favouring the production of guidelines, response plans and protocols to be adopted in future response situations (Millar and Heath, 2004). However, Pearson and Clair (1998) note that “the mere existence of policies and procedures may be false signals of preparedness” (p.69). The unique nature of such events often makes the utilization of policies and procedures developed from one event hard to translate to alternative settings, and thus such implications are often disregarded (Toft and Reynolds, 2005). With the utilization of non-traditional sources of information, and tendency to focus on practitioner oriented outcomes, emergency response research has thus far made limited inroads within theory development and thus has “not been as prevalent and impactful in mainstream management journals as we would hope or expect” (James, Wooten and Dushek, 2011, p.484).

I argue that rather than studying emergency response in terms of one-off crises events that occur (as is the focus of most research in this area), it will instead be theoretically and practically fruitful to consider issues, themes and patterns common to every response event. Rather than creating another procedure that can only be utilized in a small number of isomorphic incident settings, I instead turn to look at factors that influence how the system functions ‘in flight’ in order to ascertain how such factors can be effectively managed to optimize the system regardless of the specifics of the emergency situation being faced. This approach thus requires an alternative method to the one-off retrospective case study research that predominate this area.

To circumvent the issues outlined above and consider the basic properties of emergencies inherent in all contexts rather than a single case, I have chosen to adopt agent-based modelling computer simulation methods to study how an emergency response multiteam system may dynamically function under specific parameter settings to produce optimized or sub-optimized outcomes. The artificial nature of simulations eliminates many of the restrictions that are imposed on traditional empirical study. As outlined by Gilbert (2008), "a major advantage of agent based modelling is that the difficulties in ensuring isolation of the human system and ethical problems of experimentation are not present when one does experiments on virtual or computational systems" (p.3). As the agents are constructed from code via the specifications of the researcher, and the simulation produces its own 'virtual' data (Harrison *et al.*, 2007), there are no ethical or practical concerns when operating in computer environments (Smith and Conrey, 2007). Agent-based modelling is particularly effective, therefore, in situations such as the present one, where it is difficult to gain access to real-life data (Harrison *et al*., 2007).

The artificiality of the input data also makes it possible to run the experiments as many times as necessary in a fraction of the time and cost needed for traditional empirical work with human participants (Scholl, 2001) and enables experimentation across a wide range of parameter values. Even arbitrary or unrealistic parameter values can be tested, making it possible to test the boundary conditions for a theory even if such circumstances do not exist in the real world. This thus makes it possible to run a number of experiments on the emergency response system, providing an amount of data that would be unfeasible to gather if considering real world emergency response systems or those within training exercises, enhancing the ability for inferring effects that consistently affect the system and thus improving the ability to garner theoretically interesting outcomes. Agent-based modelling is thus a suitable methodology to adopt to prevent the issues of intractability within emergency response research.

3.4.3: Summary

The above consideration of previous research methods adopted within multiteam systems research and the emergency response literature highlights that previously adopted methods for both areas are limited in the inferences that they are able to make. Both scholarly areas are in need of research that considers real-world versions of the systems in question, and yet I have also explained how such field research would be problematic for the study of emergency response multiteam systems. Instead, agent-based modelling has been proposed as a method that circumvents these issues. It allows me to simulate a real-world emergency response multiteam system whilst avoiding the ethical and practical issues associated with direct field study. Furthermore, multiple levels of analysis and emergent properties that originate from the level of the individuals that comprise the system but manifest at the multiteam system level of analysis can be considered. It thus offers a viable alternative methodology for studying such a problematic area.

Miller (2015) contends that due to its focus on mechanisms, emergence, simplifying assumptions and abductive logical reasoning, agent-based modelling suits itself to the philosophy of critical realism, and thus this is the philosophy I have adopted to underpin this research project. This philosophy suits the research question in general, as I aim to uncover the generative mechanisms that lead to system optimization or sub-optimization in emergency response through testing the influence of a theoretically proposed mechanism within this organizational design. In the next section, I shall explicate briefly the underpinning beliefs of the critical realist school of thought, before delineating how agent-based modelling allows for the consideration of facets important to those adopting this philosophical approach.

3.5: Philosophical approach: Critical realism

Critical realism "claims a sensible middle ground between empiricism and relativism" (Demetriou, 2009, p.440). In general, those within the critical realist school of thought ontologically accept the existence of external 'truth' in a manner similar to positivists and empiricists. However, whereas positivists believe that this external reality is directly observable through the Humean notion of constant conjunction, and that the aim of investigation should be to expose covering laws of cause and effect relationships (Demetriou, 2009), those within the critical realist school of thought believe that reality has three separate domains and that only the final domain can be directly accessed. These domains are made up of (a) the domain of the real, which is the external reality that exists outside the minds of agents (and is thus intransitive), and which may not necessarily be actualized; (b) the domain of the actual, referring to the events and mechanisms from the domain of the real that are activated and accordingly become realized; and (c) the domain of the empirical, which refers to reality that is experienced by agents through the senses, thus becoming a 'representation of reality' that is transitive and value-laden (Bhaskar, 1978).

Consequently, whilst reality does have an objective externality, we are unable to experience much of this, with realists thus claiming 'transphenomenality', as knowledge is not only what it appears, but goes beyond to the enduring underlying structures that generate such appearances (Collier, 1994). Therefore, those following the critical realist school of thought believe that positivistic approaches merely uncover the experienced 'representation of reality' that are subject to social conditioning and other perceptual determinants, and that as social scientists we should be aiming to understand the ontologically deeper notion of causality that emerges from the intransitive dimensions. Social scientists should therefore "step away from the description of regularities to their explanation" (Pawson, 2000, p.288) to look at the causal relationships that underlie statistical associations, which is located at the level of the generative mechanism.

The critical realist school of thought assumes that the world is stratified and consists of hierarchically ordered levels (e.g. molecular, neuronal, psychological and sociological), where emergent properties of lower levels create the conditions for higher levels (Bhaskar, 1978). Each stratum is made up of internal structures and relations with certain 'emergent powers' that can be triggered to emanate as causal mechanisms of influence to the levels above it. These triggered generative mechanisms then produce patterns of events that are experienced in the real world, known as 'tendencies', and thus "comprise the real bases of causal laws" (Bhaskar, 1986, p.27). The critical realist school of thought believe that science should be an on-going process of digging deeper and deeper into these stratified levels of reality to identify the generative mechanisms and how these work themselves through in specific situations to result in displayed tendencies (Lawson, 1997; Pawson and Tilley, 1997). Bhaskar (1979) thus contends that realism's key question for social science is "what properties do societies and people possess that might make them possible objects of knowledge for us" (p.17).

Critical realists face a problem in such aspirations however, as mechanisms are determined within the intransitive dimension of reality which can never be directly accessed. Firstly, depending on the situational contingencies, it is possible that mechanisms never become actualized and manifest into tendencies through events at all, instead remaining as unobservable structural potentiality (Demetriou, 2009).

Secondly, even if they are triggered, they may not be realized in the consciousness of the actors who are subject to them, as the transitive conceptual schemas we employ to interrogate the world contains its own structures and mechanisms (such as ideologies) which can make it difficult to perceive the world as it really is (Vincent, 2008).

Thirdly, even if they are experienced, it is likely to be to different degrees of regularity due to noise and mechanism interaction inherent in open systems, which makes it possible for mechanisms to obscure one another and produce codetermined outcomes (Bhaskar, 1979). In such situations, it would be unfeasible to isolate a single mechanism as the cause of a particular experienced pattern of events. Adding to this the possibility for counter-phenomenality (whereby the experienced tendencies appear to contradict the deeper structures that create them: Collier, 1994) and vertical explanation (whereby mechanisms of different levels of reality may possibly generate the same event: Bhaskar, 1986), the identification of influential structures and mechanisms is extremely difficult.

Finally, the social world is in a more constant state of flux than the natural world, partly due to the nature of agents with the ability to reflect upon, reproduce or transform the very structures that determine their behaviour in the first place, it is therefore unlikely that the same structures and mechanisms will result in the same outcomes on different occasions. Taken together, this means that (a) one cannot just use the concept of a constant conjunction to look for tendencies caused by mechanisms, (b) the non-realisation of a posited mechanism cannot be taken to signify its non-existence, and (c) there is the possibility of hidden mechanisms that are never experienced.

Having acknowledged the epistemological limitations those within the critical realist school of thought face in trying to identify the ontological mechanisms in their totality, this does not undermine the use of critical realism in research. Advocates of critical realism have asserted that instead of following this 'true aim' to uncover all the possible structures and powers that may possibly influence our experiences and tendencies in the real world, scholars should attempt to "explain the occurrence of particular events in terms of conjunctions of the causal properties of various interacting mechanisms" (Porpora, 1998, p.344), adopting what Demetriou (2009) terms the 'weak programme'. This notion of a weak programme underpins the idea that researchers use the logic of retroduction to work backwards from an explanandum in the empirical world to postulate the possible mechanisms that could produce the observed effects (Blaikie, 1993; Sayer, 1992). Demetriou (2009) posits that the explanatory mechanisms uncovered through such processes must be considered as ‘heuristics’ for the identification of mechanisms in the intransitive world, putting “faith in the idea that real mechanisms have an affinity with the domains of the empirical and of the actual and thus betray something of themselves to the empirical researcher” (p.457). This means that the mechanisms themselves can only be discovered through conjecture, and thus will always be provisional, partial, and speculative in nature, open to the possibility of being fallible and extendable as knowledge grows. Critical realism therefore “rejects both verification and falsification as definitive arbiters of reality” (Scott and Briggs, 2009, p.230) and instead suggests arbitration through the logic of abduction (uncovering the best set of explanations for interpreting and understanding one’s results: Johnson and Onwuegbuzie, 2004).

In sum, in critical realism, it is generally held that mechanisms exist in a ‘nested hierarchy’ (Craver, 2001) and consequently that “for a higher-level law to be mechanically explicable, it must be realized by some lower-level mechanism” (Glennan, 1996, p.62, *cf.* Mayntz 2004). Craver (2001) posits that it is therefore possible to look at an entity at a given level in three possible ways: (a) in isolation, (b) constitutively (identifying the lower-level mechanisms that generate its activity), or (c) contextually (showing how it fits into the organization of a higher level mechanism). As this thesis aims to generate understanding of a phenomenon within a collective, the critical realist perspective suggests that to explain such social-level phenomena, one must consider both the mechanisms generated at the level of constituent individual agents and their interactions, and the new properties that emerge to have their own mechanistic powers at the collective level (Mayntz, 2004).

3.5.1: Why agent-based modelling is a suitable methodology for a critical realist

Those within the critical realist school of thought support a plurality of research methods that aid in the theory building and testing of the generative mechanisms that cause phenomena of interest (Mingers, 2004; Miller and Tsang, 2011), and thus is "compatible with a relatively wide range of research methods" (Sayer, 2000, p.19). Agent-based modelling however is not only a tool that can be utilized by critical realists, but is almost designed exclusively for research conducted on the basis of this school of thought. Miller (2015) ascribes this link between agent-based modelling and critical realism as due to the inherent focus of both on mechanisms, emergence, simplifying assumptions and abductive reasoning

As Miller (2015) contends, "the identification of generative mechanisms characterizes the explanatory strategy of modelers" (p. 178). In the creation of an agent-based model, the modeller must specify the processual mechanisms or rules that are enacted as the model is simulated. Rather than focusing on predicting outcomes from inputs, models reveal how the proposed causal mechanisms generated the outcomes of interest (Mingers, 2004). For this reason, Epstein (2006) refers to computer simulation as 'generative' social science. It is thus implicit in the modelling process that the generative mechanisms proposed to explain collective phenomena are outlined and directly simulated.

When considering mechanisms of influence, it is also important to take a dynamic perspective of how these processes occur to explain macroscopic patterns. In studying any social system, it is not only important to understand the outcomes or static events that occur, but also the processes through which they are created and change. Human interaction patterns and the flow of information through a system do not occur in a single moment, but instead occur over time. Agent-based modelling is especially good for uncovering such dynamic processes, as time is explicitly modelled within the simulation (Gilbert and Troitzsch, 2005) and one can therefore plainly see how things change or occur over time as the simulation unfolds. This is especially critical for discerning non-linear behaviours, such as tipping points, thresholds, or feedback loops that other techniques might fail to detect. Therefore agent-based modelling has opened new avenues for research that is intractable with traditional methods (Scholl, 2001) such as when phenomena are longitudinal, processual and non-linear in nature (Davis *et al.,* 2007), allowing us to understand complex real world phenomena "not as reflecting static relationships among variables but rather as emergent results of dynamically interactive processes taking place in their contexts" (Smith and Conrey, 2007, p.102). Within this research, I have proposed a possible generative mechanism that theoretically might explain why system-level sub-optimization occurs. Through modelling the dynamics of this proposed behavioural mechanism directly, agent-based modelling allows me to precisely see how the proposed mechanism influences the system-level phenomena of interest, and thus is suitable for this thesis.

Agent-based modelling, as stated previously, is also the perfect tool for studying emergence, a facet that is important to critical realists due to their view of the world as stratified into levels. As noted by Epstein (1999; 2006), agent-based modelling is a generativist tool in which macroscopic social regularities are 'grown' from the specification of lower level rules, such as how social behaviour is generated from the behaviour of individual members. Global system behaviour is unspecified, and so is allowed to emerge through processes of self-organization and interaction. This ability to capture emergent system properties by focusing on the individuals that compose it is significant, as it allows us to discover complex systems behaviour that would not have been expected if analyzing the component parts in isolation (Holland, 1999), and therefore uncover unforeseen or counterintuitive effects. As Smith and Collins (2009) articulate, "even a full understanding of these microprocesses does not suffice to predict the patterns of outcomes that emerge when multiple sources and targets of influence linked [together]... interact and mutually influence each other over time" (p.344).

Furthermore, agent-based modelling allows one to dig deeper and deeper into the stratified levels of reality simply by generating system-level dynamics from lower level specifications. For example, an agent-based model does not need to specifically focus on agents as the lowest level of analysis, but can instead study the interactions of atoms or cognition. For example, Troisi, Wong and Ratner (2005) used agent-based modelling to study molecular self-assembly. One can therefore study emergent properties from any given level of reality provided that the level the 'agent' resides at is correctly specified within the model. Thus agent-based modelling suits the study of emergence, and as stated by Kozlowski *et al*. (2013), might be one of the only quantitative tools currently existing that is able to capture this dynamic directly. Within this thesis, I am specifically interested in how interactions of agents specified at the level of the individual, placed into group structures, in turn influences system-level outcomes. I am thus interested in how the macro-level system characteristics emerge directly from the levels below, and thus agent-based modelling is the perfect tool for uncovering such dynamics.

Agent-based modelling also inherently forces the modeller to make simplifying assumptions and to relate the collective phenomena of interest to the simplest set of rules possible to sufficiently create that macro-level outcome (Simon, 1990). The exclusion of confounding elements through modelling allows the modeller to be sure that their presence did not affect the collective outcomes, and thus makes clear which limited sets of inputs generatively created the collective level outcomes and helps to separate out whether certain mechanistic explanations are more appropriate than others. This therefore provides greater transparency regarding whether a proposed generative mechanism is the cause of the phenomena of interest, and how this mechanism enacted throughout the system to create such phenomena, questions that are both of interest to critical realists. However, modellers must nonetheless attempt to balance this simplification and transparency of generative mechanisms with veridacality (i.e. the extent to which the model reflects reality) in order to make theoretical and practical contributions that are worthwhile to social science (Carley, 2009). Within my model, I have kept the model as elegant and parsimonious as possible in order to gain insight into how facets of the social identification approach might influence collective system-level optimization. Concurrently, I have modelled an emergency response system that could be true to real life to maintain a practical amount of realism without increasing complexity to the point that inferences regarding this mechanisms influence cannot be determined. This should thus ensure that theoretical insights can be garnered whilst maintaining relevance for practice, a balance that is highly sought after in organizational research (Hodgkinson and Starkey, 2011).

Agent based modelling also utilizes the same logical reasoning as that preferred by critical realists; abductive reasoning (Halas, 2011). In agent-based modelling, the modeller must use such reasoning to work backwards from a phenomenon they wish to explain to the possible mechanisms that create this phenomena. The modeller's key question is thus "what must be true about the real system in order to produce its observed dynamics" (Miller, 2015, p.180)? Agent-based modelling can be used as a tool to experiment with different 'what if....?' scenarios to uncover how different postulated micro-level specifications (i.e. proposed generative mechanisms) differentially consequence the system (Hughes *et al.*, 2012; Smith and Collins, 2009; Twomey and Cadman, 2002). Through these 'thought experiments', modellers can use unexpected findings or systems behaviour uncovered to generate new hypotheses to be tested through further empirical studies and techniques (Smith and Conrey, 2007). In this way, agent-based modelling allows for theory building and theory testing concurrently, and thus allows the speculation and testing of theories regarding the generative mechanisms believed to generate given macroscopic behaviour. As there is currently a lack of empirical research regarding the influence of social identification within multilevel multiteam systems, agent-based modelling is a suitable tool for allowing the required exploratory study whilst maintaining rigor.

As explicated above, a number of key ontological and epistemological assumptions forwarded by critical realists are directly related to how a modeller creates a model, and how this model then generates data through simulation. It allows the study of multi-level (stratified) phenomena, consideration of emergent properties that ‘grow’ between these levels of reality, and explicitly focuses on outlining the generative mechanisms that cause this growth through processes of simplification and abduction. Agent-based modelling thus is a perfectly suited tool for any scholar adopting a critical realist approach such as is adopted for this research project.

3.6: Software: NetLogo

To create an agent-based simulation, researchers have the choice of a number of possible ‘modeling environments’ (Gilbert, 2008), such as Swarm (Minar, Burkhart, Langton and Askenazi, 1996), Repast (North and Macal, 2005) and NetLogo (Wilensky, 1999). Rather than having to start completely from scratch, these computer programmes allow the researcher to use libraries of already programmed commonly used elements (known as primitives) thus making agent-based modelling more broadly accessible. They also reduce significantly the amount of time taken to develop models and decrease the chances of making errors. These environments take an ‘object oriented’ programming approach, in which model specifications are written in pseudo-code.

NetLogo, currently the most popular agent-based simulation environment (Gilbert, 2008), is the software system that will be used in the present work. This programme is suitable for both the novice and expert modeller, due to the fact it employs a mixture of “low threshold, high ceiling” language (Papert, 1980) and its capabilities for using advanced additional tools (such as a system dynamics modeller). NetLogo presents the user with three tabs: (1) an Interface tab, used to visualize and control the output from the simulation; (2) an Information tab, for providing text-based documentation regarding the nature of the simulation; and (3) a Procedures tab, used to create and write the simulation program using the NetLogo language. The framework of Netlogo that can be controlled by the researcher consists of agents (known as turtles), environmental locations (known as patches) and their interactions (which can be agent-agent, patch-patch, and agent-patch). There are no programming constructs for explicitly controlling the global structure and so global patterns must instead ‘grow’ from the behaviours and interactions of the lower-level autonomous agents and patches, therefore displaying emergence (Epstein, 1999).

A NetLogo program is made up of three parts: (1) the global variables, which specifies the nature of agents within the model and the variables available to these agents; (2) a setup procedure, which initializes the simulation; and (3) the go procedure, which activates a number of programmes and runs the simulation. The user can also add in buttons and sliders to represent a range of different values of the main parameters and thus examine the effects that changing a given parameter has on the collective patterns that emerge at higher levels of abstraction.

NetLogo is also helpful when it comes to experimentation, allowing the user to conduct experiments within the same software system through its ‘BehaviorSpace’ facility. BehaviorSpace conducts automatic repetitions of the simulation for all combinations of a specified set of parameter values and records the collective outputs of each in tables and graphs. The simulation model therefore becomes the subject of a systematic investigation and can aid in the goal of understanding the consequences of different theoretical assumptions (Smith and Conrey, 2007). NetLogo thus constitutes an ideal system for undertaking the present programme of work.

Fioretti (2013) notes that to keep the status of computer simulation to as high a standard of scientific inquiry as possible, researchers must ensure that any programming code is made publicly available. He states that this helps ensure that other scholars can verify that the model really produces the results claimed by the author, thus ensuring replicability, and for peers to verify that the same dynamic results are found across a multitude of simulation languages and platforms, a technique known as docking. Both of these aspects help improve the validity of the simulation model. I have therefore included a copy of my code within this research project, which can be found in *Appendix 1*.

3.7: Summary

In order to understand how facets of social identity influence communication patterns in emergency response, a system conceptualized as a multilevel multiteam system, I have utilized agent-based modelling methods. This method provides a number of benefits for studying complex, dynamic interactions that manifest into collective level phenomena, and allows for exploratory study whilst maintaining rigor. Furthermore, studying both emergency response and multiteam systems is problematic when utilizing traditional methodologies, but agent-based modelling is able to circumvent the problems that arise in both. Agent-based modelling has thus been shown to provide a suitable methodology for studying this complex area.

This research is also underpinned by the philosophy of critical realism. Within this chapter I have shown how agent-based modelling is a method that allows the direct study of facets that those within the critical realist school of thought hold as fundamental, and thus is suitable for answering the questions raised by scholars such as myself who follow this approach.

In the next chapter, I shall explicate the exact specifications of the model created for this specific research project, clarifying the mechanisms and parameters utilized for my agent-based modelling simulation experiments.

Chapter 4: Model Specification

4.1: Introduction

The method employed to explore the influence of identity related processes on emergency response multiteam system communicative performance is to construct an agent-based model and run a number of simulations within this model. As mentioned in the previous chapter (see *Chapter 3: Methodology*), agent-based simulation proffers a number of benefits for this research, such as the ability to concurrently consider multiple levels of analysis, a consideration of real-world dynamic and emergent processes, and the ability to achieve large data sizes in a field that would otherwise be intractable for study (e.g. Davis, Eisenhardt and Bingham, 2007; Harrison, Lin, Carroll and Carley, 2007; Hughes, Clegg, Robinson and Crowder, 2012; Macy and Willer, 2007; Smith and Conrey, 2007). The model offered here is a simplified representation of the structures, constructs and processes identified previously as relevant to the dynamic functioning of multilevel multiteam systems within the emergency response context. Specifically, the model consists of many heterogeneous agents arranged into an explicit multilevel multiteam system organizational structure who each possess differing levels of identification (conceptualized as a mixture of categorization and bias) with the multiple concurrent groupings with which they are associated. These agents must then communicate with one another effectively in order to produce the optimal conditions required for accomplished system performance.

The overall approach adopted thus enabled an examination on a systematic basis of the effects of the factors theorised variously in the preceding chapters to have influence on the dynamic functioning of emergency response multiteam system and assess their specific pattern of influence – individually and in combination – on a number of multiteam system communicative performance aspects. Specifically, I fragmented social identity (the behavioural mechanism proposed to cause breakdowns in between-team communication in emergency response, thus leading to system sub-optimization) into its constituent parts of social categorization and intergroup bias, in accordance with the categorization-elaboration model proposed by van Knippenberg *et al.* (2004).

As the system under study in this thesis is what I have termed a multilevel multiteam system (a multiteam system with more than one overlapping team network structure), two forms of categorization were considered, with agents possibly aligning themselves in accordance with their originating organizational agencies (i.e. policeman, fireman, local authority member etc.) or their level of command (i.e. bronze, silver or gold). Two biases are also considered in isolation of the categorization parameters (i.e. study two) and in interaction with them (i.e. study three): intergroup biases and information-based bias. The influence of intergroup bias is considered, and is conceptualized as the form of bias suggested by van Knippenberg *et al*. (2004) as influencing the system as a facet of social identification. The intergroup bias parameter is then supplemented by an additional form of bias (information-based bias) to ensure that any effects found are caused by the social identity focus of the intergroup bias parameter instead of as an artefact of the model mechanism.

There are three main aims that form the focus of the modelling and simulation exercise reported in this chapter, namely: (1) the influence of divergent categorizations on the functioning and communicative performance of emergency response multiteam systems, (2) the influence of intergroup bias on the functioning and communicative performance of these systems, and how this differs from the effects found for other forms of bias, and (3) how categorizations and bias interact to influence system-level communicative outcomes assumed to influence multiteam system performance.

In the following sections, I shall outline the specific composition of the model in terms of the structures, processes and agents that constitute the system and identity based mechanisms under study. I shall firstly outline the organization of the model and the problem that needs to be solved (referred to as the agents 'goals' by Hughes *et al*., 2012), followed by specifications of the exact mechanisms within the model that are utilized to reflect the categorization and bias parameters. I shall explicate in detail the communicative outcome measures of interest within this thesis, and complete the chapter with an explanation of the three studies that are conducted within this work.

4.2: Model outline

As stated previously (see *Chapter 2: Literature review*), I have proposed social identification as a possible generative mechanism that explains the repeated breakdowns in communication (and thus cognition, coordination, decision making and general performance) of emergency response multiteam systems. Thus far, little is known about exactly how social identity processes (specifically the combination of categorization and bias) operate across the multilevel multiteam system that comprises emergency response systems in the UK. In order to understand how social identity can influence system-level outputs for emergency response multiteam systems, I created a model loosely based on the MADAM model created by Hills and Todd (2008) that comprises multiple heterogeneous agents within a system that reflects the multilevel multiteam system design of the emergency response context under study. The key task of each agent is to communicate specific pieces of information throughout the system in order to reach an assigned target agent. This communication is however influenced by specific rules at the agent-level that derive from the behavioural mechanism proposed as the key cause of system sub-optimization within this work, namely, social identification.

The simulation model is designed specifically to capture the key features described in the previous chapters (see *Chapter 2: Literature Review*) in such a way as to offer a simplified representation of the realities faced in emergency response multiteam system contexts, and thus only the features essential to the problem at hand are included. Intentional simplification is actively endorsed within agent-based modelling communities in order to ensure elegance and parsimony in the theories developed (Burton and Obel, 1995; Epstein, 2006). Such simplification allows the creation and/or elucidation of explanations of complex macro-scopic social regularities from minimal generative properties, and ensures that the behaviour of the model can be easily understood. If a modeller does not intentionally simplify, they risk the model becoming so complex that it is no more transparent than the real-world system they are modelling and make it virtually impossible to draw clear conclusions (see Smith and Conrey, 2007). The goal of modelling is thus to achieve selective realism (Humphreys, 2002, 2004), limiting the model to theoretical basics whilst still capturing the essential properties in order to infer findings that are both insightful and veridical (Saatsi, 2012). I believe my assumptions and model are sufficiently realistic to gain insight into the influence of theorised social identity processes in multilevel multiteam systems whilst maintaining enough simplicity to be able to clearly determine exactly how these processes influence the system.

In line with the categorization-elaboration model (van Knippenberg *et al*., 2004), social identity is partitioned within the model into the two interlinking processes; (1) social categorization (comprised of both the grouping with which an agent aligns themself and their level of commitment to this grouping) and (2) intergroup biases that flow from these categorizations under certain circumstances of threat. According to this model, how an agent categorizes themselves influences the way they view and interact with the world, influencing their cognitions and actions in a way that aligns them more closely with the prototype of that identity. Categorizations can thus be considered in terms of how they shape the properties of an individual that will be brought to the fore in any given situation, and is mechanised into the model through influencing the properties that comprise an agent. Bias on the other hand influences whether or not an agent is willing to communicate with another agent on the basis of specific preferences, and thus can impede or facilitate knowledge transfer processes. Both categorization and bias are parameterized into the model in order to allow their systematic variation for the experimental studies that follow, and are explained in more detail below.

In this section, I shall provide an overview of the set up and processes that comprise the agent-based model utilized for studying the influence of social identity processes in emergency response multilevel multiteam systems. I shall first explain in detail how the system is created within the model, and the exact nature of the 'goal' that agents must strive for. Following this, I shall explain how both aspects of social identity mentioned above are mechanised into the model, with categorization influencing the composition of agents, and bias influencing how knowledge transfer is enacted. For additional clarity, a table summarising the parameters varied and measured within the model (*Table 3*) and a summary of the behavioural rules underpinning the agents' behaviour in the model (*Table 4*) are also provided below:

Table 3: Parameters and values within the model

Parameter	Values*	Meaning	Studies Varied in
O_N	<u>6</u>	Number of organizations (horizontal)	
C_N	<u>3</u>	Number of hierarchical levels of command (vertical)	
AT	<u>18</u>	Agent Types ($O_N * C_N$)	
AT_N	<u>2</u>	Number of agents within each agent type	
X	<u>36</u>	Number of agents ($AT * AT_N$)	
I_N	<u>5</u>	Number of pieces of information distributed across agents per simulation	
K_N	<u>10</u>	Number of properties an agent holds within their value list	
H	0-100%	Degree of agent's commitment to their *horizontal categorization* with their organization (i.e. O_N)	Studies 1 and 3
V	0-100%	Degree of agents' commitment to their *vertical categorization* with their hierarchical level (i.e. C_N)	Studies 1 and 3
J	0-100%	Degree of agents' *intergroup bias*: percentage match between the *K*-values of a source agent and those of the potential communication agent required for communication to occur	Studies 2 and 3
L	0-100%	Degree of agents' *information-based bias*: percentage match between the information's *K*-values and the *K*-values of the potential communication agent required for communication to occur	Studies 2 and 3
DV1	Measured	*Time:* Number of time ticks taken for all target agents to receive information (ranging from 0-1000 ticks)	Measured in all studies
DV2	Measured	*Propagation:* Percentage of agents to receive information (ranging from 0-100%)	Measured in all studies
DV3	Measured	*Accuracy:* Degree of match between *K*-values of agent holding information and the information itself (ranging from 0-100%)	Measured in all studies

*underlined values denote the default value

Table 4: Behavioural rules utilized by agents within the model

Behavioural Rule	Steps in this rule	Literature linked
Acquire identity values	1) Create agents 2) Assign to Horizontal and Vertical groupings 3) Assign *K* values on the basis of their commitment to categorizations.	Within UK emergency response, agents are part of both an originating agency (e.g. firemen, policemen, local authority etc.) and are then split into three operating levels (bronze, silver and gold) (e.g. Civil Contingencies Act, 2004; HM Government 2005; HM Government, 2010; Pearce and Fortune, 1995). Each of these agencies provides a potential category with which an agent can consider themselves. Agents depersonalize themselves and self-stereotype in alignment with the prototype for groupings. The degree to which an agent has commitment to this grouping determines the degree to which this process occurs with higher levels of commitment resulting in a greater degree of alignment with the prototype (e.g. Ashforth and Mael, 1989; Brown and Turner, 1981; Ellemers, De Gilder and Haslam, 2004; Ellemers, Spears and Doosje, 2002; Korte, 2007; Oakes, 1987, Turner, 1985). Thus, if the agent has a high commitment to a certain categorization, they will self-stereotype and consider themselves in terms of that category membership. This is reflected in the model through the number of their *K* values they take from that grouping.
Scan environment and decide who to communicate with	1) Move 2) Check if agents are in close proximity to which the agent may communicate through face-to-face interaction 3) Check for agents within the system who they may be able to communicate with through media channels	As agents move around the system, they come into close proximity with other agents on occasion. If an agent with information comes into close proximity with another agent, they will consider that agent for knowledge transfer, reflecting how physical proximity is often a significant driver of information exchange (i.e. Cannella, Park and Lee, 2008; Hinds and Crampton, 2014; Van den Bulte and Moenaert, 1998). Media based communication represents any communication that would occur through other mediums other than face to face communication, such as via telephone or email systems, which is representative of communication that happens in real life emergency response (Ikeda, Beroggi and Wallace, 1998).
Decide whether or not to communicate	1) Check *K* values of potential agent to see if these align with the *K* values of the self to such a degree that they satisfy the *J* criteria 2) Check *K* values of potential agent to see if these align with the *K* values of the information to such a degree that they satisfy the *L* criteria 3) If above criteria is met, pass the information to agent	The *J* parameter reflects intergroup bias, in which agents favour agents within their ‘in-group’, leading to prejudice and derogation against agents from outside of this group. Intergroup bias reduces agents willingness and desire to talk to agents from outside of their own groupings/categorizations and is incited by threat (Brewer, 1979; Hewstone, Rubin and Willis, 2002; Lau and Murninghan, 2005; van Knippenberg *et al*., 2004) There is no linked literature for the *L* parameter. This is instead included within the model to compare with the intergroup bias parameter (*J*) to ensure that effects found are not an artefact of the bias mechanism itself but due to the link with categorizations

4.2.1: Organization and problem to be solved

In order to address the forgoing issues, I specified a system consisting of X interacting agents that face a problem which requires the communication of I_N pieces of information from one agent within the system to another. This sort of problem is typical of those faced in large-scale civil emergencies where information regarding the incident or the activities of other groups must be shared in order to allow for effective cognition regarding the situation and the systems response to this, coordination of actions and decision making (see section *2.3.2: Cognition, coordination, decision making and communication in emergency response multiteam systems*).

The X agents within the system belong to one of O_N different originating organizational agencies (e.g. O_6 to represent the fire service, ambulance service, police, local authority, category 2 responder A and category 2 responder B agencies) and are concurrently organized into a hierarchy consisting of C_N different levels of command (e.g. C_3 to represent the bronze, silver and gold level of command). This creates a total of 18 possible agent types (AT) within the system ($AT = O_6 * C_3$ – e.g. possibilities of O_1C_1, O_1C_2, O_1C_3… O_6C_1, O_6C_2, O_6C_3). The total amount of agents populating the system is therefore dependent on how many of each agent type (AT_N) are simulated, with $X = AT * AT_N$. The choice of how many agents of each type were populated into the model is an arbitrary decision. To ensure the model remained manageable, two agents of each type (AT_2) are populated into the simulation space, resulting in $X = 18 * 2 = 36$ agents. Creating a system with such a complex constituent structure is important for multiteam system research such as this, as it allows for the consideration of how interactions that occur both within and between certain groupings can influence system-level outcomes (Davison *et al.*, 2012). Creating a system with the complex constituent structure is especially important considering the nature of this system as a multilevel multiteam system design, a design that has not previously been considered in multiteam systems research.

Five pieces of information (I_5) are dropped into the system, and each is assigned to a single agent at random who together become the ‘source’ agents. From the remaining agents (X_{-1}), another specific agent within the system is randomly assigned to be the ‘target’ agent, to whom the information must reach. The information is passed from the ‘source’ to the ‘target’ agent through a process of knowledge transfer, in which the information will promulgate throughout the system until it reaches the elected target agent. However, the process of knowledge transfer can be influenced by the specific properties that comprise an individual, which are influenced by their horizontal (i.e. agency) and vertical (i.e. command level) categorizations.

4.2.2: Categorization (i.e. agent composition)

The complex multilevel multiteam system design utilized in emergency response makes it possible for agents to simultaneously categorize themselves with a number of possible groupings. Two hold particular salience for agents within the context of UK emergency response systems, namely, their originating organizational agency (e.g. policeman, fireman, local authority member etc.) and their level of command (i.e. bronze, silver or gold). As specified in *Chapter 2: Literature review*, the degree to which an agent feels commitment to a specific categorization will determine the degree to which that categorization provides the blueprint for an agents thoughts and behaviours. Agents go through processes of depersonalization and self-stereotyping that shifts them towards the prototype of a specific categorization, and the greater their level of commitment to that categorization, the greater the degree to which an agent will shift towards the prototype and use membership to this grouping as the basis for perceiving and acting in the world (e.g. Ashforth and Mael, 1989; Brown and Turner, 1981; Ellemers, De Gilder and Haslam, 2004; Ellemers, Spears and Doosje, 2002; Korte, 2007; Oakes, 1987, Turner, 1985).

Categorizations along the lines of an agents originating organization (termed *horizontal categorization*) and their level of command (termed *vertical categorization*) are thus both included in the model and influence the exact attributes that each agent possesses. To operationalize the concepts of categorization (and an agent's commitment to this categorization) into the model, two parameters are thus included: horizontal categorization (H) and vertical categorization (V). These parameters influence the properties or attributes that make up individuals' self and can be utilized for self and social categorization.

To accommodate the notion of individuals possessing personal properties or attributes that are available for self and social categorization into the model, each agent possesses a K_N value list of attributes that combine to create the 'self'. These attributes represent agents' personal beliefs, attitudes, knowledge, skills and other personal properties. Each agents' K_N value list is formed of 10 values that are drawn from a full population list of 45 values, either purposefully on the basis of set parameters (i.e. for studies one and three) or at random (i.e. for study two). The two categorization parameters, horizontal categorization with an agency (i.e. an agent's $O_N; H$) and vertical categorization with their command level (i.e. an agent's $B_N; V$), are mechanized into the simulation through their influence on the configuration of agents K_N value lists. The degree to which an agent holds either of the two categorization parameters reflects the degree of commitment an agent holds to that categorization (e.g. a high H is indicative of high commitment to the agent's organizational agency categorization).

Each possible group (i.e. each O and each C) has a certain subset of values within the population list that reflect this specific grouping (essentially acting as the prototype for that categorization). The level of horizontal categorization (H) or vertical categorization (V) influences the number of an agent's K attributes that are taken from this specific group's value subset rather than from the full population of values, thus representing the depersonalization and self-stereotyping in line with the prototype that is theorised to occur as agents categorize themselves with specific groupings (e.g. Ellemers, De Gilder and Haslam, 2004; Hogg et al 1995; Korte, 2007; Reicher, 1987, 1996; Terry and Hogg, 1996).

The higher the level of categorization (i.e. a greater level of commitment to a categorization), the more of an agent's *K*-values have been taken from this subset, creating more homogeneity within each group. For example, if an agent has high commitment to their categorization as a policeman (i.e. a high level of *H*) but not so strongly as part of their silver command level (i.e. a low level of *V*), a large proportion of their 10 *K*-values will be taken from the subset of numbers that is linked with the police identity, and the rest will be a combination of those from their command level or randomly across the entire population of 45 values. On their own, these categorizations make no difference to the working of the model, but when enacted in conjunction with the 'intergroup bias' parameter that specifies rules that govern the knowledge transfer process, the level of categorization can exert significant influence.

4.2.3: Bias (i.e. knowledge transfer)

The model also includes a parameter to reflect intergroup bias, in which agents favour agents within their 'in-group', leading to prejudice and derogation against agents from outside of this group. To ensure any effects found for this variable were as a result of social identity effects (i.e. favouritism to those considered to be part of the in-group) and not an artefact of the mechanism employed within the model, a second bias parameter with an alternative focus was also included in the model for comparative purposes, termed information-based bias. Bias influences an agent's inclination towards communicating with certain other individuals, either having a preference for similarity with other agents (i.e. intergroup bias; *J*), or through having a preference for communicating only with agents who might need the information (i.e. information-based bias; *L*).

The two bias parameters are operationalized into the model through their influence on the knowledge transfer process. In each time period of the simulation (known as 'ticks'), agents holding information can pass the information to other agents in the system on the basis of two premises: (1) proximity based communication and (2) media based communication. As agents move around the system, they come into close proximity with other agents on occasion. If an agent with information comes into close proximity with another agent, they will consider that agent for knowledge transfer, reflecting how physical proximity is often a significant driver of information exchange (i.e. Cannella, Park and Lee, 2008; Hinds and Crampton, 2014; Van den Bulte and Moenaert, 1998).

For media based communication, agents will also attempt to pick any other agent within the simulation as another source for considering knowledge transfer, whether proximal to this agent or not. Media based communication therefore represents any communication that would occur through other mediums other than face to face communication, such as via telephone or email systems, which is representative of communication that happens in real life emergency response (Ikeda, Beroggi and Wallace, 1998).

Once an agent has been chosen for consideration of knowledge transfer, the source agent holding the information decides whether or not to communicate with the chosen agent on the basis of the two bias parameters; intergroup bias (J) and information-based bias (L)

Intergroup biases can be defined as more favourable responses to others categorized as in-group than others categorized as out-group catalysed by threats or challenges to the distinctiveness or value of an identity, resulting in the disruption of task-relevant information elaboration (van Knippenberg *et al.*, 2004). To implement intergroup biases into the model, a mechanism has been placed by which agents have reduced likelihood of communicating with agents with whom they share little categorical heterogeneity (i.e. are socially categorized as being an out-group member). Heterogeneity within the model is simulated in terms of the amount of K-values agents have in common. The level of intergroup bias (J) therefore reflects the minimum amount of K-values two agents must have in common before an agent will pass information it is holding, with higher levels of intergroup bias resulting in a higher percentage match requirement between the two agents. For example, if the intergroup bias parameter is set to 60%, agents will not communicate with an agent who holds less than 6 of the same *K*-values as themselves.

Information-based bias (*L*) on the other hand reflects an agent's desire to communicate only with people who might require or be able to effectively use the information they are holding. For example, this would therefore represent an agent having a bias towards only sharing information about a fire that is happening at the scene of an emergency response with firemen who might be able to utilize this information, rather than passing it to an alternative agency (such as a local authority employee) to which the information would likely be irrelevant to their functioning. This has been added into the model for three main reasons: (1) to ensure that any results found for how intergroup bias influences the system are actually caused by it being identity related and not just a facet of the percentage match requirement mechanism, (2) to see independently whether being selective in terms of who information is passed to on the basis of who might need that information will affect system-level outcomes and (3) to see if the desire to be selective in terms of informational needs changes the way that intergroup biases affect system functioning.

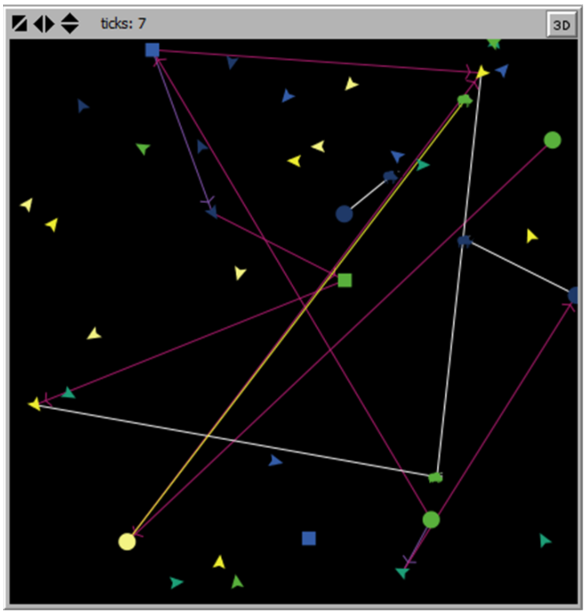
Information-based bias has therefore been added into model through the exact same mechanism as used for identity based communication but with a slight variation in focus. Instead of considering the homogeneity of the two individual agents in question for the communication procedure (as in intergroup bias), it requires homogeneity between the *K*-values of the agent being considered for the communication and the information to be shared, and thus works on the basis of being biased towards passing information only to those who might be able to utilize it. The agent therefore removes themselves from the equation to only consider whether the agent they may communicate with could utilize the information they are holding.

At every time period the model runs, all agents holding information have the opportunity to communicate on the premise of both proximity and media based communication. Information thus continues to propagate throughout the system so long as the bias parameter requirements are being met until the information reaches the randomly assigned target agent, at which point the target agent ceases further propagation of this information. This process of picking agents, deciding whether to communicate with them, and then potentially passing the information forward continues until either all information trails have reached their appropriate targets, or until the simulation stops at 1000 time ticks[5].

As mentioned in *Chapter 3: Methods,* a copy of the code utilized in NetLogo to create the below outlined model can be found in the Appendices. Moreover, screenshot of the visual display of the working model provided by NetLogo is also included below (*Figure 4*). This screenshot shows how the model converts from the syntax code (*Appendix 1*) into the 'interface' tab view of NetLogo. Such a view of the working model makes it possible for the modeller to understand specifically how the coded behaviours of agents manifest and thus allows for more robust inspection of specific elements of the model. This thus helps the modeller verify that the model is working correctly and as expected providing greater internal validation (discussed in more detail in section *4.4.1 Internal Validity* below). My model is comprised of agents, information and communication. Agents are predominantly depicted as triangles (although source agents are circular and target agents are square) who belong to different organizational agencies (depicted by their colouring; e.g. blue = police, turquoise = paramedics, green = local authority etc.) and

[5] This number was chosen arbitrarily as it provided enough time to see how the mechanized parameters influenced model outcomes without producing an amount of data that was unmanageable. Similar time points have been chosen by other influential simulation works (e.g. Siggelkow and Rivkin, 2009).

different levels of command (not depicted in the interface screen). Information is depicted by the cloud shapes in the model. Communication between the different agents is depicted by the pink and purple lines; pink lines represent media based communication and purple lines represent proximity based communication. Lines between the information and agents depict who is currently attempting to communicate that information (white lines) and whether or not the target agent has received the information (yellow lines). As can be seen in the screenshot, as the simulation executes, agents communicate with one another and create specific linkages, developing into what resembles a network diagram that shows who has communicated with whom and through what means.



Key:
Communication = Lines:
Magenta = Media based
Violet = Proximity based
White = currently attempting to communicate
Yellow = target has received information

Agent types:
Triangles = general agents
Circles = source agents
Squares = target agents
Clouds = information

Different colours for agent types denote different originating agencies (*O*) with information taking on the colour of the source agent.

Figure 4: Image displaying the graphical interface NetLogo produces during simulation

4.3: Measurements of multiteam system communicative performance

Within this simulation, I am interested in how the above mentioned social identity parameters influence multilevel multiteam system performance. In order to measure this, three outcome variables have been added into the model; 1) *time* taken for information to travel from source agent to target agent, 2) *propagation* of information throughout the system and 3) *accuracy* in terms of the percentage match between an agent and the information they hold.

The amount of *time* (*DV1*) taken for information to travel from source to target agent is measured in terms of the number of time ticks that have elapsed from when the information is dropped into the system to receipt of the information by the target agent, averaged across the five target agents to give a system-level average outcome. A measure of the amount of time taken for a process to complete is often used by agent based modelling (ABM) researchers in both organizational research in general (e.g. Aggarwal, Siggelkow and Singh, 2011; Black *et al.*, 2006; Miller, Pentland and Choi, 2012; Ren, Carley and Argote, 2006; Rudolph, Morrison and Carroll, 2009; Siggelkow and Rivkin, 2009) and the emergency response literature stream specifically (e.g. Chen, Meaker and Zhan, 2006; Chen and Zhan, 2008; Nagarajan, Shaw and Albores, 2012; Ren, Yang and Jin, 2009). Since quick receipt of critical information allows for faster and more accurate decision making by emergency response multiteam system personnel (see section *2.3.2: Cognition, coordination, decision making and communication in emergency response multiteam systems*), time is a suitable outcome variable for this research.

The second outcome measure – *propagation* (*DV2*) of information throughout the system – is a measure of the proportion of agents that have received one of the pieces of information circulating throughout the system. Computationally, it is measured as the percentage of agents who have received one of the pieces of information measured at every time tick throughout the simulation. A system-level average is then generated by averaging the scores across all pieces of information in the system. This measure is unique to the programme of study being conducted. However, it has similarities with Miller, Fabian and Lin's (2009) 'aggregate adoption rate' in which they measured the amount of product adoption rate across the system under alternative firm strategies.

In emergency response contexts, the spread of information throughout the system can be crucial for effective functioning. For example, information about the evolving situation is likely required by nearly all members of the response system in order for them to build an accurate situation awareness and make appropriate decisions (see section *2.3.2: Cognition, coordination, decision making and communication in emergency response multiteam systems*). In addition, social identity processes can lead to the fracturing of groups into 'silos', in which information is propagated around small groups of people rather than spread across the entire network. The presence of such silos has been documented in emergency response (e.g. Roberts, 2011). A measure of how far the information is able to spread across the system under various conditions of categorization and bias is thus an important indicator of performance.

Finally, *accuracy* (*DV3*)is measured in terms of the degree of match between the *K*-values of any agent currently holding information and the information itself. If there is not a close match, then the agent's abilities, skills and knowledge currently being utilized (which can shift in accordance with their current categorizations) do not match that of the information it is currently holding. Accuracy is therefore a measure of how useful a given piece of information can be in the hands of an agent.

To understand this measure of accuracy, it can be helpful to consider it in terms of the hierarchical value chain model of message content (Boisot and Canals, 2004; Kettinger and Li, 2010). It is suggested in this model that message content can be divided into three facets; data, information and knowledge. Data becomes information when it has meaning within a certain context, and this then becomes knowledge when this can be generalised and utilized across a multitude of situations/contexts. In the model presented here, agents with little accuracy match to the information would likely be holding data; content of which they cannot make much use. As they pass these data to agents who have a higher percentage match with the information, that data gains meaning as it links with the agents' prior knowledge, skills and beliefs, and they are able to divulge the data into useful parts that can be used to inform decision making, therefore becoming information or knowledge for the agent in question. For this reason, it is important in emergency response contexts that information is held by agents who might be able to make the most use of it (i.e. agents who are closely matched with the information).

Once again, the measure is averaged across all agents currently holding information in order to get a system-level average outcome measure. Measures of accuracy are also relatively common in simulation research, especially in management research utilizing NK Fitness Landscape modelling, in which comparisons are made between organizational 'sticking points' and the performance of optimum 'local peaks' to which the organization did not reach (Aggarwal, Siggelkow and Singh, 2011; Siggelkow and Rivkin, 2006; Siggelkow and Rivkin, 2009).

The focus of this research is on system-level optimization (or sub-optimization). In taking a view of phenomena as generative, in that "ensembles achieve functionalities (or properties) that their constituents lack" (Epstein, 2006, p.2), the characteristics of the whole cannot be determined by the sum of their parts. It was thus important to take the above mentioned measures at the system-level of abstraction in order to gauge how factors influencing the individual agents (i.e. rules of interaction governed by social identity) interacted to create emergent system-level phenomena.

4.4: Validation of agent-based models

Validation is an important topic within the modelling community as simulation results are determined by how the agents and their interactions are modelled (Takadama, Kawai and Koyama, 2008). In general, validation "involves examining the extent to which the output traces generated by a particular model approximates one of more stylized facts drawn from empirical research" (Windrum, Fagiolo and Moneta, 2007, p.1.5), and it is important to ensure models are grounded in real life and thus has utility for making useful insights. However, there is much debate within the community regarding how much validation is required, and the best way to achieve this. In order to be confident in the conclusions drawn from modelling studies, it is especially important that two forms of validation are performed and gathered; internal and external validity.

4.4.1: Internal validity

The internal validity of a model (also known as model verification or robustness) refers to whether the computer code is correct and free from errors. This ensures that any assertions made from the findings of the model are not based on spurious results that are artefacts of mistakes or 'bugs' in the model code, but are in fact interpretation of genuine output. To ensure the models in this thesis were free from errors, a number of different techniques were used. First, the model was primarily based on a previously published model by Hills and Todd (2008). The strategy of adapting previous models, called the TAPAS ("Take a previous model and add something") method by Frenken (2005, p.151), is recognised as a suitable starting point for modelling, both for the heuristic benefits it provides the modeller, but also the reduction of 'idiosyncratic elements' within a single model, thus thought to enhance the quality of the models.

Second, the simulation programme utilized – NetLogo – has an in-built 'check' to ensure that code is written into the model in a manner that is logical to the programming software. If the code is written in a manner that makes no sense, the programme automatically raises this bug to the programmer's attention, and will not run the model until this is resolved. This acts as an initial protection against obvious coding 'bugs' written into the code in illogical manner, and thus helps prevent spurious results.

Third, a number of strategies were used to check the model for more complex programming errors. Whilst, the Netlogo's 'check' function (mentioned above) can detect simple errors, it is not capable of finding more complex programming errors, in which the code makes programming sense but is still incorrect in terms of how the modeller determined the model should run. To avoid these, I utilized three main methods suggested in the modelling literature (e.g. Barathy and Silverman, 2010; Sargent, 2013): isolation testing, traces testing and degenerative tests. Isolation testing refers to running aspects of the model in a minimalist world and establishing the degree to which this aspect of the model conforms to the specifications and expectations of the modeller. For the models within this thesis, each new aspect of programming code was first checked in a minimalist environment to ensure it worked as I had planned before being added in to the full model. Once added in to the full model, traces testing was utilized, in which single agents within the model were systematically inspected as the model programme was run to ensure all elements were affecting the agents and their interactions as expected. Finally, degenerative tests were carried out. A degenerative test refers to interrupting specific components of the model and noting the impact on how the model runs and the results it produces (combined with further ‘traces testing’).Such degenerative tests include running the model without specific agent types, without certain aspects of the programming rules, or using extreme values to assert how these influenced how the model ran. Such tests make it easier to perceive and isolate code that is suspicious (against common sense) for re-inspection and review, preventing complex programming errors.

Through utilizing these techniques, confidence in the internal validity of the model is increased. However, cross-model validation through replication of the results would provide additional confidence in the internal validity of these results, and for this reason, I have included a copy of my code in the appendices to make this available for replication or extension.

4.4.2: External Validity

In addition to internal validity of the models, it is important to assess the external validity of the model to check the degree to which the models make assertions that can relate to the external world. This is generally thought to require asserting the degree to which the model and its findings relate to real-world empirical phenomena. However, this has been a topic of much debate within the modelling community, partly because there is no universally accepted approach to validation due to the inherent difficulty in validating models.

Agent-based models in particular are difficult to verify due to their intrinsic characteristics. Windrum *et al.* (2007) state that validation is especially difficult for agent-based models due to the inclusion of three main characteristics; (a) non-linearities and randomness in individual behaviours and interactions, (b) micro and macro variables that are governed by complex stochastic processes and (c) feedback loops between the micro and macro levels. They assert that accessing empirical data to match such complex, dynamic systems is incredibly difficult if not impossible. To avoid this, Gilbert (2004) suggests that instead of attempting to empirically match the complex stochastic processes involved in modelling, researchers should instead attempt to validate that the micro-level assumptions are adequate representations of agent activity, and that the macro-level aggregates equate to reality and expectation. However, Bharathy and Silverman (2010) argue that even this more straightforward approach is not without its difficulties, and that in many instances the ability to validate neither the micro nor macro level variables or output has been “easy nor relevant” (p. 442). By their nature, models are simplified versions of reality. Schreiber (2002) suggests agent-based models should be classified as ‘paramorphic analogues’ (p.5), as whilst they are similar to the real world they are trying to model, they are not exactly the same. This makes it difficult to try and directly compare empirical data to modelling data, as they are not directly analogous.

Not only are agent-based models in general inherently difficult to validate, but, as highlighted by numerous authors (e.g. Bharathy and Silverman, 2010; Carley, 1996; Fioretti, 2013; Macal and North, 2010; Windrum *et al*., 2007), agent-based models are not heterogeneous in design. The range and types of agent-based models are so diverse that it makes it impossible to have a universally-accepted and concrete version of validation across all agent-based models. As stated by Carley (1996, p.8) "computational models with different characteristics require different evaluation and validation schemes". In the literature, a dualistic distinction or suggestion of a 'continuum of model types' is frequently proposed (e.g. Carley, 1996; Macal and North, 2010) [6]. Generally, it is suggested that models can range from intellective models[7] on the one hand, that verge on the side of simplicity and are designed to develop understanding of basic explanatory mechanisms or gain insights into social processes or behaviour, to emulation or decision support models on the other, designed with veridicality in mind and with the aim of aiding practitioners in problem solving or decision making.

It is argued (e.g. see Bharathy and Silverman, 2010; Carley, 1996; Fioretti, 2013; Harrison *et al.,* 2007; Macal and North, 2010) that models of emulation/problem solving design require a much greater degree of external validation due to the fact that they are designed to address specific questions or aid decision making in real-world contexts. Intellective type models on the other hand are more simplistic than emulation models, and generally only include the minimal mechanisms required to explore assumptions and implications of a given theory, making them much harder to validate, and it has been questioned as to whether this is even required. Bharathy and Silverman (2010) note that "at such high levels of abstraction, it is really difficult to impose more stringent conditions of

[6] Although note that not all authors consider this continuum as a single dimension, for example, Windrum *et al.,* (2007) created an entire taxonomy of agent-based types based on dimensions such as the nature of the object under study, goal of analysis, nature of main modelling assumptions and the method of sensitivity analysis. They still argued that different model types required different forms of validation however in a similar vein to those authors making more simplistic dualistic or continuum based comparisons.

[7] The term 'Intellective models' is coined by Carley (1996), but this same type of model is also referred to as 'minimalist models' (Macal and North, 2010) or 'theory building' models (Fioretti, 2013; Harrison *et al*., 2007)

validation than analogy" (p.442), suggesting that instead of directly attempting to match such models with empirical data, similarly abstract forms of validation may be more suitable, such as interpreting and 'story telling' from the data in a manner that matches the real world and the theories investigated. Similar arguments for more abstract forms of validation have also been proposed elsewhere in the literature, with authors arguing that validation of such models is more a problem of social acceptance (Fioretti, 2013) or 'beleivability' (Gratch and Marsella, 2004) than strict coherence to an empirical data set.

The models presented in this thesis closely align with the minimalist intellective model type. They were built in order to explore the influence of social identity processes in a novel organizational design to gain proof of concept and gain further insight into how this proposed explanatory mechanism may manifest and enact within the multilevel multiteam system design, and thus were kept as simple and parsimonious as possible. To validate these models with real-world data would thus be incredibly difficult. Moreover, as outlined in the methods section of this thesis (*Chapter 3: Method*), it is difficult to study the real-world areas of both emergency response and multiteam systems that are the focus of this research, which was one of the reasons for choosing to use agent-based modelling in the first place. This means that gaining access to empirical data on this area with which to validate my models is troublesome. Other forms of validation have thus been utilized; primarily the process of grounding that is suggested by Carley (1996).

Carley (1996) asserts that grounding a model "involves establishing the reasonableness of a computational model" (p.11) and that the aim is to determine that the "simplifications made in designing the model do not seriously detract from its credibility and the likelihood that it will provide important insights" (p.12). The main ways in which this is achieved is through ensuring that the micro-specifications of the model are suitably based in theory and observations, that the applicability of the model is not overstated and that the limitations and scope conditions of the model are suitably discussed. For the models in this thesis, the mechanisms under investigation and added into the model are taken directly from the theoretical literature on social identity (see *Table 4* for further insights into the literature these behavioural rules were adapted from), and the applicability and limitations of the model are discussed in detail in *Chapter 7: Discussion*. This grounding is also enhanced through comparing the insights gained from the model with the assertions made by other authors, which can also be found in the discussion chapter.

Whilst the models presented here are grounded in theory and relate to the qualitative, empirical observations of others in emergency response contexts, further validation of the micro or macro specifications against concrete empirical data sets was not possible. Whilst this means that the assertions made within this thesis cannot be directly utilized by practitioner audiences until further validation has been gathered, the findings can still provide interesting insights that should not be omitted on this premise. Harrison *et al.* (2007) state that theoretical simulation work such as that conducted within this research project "should not be avoided simply because [empirical data on which to validate the model] is not available; it is still a legitimate scientific endeavour with the potential to make important contributions to management theory" (p. 1242). Instead, and as suggested by Carley (1996), the models in this thesis should be considered as "a hypothesis generation machine" (p.6), testing and extending theories to create insights that can be verified and validated in future research. Controversially, Carley (1996) even asserts that it is not preferential to combine both modelling and validation within a single work. Instead, she argues that models should be considered in the same manner as any theoretical article; validated through replication and extension by other authors. Her main argument for this is that validation of models should be considered as no more simplistic as validating any other form of theory, and that for presentational and practical reasons it is wise to keep validation endeavours separate to the initial modelling work. The assertions made from the models within this work should thus be validated in numerous contexts and through diverse methods in future research efforts.

4.4.3: Summary

Validation of agent-based models is clearly an area of considerable importance and debate. The models within this thesis were verified throughout the building process, with the mechanisms inputted being grounded theoretically and numerous checks, tests and inspections carried out to provide internal validation of the results. The code has also been included within the thesis to allow for replication of the simulation and its results in other simulation platforms to increase the level of verification that can be garnered from the results.

Gaining external validity of the models was however a much more complicated process. The models within this thesis are intellective in nature, attempting to gain insights into how the proposed mechanisms may manifest within a novel organizational design. It has been argued that such models require a lower degree of external validation than other forms of models, as the aim of such models is to develop understanding and help in further theorising, rather than to exactly emulate a specific context and problem for real-world decision support purposes. To achieve the aims of such intellective models means they tend to err on the side of simplicity rather than veridicality, in order to ensure parsimony and transparency to the inferences made, making the likelihood of an exact match with real-world data much harder to find.

Moreover, both the emergency response and multiteam system contexts of interest within this thesis make it difficult to gain empirical data regarding the concepts in question and their relationships. As discussed in *Chapter 3: Methods*, the emergency response context is practically and ethically very difficult to empirically research (which was part of the reason for selecting modelling as a methodology initially), and hence there is little available empirical data in this area on which to validate findings. Moreover, the multiteam systems area of research is still relatively novel and thus exiguous, and thus once again there is a scarcity of empirical data available to date on which to compare the findings of this research.

Thus, instead of gaining external validation through comparison to empirical data gathered in the real-world, I utilized grounding techniques suggested by Carley (1996); a more theoretically driven approach to validation that hopefully still inspires confidence in the findings of the model. However, future work should be conducted to further validate the findings of these models in the real world; considering this thesis as hypothesis generating and providing traction for research within a practically difficult area of study.

4.5: Studies conducted on the model

Three simulation studies were conducted on the above outlined model in order to ascertain how rules enforced at the agent-level of abstraction relating to specific social identity processes (i.e. categorization and bias) variously and conjunctively influenced emergent system-level communicative performance, and their results are presented in the following two chapters. The first study considered how varying levels of commitment to the two types of self-categorization posited as being highly salient in the emergency response system (horizontal categorization and vertical categorization) influenced communicative performance, in order to ascertain whether the grouping with which an agent categorizes themselves influences performance differentially. The second study considered the influence the two types of bias (intergroup biases and information based bias) on communicative outcomes. The results from these first two studies can be found in *Chapter 5: Results of studies considering the complex effects of social identity processes on communicative outcomes in isolation.*

The third study considered the interaction of both the categorization and bias parameters in conjunction with one another, in order to ascertain how social identity as a whole can influence communicative performance in emergency response multilevel multiteam systems. The results of this study can be found in *Chapter 6: Results of study considering the complex effects of social identity processes on communicative outcomes in* *interaction.* As suggested by Smith and Collins (2009) and Harrison *et al.* (2007), it is important to build up simulation studies in this sequential manner by adding in further contingencies incrementally. This makes it possible to ascertain exactly how each of the parameters influences system-level outcomes, and thus "clarify which mechanisms are core to a theoretical explanation" (Miller, 2015, p.180). It is therefore an approach frequently adopted and accepted by the modelling community to ensure transparency of the mechanisms and thus improve the validity of insights garnered from such an approach.

These three studies provide an in depth understanding of how certain processes constituting social identity (specifically, the commitment to various categorizations and the intergroup biases that stem from this categorization) variously influence system-level communicative performance, which I have asserted will further influence cognitive, coordinative and decision making capabilities for the system and in turn affect system-level performance.

For each study, 100 simulations were run for every condition of the experiment, with the findings being appropriated from the average scores across these 100 simulation runs. This ensures that conclusions are not being drawn on effects localised to that specific simulation run (based on the stochastic elements included in the model) and therefore increases the generalizability of the findings. Each simulation was run for 1000 cycles (time 'ticks'), at which point the simulation ended. Measures were taken at every time tick for the outcome variables of interest. This provides a large amount of data for analysis, with a total of 10,800,000 data points generated each for studies one and two[8] and 54,000,000 data points for study three[9]. The effect of the parameters on each outcome variable are tested using two way univariate analysis of variance techniques (ANOVA's)

[8] 36 total conditions, run 100 times per condition, for 1000 time ticks, measuring three outcome measures

[9] 180 total conditions, run 100 times per condition, for 1000 time ticks, measuring three outcome measures

on the average scores for each condition over 100 runs to detect main effects or interaction effects for the parameters in question.

4.5.1: Study one: The influence of horizontal and vertical categorizations on system-level communicative outcomes

The purpose of the first study is to investigate how the grouping with which an agent categorizes themselves influences system-level communicative outcomes. As mentioned previously, categorizing with a certain grouping can shape the way in which an agent thinks and acts, making aspects that relate to that identity more salient and thus primed within the mind of the agent. It is therefore possible that categorizing with different groupings may engender alternative patterns of interaction (thus influencing variously the three communicative performance indicators of interest in this programme of work). Within this first study, I therefore considered how changes to the degree of categorization (i.e. the extent to which agents depersonalize themselves to conform with the norms, goals, needs and beliefs associated with that identity) with either their organizational agency (the horizontal categorization parameter) or their hierarchical level of command (the vertical categorization parameter) influenced the system-level communicative outcomes.

Both the horizontal (i.e. agency) and vertical (i.e. command level) categorization parameters were systematically varied between 0% (i.e. the agents do not categorize with this grouping at all; low commitment) and 100% categorization (i.e. the agents wholly categorize themselves as part of this grouping, thus suggestive of full depersonalization and self-stereotyping in line with the identity associated with this category; high commitment) in increments of 20%[10], thus creating a 6 x 6 factorial experimental design. This therefore resulted in a total of 10,800,000 data points for this study. The levels of

[10] Therefore conditions of 0%, 20%, 40%, 60%, 80% and 100% degrees of categorization were utilized

intergroup and information-based bias were held constant at 25% match requirement levels in order to ensure any results found were created by the changes to categorization and not confounded by the level of bias.

This first study thus answers three questions. First, what happens to time taken, propagation of information throughout the system, and accuracy match between the agent and information if agents classify themselves in terms of their horizontal category (i.e. their originating agency; *H*) and at different degrees of this categorization (i.e. changing in accordance with the level of commitment they have with this categorization)? Second, what happens to the same communicative dependent variables if agents classify themselves in terms of their vertical category (i.e. their level of command; *V*) and at different degrees of commitment to this categorization? Finally, what happens to the system-level communicative dependent variables when these two categorization parameters (horizontal and vertical categorization) interact? This illuminates whether the different categorizations have differential impacts on communicative outcomes, or whether merely categorizing with any grouping that cuts across the system as a whole impedes communicative performance.

4.5.2: Study two: The influence of intergroup and information-based biases on system-level communicative outcomes

The purpose of the second study is to show how bias (both intergroup and information-based bias) influences system-level communicative outcomes. As mentioned previously, intergroup bias is thought to be the root cause of diversity related performance issues (van Knippenberg *et al.*, 2004) as high intergroup bias leads to in-group favouritism and out-group derogation that reduces elaboration of task-related information in multi-group contexts. In order to ensure any effects found for intergroup bias were not just an artefact of the mechanism used to operationalize this bias into the simulation model, the information-based bias parameter (the *L* parameter) was additionally added into the model for comparative purposes. Within this second study, I therefore considered how changes to the degree of intergroup and information-based biases, both in isolation and interactively, influenced the system-level communicative outcomes.

Both the intergroup bias and information-based bias parameters were systematically varied between 0% match requirements (i.e. the agents needed to have zero numbers in the *K*-values of the two objects matching before communication would commence) and 100% match requirements (i.e. the agents needed all of the *K*-values between the two focal objects before communication would commence) in increments of 20%, thus creating a 6 x 6 factorial design. This therefore resulted in a total of 10,800,000 data points for this study.

Whilst categorization was not considered directly within this study, the agents still require 10 *K*-values in order for any bias parameter to have influence, since both intergroup and information-based biases work on a mechanism of 'minimum match requirement' (see section *4.1.3: Bias*). Some degree of 'categorization' was therefore inevitable due to the nature of the population list of values from which the *K*-values are drawn being constructed of values relating to each subgroup. For this study, agents selected their *K*-values (i.e. the properties of the self) stochastically with no bias towards any specific grouping, and the resulting levels of consequent 'categorization' were measured, to ensure that the findings were related to the bias parameters only and not caused by the determination of *K*-values that occurs in categorization[11].

This second study thus answers three questions. First, what happens to time taken, propagation of information throughout the system, and accuracy match between the agent and information if a simple mechanism encouraging agents to communicate only with agents who are similar to themselves is added into the simulation (e.g. identity-based intergroup bias – parameter *J*)? Second, what happens to the same communicative outcome

[11] The degree of categorization that occurred through this stochastic assignment was measured. An average 66% categorization (with a 5% standard deviation) was found to be evident.

variables if the same mechanism, one in which a match between the *K*-values (i.e. the properties that construct the agent or information) between two elements in the system is required, but with an alternative focus for matching? Specifically, rather than matching the *K*-values between two agents (as in intergroup biases), the focus is instead on matching the *K*-values of the information to agents with similar properties, therefore encouraging agents to only communicate with agents who may be able to utilize the information effectively (e.g. information-based bias – parameter *L*). Including this additional bias parameter utilizing the same mechanism but with an alternate focus will make it clear as to whether the findings of the intergroup bias parameter are caused by its relation to social identification (i.e. the requirement for agent-agent homogeneity) or merely an artefact of the way it is operated in the simulation. Third, what happens to the system-level communicative outcome variables if these two bias parameters (intergroup bias and information-based bias) interact?

4.5.3: Study three: The interactive influence of categorization and bias on system-level communicative outcomes

The purpose of the third study was to systematically investigate whether the patterns of results found under various conditions of categorization (study one) remained steady when bias was also variable (study two). Therefore, categorization and bias were tested interactively. Both categorization and bias conjunctively form the processes of social identification, and thus changes to the grouping with which an agent categorizes themselves and the degree of commitment they feel to this categorization might influence the way in which bias affects system-level outcomes, or vice versa.

A full factorial design integrating all four parameters in the same format as was utilized in the previous studies would have been impractical for this study on the basis of the amount of data it would generate. If each of the four parameters were to be run at 20% intervals between 0-100%, this would have created a 6 x 6 x 6 x 6 factorial design, and thus a total of 1,296 conditions would be created. Considering that each condition is then run 100 times to rule out localised effects, and over 1000 time ticks, measuring three main outcome variables at every time point, this would have resulted in 388,800,000 data points; an amount of data that would be virtually unmanageable.

As the main questions to be answered by this study were whether the main and interactive effects of horizontal categorization and vertical categorization on system-level communicative outcomes remained under different variations of bias, I instead chose to run a fractional factorial design (Box and Hunter, 1961; Box, Hunter and Hunter, 2005) in which an orthogonal subset of the possible experimental runs are chosen that still allow the investigation of the most significant causal relationships for the problem at hand (for other examples of this methodology being utilized within the management field, please see Camasso and Jagannathan, 2001; Graham and Cable, 2001; Richardson, Jones, Torrance and Baguley, 2006; Tziner, 1988). The numbers of levels for the bias parameters were reduced from six to three, reflecting low, moderate and high levels of both intergroup and information based bias, and utilized in a purposefully confounding manner in order to ascertain whether changes in bias changed the pattern of results under different conditions of categorization.

Specifically, both the horizontal (i.e. agency) and vertical (i.e. command level) categorization parameters were systematically varied between 0% and 100% categorization in increments of 20%. Both forms of bias (intergroup and information-based bias) were varied across a low (5% match requirement), moderate (25% match requirement) and high condition (45% match requirement)[12]. This created a matrix of conditions broken into five main nested clusters of conditions (in term of the arrangement of the bias parameters) that allow the comparison of how different levels of horizontal and vertical categorizations influence communicative performance under conditions of high, low and mixed levels of

[12] These amounts were chosen as they were not so high that they would prevent full completion of the simulation (i.e. >60% - see study two), but would allow for an investigation of the dynamics of categorization under alternate bias conditions.

bias, creating a total of 180 conditions, and resulting in a total of 54,000,000 data points for this study.

This third study thus answers three main questions. First, does the pattern of effects found for the horizontal categorization parameter remain the same under low, moderate and high levels of bias? Second, does the pattern of effects found for the vertical categorization parameter remain the same under low, moderate and high levels of bias? Finally, do the interactive influences of horizontal and vertical categorization remain the same under the various levels of bias? This helps illuminate whether agents categorizing themselves in terms of certain groupings and at different levels of commitment is beneficial or detrimental to communicative performance differentially under various conditions of bias.

Chapter 5: Results of studies considering the complex effects of social identity processes on communicative outcomes in isolation

5.1: Introduction

In this chapter I shall discuss the results found for two studies conducted using agent-based modelling considering the isolated influence of two aspects that combine to create social identification; categorization and bias. In the studies that follow, I systematically tested different variations of possible identity configurations that could enact throughout the UK emergency response system (i.e. a multilevel multiteam system) using agent-based modelling in order to illuminate what influence they could have on communicative outcomes. Specifically, on the basis of the breakdown of identity into categorization and bias forwarded by van Knippenberg, De Dreu and Homan (2004), I considered how variations in the grouping with which agents categorized themselves, the levels of intergroup bias and what I term information-based bias in effect at the agent-level of the system influence three system-level communicative outcomes, namely; a) time taken for information to travel from source agent to target agent, b) the propagation of information throughout the system and c) the level of accuracy, as defined by the degree of match between the information itself and the properties (e.g. skills, traits, beliefs, attributes etc.) of the agent holding it.

Within this chapter, I shall explicate the findings of two studies conducted using these four parameters of interest within the model outlined in *Chapter 4: Model Specification and Analysis*. In the first study, I considered how changes in the level of commitment agents' have with both their horizontal (termed the *H* parameter) and vertical (termed the *V* parameter) grouping (i.e. their agency and command level categorizations respectively) influenced communicative outcomes when the bias parameters were held constant. Within the second study, I investigated how variations in the level of intergroup bias (termed the *J* parameter) and information-based bias (termed the *L* parameter) influences system-level communicative outcomes when categorization was allowed to stochastically fluctuate around a normal distribution. It shall be shown that the specific grouping with which an agent categorizes themselves, and their level of commitment to this grouping, can determine whether the system optimizes or sub-optimizes in terms of communicative outcomes. Furthermore, the level of bias is also found to influence the system, with high levels of bias resulting in reduced system-level communicative performance. However, it shall be shown that the exact form that the bias takes determines the *way* in which communicative outcomes at the system level are decremented.

5.2: Study one: The influence of horizontal and vertical categorizations on system-level communicative outcomes

The purpose of this study was to investigate how the grouping with which agents categorizes themselves, and the level of commitment the agent feels towards this categorization, influences system-level communicative outcomes. Specifically, agents could categorize themselves in terms of their horizontal categorization (referring to their originating agency category – parameter *H*) or their vertical categorization (referring to their level of command – parameter *V*). Not only can the grouping with which the agents' categorize themselves differ, but the degree to which agents class themselves as part of this categorization can also diverge (i.e. their level of commitment; Ellemers *et al*., 2002), often in line with the degree of salience or import placed on that identity. Categorizations are mechanised into the model in terms of the amount of an agents' *K*-values that are comprised of values from the specific subsection of values that aligns with this identity, thus increasing homogeneity within groups and heterogeneity between them if categorization is high. Table 5 below shows the exact parameter changes utilized within this study:

Table 5: Parameter values in study one

Independent Variables				
Bias Parameters		***Categorization Parameters***		**Total conditions**
Intergroup (J)	***Information -based (L)***	***Horizontal (H)***	***Vertical (V)***	
Held constant at 25%	Held constant at 25%	0, 20, 40, 60, 80, 100	0, 20, 40, 60, 80, 100	36 Conditions

Notes: intergroup = match required between two agents; information-based = match required between agent and information ; horizontal = with agency grouping; vertical = with command level

In the following sections, I shall elucidate the findings of the simulation study on each communicative outcome variable separately, followed by an integrated summary of these findings together and what this means for the multilevel multiteam system in study here. The effect of the parameters on each outcome variable are tested using two way univariate ANOVA's on the average scores for each condition over 100 runs to detect main effects for both the *H* parameter (horizontal categorization with one's agency) and *V* parameter (vertical categorization with one's command level), and to detect any interaction effects that also existed. All ANOVA outputs for all three studies can be found in *Appendix 2*.

5.2.1: Time taken

The first objective of study one was to examine the effects of increases in agents' commitment to their horizontal and vertical categorization on the amount of time taken for information to travel from source agent to target agent. The analysis showed that both forms of categorization significantly influenced how much time was taken for information to travel from source to target agent, but in divergent ways.

As seen in *Figure 5*, a significant relationship between the level of horizontal categorization and the amount of time taken for information to travel from source to target was found (F (5, 3564) = 63.31, P< 0.01). Specifically, increases in the level of horizontal categorization result in an increase in the amount of time taken. This effect is even more pronounced after commitment with the horizontal categorization reaches levels of 60% and above, with only a 13% increase in the amount of time taken between 0% and 40% horizontal categorization, but a 32% increase in the amount of time taken between 60% and 100% horizontal categorization. Therefore, any increase in the level of horizontal identification within the system appears to have a negative influence on the system in terms of the amount of time taken for the information to travel from source to target.

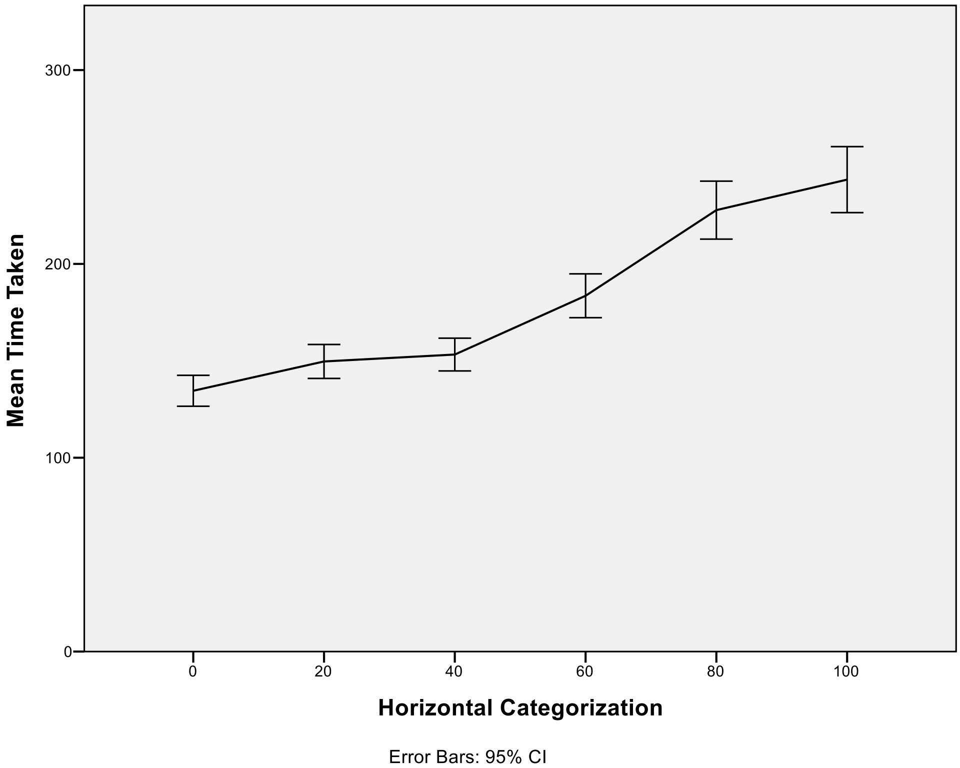


Figure 5: Changes in mean time taken until information reaches target agents as a function of horizontal categorization (H)

Changes in the level of commitment to agents' vertical categorization was also found to have a significant influence on the amount of time taken for information to travel from source to target (F (5, 3564) = 49.75, P< 0.01). However, the pattern of results is very different to those found for changes in horizontal identification. Specifically, increases in the level of commitment to vertical categorizations led to decreases in the amount of time taken for information to travel from source to target agent. As can be seen in *Figure 6*, a sigmoidal relationship was found, in which increases in vertical categorization initially result in little to no change in the amount of time taken, but then at moderate levels of vertical categorization (i.e. between 40% and 60%) a significant decrease in the amount of time is evinced, before once again stabilizing at high levels of vertical categorization. The time taken was quickest at these high levels of vertical categorization (from 60% to 100%), and slowest at low levels of vertical categorization (i.e. from 0% to 40%), with a decrease of 39% between the slowest (20% vertical categorization) and fastest (80% vertical categorization) times. High levels of commitment to agents' vertical categorization thus benefited the system in terms of time taken for information to travel from source to target agent.

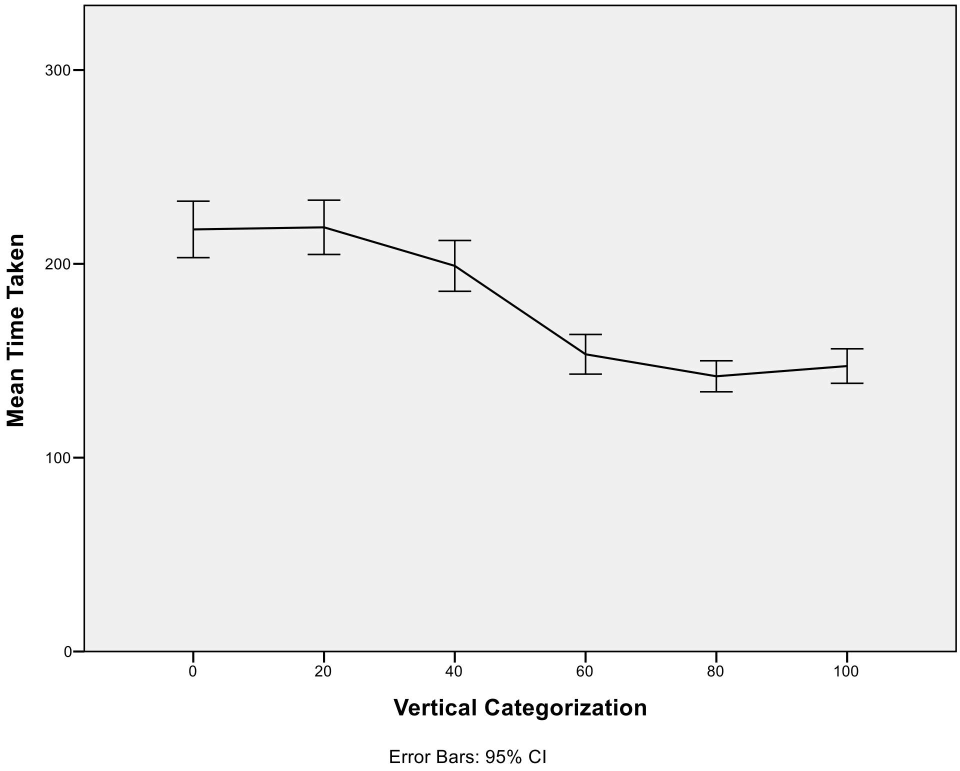


Figure 6: Changes in mean time taken until information reaches target agents as a function of vertical categorization (V)

A significant interaction between horizontal and vertical categorizations on the amount of time taken for information to travel from source agent to target agent was also found (F (25, 3564) = 13.05, P< 0.01). The most significant point to note regarding this interaction (*Figure 7*) is that when horizontal categorization is low, the amount of time taken for information to travel from source agent to target agent does not differ significantly across the different levels of vertical categorization, however, when horizontal categorization is high (i.e. 60% categorization and above), a significant increase in the amount of time taken is witnessed at low levels of vertical categorization, but the amount of time taken is not significantly different to other levels when vertical categorization is also high.

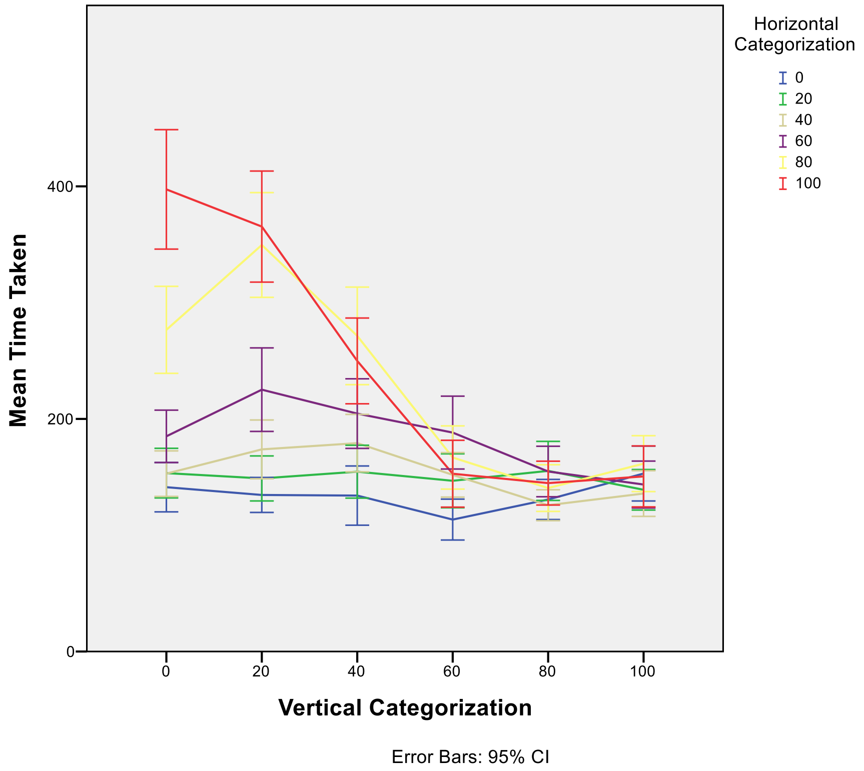


Figure 7: Changes in mean time taken until information reaches target agents as a function of the interaction of horizontal categorization (H) and vertical categorization (V)

The above results suggest that commitment to the two categorization parameters has significant divergent influence on the amount of time taken for information to travel from source to target agent. The analysis showed that increases in the level of commitment agents have with their originating agency categorization *(H)* led to linear increases in the amount of time taken for information to travel to the target agent, but that this effect can be reduced if agents' commitment to their command level categorization (*V*) is also significantly high. The reduction in time taken is substantial enough to completely protect against the negative influence of categorizing with their organizational agency (*H*), with the amount of time taken for information to reach the target agent being no longer significantly different from when this agency categorization (*H*) was low if command level categorization (*V*) is high enough.

5.2.2: Propagation of information

The results in this section reveal what happens if agents' commitment to their horizontal and vertical categorization is systematically varied, focusing on the effects on propagation. Once again, the analysis showed that both forms of categorization significantly influenced how much propagation could be achieved in divergent ways in a manner that echoes that observed for the time taken parameter.

As can be seen in *Figure 8*, increases in the level of horizontal categorization led to significant decreases in the percentage of agents who receive the information (F (5, 36000) = 1178.01, P< 0.01). This decrease is linear in nature, with an average decrease of 3% between each level increase in commitment to the horizontal categorization, and a total reduction of 14.5% in the amount of agents communicated with between the highest levels at 0% commitment and the lowest levels at 100% commitment to their horizontal categorizations.

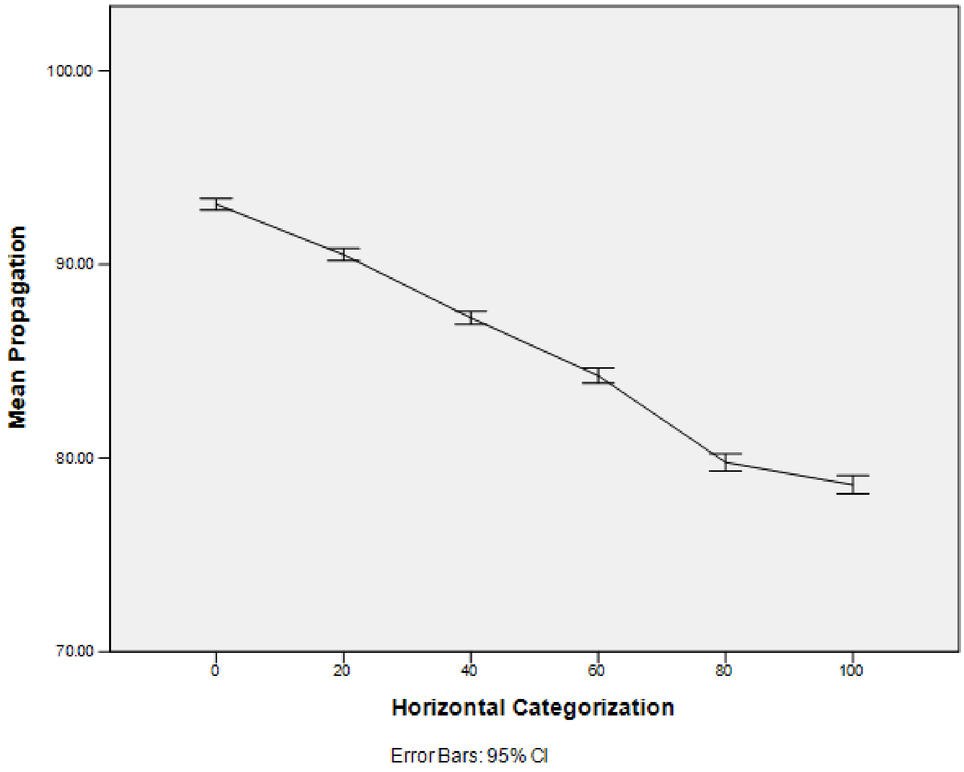


Figure 8: Changes in mean percentage of agents communicated with as a function of horizontal categorization (H)

When considered over time (*Figure 9*), it is possible to see that whilst each value of horizontal categorization results in different levels of propagation, stabilization at the uppermost value for each level of horizontal categorization occurs at around the same time; around 200 ticks. This shows that no matter how long the simulation is allowed to run for, these are the highest levels of propagation the system will be able to achieve for these levels of horizontal categorization.

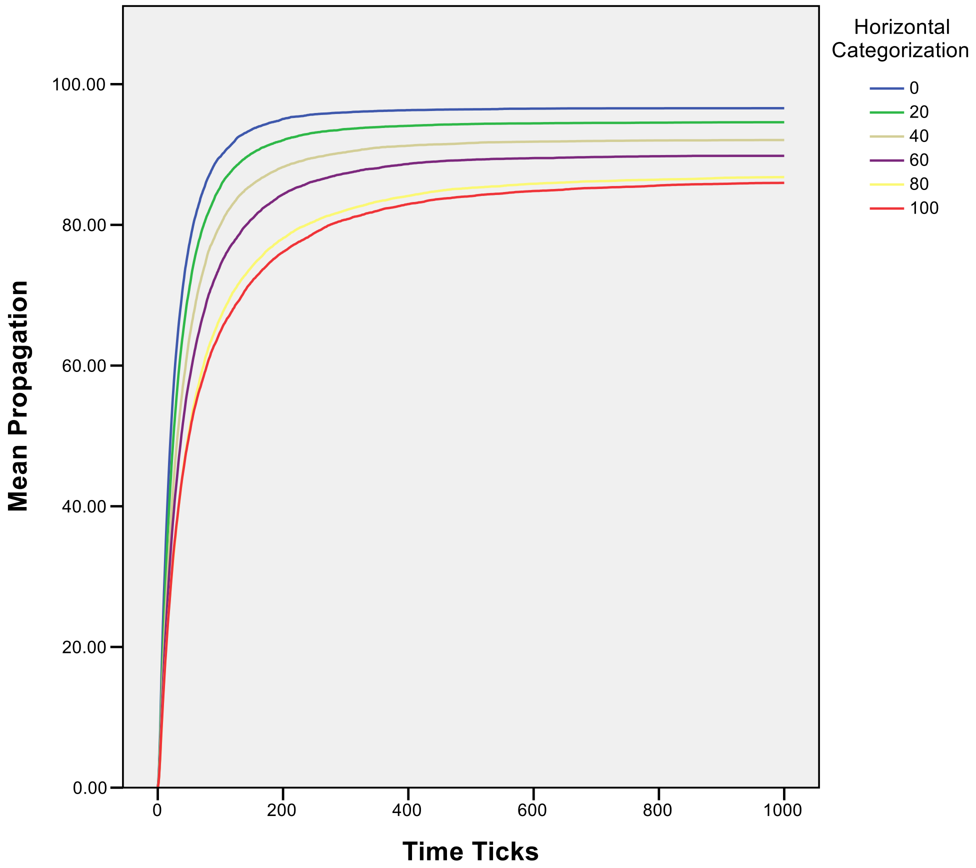


Figure 9: Changes in mean percentage of agents communicated with as a function of horizontal categorization (H) over time

Interestingly, the pattern of findings for the effect of vertical categorization on propagation is starkly different to the results of horizontal categorization, with vertical categorization displaying a beneficial influence on the amount of agents who receive the information. As can be seen in *Figure 10*, a significant influence of vertical categorization on the mean percentage of agents communicated with was found (F (5, 36000) = 1562.84, P< 0.01). Specifically, the percentage of agents communicated with initially shows a 4% decrease when the level of vertical categorization increases from 0% to 20% commitment to the categorization, but this is then followed by a significant increase in the proportion of agents communicated with over moderate levels of commitment to their vertical categorization (a 20% increase in the percentage of agents who receive information is witnessed between 20% and 80% levels of vertical categorization) that eventually stable out at high levels of vertical categorization at around 92% system propagation. For high system propagation, high levels of vertical identification are therefore beneficial.

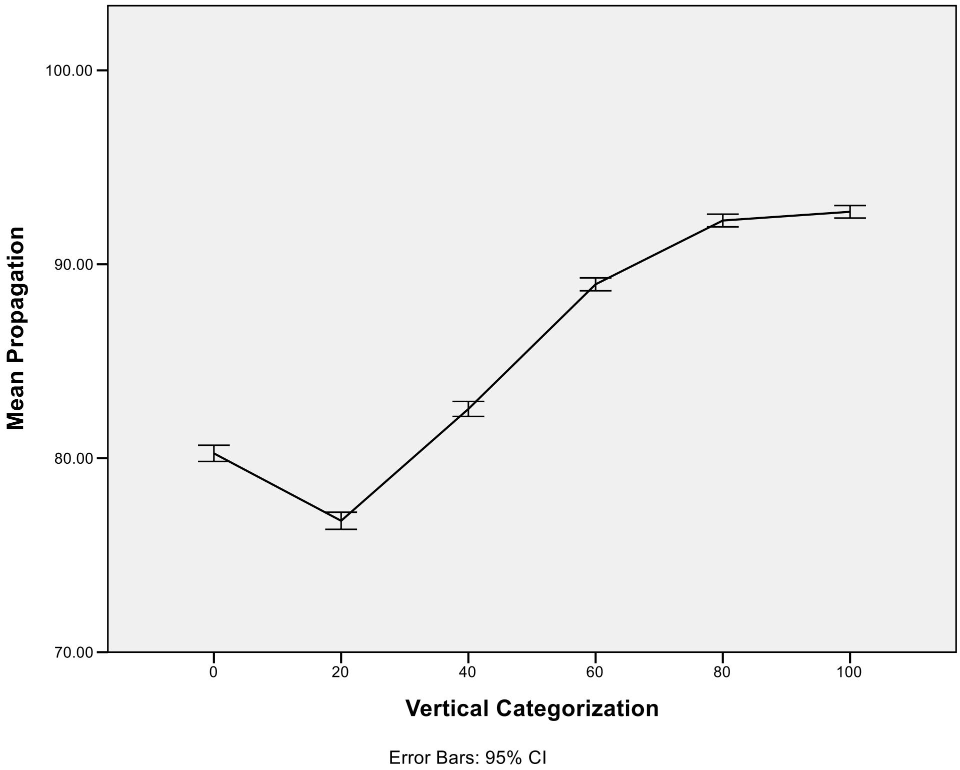


Figure 10: Changes in mean percentage of agents communicated with as a function of vertical categorization (V)

When considered over time (*Figure 11*), a similar occurrence to that noted for changes in the level of horizontal categorization can be seen, in that all levels of vertical categorization seem to stabilize at around the 200 time tick point, but instead of higher levels resulting in lower propagation performance as they did for horizontal categorization, high levels of vertical categorization actually result in the highest performance.

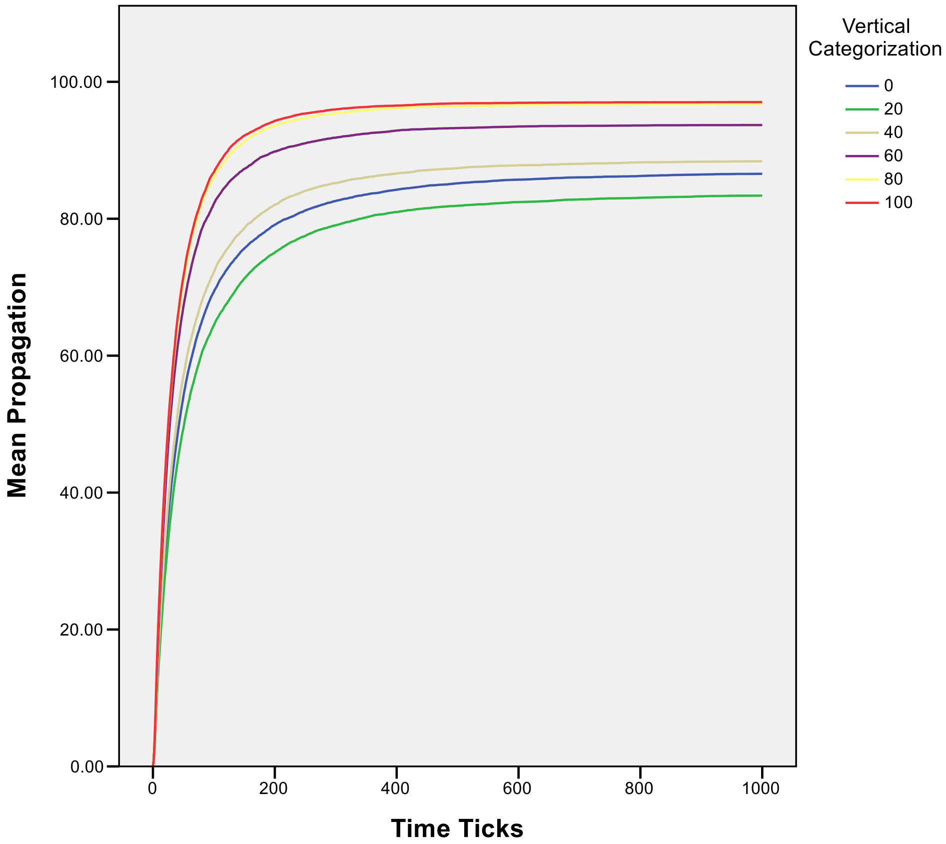


Figure 11: Changes in mean percentage of agents communicated with as a function of vertical categorization (V) over time

A significant interaction between both forms of categorization on the level of system propagation was also found (F (25, 36000) = 176.55, P< 0.01). As can be seen in *Figure 12*, when vertical categorization is at low levels, high levels of horizontal categorization result in notably lower levels of system propagation. When vertical categorization is high however (60% commitment and above), there does not appear to be any divergence in the scores across the levels of horizontal categorization, and all remain at their uppermost levels. This therefore shows that having high levels of vertical categorization can protect against the negative effects of a high horizontal categorization on system performance in terms of the percentage of agents communicated with.

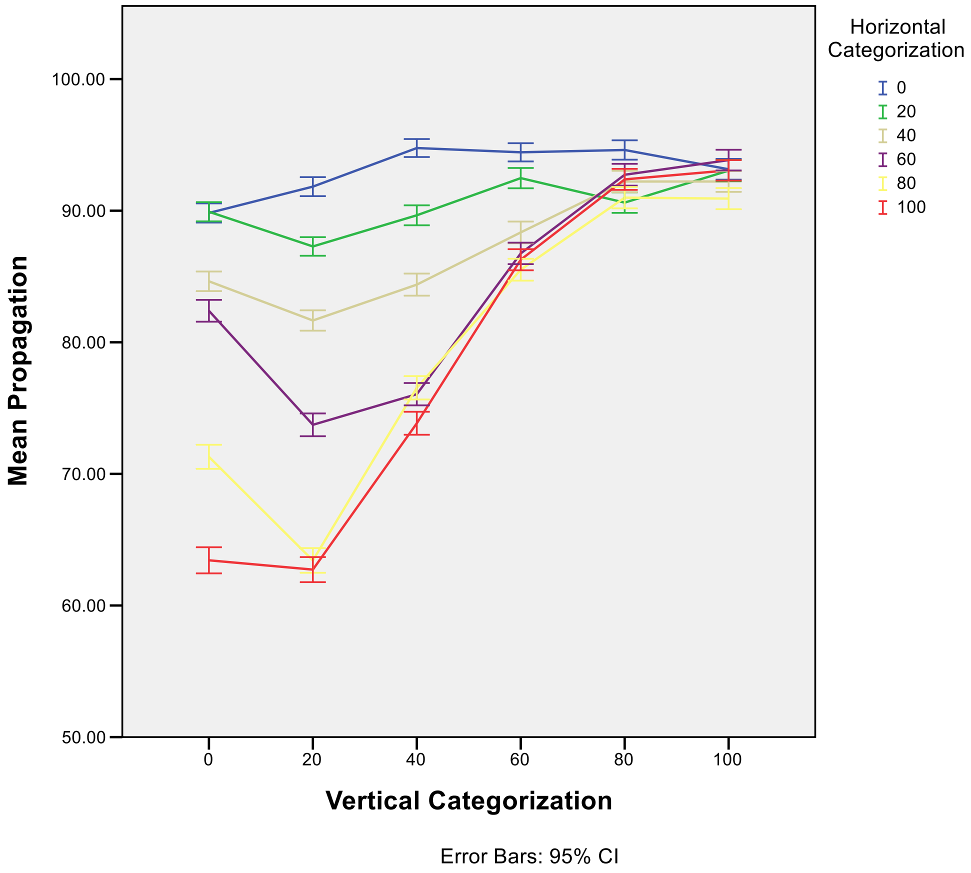


Figure 12: Changes in mean percentage of agents communicated with as a function of the interaction of horizontal categorization (H) and vertical categorization (V)

In sum, the results regarding propagation suggest that commitment to the two categorization parameters once again has significant divergent influence on the outcome variable in question. The analysis showed that increases in the level of commitment agents have towards their originating organizational agency (*H*) were significantly detrimental for the system. Alternatively, if commitment to the command level categorization (*V*) is high enough, then it once again is able to protect the system against the negative influence of agency categorizations (*H*), and even displays performance benefits in terms of the amount of agents communicated with compared to if both categorizations were low. Categorizing with one's level of command (*V*) is thus not only beneficial for preventing negative repercussions of other possible categorizations, but is actually shown to improve performance in its own right.

5.2.3: Accuracy

The third objective of study one was to examine the effects of increases in agents' commitment to their horizontal and vertical categorization on system-level accuracy. The analysis showed that the level of horizontal categorization (with their originating agency) had a significant influence on the average level of accuracy found across the system (F (5, 36000) = 224.24, P< 0.01). Specifically, as the level of horizontal categorization increases, the level of accuracy significantly decreases (see *Figure 13*). In general, this downward trend appears to be linear in nature, although a slight increase in the decline is witnessed at the highest levels of horizontal categorization. Each parameter increase in horizontal categorization results in a small but significant decrease in the percentage of agents communicated with that ranges from between 1% (between the low levels of horizontal categorization) to 4% (between 60% and 80% horizontal categorization) with an average change of 2% decrease between levels, resulting in a total decrease of almost 10% accuracy as horizontal categorization increases.

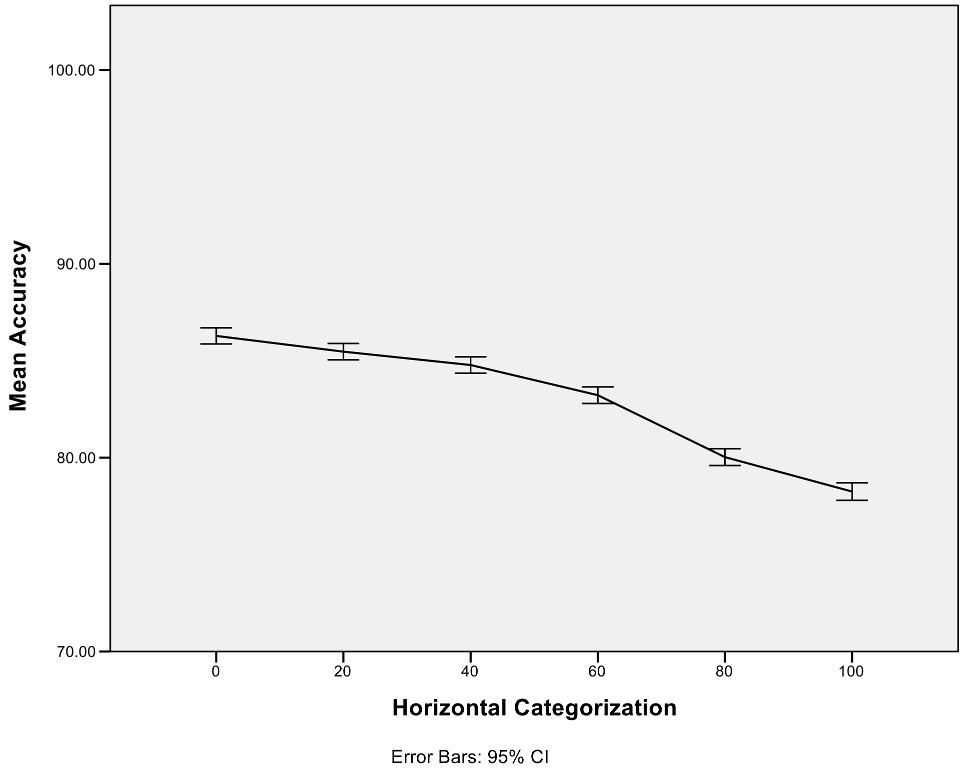


Figure 13: Changes in average system-level accuracy as a function of horizontal categorization (H)

When considered over time (*Figure 14*), it can be seen that by the 1000th time tick, almost all levels of horizontal categorization have converged at the highest level of accuracy, however, the different levels of horizontal categorizations reach this same amount of accuracy at different paces, with high levels of horizontal categorization taking longer to reach this level than when horizontal categorization is low. This therefore suggests that if the system in question has as much time as required to solve the task, horizontal categorization will not be problematic in terms of accuracy. However, if time pressures exist within the system (such as in emergency response multiteam systems), then lower levels of horizontal categorization would be preferable to reach the high levels of accuracy faster.

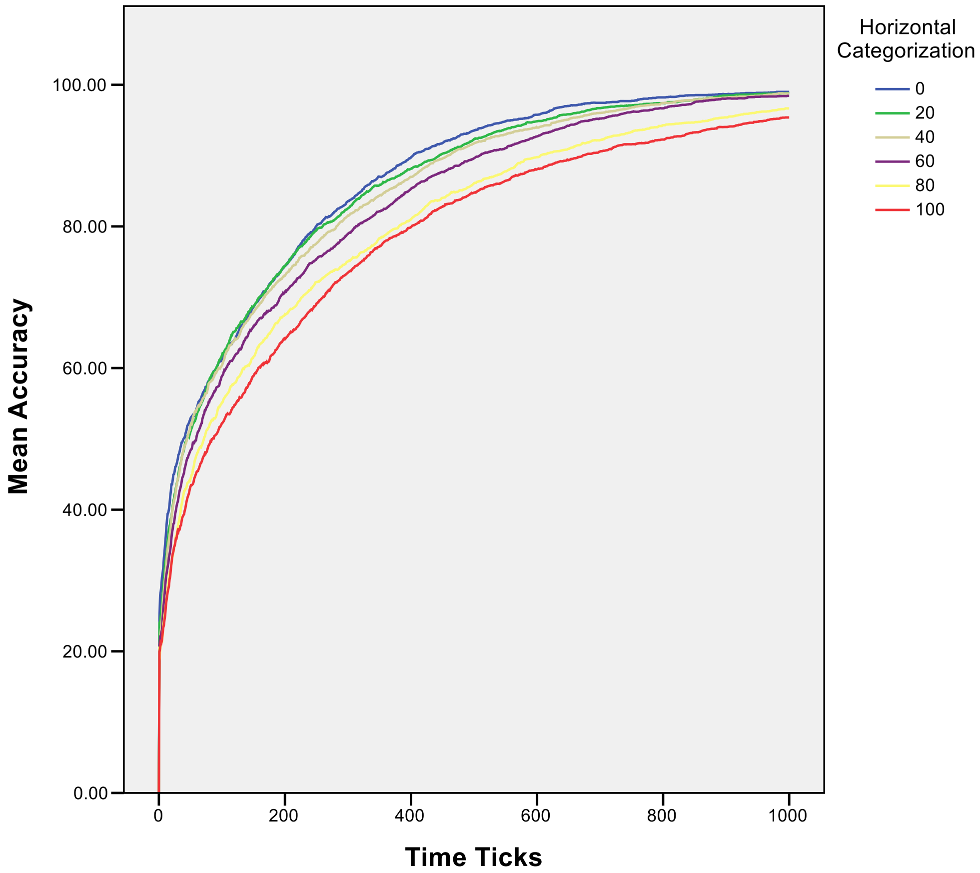


Figure 14: Changes in average system-level accuracy as a function of horizontal categorization (H) over time

A significant relationship was also found between the level of vertical categorization and the average level of accuracy across the system (F (5, 36000) = 63.53, P< 0.01). Whilst increases in vertical categorization resulted in reduced accuracy performance in the same manner as horizontal categorization, it differed in that rather than also showing a general decrease in accuracy as categorization increases, accuracy only began to decrease after vertical categorization reached levels of 60% and above (*Figure 15*).

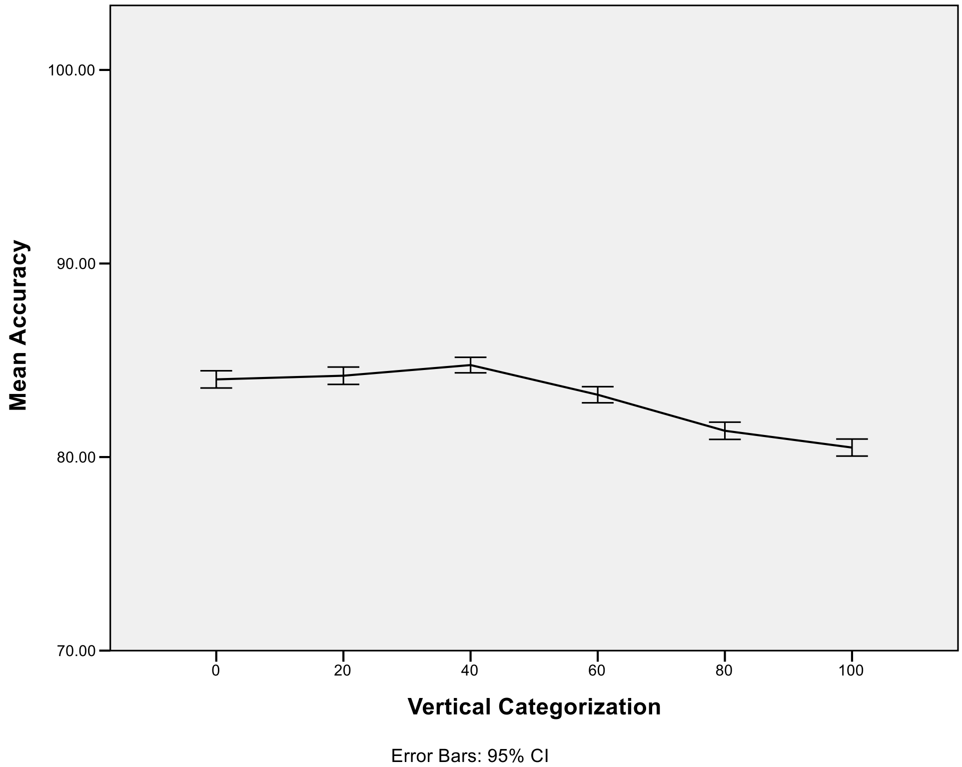


Figure 15: Changes in average system-level accuracy as a function of vertical categorization (V)

When considered over time (*Figure 16*), the pattern shows similarities to that witnessed with changes in the horizontal categorization parameter, in that convergence is apparent by the end of the simulation. However, for vertical categorization, this convergence happens much sooner (at around the 700th time tick instead of the 1000th) and high levels of vertical categorization actually appear to result in higher levels of accuracy by the 1000th time tick than low levels of categorization. This therefore suggests that the negative influence of high levels of vertical categorization on system-level accuracy appear to be less detrimental than those of horizontal categorization on system-level accuracy.

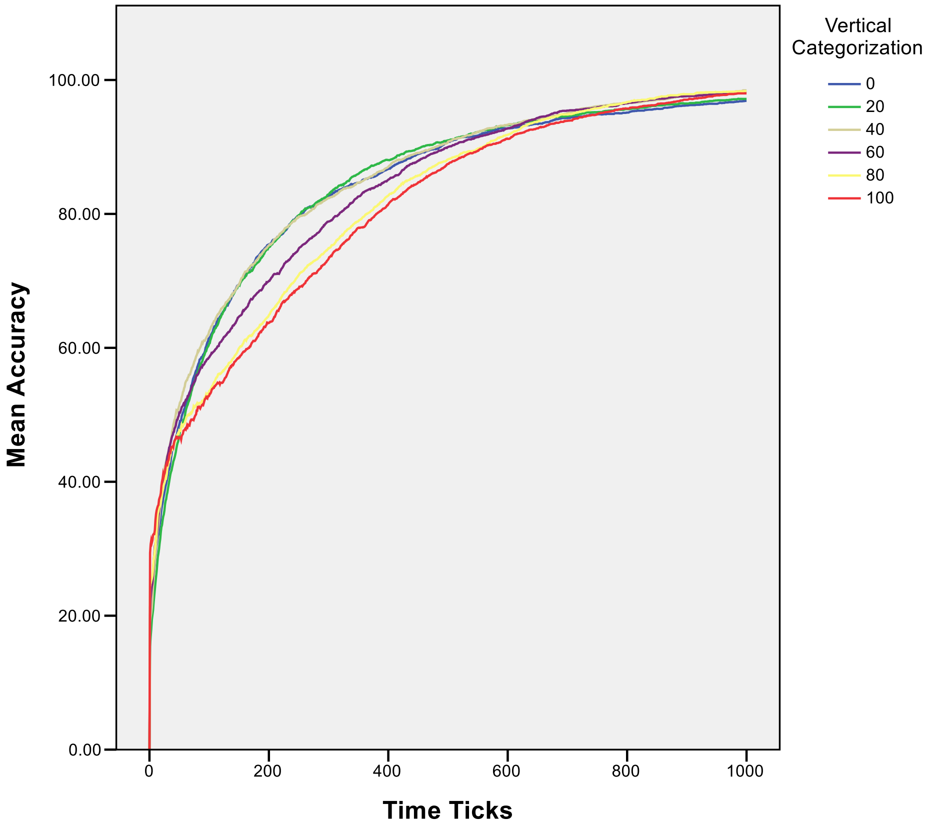


Figure 16: Changes in average system-level accuracy as a function of vertical categorization (V) on time

As can be seen in *Figure 17*, a significant interaction between horizontal and vertical categorizations on system-level accuracy was also found (F (25, 36000) = 49.06, P<0.01). Specifically, at low to moderate levels of horizontal categorization (i.e. between 0% and 60%), a general downward trend in accuracy can be identified across the levels of vertical categorization, with high levels of vertical categorization resulting in the lowest accuracy scores. However, when horizontal categorization is at high levels (i.e. 80% and 100%), then system-level accuracy is actually lowest at low levels of vertical categorization, with increases in vertical categorization up until 60% resulting in improved accuracy performance in these conditions. Following this, the results converge with those of the other levels of horizontal categorizations, with a small but significant general downward trend being identified. This thus once again shows that moderate-high levels of vertical categorization can help to protect the system against the negative influence of high levels of horizontal categorization on system-level accuracy.

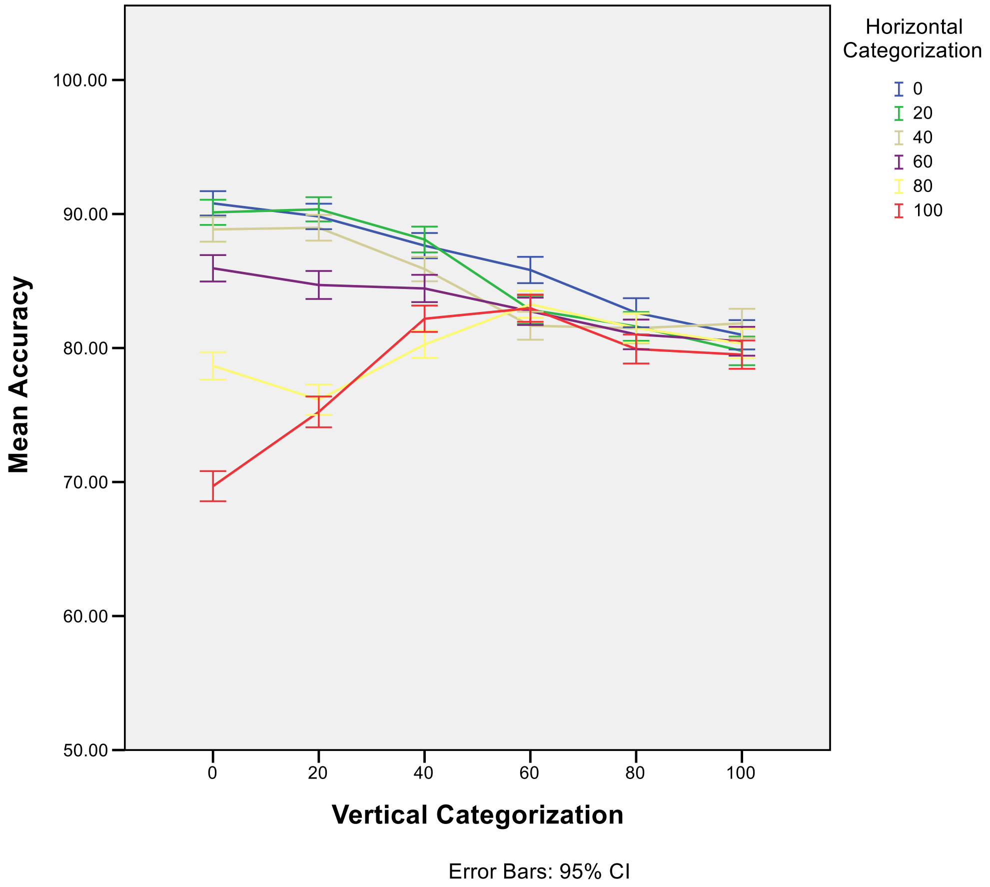


Figure 17: Changes in average system-level accuracy as a function of the interaction of horizontal categorization (H) and vertical categorization (V)

Analysis of the results of the categorization parameters on system-level accuracy showed that increases in either form of categorization, either with one's originating organization (*H*) or their level of command (*V*), has negative repercussions in terms of system-level accuracy. This effect is more pronounced for high levels of agency categorization (*H*). Whilst agents categorizing in terms of their level of command (*V*) is detrimental for the system, it still holds protective qualities against the even more adverse influence of a high agency categorization (*H*) in that if commitment to agency categorizations are high, higher accuracy levels can be achieved if commitment with their bronze, silver or gold level of command categorizations (*V*) are also high.

5.2.4: Summary of study one results

The purpose of study one was to investigate how the grouping with which an agent categorizes themselves influences system-level communicative outcomes. Taken together, the findings reveal some interesting and counterintuitive effects on the three indicators of communicative performance (time, propagation and accuracy) when the grouping with which agents categorize themselves is systematically changed within the model. Specifically, increases in the degree of commitment agents have with their originating organizational categorization (e.g. the police, ambulance service, and private organization - *H*) led to a linear decrease in performance across all three system-level communicative measures. Alternatively, if agents had high enough commitment to their level of command categorization (*V*), then the system actually benefited in terms of both the speed with which information is received by the target agent and the proportion of agents within the system who received the information; facets that would both significantly benefit emergency response systems. Categorization along the lines of command levels (*V*) was also found to not only benefit the system in isolation, but was actually able to negate the negative influences of categorization with agency groupings (*H*) when the two are interacted together.

This study thus suggests that the grouping with which an agent categorizes themself is significantly influential on how the system is then able to function communicatively, and can thus be leveraged as a possible route to reducing system sub-optimization in contexts adopting the multilevel multiteam system design (e.g. emergency response).

5.3: Study two: The influence of intergroup and information-based biases on system-level communicative outcomes

The purpose of this second study is to show how bias influences system-level communicative outcomes. Specifically, two forms of bias are considered, intergroup bias in which agents are only willing to communicate with other similar agents (parameter *J*), and information-based bias, in which agents are only willing to communicate with agents who may be able to make use of the information in question (parameter *L*). The information-based bias parameter is added to ensure that the results found for the intergroup bias parameter are caused by its specific social identity focus, and not an artefact of the parameter being mechanised into the model. Both of these variables were therefore mechanised into the model in the same way, in terms of the percentage match between the focal objects *K*-values, but with divergent focus (i.e. *K*-value match between agents for intergroup biases, or between an agent and information for information-based bias), and agents are unwilling to communicate with individuals who do not meet or surpass the specified threshold match. These mechanisms can thus be thought of as exclusionary, as instead of positively biasing individuals to seek out agents with the requested match requirements, they instead impede communication through increasing agents' information sharing discretion. Table 6 below shows the exact parameter changes utilized within this study.

In the following sections, I shall elucidate the findings of the simulation study on each communicative outcome variable separately, followed by an integrated summary of these findings together and what this means for the multilevel multiteam system in study here.

Table 6: Parameter values in study two:

Independent Variables				**Total conditions**
Bias Parameters		***Categorization Parameters***		
Intergroup (J)	***Information -based (L)***	***Horizontal (H)***	***Vertical (V)***	
0, 20, 40, 60, 80, 100	0, 20, 40, 60, 80, 100	Allowed to stochastically vary	Allowed to stochastically vary	36 Conditions

Notes: intergroup = match required between two agents; information-based = match required between agent and information ; horizontal = with agency grouping; vertical = with command level

5.3.1: Time taken

The first objective of study two was to examine the effects of increases in the level of intergroup and information-based biases on the amount of time taken for information to travel from source agent to target agent. The analysis showed that both forms of bias significantly increased how much time was taken for information to travel from source to target agent, but that the extent of their influence is different.

As seen in *Figure 18*, the level of intergroup bias (parameter *J*) significantly influenced the amount of time taken for information to reach the target agent (F (5, 3564) = 5571.26, P< 0.01). Specifically, as the level of intergroup bias increased, an immediate and exponential increase in the amount of time taken for the information to reach the target agent was witnessed. For example, there is a 145% increase in the time taken just by increasing the level of intergroup bias (*J*) from a 0% to a 20% match requirement. As very few of the simulation runs were able to complete before the 1000 time step threshold once intergroup bias was set at 60% match requirement and above, I cannot conclusively suggest how this relationship would develop at higher levels of intergroup bias from this set of simulations. This relationship could thus be an exponential/power relationship (in which the amount of time taken for the information to reach the target would continue to increase as the level of intergroup bias increases) or a sigmoidal relationship (in which the level of increase would reduce as the level of intergroup bias increases, starting to flatten out, as is viewed on the graph below). This would therefore require further study to fully elucidate, however, it is clear that high levels of intergroup bias significantly increase the amount of time taken for information to travel from source agent to target agent; an effect that would be significantly detrimental for system optimization.

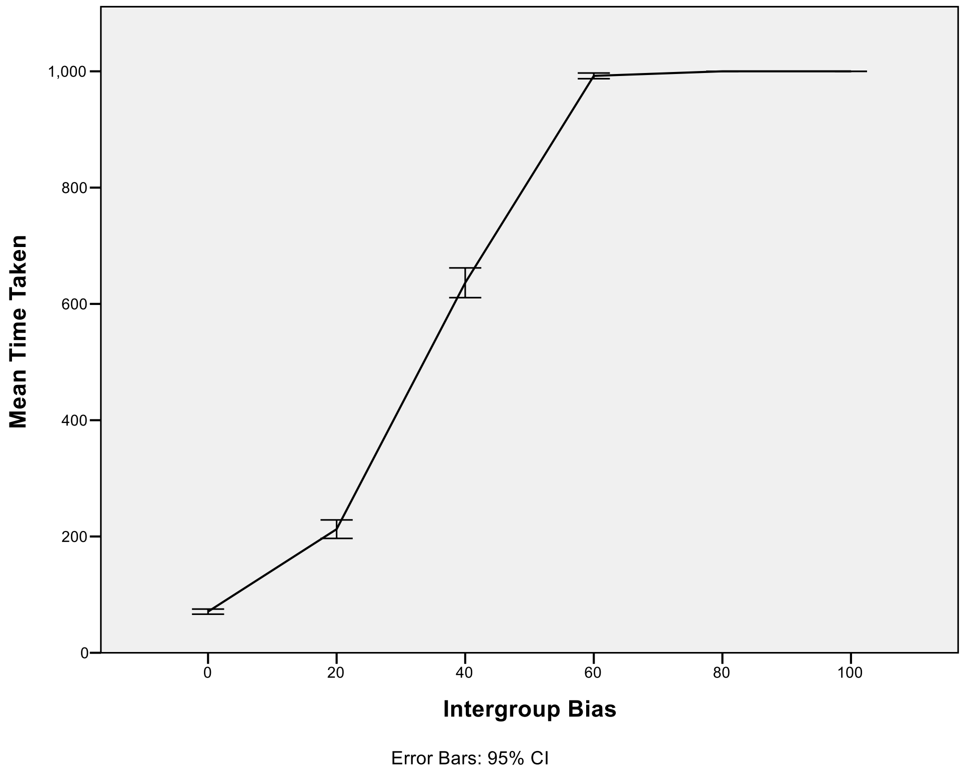


Figure 18: Changes in mean time taken until information reaches target agents as a function of intergroup bias (J)

The level of information-based bias (parameter *L*) also had a significant main effect on the amount of time taken for information to reach the target agent (F (5, 3564) = 69.93, P<0.01). However, this effect differed from that of the intergroup bias (*J*) parameter in that a U-shaped distribution was found (See *Figure 19*), with a slight significant improvement in time performance (i.e. reduced time taken for the information to travel from source to target agent) at low level increases in information-based bias from 0% to 40% match requirements, followed by further increases in information-based bias once again diminishing performance. Small amounts of information-based bias are therefore beneficial for the system in terms of the amount of time taken, whereas high levels of communicative discretion on the basis of the information being shared increases the amount of time taken for information to reach the specified target agent who can appropriately use this information. Low levels of information-based bias may therefore be beneficial for performance in terms of the amount of time taken for information to reach the desired target agent, but if this becomes too high it will detriment communication within the system.

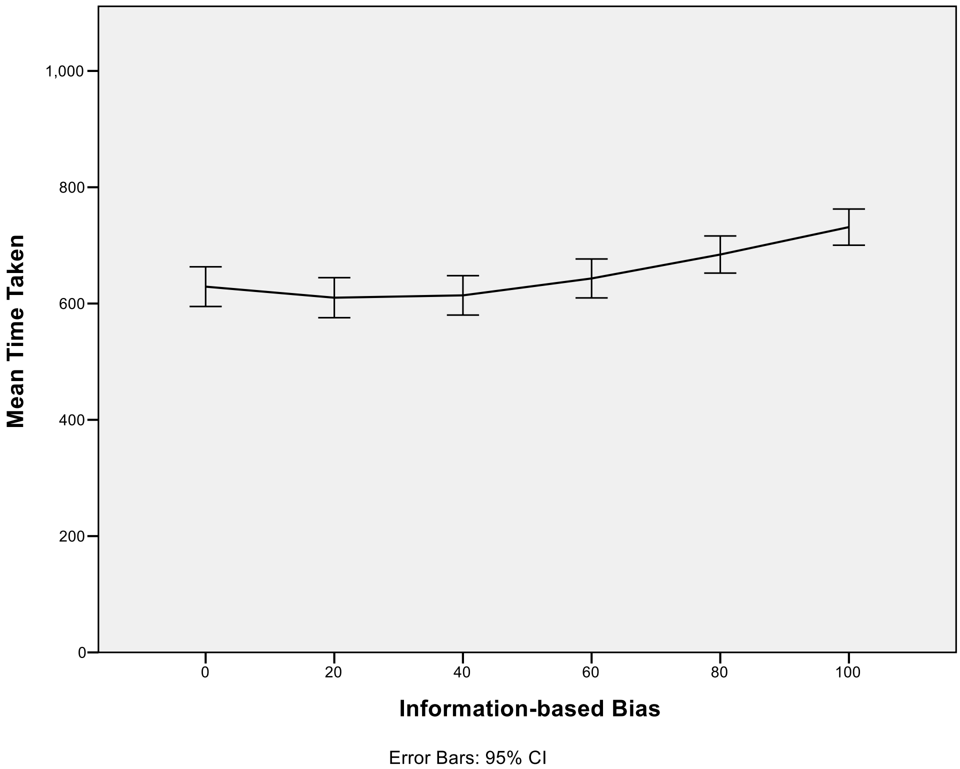


Figure 19: Changes in mean time taken until information reaches target agents as a function of information-based bias (L)

Finally, as can be seen in *Figure 20,* a significant interaction of both the intergroup bias (*J*) and information-based bias (*L*) parameters on time taken for information to travel from source to target was found (*F* (25, 3564) = 28.32, *P*<0.01). Specifically, when the intergroup bias parameter was set at 0% match requirement, the level of information-based bias had very little influence on time. However, as intergroup biases increase to 20% and 40% match requirements, moderate-level ranges of information-based bias (i.e. 20% and 40% match requirements) resulted in significantly improved time outcomes compared to information-based bias at 0% match requirement. Small amounts of information-based bias (*L* match requirement) therefore helped protect the system against the negative influence of increased levels of intergroup bias (*J* match requirement) on the amount of time taken for the information to travel from source to target.

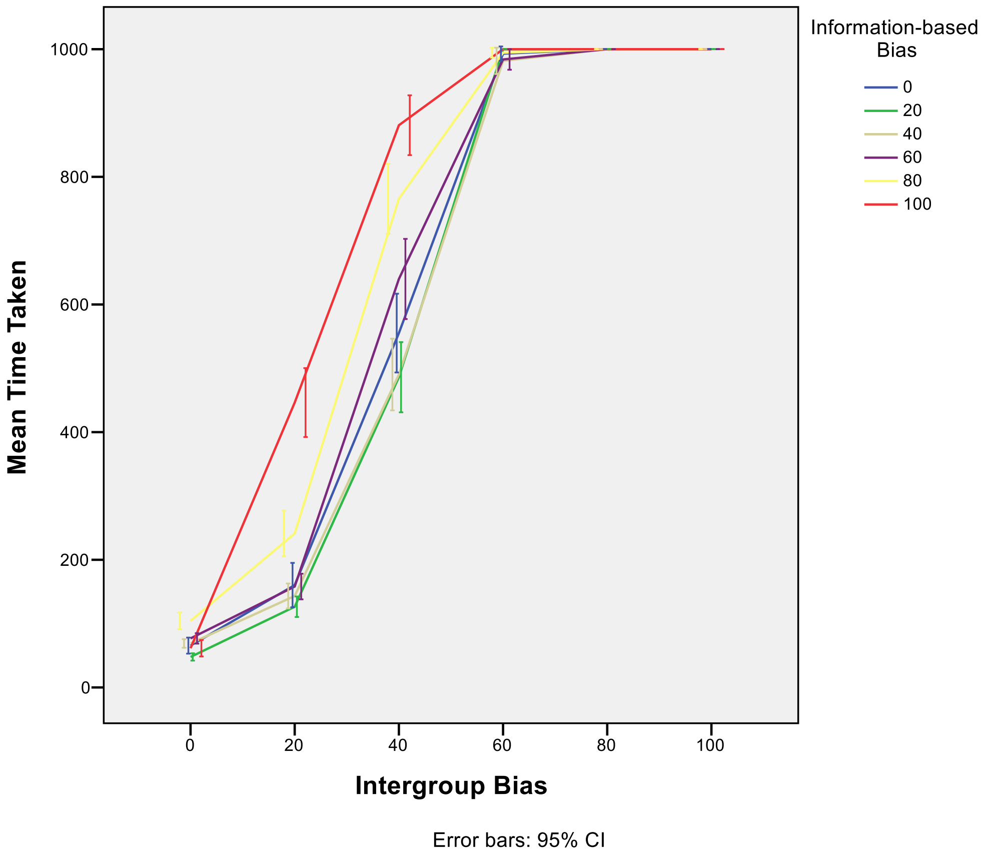


Figure 20: Changes in mean time taken until information reaches target agents as a function of the interaction of intergroup bias (J) and information-based bias (L)

In sum, the results show that intergroup bias (*J*) is significantly detrimental to system performance in terms of the amount of time taken for information to travel from source agent to target agent, to the extent that the system generally fails to complete within the allotted 1000 time tick cycles after intergroup bias has increased above moderate levels. Information-based biases (*L*), in which agents are unwilling to share information with people who do not have a certain degree of skills match with the information itself, also leads to an increase in the amount of time taken until target agents receive the information, however, to a much lesser extent that that witnessed for intergroup biases. The difference between the outcomes for information-based bias compared to those of intergroup bias founded through identity for this variable provides initial support that the negative repercussions found for intergroup bias are not just a facet of the mechanism in the model (i.e. *K*-value match requirements) but are specifically related to the need for homogeneity between agents.

5.3.2: Propagation of information

The results in this section reveal what happens if agents use their discretion to discriminate against agents from whom they differ (i.e. for intergroup bias), or against those agents that do not have close links with the information being shared (i.e. for information-based bias) focusing on the effects on propagation.

As seen in *Figure 21*, higher levels of intergroup bias (*J* match requirement) resulted in significantly reduced levels of information propagation throughout the system (F (5, 3600) = 50437.45, P<0.01). This takes a sigmoidal form, in that starting from the point of minimum match requirements (i.e. J = 0% match requirement), adding further intergroup bias slowly decreases the level of propagation evinced. This rate of decrease speeds up as further intergroup bias is added (specifically at 60% and 80% *J* match requirement levels), in that as intergroup bias increases, fewer members of the system are being communicated with. Eventually however, the influence of intergroup bias increases diminishes and further increases no longer lead to such significant reductions in the propagation of information, thus resulting in the curve flattening out. This suggests some significant tipping point thresholds within the moderate-range of intergroup bias, at which too much bias undermines the entire system.

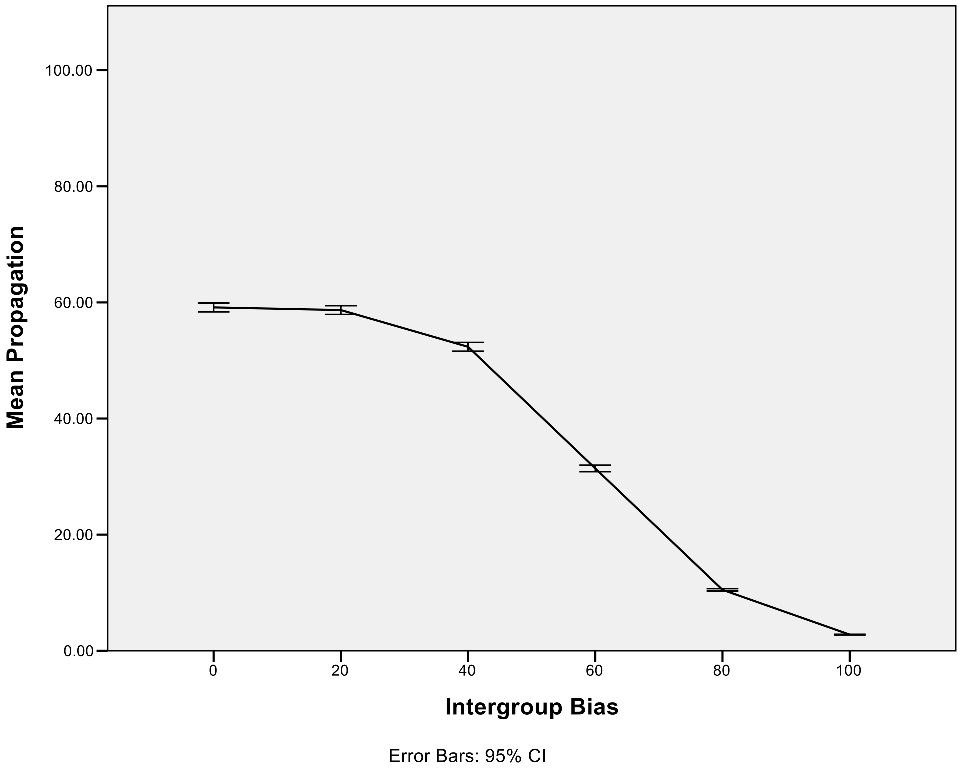


Figure 21: Changes in mean percentage of agents communicated with as a function of intergroup bias (J)

Moreover, as can be seen in *Figure 22*, higher levels of intergroup bias also increased the amount of time taken before the propagation figure stabilized at its highest possible value, taking under 100 time ticks at a 0% *J* match requirement (i.e. low requirement for agent-agent homogeneity), compared to 400 time ticks at a 40% *J* match requirement (i.e. where high intergroup bias results in increased requirement for agent homogeneity). When intergroup biases increases above 60% *J* match requirement, stabilization of the models propagation is no longer evinced within the 1000 time tick threshold of this model.

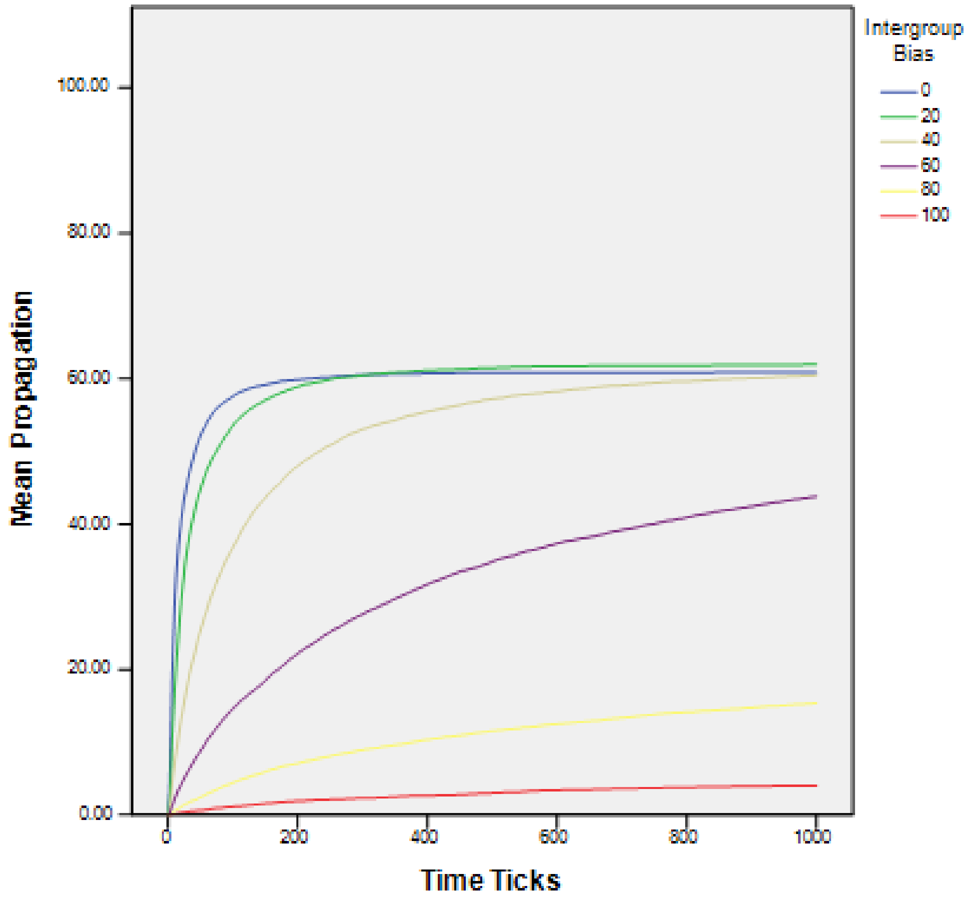


Figure 22: Changes in mean percentage of agents communicated with as a function of intergroup bias (J) over time

The level of information-based bias (the *L* parameter) also had a significant main effect on the number of agents who received the information (*F* (5, 3600) = 34249.22, *P*<0.01). This effect is evinced in the same manner as that of intergroup bias (i.e. changes to the level of homogeneity required between agents), in that it once again displays a decrease in propagation performance outcomes as information-based bias increases in a sigmoidal form, with incremental changes in the moderate-level of information-based bias (*L* match requirements) having the most significant influence on the level of information propagation throughout the system (see *Figure 23*).

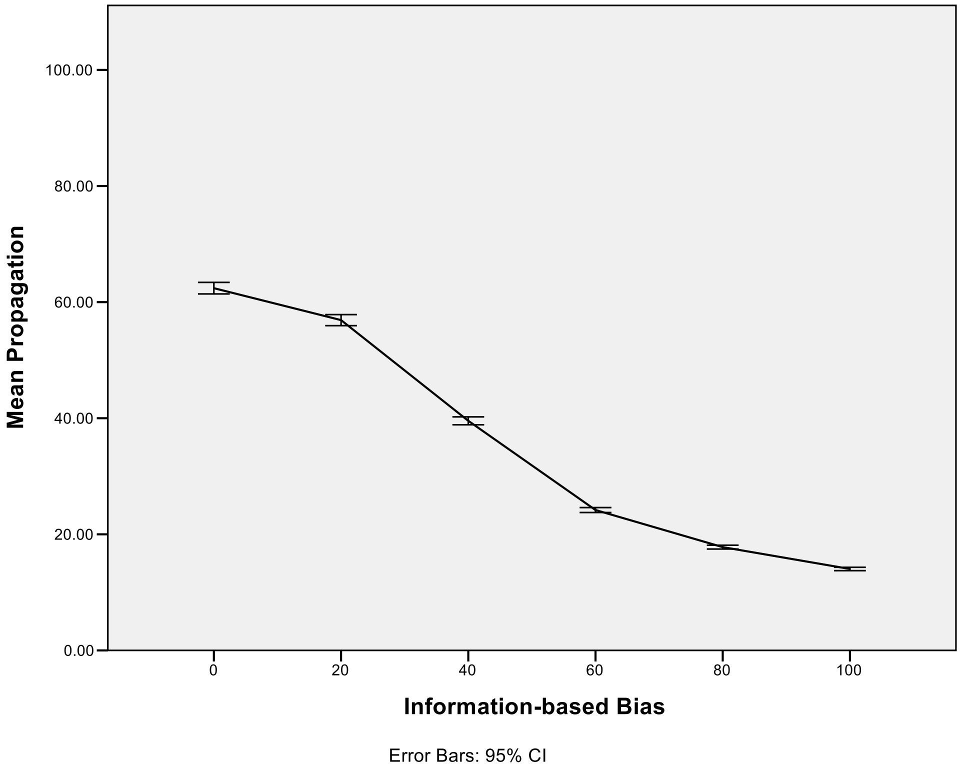


Figure 23: Changes in mean percentage of agents communicated with as a function of information-based bias (L)

However unlike intergroup bias effects, when considered over time (*Figure 24*), stabilization of the system still appears to occur at around the same point in time (at around 100 time ticks) at all levels of information-based bias (*L* match requirement), even though the value of these stabilized levels may vary. This thus displays how information-based bias influences the maximal levels of propagation that can be achieved, rather than on how quickly the system is able to achieve these maximal levels.

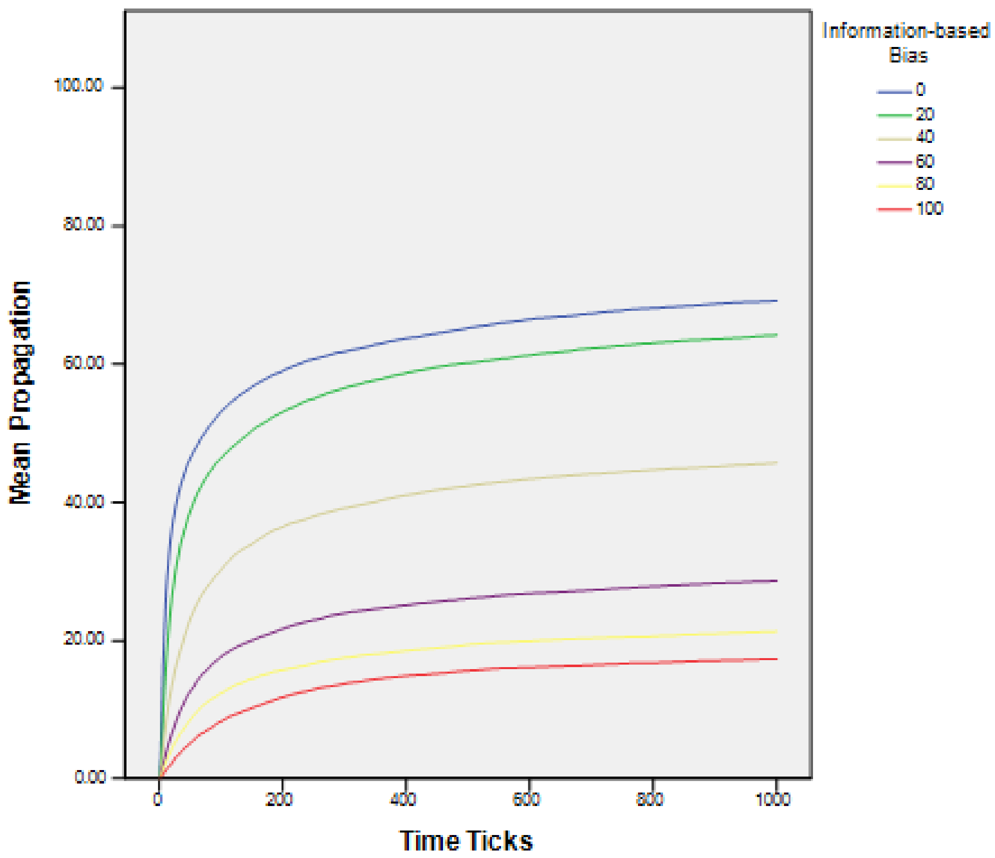


Figure 24: Changes in mean percentage of agents communicated with as a function of information-based bias (L) over time

Finally, a significant interaction of both the intergroup and information-based biases (the *J* and *L* parameters together) on the percentage of agents communicated with was evinced (F (25, 3600) = 2380.21, P<0.01). The same sigmoidal form demonstrated for intergroup bias and information-based bias individually was exhibited in this interaction (*Figure 25*), with the most significant decreases in system propagation in comparison with the previous level occurring at medium levels of match requirements for both (i.e. between 40% and 80% in both parameters). However, this effect is much more significant for low levels of each parameter, in that the difference in the propagation scores between 0% and 100% *J* match requirements (high intergroup bias resulting in the need for complete homogeneity of agents for communication to take place) is more marked at lower levels of information-based bias (*L* match requirements) as compared to high levels of information-based bias. This means that if one of the parameters is at a low level of importance for agents, changes in the other parameter become much more significant for the system than if that first parameter were at a high level of importance for agents.

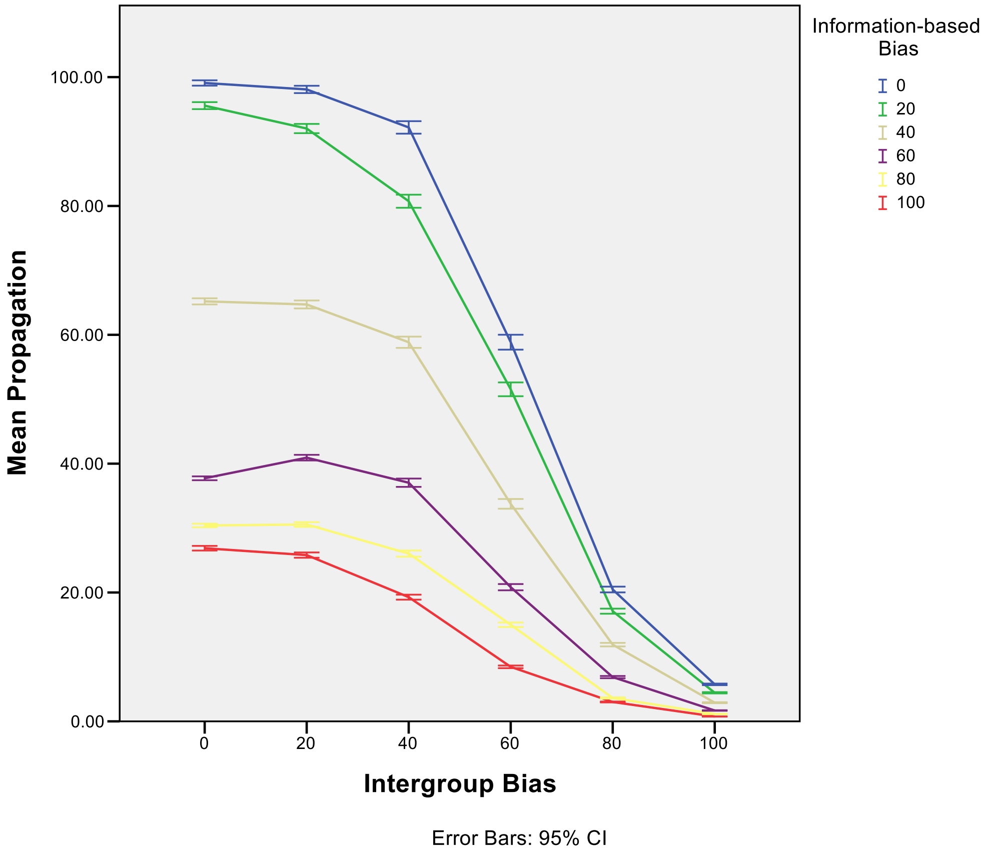


Figure 25: Changes in mean percentage of agents communicated with as a function of the interaction of intergroup (J) and information-based biases (L)

Overall, the results show that if agents use their discretion to discriminate against agents from whom they differ (i.e. for intergroup bias; *J*), or against those agents that do not have close links with the information being shared (i.e. for information-based bias; *L*), these biases will significantly reduce the level of propagation throughout the system. Although any increase in the amount of either bias will have negative repercussions for the system, the effects of bias on propagation are characterised by a significant tipping point: the effects of both types of bias reach a point whereby any further increases in bias lead to significantly large reductions in propagation performance. Further analysis shows that this influence is due to intergroup biases slowing down how quickly the system can reach its highest possible levels of propagation, whilst information-based bias influences the maximal level that can be reached. Intergroup biases thus mainly exert a negative influence on system-level performance through slowing down how quickly system optimization (determined by other influences) can be achieved.

5.3.3: Accuracy

In this section, I considered the influence of the two forms of bias on the level of accuracy that can be achieved. Analysis showed that the level of intergroup bias (J) significantly influenced the average level of accuracy in terms of the average degree of match between the information and the agent holding it that the system was able to generate (F (5, 3600) = 43920.77, $P<0.01$). Specifically, this relationship was found to be sigmoidal in form (see *Figure 26*), with incremental increases in the level of intergroup bias resulting in lower levels of accuracy, with the largest impacts of incremental changes to this form of bias occurring at the moderate range values between 40% and 80% match requirements.

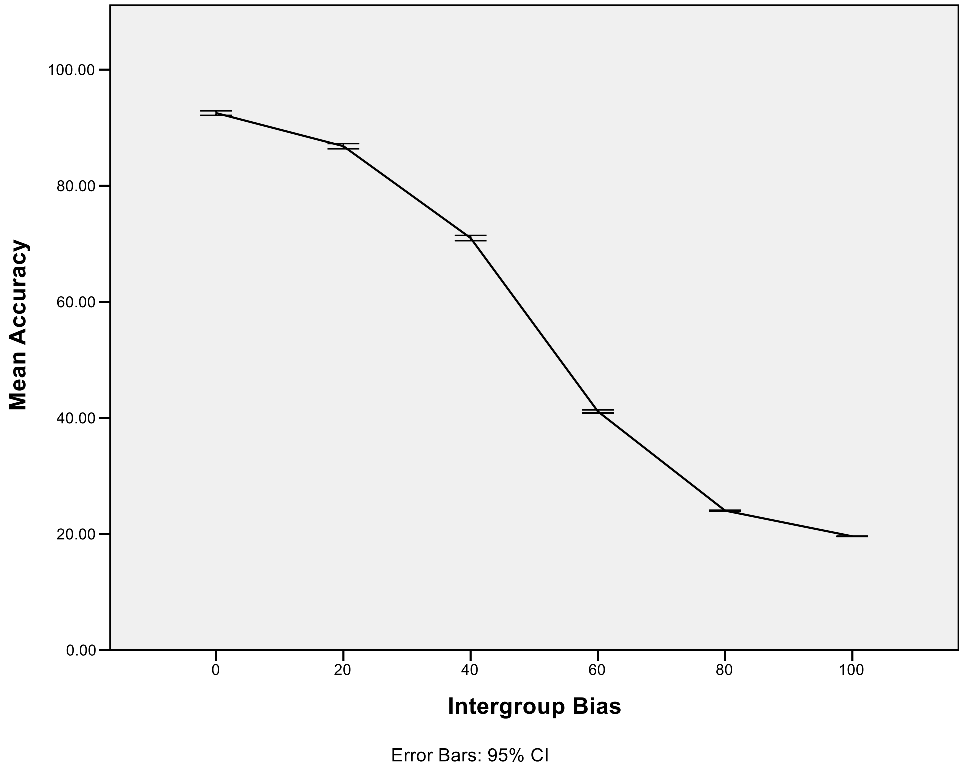


Figure 26: Changes in average system-level accuracy as a function of intergroup bias (J)

Moreover, not only did higher levels of intergroup bias result in lower levels of accuracy, but when considered over the 1000 time tick duration (*Figure 27*), it can be seen that higher levels of intergroup bias also resulted in a much flatter curve thus displaying slower growth to maximum accuracy. This therefore means that increases in the desire for homogeneity between agents for them to communicate results in reduced accuracy for a system such as this, and that it will take longer to develop any beneficial level of accuracy than if such a requirement did not exist at all.

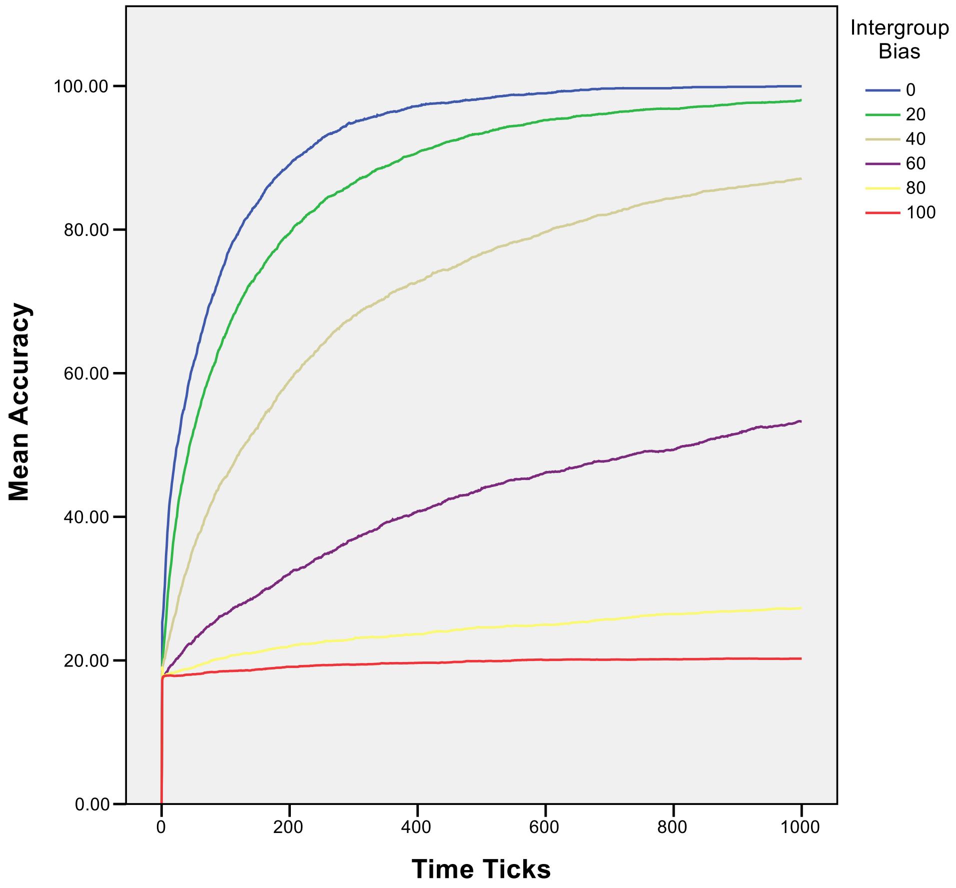


Figure 27: Changes in average system-level accuracy as a function of intergroup bias (J) over time

The level of information-based bias also had a significant main effect on the average level of accuracy (F (5, 3600) = 808.62, P<0.01), although this relationship was very different to that identified between intergroup bias and accuracy discussed above. As seen in *Figure 28*, instead of a general reduction in accuracy as the level of information-based bias increased (as it did for intergroup bias), an inverse U-shaped relationship was observed, with the highest levels of accuracy recorded when information-based bias was set at a 40% match requirement, and significantly reduced levels of accuracy recorded when information-based bias was required at either 0% or 100% L match requirement. The beneficial effect was small though, in that only a 10.78% improvement to accuracy can be observed when there is an increase in information-based bias from 0% to 40% L match requirement. However, this does show that moderate levels of information-based bias do result in improved performance in terms of accuracy.

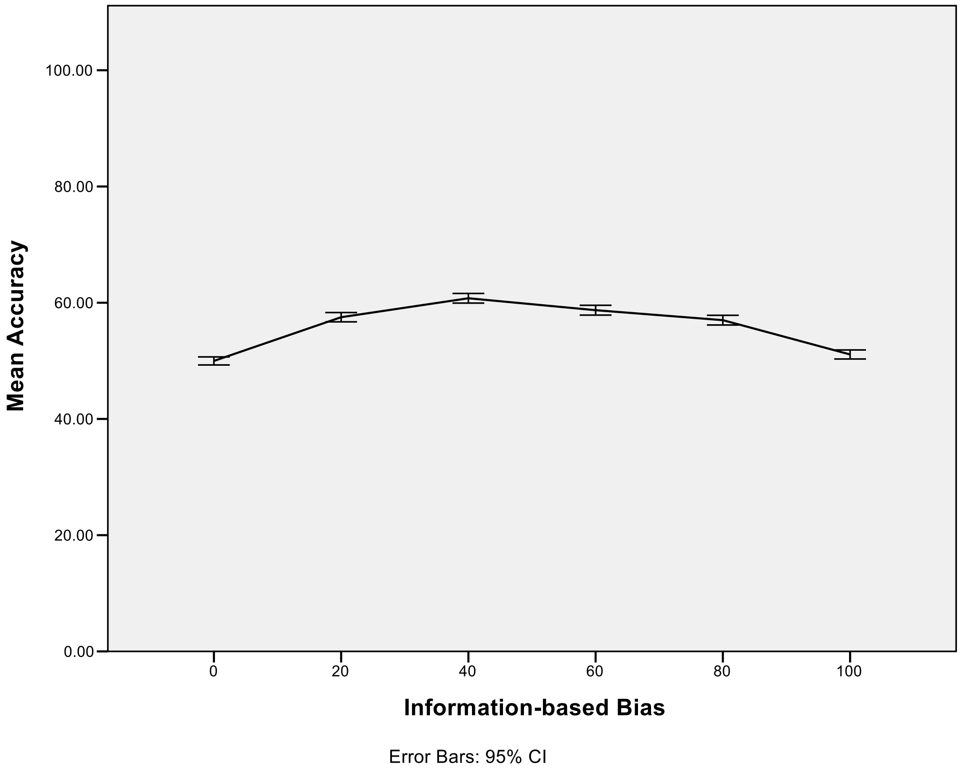


Figure 28: Changes in average system-level accuracy as a function of information-based bias (L)

The fact that the beneficial effect of moderate levels of information-based bias was small can also be observed when considered over the duration of the simulation (*Figure 29*) in that both the actual levels reached and the amount of time taken to reach these levels (the curve) is only slightly (yet significantly) reduced for information-based bias at levels of 0% or 100% *L* match requirement in comparison with those in the moderate-level ranges.

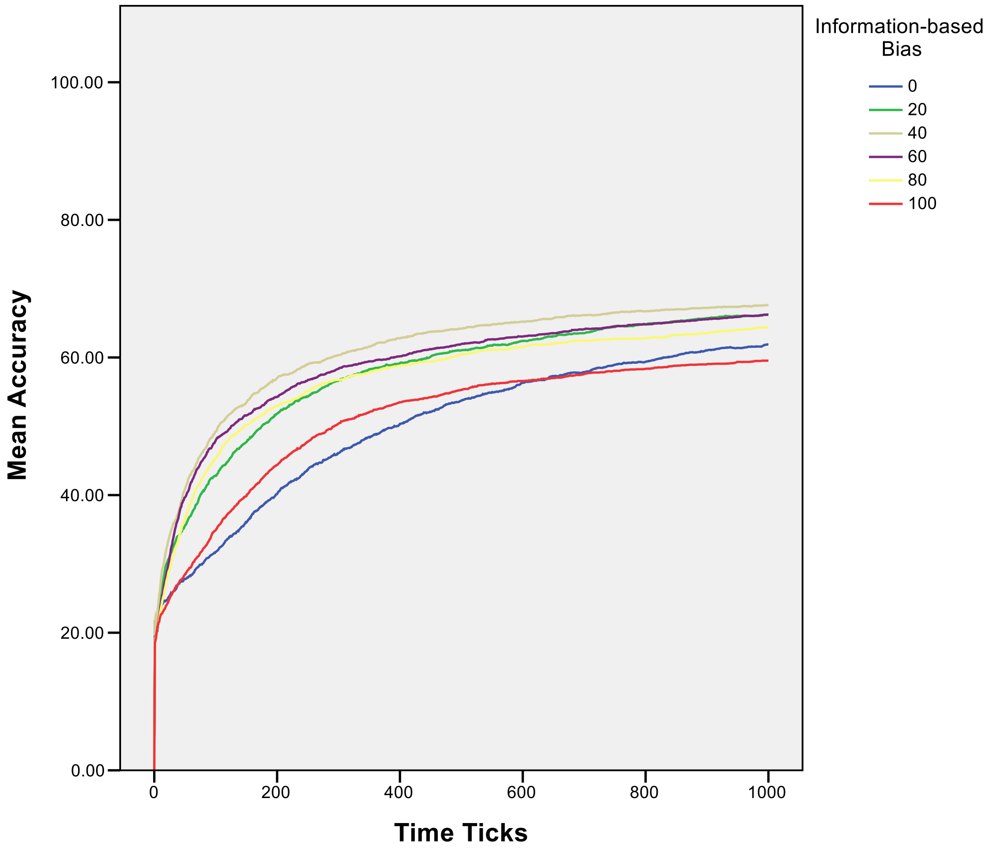


Figure 29: Changes in average system-level accuracy as a function of information-based bias (L) over time

Finally, a significant interaction of intergroup and information-based bias on the average percentage accuracy match achieved was also found (F (25, 3600) = 128.92, P<0.01). Specifically, as can be seen in *Figure 30*, moderate levels of information-based bias (especially 40% L match requirement) helped protect the system from the negative effect of intergroup bias on accuracy levels. At every level of intergroup bias (J), the worst performance was exhibited when information-based bias was either set at 0% match requirement or 100% match requirement. Which of these levels of information-based bias has the most significant negative impact on accuracy depends on the level of intergroup bias, with low information-based bias (i.e. 0% L match requirement) displaying the worst performance until a tipping point at moderate levels of intergroup bias (40% J match requirement), at which point a high levels of information based bias (e.g. 100% match requirement for L) displays the worst performance due to having a stronger sigmoidal form. This therefore means that at low levels of intergroup bias, any amount of additional information-based bias will benefit the system, whereas at higher levels of intergroup bias, having a heightened bias for information matching as well as the intergroup bias will lead to further diminishing returns.

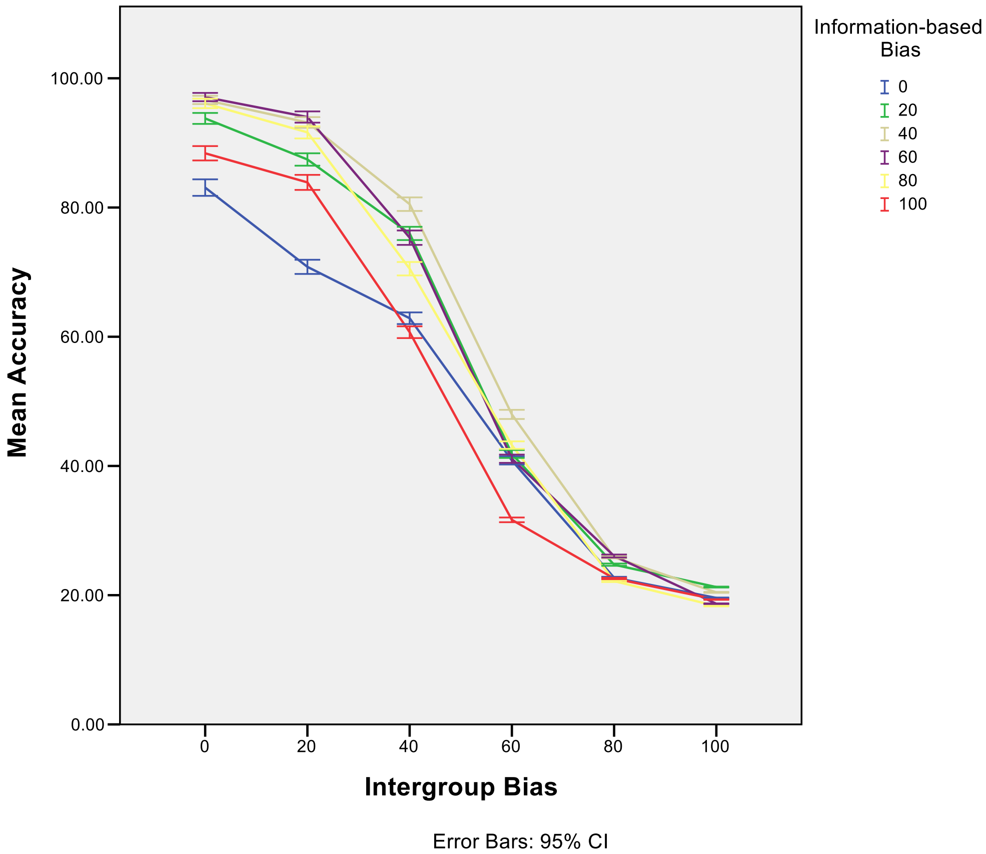


Figure 30: Changes in average system-level accuracy as a function of the interaction of intergroup bias (J) and information-based bias (L)

Analysis of the results of the bias parameters on accuracy shows that intergroup bias (*J*), in which agents are only willing to communicate with other similar agents, once again results in significantly reduced communicative performance, in this instance in terms of accuracy. However, information-based bias (*L*), in which agents are only willing to communicate information to people who have enough skills/traits to make use of the information, instead leads to some accuracy improvements at moderate levels of bias. This therefore once again is indicative that it is specifically the bias related to social identification (intergroup bias) and not bias per se that leads to detrimental communicative performance for systems of this design. Specifically, intergroup biases slowed how quickly maximal levels of accuracy could be achieved.

5.3.4: Summary of study two results

The purpose of this second study was to show how bias (both intergroup and information-based) influence system-level communicative outcomes. Taken together, the findings reveal some interesting effects on the three indicators of communicative-performance (time, propagation and accuracy) when the degree to which agents show discretion with whom they communicate on the basis of bias is systematically changed within the model. Specifically, increases in both forms of bias can be detrimental to the system. This is especially true when both forms of bias are high at the same time.

High levels of intergroup bias (J), in which agents were motivated to only communicate with other similar agents, were found to slow communication between agents to such an extent that the simulation barely completes within the 1000 time tick limit, and also led to reductions in the proportion of agents communicated with and the degree of accuracy that can be reached through slowing how quickly maximal levels of each could be achieved. Whilst still unfavourable, information-based bias (L) was found to be less significantly adverse for the system, in that increases in this form of bias did not prevent the simulation from completing within the allotted time and actually yielded some performance benefits at moderate levels in terms of accuracy.

The divergent findings between these two forms of bias is indicative that it is specifically the focus of bias, and not just the bias mechanism implanted into the model per se, that causes system sub-optimization to the extent that a system can completely fail. Specifically, bias incited by social identity (i.e. J) can lead to reductions in the speed of communication, and if high enough, can disrupt communication to such an extent that the system can completely fail to achieve its goal. This study thus suggests that systems such as those employed in emergency response should avoid the pitfalls of intergroup bias to whatever extent is possible, as any increases in this form of bias can lead to a significant lack of information sharing that would in turn disrupt collective cognition, coordination and decision making, fracturing the response and preventing effective functioning.

5.4: Conclusion

Overall, the above two studies show some interesting and counterintuitive effects of categorization and bias. Specifically, the grouping with which agents categorize themselves was found to have a significant influence on system-level communicative performance. If agents had strong commitment to their originating organizational agency categorization (*H*), then the system sub-optimized across all three communicative performance outcomes. However, if agents instead committed highly to their level of command categorization (*V*), then this enhanced communicative outcomes, and protected the system against the negative influences of horizontal categorization. In terms of intergroup bias (the form of bias that is of special interest within this study due to its link with social identity theory), this was found to detriment the system across all three performance indicators. Moderate to high levels of intergroup bias slowed down information exchange to such an extent that information rarely propagated throughout the system to reach the desired target agents, preventing full completion of the simulation within the allotted time (i.e. 1000 ticks).

However, whilst these results are interesting in their own right, it is possible that they only stand true under the exact configuration exhibited for the other variable. For example, the interesting and counterintuitive influences found for vertical categorization in study one might have only existed under the specific conditions of intergroup and information-based bias investigated within that study. This is especially true considering that variations to the bias parameters did create significantly different influences on communicative performance in study two. It was therefore imperative to investigate whether the beneficial influence of vertical categorization would still exist under different conditions of bias. Moreover, van Knippenberg *et al*. (2004) suggested that intergroup biases result in disruption to elaboration between agents who view themselves as existing within different categories. The exact nature of the categorization (i.e. to which grouping it is with and the level of commitment to this grouping) might also have an influence on how intergroup biases influence communicative performance at the system-level. It was therefore also imperative to consider whether changes to the level of commitment to different categorizations influenced the way in which bias influenced system-level communicative outcomes. A third study was thus conducted in order to ascertain whether these effects stood true when the categorization and bias parameters were interacted systematically.

Chapter 6: Results of study considering the complex effects of social identity processes on communicative outcomes in interaction

6.1: Introduction to study three

The purpose of this study was to investigate systematically whether the pattern of findings concerning categorization and bias in isolation from studies one and two (see sections *5.1* and *5.2*) remain the same when all four parameters were varied conjunctively. It was important to test this interactive influence of bias and categorization together, as categorization and bias are thought to conjunctively create the processes of social identity (van Knippenberg *et al*., 2004) and the findings of the previous two studies might only be true under the specific parameter settings considered.

A fractional factorial design was selected for this study, as a full factorial design would generate too much data to be manageable. Both horizontal categorization (*H*) and vertical categorization (*V*) were once again considered over the full range of possible values (i.e. between 0-100% commitment in increments of 20). The intergroup (*J*) and information-based (*L*) bias parameters were however aggregated into five nested clusters of conditions (referred to going forward as 'the bias conditions') that allow the comparison of how different levels of horizontal and vertical categorizations influence communicative performance under conditions of high, low and mixed levels of bias. Specifically, the combinations of low intergroup/low information-based biases (cluster one), low intergroup/high information-based biases (cluster two), moderate intergroup/moderate information-based biases (cluster three), high intergroup/low information-based biases (cluster four) and high intergroup/high information-based biases (cluster five) were considered. Table 7 shows the exact parameter changes utilized within this study.

Table 7: Fractional factorial design outline for study three

NC	*Independent Variables*				Total conditions
	Bias Parameters		***Categorization Parameters***		
	Intergroup	***Information-based***	***Horizontal***	***Vertical***	
1	Low (5%)	Low (5%)	0, 20, 40, 60, 80, 100	0, 20, 40, 60, 80, 100	36 Conditions
2	Low (5%)	High (45%)	0, 20, 40, 60, 80, 100	0, 20, 40, 60, 80, 100	36 Conditions
3	Moderate (25%)	Moderate (25%)	0, 20, 40, 60, 80, 100	0, 20, 40, 60, 80, 100	36 Conditions
4	High (45%)	Low (5%)	0, 20, 40, 60, 80, 100	0, 20, 40, 60, 80, 100	36 Conditions
5	High (45%)	High (45%)	0, 20, 40, 60, 80, 100	0, 20, 40, 60, 80, 100	36 Conditions
					Total = 180 conditions

Notes: NC = Nested cluster of bias conditions; intergroup = match required between two agents; information-based = match required between agent and information; horizontal = with agency grouping; vertical = with command level; figures in brackets denote the values of agents' and information K-value match requirement for communication.

In the following sections, I shall elucidate the findings of the simulation study on each communicative outcome variable separately, followed by an integrated summary of these findings together and what this means for the multilevel multiteam system in study here.

6.2: Time Taken

In this section, I considered the how systematically changing agents' level of commitment to their horizontal and vertical categorization influenced the amount of time taken for information to travel from source agent to target agent under five different conditions of bias. The analysis showed that the way in which categorizations influence the amount of time taken for information to reach the target agent is governed by the degree of intergroup bias also exhibited within that system. I shall now present these results, first considering the interactive influence of horizontal categorization in conjunction with the bias conditions on amount of time taken, followed by a discussion of vertical categorization interacting with the bias conditions, and finally considering the interactive influences of horizontal and vertical categorizations across the different bias conditions.

6.2.1: The interactive influence of bias and horizontal categorization on time

As can be seen in *Figure 31*, a significant interaction between the level of horizontal categorization (agents categorizing themselves as part of their organizational agency; i.e. policemen, fire-service, private organization, etc.) and the bias conditions (i.e. cluster one = low/low; cluster two = low/high etc.) on the time taken for information to travel from source agent to target agent was found (F (20, 17970) = 13.16, P<0.01).

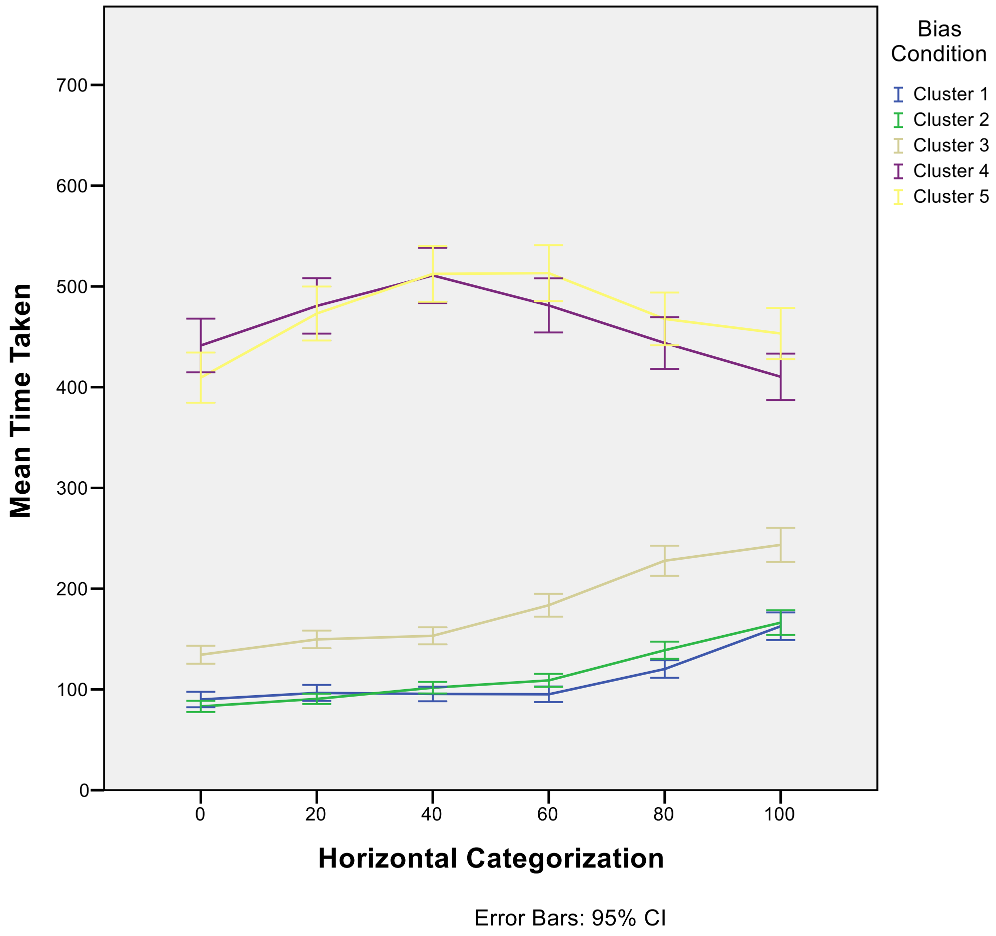


Figure 31: Changes in mean time taken until information reaches target agents as a function of horizontal categorization (H) and the bias conditions

Notes: Cluster 1 = low J, low L; Cluster 2 = low J, high L; Cluster 3 = moderate J, moderate L; Cluster 4 = high J, low L; Cluster 5 = high J, high L

Post hoc tests show that the main bias parameter to influence the time taken is intergroup bias (*J*) as opposed to information-based bias (*L*). The specific results that make this apparent is that differences between bias conditions with the same intergroup bias match requirements (e.g. cluster one where both biases are low and cluster two where intergroup bias is again low but information-based bias is classed as high) proved to be non-significant (at the P=0.05 level) whereas results from bias conditions with different intergroup bias match requirements (e.g. cluster one where both biases are low and cluster four where information-based bias is also low but intergroup bias is high) are significant (at the P<0.01 level). Similar patterns of results for bias conditions that contain the same level of intergroup bias are also easily recognizable in *Figure 31.* The fact that results within the same intergroup bias condition reflected the same scores shows that out of the bias conditions, only intergroup bias has a significant influence on how the categorization parameters influence the amount of time taken for information to reach the target agent.

Interestingly, the results show that changes to the level of commitment to horizontal categorizations under bias conditions with low and moderate intergroup biases display the same pattern of results just at slightly different ranges of time, whereas when intergroup biases are high, the pattern completely changes. Under both of low and moderate bias conditions (i.e. clusters one, two and three), the amount of time taken remained stable level between low to moderate levels of commitment with horizontal categorizations (0% - 40% commitment) followed by a slight linear increase in the amount of time taken as commitment to horizontal categorizations rises to high levels (60% categorization and above) with an average overall increase of 88 time ticks taken when horizontal categorization rises from 0% to 100% commitment. Therefore, when intergroup biases are at a low or moderate level, increases in the level of horizontal categorization have a negative impact on performance in terms of the amount of time taken for information to travel from source to target.

Whilst the pattern of results remains the same between bias conditions with low or moderate levels of intergroup bias (clusters one, two and three), the range of scores over which this pattern is evident changes, taking 70 time ticks longer on average when intergroup biases are moderate compared to low. This therefore reflects that increases in intergroup biases will still reduce system-level performance in terms of time taken, even if they do not alter the pattern of results.

When the bias condition includes high levels of intergroup bias however (i.e. 45% match requirement; clusters four and five), the results not only differed from those of the other conditions in terms of the range of time scores evident, but also in terms of the pattern of results. This means that the level of intergroup bias doesn't just affect the amount of time taken in isolation, but actually influences the way in which horizontal categorization influences communicative performance in terms of the amount of time taken. Rather than a stable and then increasing pattern in the amount of time taken (as witnessed for categories with low and moderate levels of intergroup bias), an inverted U-shaped pattern is witnessed across the different levels of horizontal categorization when intergroup bias is high. Specifically, a significant increase in the amount of time taken for information to reach the target agent (an increase of 86 time ticks on average) is evident between 0% and moderate levels of horizontal categorization (i.e.40% or 60% categorization), followed by a significant decrease in the amount of time taken back to levels that nearly match those witnessed at 0% horizontal categorization levels. Therefore, when intergroup biases are high, then very high or very low levels of horizontal categorization can benefit the system over moderate levels of horizontal categorization in terms of the amount of time taken for information to travel from source to target agent.

In terms of the range of scores over which the alternate pattern of results for high intergroup biases appear, these are significantly higher than those witnessed at low or moderate levels of intergroup bias, with it taking an average 305 ticks longer when intergroup bias is set at a high match requirement (i.e. 45% *J* match requirement) than moderate level intergroup biases (i.e. 25% *J* match requirement), and 375 ticks longer for high intergroup biases (45%) than low level intergroup biases (i.e. 5% *J* match requirement).

The significant differences evident between both the range of time scores and pattern of effects is suggestive of a possible tipping point that exists between moderate and high levels of intergroup bias. Put simply, this means that the effect of intergroup bias is not linear in nature, and instead, that small level changes may not lead to significantly detrimental effects until a specific threshold level between moderate and high levels of bias is reached, after which bias significantly disrupts system functioning.

These results suggest intergroup biases have the most significant impact of the biases on the amount of time taken for information to travel from source to target agent. The lower the level of intergroup bias, the faster information is able to travel from source to target agent on average, with the amount of time taken increasing in a non-linear manner as the level of intergroup bias increases. Whilst horizontal categorization does have a significant influence on the amount of time taken for information to travel from source to target ($F(5, 17970) = 23.463$, $P<0.01$), the way in which it influences the outcome is almost totally driven by the intergroup bias condition with the pattern of results over the horizontal categorization parameter changing in accordance with this. At low/moderate levels of intergroup bias, increases in horizontal categorization will have deleterious effects for the system, whereas at high levels of intergroup bias, extreme levels of horizontal categorization benefit the system, with moderate levels of horizontal categorization having the most destructive effects.

6.2.2: The interactive influence of bias and vertical categorization on time

As can be seen in *Figure 32*, a significant interaction between the level of vertical categorization (agents categorizing themselves as part of their hierarchical command level of bronze, silver or gold) and the bias conditions on the time taken for information to travel from source to target agent was found ($F(5, 17970) = 681636$, $P<0.01$). A number of similarities and differences between the results of the bias conditions over the vertical categorization parameter to those found over the horizontal categorization parameter (discussed above) are evident.

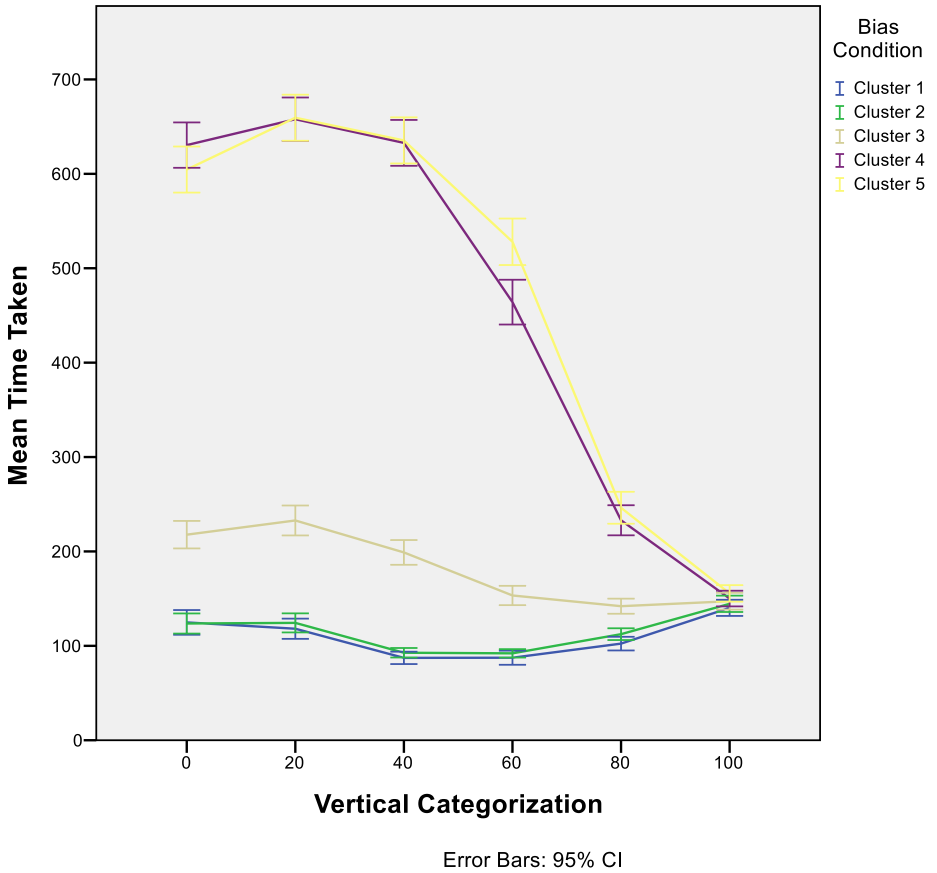


Figure 32: Changes in mean time taken until information reaches target agents as a function of vertical categorization (V) and the bias conditions

Notes: Cluster 1 = low J, low L; Cluster 2 = low J, high L; Cluster 3 = moderate J, moderate L; Cluster 4 = high J, low L; Cluster 5 = high J, high L

Once again, the post hoc tests show that the main influence in terms of the bias conditions is the level of intergroup bias more so than the level of information-based bias. Specifically, significant differences in the amount of time taken are witnessed between bias conditions with different levels of intergroup bias (i.e. clusters one and four or two and five), whilst results between bias conditions with the same level of intergroup bias but with different levels of information-based bias (clusters one and two or four and five) do not display significant differences in the amount of time taken for information to reach the target agent. This therefore shows that information-based bias does not affect how long it takes for information to travel from source agent to target agent whereas intergroup biases have significant influence on this relationship when considered in conjunction with vertical categorization.

The influence of intergroup bias is generally negative for the amount of time taken for information to reach the target agents, with a significant jump in the amount of time taken between conditions with low or moderate levels of intergroup bias (clusters one, two and three) and those with high levels of intergroup bias (clusters four and five). On average, conditions with high intergroup bias had scores that were 284 ticks higher than those found for the cluster with moderate levels of intergroup bias (cluster three), which in turn was 70 ticks higher on average than the scores for conditions with low levels of intergroup bias. The significant differences between these average times is again indicative of a tipping point threshold level of intergroup bias that lies somewhere between moderate (25% *J* match requirement) and high (45% *J* match requirement) levels of bias, over which the amount of time taken for information to travel from source to target agent will be significantly decremented.

However, whilst the level of intergroup biases significantly influences the amount of time taken in terms of range, the overall patterns of results are similar across all intergroup bias conditions. This therefore suggests that, in contrast to the horizontal categorization effects seen above, vertical categorization governs the pattern regardless of the level of intergroup bias. Specifically, an initial stabilization or increase in the amount of time is followed by the amount of time decreasing, and eventually time scores over all conditions of bias converge at the same low score of 148 time ticks (on average).

Whilst the pattern of results remains essentially the same across the different conditions of vertical categorization, the magnitude of this pattern changes according to the level of intergroup bias. Clusters exhibiting high intergroup bias conditions (clusters four and five) display an extreme sigmoidal form that ranges from 630 ticks at their longest and only 156 ticks at their shortest times, whilst bias conditions exhibiting low levels of intergroup bias (clusters one and two) display results that only range from 145 ticks at their longest times to 87 ticks at their shortest times. What this means is that high levels of vertical categorization display little benefit in terms of reducing the amount of time taken when intergroup biases were low, as the entire pattern exists at a range of scores that was low to begin with, but that when intergroup biases are high, high levels of commitment to vertical categorizations had a substantially beneficial influence.

The converging of scores witnessed at high levels of vertical categorization thus highlights the significant influence that categorizing oneself as part of the hierarchical command level (bronze, silver or gold) can have on the amount of time taken for information to travel from source to target, a main effect noted in the ANOVA scores (F (5, 17970) = 681.636, P<0.01). High levels of vertical categorization can thus protect the system (in terms of the amount of time taken for information to travel from source agent to target agent) from high levels of intergroup bias.

In sum, information-based bias does not seem to exhibit any influence on the amount of time taken for information to travel from source agent to target agent. High levels of intergroup bias have significantly detrimental influence on the amount of time taken for information to travel from source to target agent, but high levels of vertical categorization can help negate these negative effects, reducing the amount of time taken for information to reach the target agent to the same as when low intergroup bias is exhibited. However, if intergroup bias is low to begin with, then moderate levels of vertical categorization are instead slightly preferable.

6.2.3: The interactive influence of horizontal and vertical identification on time considered across each bias condition

When considering whether the two categorizations (horizontal with agencies and vertical with level of command) interact to influence the amount of time taken differently under different bias conditions, the results show that the way in which the categorizations interact is determined by the level of intergroup bias. A significant interaction between the categorization parameters on the amount of time taken for information to travel from source agent to target agents was found under every cluster of bias conditions (please see Table 8 for the individual ANOVA scores).

Table 8: ANOVA scores for the interaction between horizontal and vertical categorization for each bias condition on time taken

Bias Condition	***F score***
Cluster 1: low *J*, low *L*	$F(25, 3564) = 18.253$, $P<0.05$
Cluster 2: low *J*, high *L*	$F(25, 3564) = 24.426$, $P<0.05$
Cluster 3: moderate *J*, moderate *L*	$F(25, 3564) = 13.048$, $P<0.05$
Cluster 4: high *J*, low *L*	$F(25, 3564) = 9.036$, $P<0.05$
Cluster 5: high *J*, high *L*	$F(25, 3564) = 10.457$, $P<0.05$

As expected from the above analyses where horizontal and vertical categorizations individually interact with bias, intergroup biases once again have the most significant influence (compared with information-based bias) over how the categorization parameters interact to influence the amount of time taken for information to travel from source to target agent. This can clearly be seen within the graphs, as bias conditions with low or moderate amounts of intergroup bias (clusters one, two and three; *Figures 33 A, B* and *C* respectively) reflect very similar patterns of results, whilst conditions exhibiting high levels of intergroup bias (clusters four and five; *Figures 33 D* and *E* respectively) show completely different patterns of results.

Specifically, *Figures 33 A, B* and *C* show that when low or moderate levels of intergroup bias is exhibited within the cluster (clusters one, two and three), high levels of commitment to horizontal categorizations yield the slowest times when commitment to vertical categorizations is low (176 time ticks more on average for 100% horizontal categorization than other levels of horizontal categorization when vertical categorization is between 0-20% and intergroup bias is also low and 187 ticks more than other levels of horizontal categorization when intergroup biases are moderate) but decreases to the same time ranges as the other levels of horizontal categorization once moderate levels of vertical categorization (40-60% commitment and above) are reached.

In contrast, *Figures 33 D* and *E* show that at high levels of intergroup bias (clusters four and five), the pattern changes significantly. Specifically, a sigmoidal form is witnessed at low to moderate levels of commitment to the horizontal categorization, in which increases in commitment to vertical categorizations results in improved performance, whereas an inverted U-shaped pattern is witnessed when commitment to horizontal categorizations is high, with the worst performance witnessed at moderate levels of vertical categorization commitment.

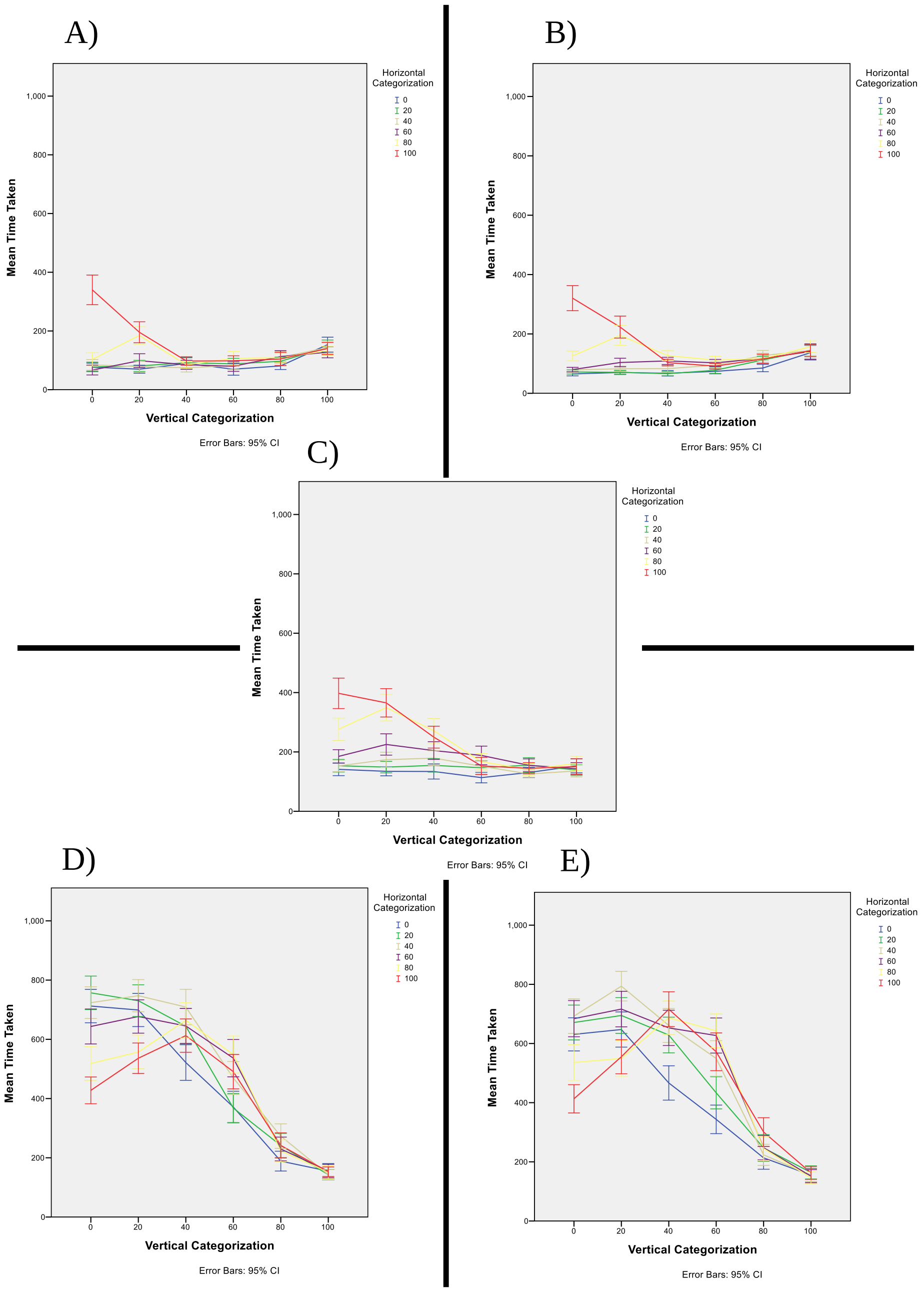


Figure 33: Changes in mean time taken until information reaches target agents as a function of the interaction of horizontal categorization (H) and vertical categorization (V) across the different clusters of bias

Notes: Graph A = Cluster 1 (low J, low L); Graph B = Cluster 2 (low J, high L); Graph C = Cluster 3 (moderate J, moderate L); Graph D = Cluster 4 (high J, low L); Graph E = Cluster 5 (high J, high L)

At low levels of vertical categorization, having a high horizontal categorization actually results in the fastest performance, whereas having moderate levels of horizontal categorization results in the worst performance. However, from moderate levels of vertical categorization the range of scores becomes relatively similar for all categories of horizontal categorization, with slightly improved performance observed when horizontal categorization is low. When vertical categorization is high (80-100% commitment), the time scores all converge and become non-significant regardless of the level of commitment to horizontal categorizations. This convergence is also at a level that is the quickest time. This therefore means that intergroup biases govern the way in which horizontal categorization influences performance in terms of time, but that high commitment to vertical categorizations can completely remove any negative influence of either horizontal categorization or intergroup bias.

The interaction results reflect a number of key points in regards to the influence of the different parameters when considered in interaction on the amount of time taken for information to travel from source to target agent.

First, the level of intergroup bias has the most significant influence on how the system behaves in regards to time taken, with the patterns of results and interactions for the categorization conditions changing radically under different parameter conditions of intergroup bias. Second, this influence of intergroup bias appears to display a possible threshold point that lies somewhere between 25% match requirement and 45% match requirement, with any higher levels of intergroup bias resulting in reduced optimization for the system. Third, the information-based bias parameter appears to have very little effect on the amount of time taken, with no significant differences witnessed between conditions exhibiting the same levels of intergroup bias but divergent information-based bias levels. Finally, the vertical categorization parameter appears to have the power to nullify negative influences of horizontal categorization, reducing the amount of time taken in most circumstances and reducing the range of scores across all levels of horizontal categorization so that agents categorizing themselves as part of their originating organizational agency no longer has a significant influence on the amount of time taken.

In general, having a high level of vertical categorization with the agents level of command benefits the system in terms of time taken if intergroup biases are moderate or high, whilst a moderate level of vertical categorization (i.e. 60% categorization) is preferential if intergroup biases are low. Low levels of vertical categorization are only advantageous in a very small number of circumstances (i.e. low intergroup biases combined with a low categorization with one's agency).

6.3: Propagation of information throughout the system

The results of the previous section showed that intergroup biases have significant negative influence on the amount of time it takes for information to travel from source agent to target agent, and that this relationship is accentuated when agents categorize themselves horizontally, i.e. as part of their originating organizational agency. However, if agents categorized themselves vertically, i.e. as part of their level of command, this helped negate the negative influences of horizontal categorization and intergroup biases in most circumstances. In contrast to what was found for the interactive effects of the bias and categorization parameters on time taken, in this section I report results showing that when considering the influence of the same parameters on propagation of information throughout the system, information-based bias has a more substantial influence on the results. Similarly however, the results also show that high levels of vertical categorization can once again protect the system from the negative influences of bias and horizontal categorization.

I shall now present these results, first considering the interactive influence of horizontal categorization in conjunction with the bias parameters on the level of propagation afforded, followed by a discussion of vertical categorization interacting with the bias conditions, and finally considering the interactive influences of horizontal and vertical categorizations across the different bias conditions.

6.3.1: The interactive influence of bias and horizontal categorization on propagation

Analysis of the interactive influence of horizontal categorization and the bias conditions shows that horizontal categorization has a significant influence on the level of propagation witnessed across the system, but that the exact nature of this influence (e.g. the level of propagation and pattern of results across the different levels of horizontal categorization) is determined by the interactive influence of the bias parameters, with information-based bias displaying the most significant influence on these patterns. A significant interaction between the level of horizontal categorization and the bias condition on the percentage of agents within the system who received the information was found ($F(20, 180150) = 125.615$, $P<0.01$). Whilst the post hoc results suggest that both intergroup and information-based biases have a significant influence on the level of information propagation experienced (with the main effect ANOVA score of $F(4, 180150) = 16777.906$, $P<0.01$), from *Figure 34* it can be seen that the level of information-based bias has the stronger influence on the level of propagation witnessed over different levels of horizontal categorization, as results that are in bias conditions with the same level of information-based bias but different levels of intergroup bias (clusters one and four or two and five) are much closer in their scores than clusters exhibiting the same amounts of intergroup bias (clusters one and two or four and five).

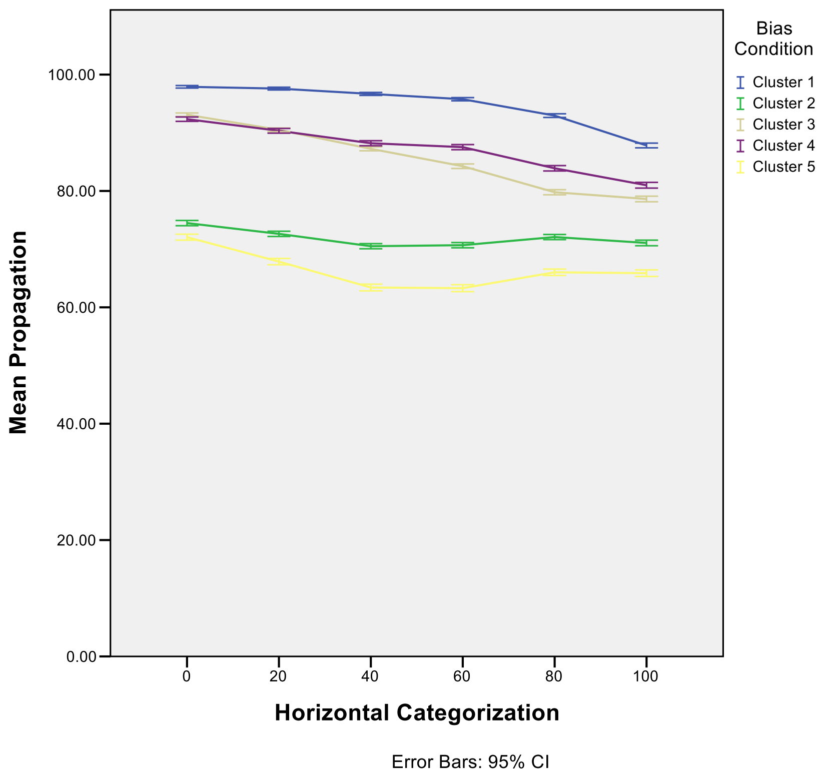


Figure 34: Changes in mean percentage of agents communicated with as a function of horizontal categorization (H) and the bias conditions

Notes: Cluster 1 = low J, low L; Cluster 2 = low J, high L; Cluster 3 = moderate J, moderate L; Cluster 4 = high J, low L; Cluster 5 = high J, high L

Specifically, high levels of information-based bias is found to negatively influence the amount of agents who receive the information, with clusters with a 5% *L* match requirement (low level of information-based bias; clusters one and four) generating the highest propagation scores; 22% higher than their high information-based bias cluster equivalents. Whilst the level of information-based bias is the most significant factor, the level of intergroup bias does still appear to show significant importance for the propagation outcome, with clusters exhibiting lower levels of intergroup bias (clusters one and two) outperforming their high level intergroup bias cluster equivalents (clusters four and five) by an average 7% propagation. In contrast to the findings for the time taken outcome measure, in which only intergroup bias was found to influence outcomes, an interaction between both forms of bias together thus influenced the levels of propagation that could be achieved, with high levels of either forms of bias negatively influencing propagation scores.

The level of horizontal categorization also has a significant influence on the percentage of agents communicated with, both independently ($F(5, 180150) = 1110.545$, $P<0.01$) and in interaction with the bias parameters (*F* value above). Specifically, if information-based bias is set to low or moderate level match requirement levels, then the percentage of agents communicated with decreases as horizontal categorization increases, at a rate that is relatively linear for clusters four (high intergroup bias and low information-based bias) and three (moderate levels of both biases), but exponential for cluster one (low intergroup bias and low information-based bias).

Alternatively, when information-based bias is set to high levels of match requirement (i.e. 45%), the pattern changes with a slight inverted U-shaped pattern emerging, in which an initial decrease between 0-40% horizontal categorization is followed by a stabilisation and increase in propagation scores as horizontal categorization increases to 80% at which point the level of propagation exhibited then stabilises. The influence of intergroup bias however only appears to be in the degree of propagation, and not the pattern of results.

The differences in the pattern of results witnessed between clusters with low/moderate levels of information-based bias (clusters one, three and four) and clusters with high levels of information-based bias (clusters two and five) across the levels of horizontal categorization is reflective of a possible threshold level that exists between 25% and 45% match requirement on the information-based bias parameter. This is an interesting outcome, as it has similarity to the threshold identified in the time taken outcome measure, however, this time with the information-based bias parameter rather than the intergroup bias parameter. This shows that the effects of both forms of bias are not linear on communicative performance, but instead display only small degrees of influence until a specific threshold level between moderate and high levels of bias is reached, after which bias significantly disrupts the system.

When the influence of horizontal categorization on system propagation under the different bias conditions is considered over time (*Figure 35*), the significant influence that the information-based bias parameter becomes even more evident, with the level of propagation stabilizing at much lower levels in both the conditions where information-based bias is high (45%; clusters two and five) compared to all other levels. This shows that it is not merely a case that the propagation was slower in these circumstances which led to reduced propagation, but specifically that there was less possible propagation that could occur under these rule conditions. The pattern of results also differed significantly when information-based bias was high compared to all other conditions, in that high levels of horizontal categorization (100% categorization) no longer displayed the slowest times. Instead, when information-based bias was high, the highest levels of horizontal categorization actually took longer to stabilize than the other levels, and were consequently able to reach higher levels of propagation at this stabilized level than moderate levels of horizontal categorization, whereas the results for clusters with low or moderate levels of information-based bias display a clear decrease in the amount of propagation at which the levels stabilized as horizontal categorization increased.

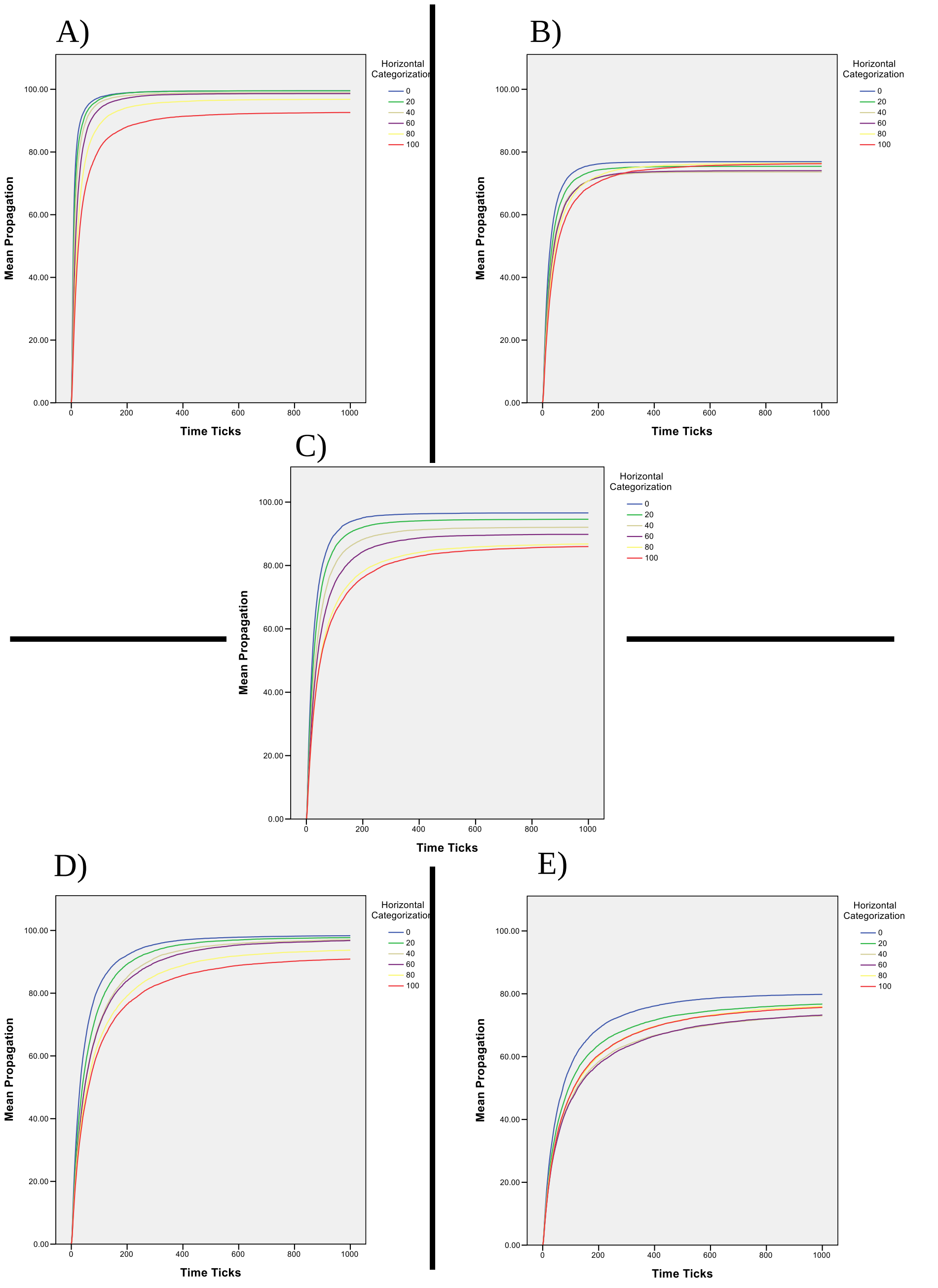


Figure 35: Changes in mean percentage of agents communicated with as a function of horizontal categorization (H) over time across the different clusters of bias

Notes: Graph A = Cluster 1 (low J, low L); Graph B = Cluster 2 (low J, high L); Graph C = Cluster 3 (moderate J, moderate L); Graph D = Cluster 4 (high J, low L); Graph E = Cluster 5 (high J, high L)

In terms of the influence of intergroup bias, it was found that having low levels of intergroup bias results in the simulation being able to reach its stabilization levels faster than if intergroup biases are high. This suggests that for propagation, the information-based bias parameter can significantly influence what level of propagation is possible for the system to achieve, whereas the intergroup bias parameter will influence how quickly this stabilization level can be achieved which explains how these two parameters interact to produce the overall results seen for propagation.

6.3.2: The interactive influence of bias and vertical categorization on propagation

Analysis of the interactive influence of vertical categorization in conjunction with the bias conditions find that similarly to the above, an interactive influence of both forms of bias on how vertical categorization then influences levels of propagation throughout the system was found, with information-based bias having the stronger influence. This interactive influence was found to be significant ($F(20, 180150) = 1814.451$, $P<0.01$), with both the post hoc tests and *Figure 36* reflecting significant differences in the range of scores for results in different conditions. Once again, there is greater similarity between scores for clusters exhibiting the same amount of information-based bias (clusters one and four or two and five) than those exhibiting the same amount of intergroup bias (clusters one and two or four and five), with low information-based bias resulting in the greatest propagation of information, and high information-based bias resulting in the lowest. The intergroup bias parameter also displays an influence over the level of propagation, but this influence is more apparent when information-based biases are low (i.e. if information-based biases are high then as this form of bias displays stronger influence on the propagation outcome measure and thus intergroup biases have less influence).

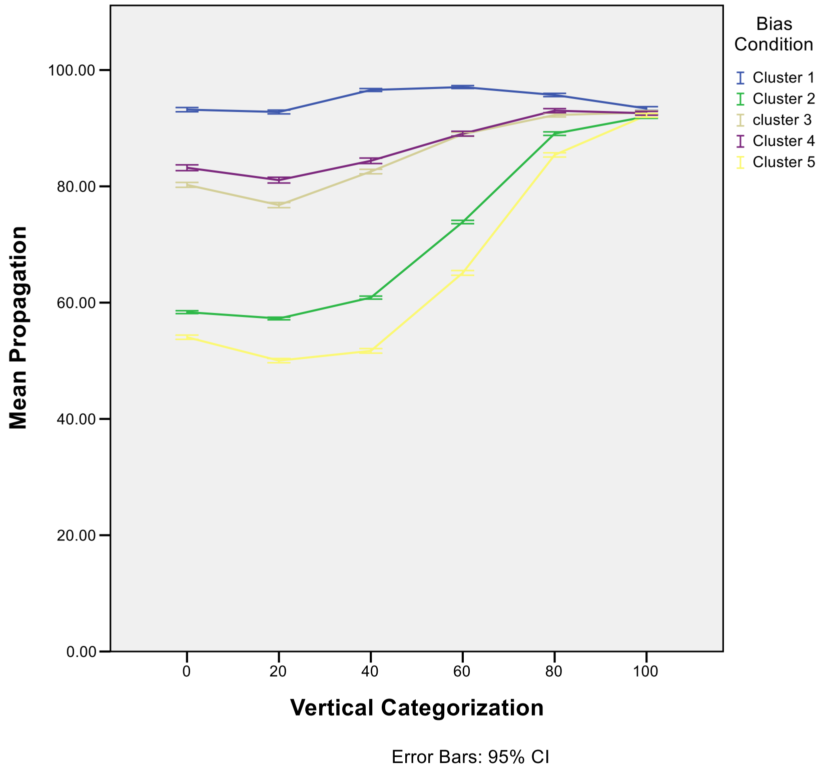


Figure 36: Changes in mean percentage of agents communicated with as a function of vertical categorization (V) and the bias conditions

Notes: Cluster 1 = low J, low L; Cluster 2 = low J, high L; Cluster 3 = moderate J, moderate L; Cluster 4 = high J, low L; Cluster 5 = high J, high L

However, whilst the bias parameters do have significant influence on the level of propagation, with high levels of information based-bias being especially detrimental to the amount of propagation witnessed across the system, having high levels of vertical categorization is again found to protect against this negative influence. Specifically, large variations in the percentage of agents communicated with across the different bias conditions are evident when vertical categorization is low, but gradually reduce as categorization increases, eventually resulting in non-significant differences between the bias conditions when vertical categorization is at 100%, with a score that is relatively high on the scale (92.6% propagation on average). This suggests that high levels of vertical categorization can completely nullify the negative effects of the bias conditions on system propagation.

Similar to the results found for horizontal categorization (see section *6.3.1*), further analysis considering how vertical categorization influences propagation of information over time (i.e. across the 1000 time ticks the simulation is run for) across the different bias conditions reveals that information-based biases reduce the levels of propagation it is possible for the system to reach (see *Figure 37*). However, in comparison to those found for the horizontal categorization parameter in which the possible levels of propagation achievable were reduced for high levels of categorization under high information-based bias conditions, information-based bias in this instance leads to a reduction of the possible levels of propagation achievable for low levels of vertical categorization, with high levels of categorization stabilizing at significantly higher levels of propagation. The only instance in which high levels of vertical categorization did not result in optimum performance is for cluster one (*Figure 37 A*), in which both bias parameters are low. In this instance, moderate levels of vertical categorization are instead preferable, but low levels of vertical categorization still result in the lowest propagation levels. In practice, this means that practitioners would, in nearly all circumstances, benefit from increasing the level of categorization agents hold with their command level (i.e. their vertical categorization), and that even when this is not the preferable course of action, the reductions to performance are only small compared to the benefits gleaned if either form of bias is existing within the system.

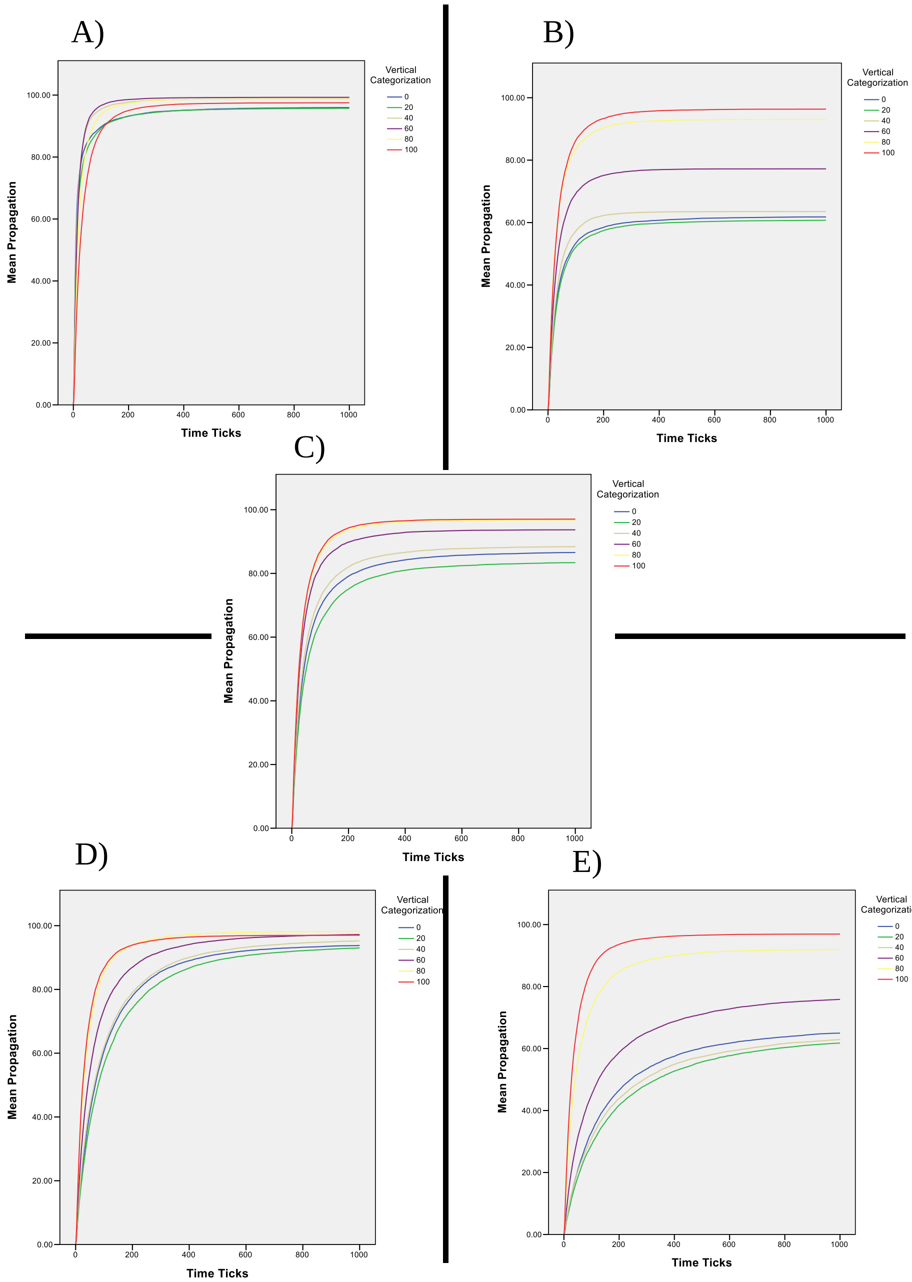


Figure 37: Changes in mean percentage of agents communicated with as a function of vertical categorization (V) over time across the different clusters of bias

Notes: Graph A = Cluster 1 (low J, low L); Graph B = Cluster 2 (low J, high L); Graph C = Cluster 3 (moderate J, moderate L); Graph D = Cluster 4 (high J, low L); Graph E = Cluster 5 (high J, high L)

6.3.3: The interactive influence of horizontal and vertical identification on propagation considered across each bias condition

As would be expected from the findings of horizontal and vertical categorization separately, when they are in interaction, the level of information-based bias once again had the most significant influence out of the bias parameters on propagation levels, with high levels of information-based bias being significantly detrimental for propagation (see ANOVA scores in table 9 below). This can be seen clearly in *Figure 38*, as the graphs reflecting the interactive influences of categorization when information-based bias parameters are high (clusters two and five; *Figure 38 B* and *E* respectively) display a significantly different pattern of interaction (between the categorization parameters) than when information-based bias is low (clusters one and four; *Figure 38 A* and *D* respectively).

Table 9: ANOVA scores for the interaction between horizontal and vertical categorization for each bias condition on propagation

Bias Condition	***F score***
Cluster 1: low *J*, low *L*	$F(25, 36000) = 258.658$, $P<0.05$
Cluster 2: low *J*, high *L*	$F(25, 36000) = 152.432$, $P<0.05$
Cluster 3: moderate *J*, moderate *L*	$F(25, 36000) = 176.547$, $P<0.05$
Cluster 4: high *J*, low *L*	$F(25, 36000) = 9.036$, $P<0.05$
Cluster 5: high *J*, high *L*	$F(25, 36000) = 93.351$, $P<0.05$

Specifically, if information-based biases are low, then results remain stable or improve slightly as the level of vertical categorization increases. Improvements to performance from increases in vertical categorization are especially evident when levels of horizontal categorization are also high. Systems with low vertical categorization (categorization with one's level of command) but high horizontal categorization

(categorization with one's originating organizational agency) are found to have significantly reduced performance in terms of propagation of

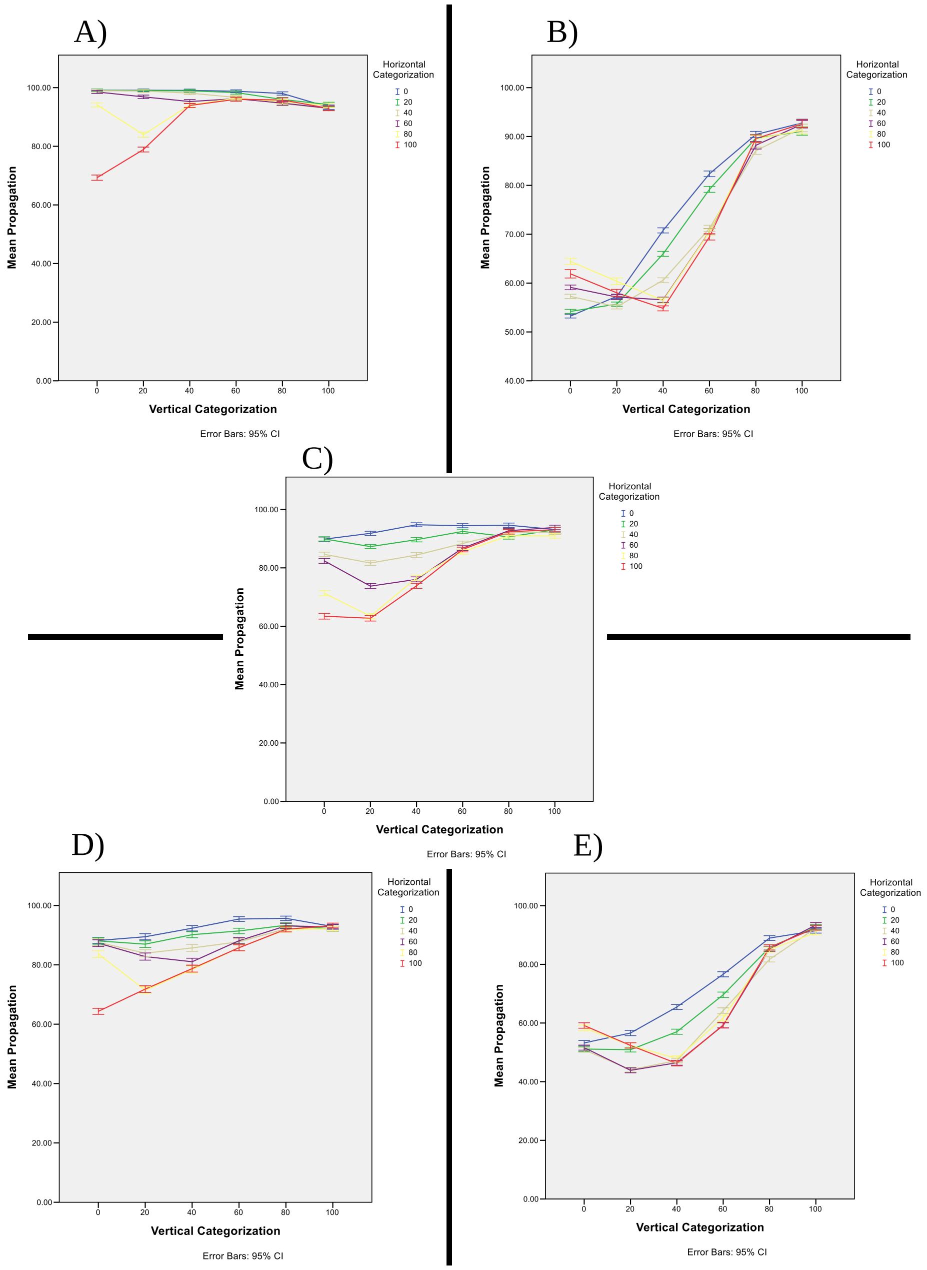


Figure 38: Changes in mean percentage of agents communicated with as a function of the interaction of horizontal categorization (H) and vertical categorization (V) across the different clusters of bias

Notes: Graph A = Cluster 1 (low J, low L); Graph B = Cluster 2 (low J, high L); Graph C = Cluster 3 (moderate J, moderate L); Graph D = Cluster 4 (high J, low L); Graph E = Cluster 5 (high J, high L)

information, with 26% fewer agents receiving the information on average[13]. However, as vertical categorization increases, the level of horizontal categorization no longer has a significant influence on the level of propagation as all scores converge at the same high amount; an average of 93% propagation.

When information-based biases are high however, low levels of vertical categorization have a substantially more negative effect on propagation than when information-based biases were low. When vertical categorization is low, it is beneficial to have a high amount of horizontal categorization. However, as vertical categorization levels increase, the performance benefits of high horizontal categorization immediately diminish, instead resulting in the lowest levels of propagation. In general, increases in vertical categorization benefit the system under conditions of high information-based bias, once again causing the results across all levels of horizontal categorization to converge at point so that differences between them become insignificant. At the highest levels of vertical categorization the negative influence of information-based bias is also nullified, with the propagation scores matching those achieved by clusters with low information-based bias. Whilst information-based bias does have significant negative repercussions for the system in terms of propagation of information, vertical categorization is therefore able to protect the system against this negative influence, so long as the amount of categorization garnered with one's command level is significantly high.

In sum, information-based bias especially is found to be significantly detrimental for propagation of information. Intergroup biases also display a slight influence, but predominantly in the form of slowing how quickly the highest levels of propagation can be reached. Intergroup biases thus do not appear to influence the patterns of results found, but just the range over which these propagation scores occur. Low horizontal categorization appears to be negative for propagation of information scores across most conditions of

[13] This score found when horizontal categorization is at 100% compared to all other levels of horizontal categorization when vertical categorization is at 0% and information based bias is low (i.e. clusters one and four).

bias, although there is an exception to this if vertical categorization is low in cluster four (where intergroup biases are high but information-based biases are low) in which instance high horizontal categorization is optimal. High levels of vertical categorization with an agents' hierarchical level of command however appears to have a protective quality against these other detrimental parameters, with all scores converging at around 93% propagation if vertical categorization is 100%, regardless of the levels of the other parameters.

6.4: Accuracy

Within this section I considered how systematically changing agents' level of commitment to their horizontal and vertical categorization influenced the level of accuracy that could be achieved, defined as the degree of match between the *K*-values of information and the agent holding that information at that particular moment in time, under five different conditions of bias. The analysis showed that the bias parameters differentially influenced the level of accuracy that could be achieved, but that the level of commitment to vertical categorizations once again had the most significant influence on whether performance was optimal or sub-optimal. I shall now present these results, first considering the interactive influence of horizontal categorization in conjunction with the bias parameters on the level of propagation afforded, followed by a discussion of vertical categorization interacting with the bias conditions, and finally considering the interactive influences of horizontal and vertical categorizations across the different bias conditions.

6.4.1: The interactive influence of bias and horizontal categorization on accuracy

Analysis of the interactive influence of horizontal categorization and the bias conditions shows the levels of bias interactively determine the manner in which horizontal categorization influences the degree of accuracy that can be achieved. As can be seen in

Figure 39, a significant interaction between the level of horizontal categorization and the bias cluster condition on the level of accuracy was found ($F(20, 180150) = 62.855$, $P<0.01$). Both bias parameters are shown to have significant influence on how the level of horizontal categorization with one's agency impacts on the mean level of accuracy attained across the system, with optimization evinced at low levels of intergroup bias and high levels of information-based bias. Conditions with low intergroup bias (clusters one and two) significantly outperformed their high intergroup bias equivalent conditions (clusters four and five respectively) by around 15% accuracy on average, whilst conditions with high information-based bias (clusters two and five) outperformed their low bias condition equivalents (clusters one and four respectively) by 8.3% accuracy on average. Condition two, in which intergroup bias is low but information based bias is high, therefore performs best in terms of accuracy across all levels of horizontal categorization.

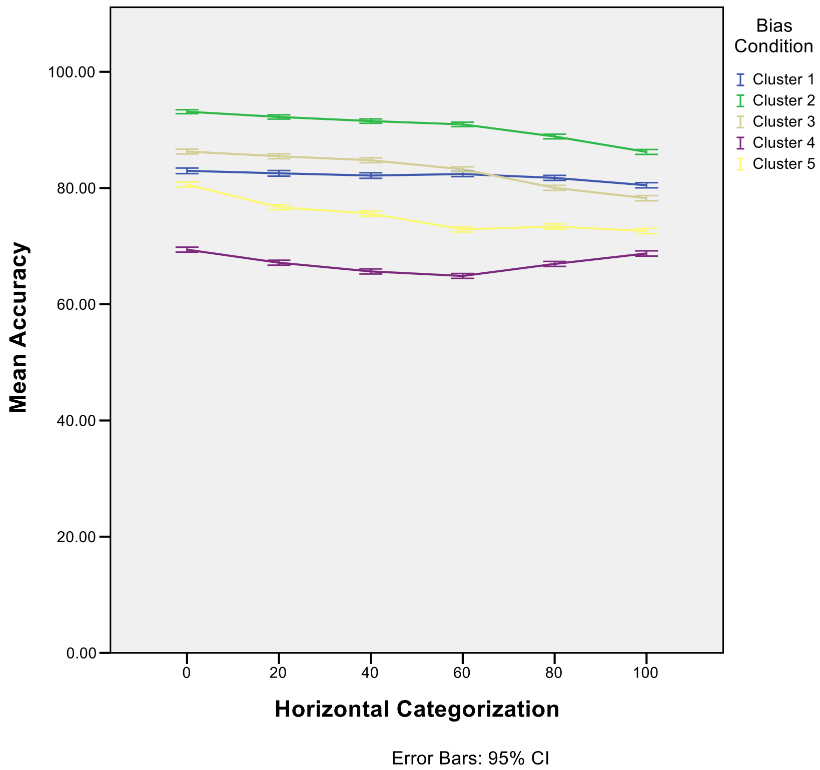


Figure 39: Changes in average systems level accuracy as a function of horizontal categorization (H) and the bias conditions

Notes: Cluster 1 = low J, low L; Cluster 2 = low J, high L; Cluster 3 = moderate J, moderate L; Cluster 4 = high J, low L; Cluster 5 = high J, high L

The way in which horizontal categorization influences the amount of accuracy that can be achieved is predominantly influenced by the interactive influence of the bias parameters. There is no discernible relationship between the patterns that are found and either bias parameter in isolation. For example, cluster one in which both biases are low, does not show any significant change in the level of accuracy achieved as horizontal categorization increases. However, clusters two (low intergroup bias, high information-based bias), three (moderate levels of both forms of bias) and five (both intergroup biases are high) all show decreases in accuracy performance as categorization increases, and cluster four, with high levels of intergroup bias and low levels of information-based bias has a U-shaped performance curve, in which high and low levels of categorization outperform moderate levels of horizontal categorization in terms of accuracy. However, whilst significant ($F(5, 180150) = 373.227$, $P<0.01$), the influence of horizontal categorization on accuracy is very small compared to that of the bias conditions, with only a maximum change of 8% accuracy displayed across any of the conditions[14]. In general however, having a low horizontal categorization results in the highest accuracy performance, and having a high horizontal categorization is the least[15].

When the influence of horizontal categorization in interaction with the bias conditions on system-level accuracy is considered over time (*Figure 40*), the interaction effect of both the bias parameters is once again discernible, with every graph displaying different patterns of results with no obvious pattern linked to either bias in particular. It is therefore virtually impossible to discern any themes in patterns in relation to any one of the variables in isolation. In general, high horizontal categorization is the worst performer in all conditions of bias except cluster four (high intergroup bias, low information-based bias; *Figure 40 D*), in which the opposite is found, with high levels of categorization almost

[14] This 8% change was achieved by cluster three, where both forms of bias were moderate.
[15] Except in the circumstance of cluster four as mentioned previously, in which high levels of horizontal categorization improve performance compared to moderate levels.

matching the same scores and pattern over ticks as at low levels of categorization. Stabilization is generally relatively slow except in the case of cluster two (low intergroup bias, high information-based bias; *Figure 40 B*) in which stabilization begins for low levels of categorization at around 200 time ticks compared to around 600 ticks for cluster one (low on both biases; *Figure 40 A*) and cluster three (moderate on both biases; *Figure 40 C*). Alternatively, when intergroup bias is high (clusters four and five), accuracy scores are still growing at the end of the 1000 time ticks (i.e. stabilization has not quite been reached), and the overall scores are lower than their low and moderate intergroup bias counterparts.

When information-based bias is low (clusters one and four; *Figures 40 A and D*) very little difference in the scores across the levels of categorization is seen until around 500 time ticks, whereas differentiation in the other conditions occurs almost immediately. Whilst these patterns are not consistent across all the conditions, this does still seem to reflect that information-based bias affects how accurate a system can be, whilst intergroup bias affects how quickly the possible levels of accuracy can be reached, which helps explain the differences witnessed on average for the simulations mentioned previously (*Figure 39* [above]).

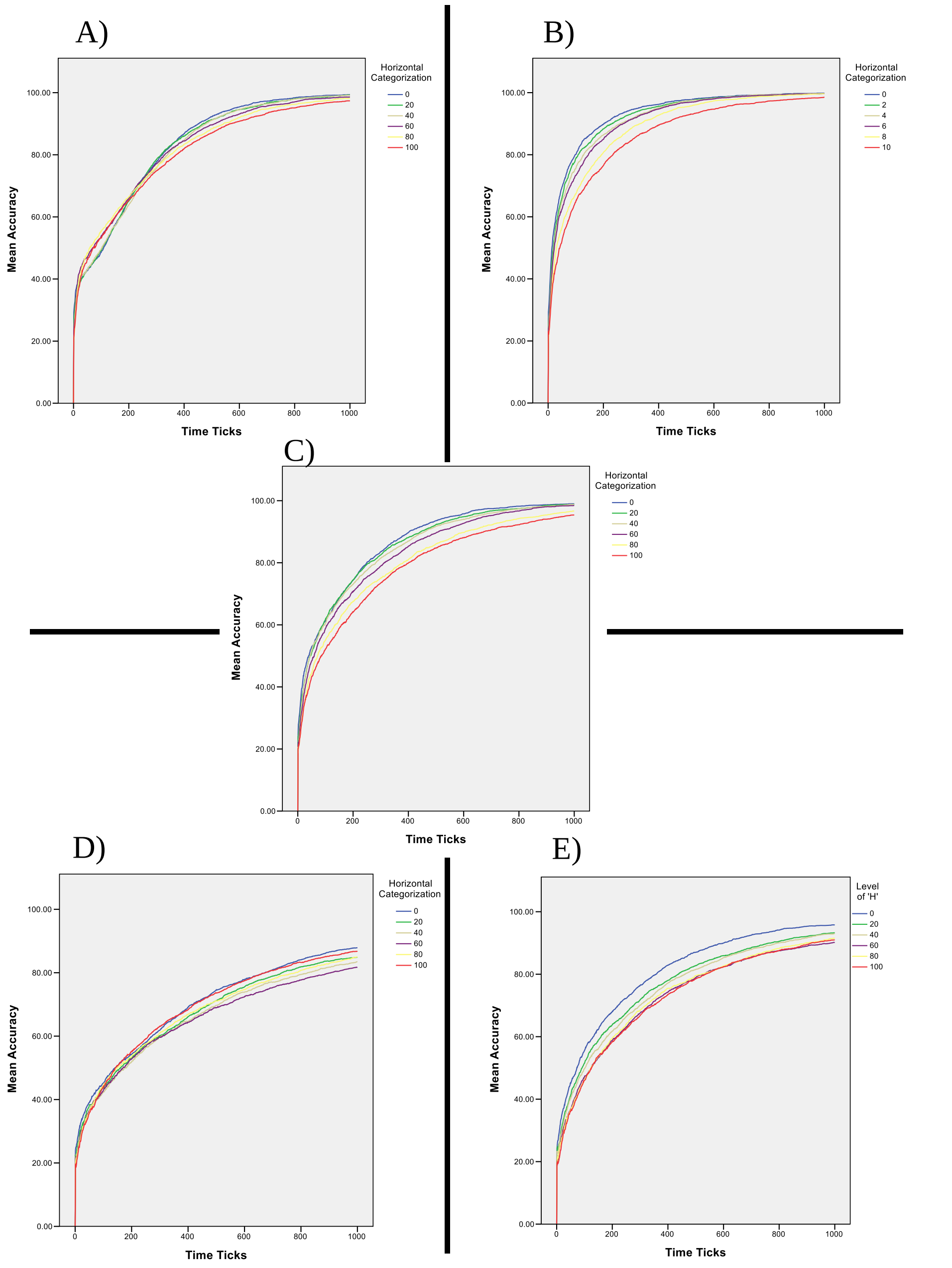


Figure 40: Changes in average system-level accuracy as a function of horizontal categorization (H) over time across the different clusters of bias

Notes: Graph A = Cluster 1 (low J, low L); Graph B = Cluster 2 (low J, high L); Graph C = Cluster 3 (moderate J, moderate L); Graph D = Cluster 4 (high J, low L); Graph E = Cluster 5 (high J, high L)

6.4.2: The interactive influence of bias and vertical categorization on accuracy

Analysis of the interactive influence of vertical categorization and the bias conditions was found to be significant ($F(20, 180150) = 487.345$, $P<0.01$), displaying similarities and differences to when the results were considered over horizontal categorization (section *6.4.1* above). Similarly, high intergroup bias has negative repercussions for accuracy whilst information-based bias increases accuracy. As can be seen in *Figure 41,* conditions with low intergroup bias (clusters one and two) outperformed their high intergroup bias equivalents (clusters four and five) by an average 15% accuracy, and conditions with high information-based bias (conditions two and five) in turn outperformed their low information-based bias equivalents (clusters one and four) by an average 8.3% accuracy. The low intergroup bias conditions resulted in the highest accuracy across all levels of categorization, and condition two (low intergroup bias, high information-based bias) is once again is the optimal performer. Neither of the bias parameters displays more obvious influence over the effect of vertical categorization on accuracy, with it appearing to be a combination of the two that dictates the relationship in a manner that is similar to that witnessed in the above section considering horizontal categorization.

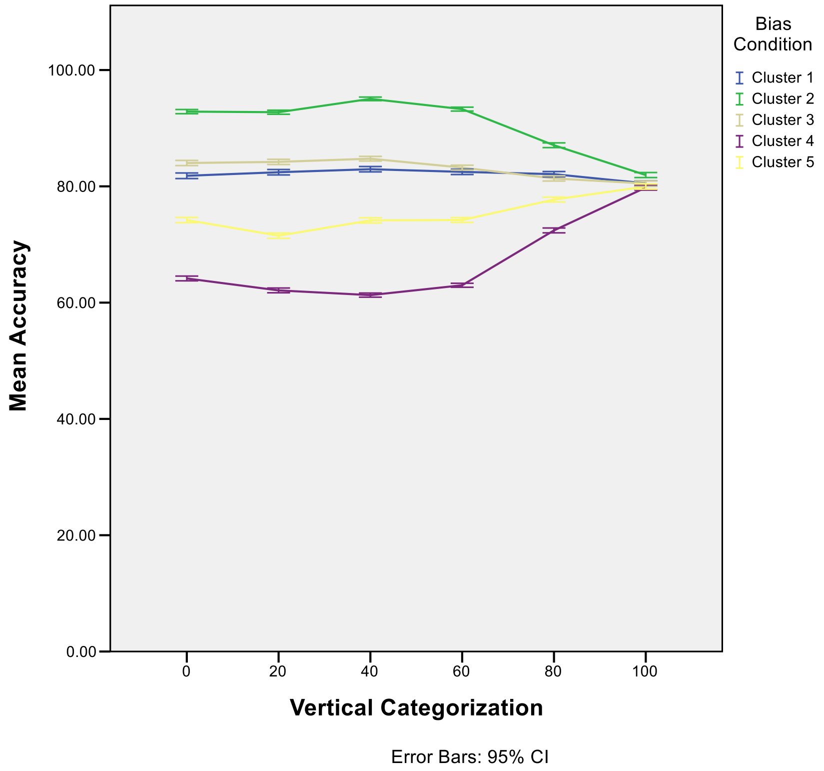


Figure 41: Changes in average systems level accuracy as a function of vertical categorization (V) and the bias conditions

Notes: Cluster 1 = low J, low L; Cluster 2 = low J, high L; Cluster 3 = moderate J, moderate L; Cluster 4 = high J, low L; Cluster 5 = high J, high L

However, in this instance vertical categorization is able to negate some of the negative influence of bias on the outcome in question. Instead of the bias parameters governing how categorization influenced accuracy outcomes, when vertical categorization is considered instead, it appears that the level of categorization determines how the bias parameters influence accuracy performance ($F(5, 180150) = 50.766$, $P<0.05$). Once vertical categorization has increased above 60% categorization, the scores across all bias conditions begin to converge, eventually all reaching the same point when vertical categorization is at its highest level, providing an average accuracy level of 80%. This converged score is not the highest level of accuracy performance (which is instead witnessed at moderate vertical categorization and low intergroup bias but high information-based bias), but does negate the negative influence of high intergroup bias on accuracy performance, with both clusters four (high for intergroup bias but low for information based bias) and five (high for both biases) improving significantly. Vertical categorization can thus help reduce the negative influence of bias on the system in terms of accuracy.

When considered over the 1000 time ticks the simulation runs for, the influence of the intergroup bias parameter becomes even more obvious. At low and moderate levels of intergroup bias, high levels of vertical categorization result in the lowest performance across all time ticks (*Figure 42 A, B and C*), whereas when intergroup biases are high, then high categorization results in the highest performance across all time ticks (*Figure 42 D* and *E*). Moreover, the scores at low and moderate levels of intergroup bias are able to converge at the same level of accuracy for all levels of vertical categorization by the 1000th time tick, whereas if intergroup bias is high the scores seem to diverge from each other further as the simulation continues. This therefore once again shows how high levels of intergroup bias are significantly negative for the system in terms of accuracy, unless a high level of vertical categorization is also apparent in which this negative influence is negated.

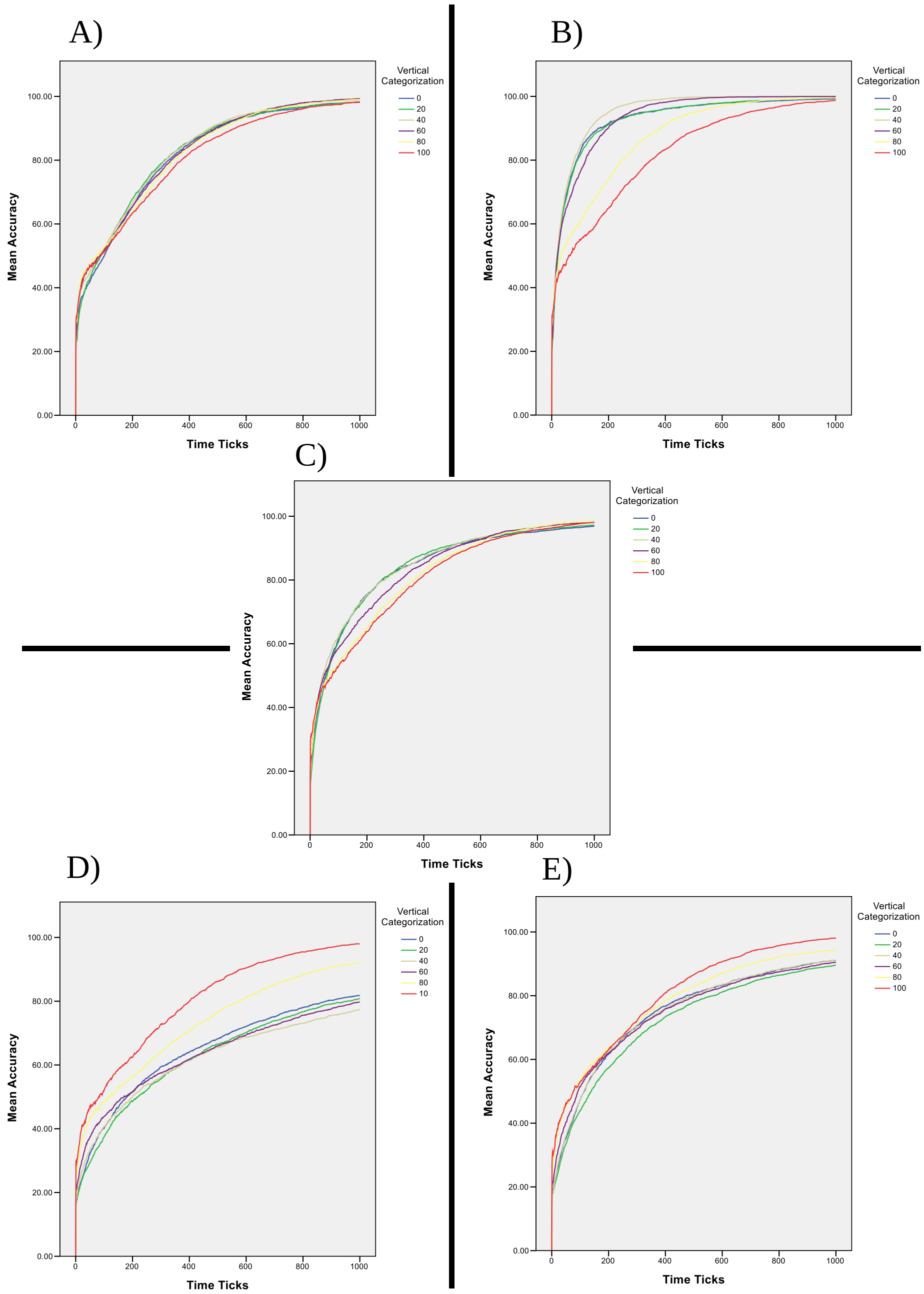


Figure 42: Changes in average system-level accuracy as a function of vertical categorization (V) over time across the different clusters of bias

Notes: Graph A = Cluster 1 (low J, low L); Graph B = Cluster 2 (low J, high L); Graph C = Cluster 3 (moderate J, moderate L); Graph D = Cluster 4 (high J, low L); Graph E = Cluster 5 (high J, high L)

6.4.3: The interactive influence of horizontal and vertical identification on accuracy considered across each bias condition

Analysis of the interactive influence of both forms of categorization (vertical and horizontal) under the different conditions of bias shows similar results to those found above, with high levels of vertical categorization able to consolidate all scores at around 80% accuracy, regardless of the level of bias or horizontal categorization that also exist in the model (See Table 10 below for the individual ANOVA scores).

Table 10: ANOVA scores for the interaction between horizontal and vertical categorization for each bias condition on accuracy

Bias Condition	***F score***
Cluster 1: low *J*, low *L*	$F(25, 36000) = 8.454$, $P<0.05$
Cluster 2: low *J*, high *L*	$F(25, 36000) = 53.348$, $P<0.05$
Cluster 3: moderate *J*, moderate *L*	$F(25, 36000) = 49.057$, $P<0.05$
Cluster 4: high *J*, low *L*	$F(25, 36000) = 22.302$, $P<0.05$
Cluster 5: high *J*, high *L*	$F(25, 36000) = 18.865$, $P<0.05$

The way in which horizontal and vertical categorization interacted below the convergence point at high levels of vertical categorization is most influenced by the intergroup bias parameter, as when intergroup bias is low or moderate (clusters one, two and three; *Figures 43 A*, *B* and *C* respectively), high levels of horizontal categorization (of 100% categorization) resulted in significantly lower performance. On the contrary, if intergroup bias was high (clusters four and five, *Figures 43 D* and *E* respectively), then high levels of horizontal categorization did not have the worst influence, and actually resulted in the best performance when information-based bias and vertical categorization were conjunctively both low.

These results therefore again reflect how intergroup bias is especially negative for system-level communicative outcomes, and that some degree of categorization with any grouping when this bias is highly evident can actually be beneficial. If vertical categorization is high, it can negate the negative influences of all other identity-based parameters on communicative performance outcomes. However, the beneficial influence of vertical categorization appears to only be positive in terms of the identity related parameters (horizontal categorization and intergroup bias), as it did not display any performance benefits for results when information-based biases were high.

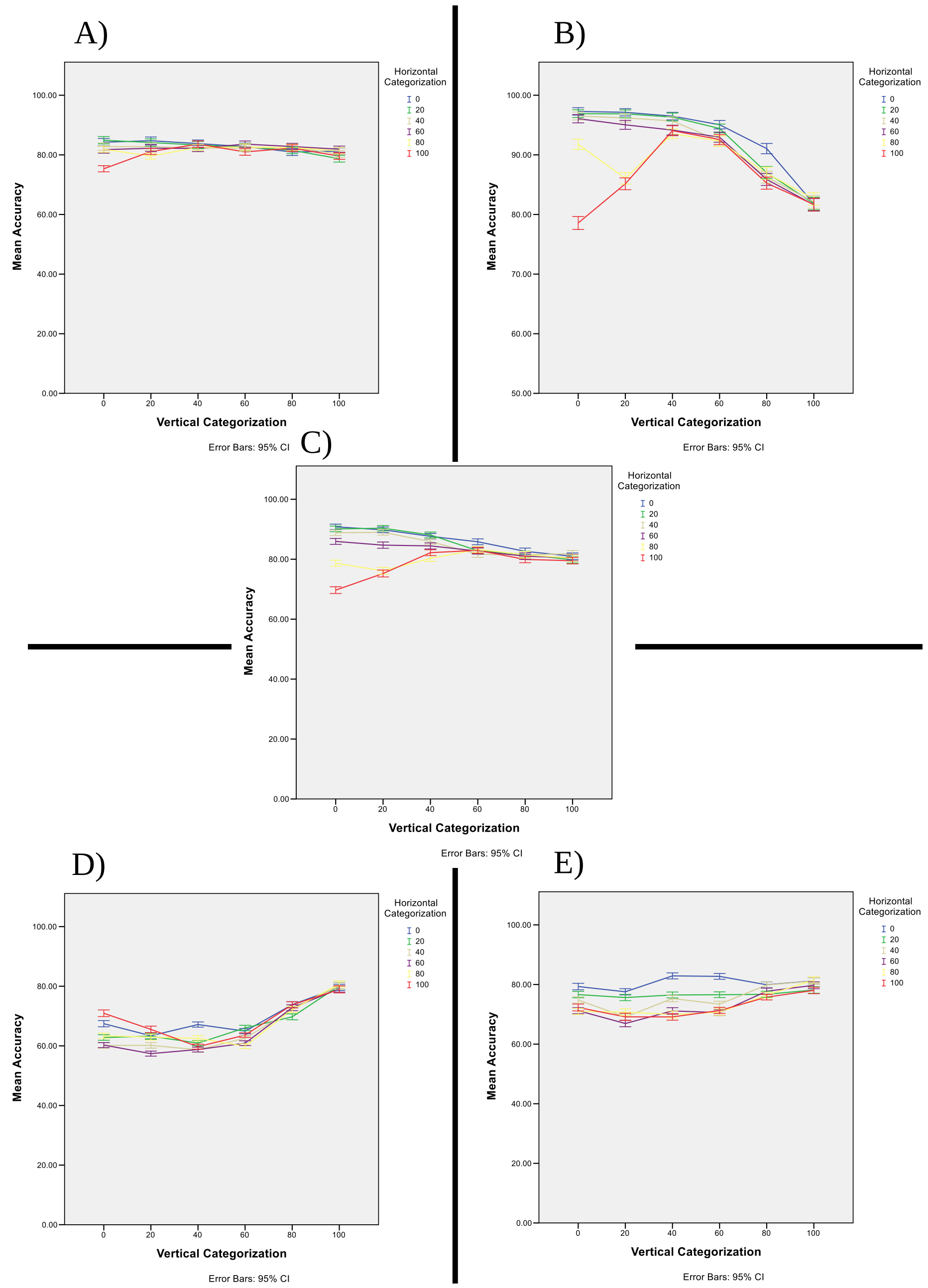


Figure 43: Changes in average systems level accuracy as a function of the interaction of horizontal categorization (H) and vertical categorization (V) across the different clusters of bias

Notes: Graph A = Cluster 1 (low J, low L); Graph B = Cluster 2 (low J, high L); Graph C = Cluster 3 (moderate J, moderate L); Graph D = Cluster 4 (high J, low L); Graph E = Cluster 5 (high J, high L)

6.5: Summary of study three results

The purpose of this third study was to investigate systematically whether the pattern of findings concerning categorization and bias in isolation from studies one and two remain the same when all four parameters were varied conjunctively. Overall, the results of study three diverged from those in the original studies in important ways. Specifically, study three showed that the effects of categorization on communication and performance depend on the levels of bias evident among agents. For instance, whereas study one showed that horizontal categorization with one's agency was found to have negative repercussions for system performance, study three showed that horizontal categorization can actually *improve* time performance under certain conditions of bias. Specifically, when intergroup biases are high, high levels of commitment to horizontal categorizations actually *reduce* communication time (i.e. the amount of time taken for information to travel from source to target agent) compared to moderate levels of commitment with this grouping. Moreover, the results of study three showed that high levels of vertical categorization did not always produce optimal performance (as suggested by study ones results), and instead could reduce performance under certain conditions of bias. However, despite these discrepancies, the overall pattern of results found in the first two studies did seem to reappear within this third study.

Three main outcomes can be discerned from this study. First, the two bias parameters influence the system differently. Second, intergroup bias is significantly detrimental for performance across all three system-level communicative measures. Third, high levels of vertical categorization are able to protect the system from the negative influences of the other parameters.

The two bias parameters differentially influenced the performance of the system. Intergroup bias exerted the most significant influence on how long it took for information to travel from source agent to target agent, taking significantly longer at high levels of bias. Moreover, intergroup bias also delayed how quickly the system was able to reach maximal levels of propagation and accuracy. In contrast, increases in information-based bias did not influence time taken, but did influence the other outcome variables. Specifically, information-based biases reduced the level of propagation that could be reached whilst concurrently increasing the possible levels of accuracy the system could achieve. The divergent effects of the bias parameters provides evidence that the purely negative repercussions caused by intergroup bias are as a result of its social identity focus, and not merely an artefact of a bias parameter being included within the simulations. Even though the bias parameters were limited to only reaching 45% match requirement during this simulation, at this level of intergroup bias the system was still significantly ineffectual at this moderate level of bias. This thus shows that practitioners should be especially careful to try and prevent intergroup bias from fostering within the emergency response environment. Furthermore, any tool or practice that could be utilized to protect against the negative effect of intergroup bias should be coveted.

Whilst some divergent results were found within this study for the effect of horizontal categorization on system performance (as its influence depends on the levels of bias and vertical categorization that concurrently exist within the context space), horizontal categorization with one’s originating agency in general does not display performance benefits, and in most condition settings still yielded the lowest performance for system-level communication. In contrast, vertical categorization with one’s command level did display performance benefits in terms of time taken and propagation and in some instances for accuracy also. Specifically, vertical categorization was shown to have a protective quality for the system, protecting against any negative influence of horizontal categorization and causing the scores for each outcome parameter to converge at a single point. Moreover, within this study it was found that vertical categorization can even protect against the negative influence of both bias parameters, converging the scores across the bias conditions to a single point also. With the exception of accuracy, this converged point at high levels of vertical categorizations was generally in higher range of scores, often displaying the highest performance. Even when the score achieved at high levels of categorization were not the highest, it was only negligibly lower than the optimum performance for both time taken and propagation performance. For accuracy, the scores instead converge within the middle range of accuracy scores rather than the top range.

6.6: Conclusion

In conclusion, the findings of study three suggest some interesting and counterintuitive effects. The two bias parameters displayed different degrees of influence on the three outcome measures. This difference between the two forms of bias concretely showed that the effects found for intergroup bias were as a result of its identity based focus rather than as an artefact of a bias mechanism implanted into the model. Intergroup bias itself, the bias parameter of specific interest in this research project, displayed a negative influence on performance for all three system-level communicative variables, mostly through its influence on how quickly the system could communicate (i.e. for time) or maximal performance could be reached (i.e. for propagation and accuracy).

In terms of the categorization parameters, it was generally found that their influence was determined by the levels of bias that concurrently existed in the model, which is what would be expected considering that categorization itself is not thought to adversely influence task-related information elaboration unless intergroup bias is also fostered (Van Knippenberg *et al.*, 2004). However, it was found that changing the grouping with which agents categorize themselves and the level of commitment to this categorization can significantly change the way in which the system functions under the different bias conditions. Specifically, high commitment to horizontal categorizations usually led to performance losses across the three outcome measures. Alternatively, however, high commitment to vertical categorizations allowed agents to ‘cut through’ the negative effects of the other social identification related parameters (intergroup bias and horizontal categorization), without having to try and reduce the degree of categorization an agent has with their originating organization or the level of bias.

In the following discussion, I shall discuss these findings in relation to the current literature to show how they contribute to the current discussions occurring within the emergency response, multiteam systems and social identity literatures, and how they might provide a legitimate tool for practitioners to utilize to prevent significant sub-optimizations of systems during emergency responding.

Chapter 7: Discussion

7.1: Introduction

The main aim of this thesis was to illuminate in detail the effects of a generative behavioural mechanism proposed to explain the system sub-optimization that has been repeatedly found to occur in emergency response to large-scale civil emergencies. Specifically, I proposed that social identification processes – the groupings with which agents categorized themselves, their level of commitment to that categorization, and intergroup biases – enacted within a complex, ad-hoc multilevel multiteam system, would have significant influence on between-team communications. Consequently, this would then have an impact on cognition, coordination and decision making in emergency response systems resulting in reduced system performance. To date, few studies have explicitly considered the role of social identity in multiteam systems empirically (*cf.* Williams, 2011; Cuijpers *et al.*, 2015), and none have taken a consideration of an entire multiteam system within a real world context.

Utilizing agent-based modelling techniques, I have shown that social identity processes can indeed help explain breakdowns in communication, but contrarily, can also provide the mechanism by which such negative outcomes might be controlled or reduced. This therefore provides an improved understanding of why emergency response multiteam systems can sub-optimize, but also how there are instances in which agents are able to 'cut through' identity concerns and remain effective. The results point to some counterintuitive effects that challenge current research and theory in this area and have specific theoretical implications for understanding multiteam systems, emergency response systems and social identification itself.

In this chapter, I shall first explain my findings and how they relate to current literature before exploring the implications for theory that can be extracted from this. The specific practical implications elicited from the findings are also offered, and methodological contributions are forwarded. Finally, the limitations of the current research are explicated and possible directions for future research are proposed.

7.2: Theoretical insights

7.2.1: Social identity processes can explain system sub-optimization

This research highlights that taking an identity perspective can help explain breakdowns in communication that have been found to occur within emergency response multiteam systems, and questions our current understanding of identification in such systems. I found that if agents had a high level of commitment to their horizontal categorization (i.e. agents categorizing themselves as part of their originating agency; fire, police, government etc.) and high levels of intergroup bias, both in isolation and in conjunction with one another, then this resulted in negative communicative outcomes for the system. Specifically, horizontal categorization had a significant negative impact on communication performance that deteriorates as agents increase their commitment to their horizontal categorization. Intergroup biases have significant negative influence on how quickly the target agent would receive information, and slowed how quickly maximal levels of propagation and accuracy could be achieved.

These findings provide initial empirical evidence for my theorised explanation of communication breakdown in emergency response multiteam systems, as social identity processes do contribute significantly to decreased communicative performance within the simulations offered in this research. Finding that social identity does indeed cause communication breakdown in the context of multiple groupings is relatively unsurprising when one considers that the social identity approach predominantly focuses on how between-team processes will be harder to enact due to the divisions of ‘us’ and ‘them’ (e.g.

Brewer, 1979; Ellemers *et al.*, 2004; Hewstone *et al.* 2002; Tajfel, 1982; Turner, 1975; van Knippenberg *et al.* 2004). However, this research does help provide proof that social identity processes manifesting throughout the multilevel multiteam system organizational design is likely to cause the fractures repeatedly observed in such contexts.

Finding that social identity processes can explain communication breakdown in multiteam systems also accords with the assertions made in the theoretical literature on social identity in multiteam systems thus far, in that because between-team dynamics are integral to the overall success of highly interdependent multiteam systems (e.g. Hoegl *et al.*, 2004; Marks *et al.*, 2005) and multiteam systems also have inherently high heterogeneity (DeChurch and Mathieu, 2009) social identity issues are likely a factor of critical importance for multiteam systems (e.g. Connaughton *et al.*, 2012; Cuijpers *et al.*, 2015; Hinsz and Betts, 2012; Keyton *et al.*, 2012; Williams, 2011).

7.2.2: The benefits of vertical categorization

Counterintuitively, I also found that increasing the level of commitment agents had with their vertical categorization (i.e. agents categorizing themselves as part of their hierarchical level of command; bronze, silver or gold) can negate the negative influence of horizontal categorization and intergroup bias on communicative outcomes. Social identity processes can therefore not only explain when and how system sub-optimization may be apparent, but also instances in which social identity can be ‘cut through’ and not result in sub-optimal performance.

The fact that categorizing in line with the vertical grouping benefited system-level communicative performance is surprising. The social identity literature in general (including self and social categorization) would suggest that categorizing as part of any grouping that cut across the system would lead to competitive behaviours and likely have negative repercussions for between-team functioning (Tajfel and Turner, 1979), thus deteriorating performance at the system level. This is especially true if intergroup biases were allowed to manifest as a result of categorizations (van Knippenberg *et al*. 2004). Moreover, previous theorising into the influence of social identity in multiteam systems has suggested that component team identification in isolation (i.e. not in conjunction with a superordinate identity) would have negative repercussions for system-level outcomes (e.g. Connaughton *et al.*, 2012; Cuijpers *et al.*, 2015; Hinsz and Betts, 2012). For example, whilst theorising about the potential influence of identity in multiteam systems and proffering a number of research questions and propositions regarding this, Connaughton *et al*. (2012) stated that "the enactment of strong organizational and/or team identities among component team members may threaten the [multiteam systems] effectiveness" (p.135). My research, however, has shown that a form of component team-only identification *can* be beneficial for multiteam systems in certain contexts.

Whilst finding that categorizing as part of a grouping that cuts across the system can be beneficial is theoretically surprising, it does align with previous multiteam system research by Williams (2011) in her qualitative study of emergency response multiteam system frontline staff (i.e. the bronze command of my system). In contrast to the 'transient we' identity she had theorised as necessary for effective performance, Williams instead found that the system worked effectively by being a "collection of us's" (p.155) closely aligned through leadership. This research thus agrees with the notion that categorizing with a specific component team group can still result in successful multiteam system performance. My research however offers a deeper explanation as to how this 'collection of us's' managed to function effectively in certain contexts whilst in others system sub-optimization occurs. Specifically, my research suggests that it is not merely that a 'collection of us's' exists, but exactly where the agents envisage the 'us' can determine the system outcomes as successful or abortive. My model and simulations suggest that agents must align with their vertical categorization for the system to be effective.

Not only is the beneficial influence of vertical categorization on system performance surprising and provides explanation for other counterintuitive multiteam systems research, but it also provides an alternative tool to superordinate or dual identities for managing identity effects. Most research into social identity in general (e.g. Ehrke, Berthold and Steffens, 2014; Greenaway *et al.*, 2015; Halabi, Dovidio and Nadler, 2013; Lee, Adair, Mannix and Kim, 2012), and especially within multiteam systems (e.g. Connaughton *et al*., 2012; Cuijpers *et al.*, 2015; Hinsz and Betts, 2012) has suggested that a superordinate or dual identity is required for effective systems performance. However, I stated in sections *2.4.2* and *2.4.3* of the literature review that fostering a superordinate identity would be difficult within an emergency response multiteam system due to the size and amorphous nature of the system and due to the inherent time pressure that exists in emergency response. Enhancing agents' commitment to their level of command identity thus provides a viable alternative for settings such as emergency response, where more abstract levels of categorization may prove too complex and hard for individuals to visualize or commit to.

Furthermore, if leaders are able to focus on improving within team dynamics for vertical component teams, additional benefits over and above improved communicative performance might also be gleaned. In contrast to most research in multiteam systems, some additional studies have also found within-team cohesion or processes to benefit multiteam systems performance (e.g. Bienefeld and Grote, 2014; Davison *et al.,* 2012; Milliken, Hom and Manz, 2010). For example, Milliken *et al.* (2010) found that when the multiteam system comprised of teams that were highly cohesive, self-managing tendencies resulted in greater performance benefits at the multiteam system level. Similarly, Bienefeld and Grote (2014) found that component teams could act as 'safe harbours' supporting their members through increased psychological safety in their 'speaking up' actions (i.e. challenging the actions or decisions of superiors) between agents and leaders belonging to different component teams, which they suggest can be critical as a final safety mechanism to prevent critical failures. Finally, Davison *et al.* (2012) found that coordination within teams was critical for multiteam system functioning, whereas coordination enacted across team boundaries at the component level could be detrimental to performance. If within-team processes and cohesion are thus enhanced through increasing commitment to vertical categorizations, the system might additionally benefit from some of these outcomes, likely accelerating multiteam systems performance improvements.

7.2.3: Understanding different types of multiteam systems

7.2.3.1: Size of the multiteam system

The research into the influence of social identity in multiteam systems to date has been sparse and contradictory, and I believe the main reason for the inconsistency is due to the type of multiteam system under study, specifically in terms of the size of the system and its component parts. Theoretical work suggested that building a dual identity would be beneficial for multiteam systems (e.g. Connaughton *et al*., 2012; Hinsz and Betts, 2012) and yet neither of the two empirical studies conducted in this area agreed with this notion. Instead, Cuijpers *et al.* (2015) found that only a superordinate identity (without the corresponding component team identification required for dual identification) was preferential, whilst Williams (2011) found that no superordinate identity was fostered at all, and yet the system remained successful.

As already stated, my research aligns most closely with that of Williams (2011), in that component-team level categorization was found to produce effective outcomes without agents having to simultaneously identify with a superordinate identity. This therefore completely contradicts the research by Cuijpers *et al.* (2015). I did not directly consider the influence of a superordinate identity within this thesis, due to already theorising that one would not be fruitful in the emergency response context under study, and therefore my research does not directly contradict the theorising by Connaughton *et al*.

(2012) or Hinsz and Betts (2012). However, Williams (2011), who considered a similar context to my research, did investigate whether a superordinate identity was fostered and found no evidence of this, providing further support for my theorising that a superordinate identity cannot be easily garnered in emergency response systems.

I argue that the reason for the discrepancy between the findings of Cuijpers *et al* (2015) study and the empirical research by myself and Williams (2011) is due to the *size* and *compositional complexity* of multiteam system under study. In Cuijpers *et al*.'s command and control firefighting simulation, only 4 individual members were bound together to form the multiteam system, being organized into two teams with two individuals in each. In such a small system, fostering a superordinate identity would prove much easier and more useful than in systems that are large and compositionally complex, such as in emergency response systems, where upwards of 6 different teams with numerous individuals in each are regularly employed to tackle highly turbulent task environments.

In their typology of multiteam system characteristics, Zaccaro *et al.* (2012) highlighted that compositional attributes, such as the number and size of component teams, can affect the dynamics of multiteam system functioning. They specifically stated that as the number of teams constructing the multiteam system increased, "overall interdependence across the [multiteam system] may begin to exhibit more complex patterns" (p.13) as goal hierarchies become flatter and between-team interactions less integrated than multiteam systems with only a small number and size of component teams. On a similar basis, Davison *et al.* (2012) criticised multiteam systems research utilizing small scale designs such as that utilized in Cuijpers *et al* (2015) study, arguing that research using small multiteam systems with little unique specialization are unlikely to trigger the important within- and between-team dynamics that occur in multiteam systems and separate them from other organizational designs, thus arguing that these designs are testing multiteam systems that are indistinguishable from traditional teams.

I therefore believe that the main reason for the divergent findings regarding the influence of social identity in multiteam systems to date is due to the different types of multiteam system under study. In my research, and the real-world empirical study by Williams (2011), the multiteam systems were large, amorphous, ad hoc and comprised of a large number of component teams. Moreover, the system studied within this programme of work had additional compositional complexities due to the multilevel multiteam system design utilized. In contrast, the study by Cuijpers *et al* (2015) only considered a very small and compositionally simple multiteam system. The two different systems, whilst both being considered multiteam systems, likely diverge in their dynamics and require different mechanisms to function effectively. This is likely the reason for the inconsistent results of studies considering the influence of social identity in multiteam systems, and suggests that multiteam systems research might only be generalizable to other multiteam systems of a similar design (type/size).

7.2.3.2: Integrative and representative teams

As stated above, it is counterintuitive that increasing agents' commitment to their vertical categorization is beneficial for system-level outcomes. This is especially interesting as it is only commitment with that specific grouping that is of benefit, not high commitment to any grouping. One possible reason for this could be due to the *type* of team that compose the system. Keyton *et al.* (2012) distinguished between multiteam systems composed of integrative teams, in that the teams that enter into the multiteam system do so in an intact fashion, and those composed of representative teams in which the teams are composed by individuals who represent different organizations in order to devise mutually beneficial solutions. Within the British emergency response context under study, the system is comprised of both integrative (i.e. horizontal agencies) and representative (i.e. vertical levels of command) teams that criss-cross each other in a matrix type design. I believe that whether within-team cohesiveness resulting from high commitment to categorizations is beneficial for the system depends on which type of team that component team is.

Keyton *et al.* (2012) contend that when a multiteam system is composed of representative teams, the entire collaborative system becomes double embedded, both at the team level and the between-team level as the interdependencies increase between individuals, evoking a greater degree of complexity for coordination. I suggest that if component teams are integrative in nature, the between team coordination is paramount to multiteam success, whereas if component teams are representative in nature, within team dynamics increase in importance. This is likely to be especially true in matrix type designs constructed of teams of individuals who represent organizations that also exist within the same system in an integrative manner. If within team dynamics within the representative groups are managed correctly, this would allow for improved cross-pollination between the integrative teams that they represent, and thus benefit the between team dynamics of the integrative teams. Therefore, fostering a strong categorization with one's representative team (i.e. vertical level of command) would not only benefit the performance and outcomes of that specific team, but also likely the between team coordination of the integrative teams they broker for. Whilst the assertion that categorizing with representative component teams can benefit multiteam system performance appears intuitive, further study would be required to investigate the validity of this theorising.

7.2.3.3: Summary

The finding that augmenting vertical identification can benefit system-level communicative outcomes thus offers a potential alternative for large-scale multiteam systems comprised of numerous groups from disparate organizations in both integrative and representative formats, such as the one considered during this programme of work. In such systems, I believe it is unlikely that attempting to foster a superordinate identity would lead to performance benefits, especially given how difficult and time consuming such a feat would be to achieve in the emergency response context. Instead, fostering a strong categorization with one's representative team (i.e. vertical level of command) would instead benefit not only the performance and outcomes of that specific team but also likely the between team coordination of the integrative teams they broker for, thus representing a viable alternative solution. This could therefore suggest an important boundary condition to the findings of Cuijper *et al.* (2015), in that for small multiteam systems that comprise only of integrative teams, a superordinate identity might be the preferred form of identity based management, whereas when the system increases in size and compositional complexity, careful management of the 'collection of us's' might be a more suitable strategy. In relating the findings of this research to other theory and research within the multiteam systems literature, some important theoretical implications can be drawn that should be taken into consideration during future research into multiteam systems.

7.3: Theoretical implications

7.3.1: Implications for Multiteam Systems Theory

The theorising and empirical research within this thesis meet the calls for further research into the influence of emergent states on multiteam system functioning and specifically for research into the influence of social identification within such systems that have recently been requested in the multiteam systems literature (i.e. Connaughton *et al.*, 2012; DeChurch and Zaccaro, 2010). In so doing, I have been able to provide further understanding of how aspects of social identity can influence the multiteam system to produce both optimal and sub-optimal performance outcomes, and provided merit to the assertion that scholars should distinguish between different types of multiteam systems.

The findings of this research contradict most of the current theorising regarding social identity in multiteam systems, which suggests that a superordinate or dual identity is required. Instead, in my research, I found that the system was able to function effectively whilst only holding identification at a team level.

This suggestion does align with previous research by Williams (2011), but also provides further insight. Rather than the general assertions of Williams (2011) and Millikin *et al.* (2010) that within-team cohesion can benefit multiteam systems performance, my research suggests that multiteam systems effectiveness depends specifically on *which* team this cohesion is built in. This assertion can help explain Williams (2011) findings. Her research only considered the frontline emergency responders within her multiteam system; what would be referred to as the bronze command within the British emergency response system; and ignored the rest of the system. She found that most coordination occurred through leadership, but did not consider how coordinated functioning at this level of the system could manifest. My research has provided an explanation for this, suggesting that within team identification within what is essentially the 'leader teams' will allow for effective communications between the integrative systems they broker for, and likely result in enhanced cognitive and collaborative outcomes also.

The findings of the simulation studies have also highlighted a viable alternative to the propositions forwarded thus far in multiteam systems research, suggesting that instead of attempting to build a superordinate or dual identity (which I have previously argued would be time consuming, difficult, and risky in a multiteam system in the form of that under study), leaders could attempt to foster vertical identification at the representative team level in order to enhance system-level communicative outcomes. This research thus helps answer one of the most critical questions posited in Connaughton *et al*.'s (2012) theoretical article regarding whether or not a shared multiteam systems identity (i.e. superordinate identity) exists or is even necessary. I propose that the answer to this is a tentative 'sometimes'. Specifically, the answer is likely more conclusively 'yes' when the system is small and composed of integrative teams, but likely 'no' in larger systems composed of representative teams.

Moreover, on the basis of this finding and in theorising as to why this diverges from the empirical findings by Cuijpers *et al*. (2015) and theorising by Connaughton *et al.*, (2012) and Hinsz and Betts (2012) regarding the requirement for a superordinate identification for effective system performance, I have been able to establish that the distinction between multiteam systems composed of integrative or representative teams suggested by Keyton *et al.* (2012) could present difficulties in generalizing research from one form of multiteam system to the other. I believe that significantly different dynamics will occur within these different forms of multiteam system, specifically regarding the requirements for within- or between-team emergent states and processes.

As empirical research in multiteam systems thus far has predominantly utilized scaled-world simulation (Marks, Mathieu and Zaccaro, 2004) to study the different processes required for effective and sub-optimal multiteam systems performance (e.g. DeChurch and Marks, 2006; Lanaj *et al.* 2013; Marks *et al.*, 2005), a methodology that generally reduces these complex organizations to only two or three integrative teams with only a small degree of unique specialization differing between them (for an exception to this, please see the simulation study by Davison *et al.*, 2012), it is likely that their findings will not be generalizable to some of the more complex forms of multiteam systems evident in the real world such as the emergency response system under study in this programme of work. This is not to say that this form of research is unimportant or not authentic to certain multiteam system forms; on the contrary, this research has illuminated findings that do explain the dynamics of certain multiteam systems quite coherently. Rather, this research may only be fully encapsulating the dynamics of a certain form of multiteam system; one that is small in the number and size of component teams and predominantly composed of integrative teams. The significant theoretical implication of this is that for future research on multiteam systems, it will be of critical importance to fully understand and explicate the characteristics of the multiteam system under investigation, and understanding that the findings will not necessarily generalize to multiteam systems with alternative compositional attributes.

These findings thus provide significant merit to those who have attempted to distinguish different forms of multiteam systems thus far, such as the distinction of integrative and representative teams by Keyton *et al.* (2012); the separation of internal multiteam systems compared to cross-boundary (i.e. mixed organizational) multiteam systems by Mathieu *et al.*(2001); the discernment of 'ad hoc' multiteam systems from 'normal' multiteam systems by Bienefeld and Grote (2014); the typology of multiteam systems characteristics in terms of compositional attributes, linkage attributes and developmental attributes by Zaccaro *et al.* (2012); and the advancement of multiteam systems with members who hold multiple component team memberships by O'Leary, Woolley and Mortensen (2012). By gaining further understanding regarding how multiteam systems can diverge in organization, we can begin to piece together how the processes within these systems might also diverge, and thus gain a more accurate and useful understanding of multiteam system functioning.

This thesis also provides warrant to the assertions made by multiteam systems scholars for further research into real world contextually based multiteam systems (e.g. Davison *et* al, 2012; DeChurch and Marks, 2006; Cuijpers *et al.*, 2015). To date, much of the findings of research in real-world multiteam systems has deviated from that found in the lab based scaled-world simulations, and it is thus only through this empirical study in situ that we have been able to distinguish that these differences might be caused by divergent characteristics of the multiteam systems under study in each of these contrasting contexts. Further research should continue along both veins, and could even also adopt methodologies that allow for a 'middle road' between the two, such as the agent-based modelling utilized within this thesis. Through the application of this novel methodology, I have been able to study a contextually rich multiteam system in a systematic experimental way, thus affording methodological benefits from both the alternative streams of in-vitro and in-vivo research.

7.3.2: Implications for Social Identity theory

The research findings presented within this programme of work have not only had implications for theory regarding multiteam systems, but also for social identity research itself. Similarly to the social identity research within multiteam systems, general social identity research currently still clings to the concept of superordinate or dual identification as the panacea of identity management for effective performance (e.g. Lee *et al.,* 2012; Halabi *et al.*, 2013; Ehrke *et al.*, 2014; Greenaway *et al.*, 2015) even though other research has now shown that this conceptualization is limited (e.g. Lowe and Muldoon, 2014; Verkuyten, Martinovic and Smeekes, 2014). For example, contrary to expectations, Rabinovich and Morton (2011) found that willingness to contribute to a shared resource was higher when subordinate rather than superordinate identities were activated. My research has provided further evidence into the limitations of superordinate identification as the core of effective identity management, suggesting that in certain organizational forms made up of numerous categorical groupings with complex associated interdependencies, other forms of identity management might instead be advocated.

The reason for discrepancy between the work in this thesis and numerous social identity studies could be because of the predominance of what van Knippenberg and Ellemers (1990) refer to as a socially competitive ‘zero sum’ conception of identity, referring to the fact that most social identity research takes a unidimensional perspective of identity by studying systems consisting of a single ingroup against a single outgroup categorization rather than considering the multidimensional social comparison processes that occur when numerous groups co-exist within a given context. This form of research is analogous to the limitations of studying multiteam systems comprised of only small integrative multiteam systems, in that the lacking contextual richness leads to an omission of the consideration of more complex dynamics that can be at play.

Within this research, a more nuanced conceptualization of identity was adopted, splitting social identity into both the components of self-categorization (and the level of commitment to this categorization) and intergroup biases as suggested by van Knippenberg *et al*. (2004). Moreover, multiple groupings were included, with six possible horizontal categorizations and three possible vertical categorizations all residing within the same system. In doing so, I have been able to show that the divergent groupings with which agents can categorize themselves can have completely different influences on system functioning, with categorization with the horizontal grouping displaying negative effects whilst categorization with the vertical grouping had beneficial influences. Moreover, high commitment to vertical categorizations was even found to negate the negative influences of intergroup biases. This therefore suggests that nuancing the notion of identity within social identity research would likely be of benefit for truly understanding how identity can manifest throughout a system and influence system performance.

7.3.3: Implications for the Emergency Response literature

A number of scoping studies carried out by emergency response academics and practitioners in conjunction have pointed to a need for further research into inter-agency communication and collaboration in emergency response contexts (e.g. Altevogt, Pope, Hill and Shine, 2008; Boyd, Chambers, French, King, Shaw and Whitehead, 2012; Boyd, Chambers, French, Shaw, King and Whitehead, 2014; Mackway-Jones and Carley, 2012; Yeager, Menachemi, McCormick and Ginter, 2010), with others identifying that the current research that does exist on inter-agency communication and coordination is of relatively low quality (Acosta *et al*., 2009). My research thus heeds this call, and in so doing has advanced a number of theoretical insights with implications for emergency response research and practice.

First, my research provides empirical evidence that identity driven processes can provide a possible explanation regarding both past system failures and past system successes in regards to emergency response effectiveness. Specifically, I posit that emergency response systems who fail likely comprise of agents holding high horizontal identifications with their originating organizations, whereas those that succeed have perhaps inadvertently increased vertical categorization within their vertical levels of command. Whilst there might be other possible reasons behind system failures and successes, understanding how identification facets can influence system-level performance in such systems does suggest an important contention for consideration in future research and practical guidance.

Social identity thus provides an alternative perspective not currently considered in the debate regarding system stub-optimization in emergency response. Rather than a consideration of the nature of the system (such as in the command and control or the coordination models debate), or in looking at what I have suggested are the symptoms of a sub-optimal system (i.e. 'the four C's' of emergency management: communication, coordination, control and cognition; Buchanan and Denyer, 2013; Comfort, 2007), considering how social identity manifests and influences system-level functioning might provide a more fruitful perspective. Understanding the influence of social identity allows us to consider the generative cause of communication breakdown regardless of the level of centralised design adopted, and might present viable tools for managing how effective the system can be. This is thus a perspective that emergency response scholars should consider when they discuss the nature of system sub-optimization going forward.

Second, this research provides a viable approach to inciting effective communication and coordination in emergency response via increasing within team categorization at each of the hierarchical levels. In her review of practitioner documents for coordinated action as part of her PhD thesis, Williams (2011) found that the guidelines generally just asserted that between team coordination and communication were important, with little explication as to how this could actually be enacted within the context of emergency response. In suggesting a possible mechanism that can be utilized within emergency response to encourage such sought-after interactive processes, my research has helped advance our understanding of how we can improve the effectiveness of emergency response systems.

The suggestions of a possible mechanism that can be utilized by emergency response practitioners to enhance communicative performance is especially critical considering the relatively recent paradigm shift that has occurred in the emergency response literature and practice, from a focus on 'command and control' management models to 'coordination' models that propose that decentralized decision making coupled with cooperation, flexibility and initiative among emergency responders is a more appropriate form of management in large-scale emergency situations (e.g. Dynes, 1994; Dynes and Quarantelli, 1969; Comfort, 2007; Groenendaal *et al.*, 2013; Quarantelli, 1988). Whilst Dynes (1994) argued that "the core of emergency planning should be directed towards mechanisms, techniques and facilities which promote inter-organizational coordination and common decision making, rather than in hypothetically establishing the "proper" authority relationships" (p.150), it is clear from the lack of explicit guidelines in practitioner codes of practice regarding such mechanisms, techniques and facilities that these have thus far not been well understood and integrated into practice. The suggestion of a possible mechanism that could be employed in emergency response contexts to enhance such processes is therefore a critical theoretical contribution to the emergency response domain.

Finally, my research helps fill one of the gaps identified in a scoping study by Lee *et al*. (2012) in terms of the lack of research conducted within the UK emergency response context, as this research was specifically based around the current organization of emergency response responders into the bronze, silver and gold multiteam system command structure. As a consequence, my research has highlighted an explanatory mechanism as to how structuring the system in this manner can benefit emergency response, as through this structure, specific groupings emerge that if made salient enough for categorization, could enhance communicative outcomes at the system level. This research therefore agrees with the notion of command and control, as without this specific structure being adopted in the UK, there would be no vertical teams with which agents can identify to improve systems performance. Moreover, in line with the call from Leonard and Howitt (2010) to “harmonize on and practice making this system work” (p.383) rather than completely redesigning the system, through my research I have been able to derive a possible mechanism through which functioning can be improved within the current organizational design.

The UK command structure creates the conditions for a form of multiple team membership not considered by O’Leary *et al*., (2012), in that the multiple teams with which agents identify cut across one another at both the integrative and representative team level. In cross-cutting categorizations in this manner, enhanced within team cohesion at the representative team level (i.e., vertical categorization with one’s hierarchical command level) also has knock on benefits for the integration of the integrative teams (i.e. one’s horizontal organizational identity), whilst being able to avoid the pitfalls of strong cohesion resulting in silo based communication.

Furthermore, having the representative team design allows the system to benefit from what Hogg, van Knippenberg and Rast (2012) refer to as a boundary spanning leadership ‘coalition’, in which they posit that systems composed of multiple teams will likely function more effectively if individuals from each component team (or in this instance, membership within their integrative team) are designated boundary spanners who help the component teams share information and coordinate collective actions. Whilst I would argue that a form of connective leadership within this coalition would likely still be necessary, my research has empirically shown the suggested performance improvements of leadership coalitions such as this to be a significant possibility, and thus having the emergency response system structured in such a way as to allow this to be a reality is hugely profitable.

7.4: Practical Implications

The findings of this research suggest a possible mechanism through which the effects of identity can be managed which can be used by emergency response practitioners upon validation in further research. Specifically, my findings suggest that practitioners might be able to enhance system-level communicative outcomes through the careful management of categorizations. If practitioners are able to foster commitment to vertical categorizations, this should result in the system maintaining optimal performance. Utilizing vertical categorizations effectively thus provides a viable tool through which practitioners can enhance system performance.

Within this section I shall first outline why this potential tool is likely especially beneficial in emergency response contexts, forwarding three main reasons. First, I argue that in the emergency response contexts, other forms of identity management might have significantly more significant negative repercussions, and thus this method of identity management offers a more viable option. Second, I argue that emergency response contexts are situations in which there is a higher risk of fostering identities that result in negative repercussions for the system, and thus a solution to this is desperately required. Finally, I argue that a mechanism that enhances communication is especially warranted in the emergency response context. Following this discussion, I shall then elucidate some of the potential pitfalls that practitioners could be faced with in trying to utilize this tool.

7.4.1: A viable alternative to other forms of identity management

As mentioned previously, other forms of identity management in a system composed in this manner would likely be difficult, time consuming and risky. Any attempts to reduce identifications or to create superordinate categorizations could paradoxically result in increased identification with social categories that are most highly salient to the individual and perceived as coming under threat through the attempted suppression. Within the emergency response context under study, my results have shown that if the identity to which an individual became even more entrenched was their horizontal agency identity, this might have severe negative results for the system.

Moreover, even if superordinate or dual identities were a valid form of identity management for systems with the compositional features identified within this context, I believe that the time required to foster such identities would likely be counterproductive to effective response operations. Haslam *et al*. (2003) proposed the ASPIRe model as a practical guideline for creating dual identification within organizations; to my best knowledge, one of the few practical guidelines that has been proposed in literature to date. In the ASPIRe model, they identify a four step process for ensuring that new collective identities can be forged without also causing distinctiveness or value threats for sub-identities. Whilst these guidelines appear very cohesive and compelling, and likely are effective if used appropriately within organizational settings, a four stage process such as this would be impractical in emergency response settings where rapid action is required in order to prevent further escalation of the emergency and to protect human welfare, the environment, and security from serious damage.

My research has thus identified an alternative solution that might be more employable in such a time-pressured system without the associated risks, as the scale of the target to which agents need to identify is smaller, and thus less likely to trigger issues of over-inclusiveness. Moreover, in accordance with the suggestions of Turner, Oaks, Haslam and McGarty (1994), it would likely be easier to create salience for this categorization than a superordinate identity, as responders are generally already accustomed to the level of command at which they sit (thus aiding cognitive accessibility), and it is a meaningful categorization in terms of creating similarities and differences between groups (i.e. comparative fit) and in terms of expectations and frames of reference to which they engender in relation to the tasks at hand (i.e. normative fit).

7.4.2: The negative repercussions of ignoring identity

Not only would other forms of identity management potentially risk entrenching negative identities further, but ignoring social identities completely would likely result in negative repercussions for emergency response systems. I argue that individuals within the context of emergency response are significantly more prone to categorizing with their horizontal grouping (i.e. the integrative team of their originating organizations), to which my research has elucidated associated negative system-level repercussions. Thus a solution that helps circumvent this issue is of critical import in emergency response contexts.

There are two main reasons for positing that individuals in emergency response contexts are more liable to fall into horizontal categorizations: (1) the salience of horizontal categorizations and (2) the level of uncertainty in emergency response. In emergency response, horizontal categorizations hold enhanced salience due to the high levels of cognitive accessibility, comparative fit and normative fit this categorization engenders. Emergency responders work within their originating organizations on a day to day basis, have had time to develop interpersonal relationships with fellow team-mates, wear uniforms that reflect their organization and enact specialized duties (i.e. police enforce the law and limit civil disorder, firemen extinguish hazardous fires and rescue people from dangerous situations, while members of the ambulance service care for injured or unwell persons). If practitioners thus ignore identity concerns in emergency response, there is a high chance that horizontal categorizations will come to the fore due to their elevated levels of salience, but this has been shown in this work to have negative repercussions for system-level communicative performance.

Within emergency response contexts, the issue of horizontal categorization is further compounded due to the high levels of uncertainty engendered in this context. Mullin and Hogg (1998) found that situations of uncertainty (both task and situational uncertainty) led to greater identification with the in-group as an uncertainty-avoidance mechanism. They empirically showed that in identifying more strongly, individuals then felt reduced uncertainty, as the identity provides guidelines in how an individual should think and behave. Thus in emergency response situations, in which uncertainty is an innate quality, individuals have increased desire to identify with the most salient category in order to reduce this negative emotional state. By providing these individuals with a salient identity that can enhance group outcomes, namely their hierarchical grouping, instead of placidly allowing them to identify with their horizontal agency, we can manage these responses in a way that achieves positive system-level outcomes rather than system sub-optimization. It is only through developing our understanding of how managing and shaping individuals through their identities in this manner can significantly shift the shape of system-level performance outcomes from detrimental to beneficial that we can teach leaders how to facilitate such system performance.

7.4.3: The transient and time-pressured nature of emergency response

Enhancing responders categorizations with appropriate system groupings in order to enhance communicative outcomes would be of extreme import in emergency response contexts moreso than others due to the transient nature of the system. As emergency response multilevel multiteam systems only emerge in response to large-scale civil emergencies, and thus come together in the moment and must immediately start working in a coordinated fashion, communicative aspects will be even more critical than normal. Bienefeld and Grote (2014) suggested that communication is more critical in what they term ‘ad hoc’ multiteam systems as opposed to ‘normal multiteam systems’ as implicit coordination structures (such as transactive memory systems) are unlikely to be as developed as in normal multiteam systems that function together on a daily or regular basis, and hence these need to be ‘grown’. Moreover, in an emergency response situation, coordinating structures such as standardization of roles cannot be utilized due to the fact that roles, structures and tasks are highly contingent on the unique situation in question, and thus are highly capricious. Explicit coordination, carried out through communication, is thus more essential than in setting that are less transient. As the research conducted in this thesis explicitly showed that the successful management of identities resulted in improved communicative outcomes specifically, this is thus a mechanism of even greater importance in emergency response systems.

7.4.4: The potential pitfalls of vertical categorization

However, whilst I have been expounding the benefits of enhancing categorizations with responders’ hierarchical levels of command for beneficial system-level outcomes, my research also highlighted that there are some dangerous traps that could be fallen into in utilizing this technique. This therefore has significant implications in emergency response practitioners.

First, the empirics showed that whilst high levels of vertical categorization generally had beneficial outcomes for the system, there were instances in which it did not lead to the optimal performance (which instead existed at moderate levels of vertical categorization). Moreover, there were also a number of instances in which only reaching a moderate level of vertical categorization was found to have negative repercussions for system-level communicative performance. In general, moderate levels of vertical identification had negative performance repercussions when horizontal identification and intergroup biases were both high, and in such circumstances, a *very* high level of vertical categorization was required to counteract the negative implications the two other variables had on system performance. In terms of when a very high vertical categorization had negative system-level repercussions, this tended to be when intergroup biases were low. Whilst I would still generally assert that increasing vertical identification with an agents hierarchical level of command is an important technique that leaders should add into their arsenal for enhancing the performance of the multiteam system as a whole, this does highlight how leaders would have to delicately balance identity concerns in order to appropriate optimal performance.

Second, it is possible that utilizing this technique might be more useful in some teams than in others. For example, the silver and gold command levels both enact activities that are generally more cognitive and creative in nature such as problem solving in terms of resource allocation, whereas bronze command tend to enact behaviours that are more routine and have a greater level of pooled interdependence than at the higher levels of command. Keyton *et al*. (2012) contended that when tasks were less routine and more abstract and creative in nature, “communication among team members is necessary to share ideas, critique information shared, and develop innovative ideas” (p.176). It is therefore possible that enhancing vertical categorizations of hierarchical command level might have a more substantial beneficial outcome when conducted at the silver and gold levels of command than at the bronze command level. This therefore suggests that a distinction of the type of task being conducted by the component team in question might influence the degree to which my proposed mechanism (enhanced vertical identification) can benefit system performance, a notion that has already been suggested by DeChurch and Marks (2006) and Keyton *et al*. (2012). Obviously, further research would be required to delineate whether task type also had an impact on the system-level influence of fostering a high categorization with the vertical hierarchy empirically.

Finally, increasing agents' categorization with their vertical level of command, whilst easier than attempting to reduce identifications or creating a superordinate or dual identity, will not be a simple feat to achieve. These identities are significantly more transient than the responders' organizational (horizontal) categorization, and as pointed out by Keyton *et al*. (2012), taking the time to develop team identification within a short horizon span can be especially difficult.

The above highlighted 'traps' that might prevent the successful managing of identification facets for optimal systems performance are exhibitive of a need for highly skilled leaders to navigate such complex identity concerns. I thus believe this to be indicative of the need for leaders within multiteam systems to act as 'identity entrepreneurs' (Haslam, Reicher and Platow, 2011), carefully 'crafting a sense of us' by creating and changing particular definitions of the world. Rather than the previous focus in the literature on specific leader activities such as sensemaking and sensegiving, authoritative decision making and commanders of action, a number of academics in the team literature, multiteam systems literature and emergency response literature are recently beginning to pronounce the idea that leaders should instead be 'connectors', 'facilitators' and 'coordinators', stimulating distributed sensemaking, teamwork and coordination, and decentralized decision making (e.g. Ascendio *et al.*, 2012; Avolio, Walambwa and Weber, 2009; DeChurch and Marks, 2006; Goodwin *et al.*, 2012; Moynihan, 2009; Zaccaro, Rittman and Marks, 2001). My research helps explain how leaders might be able to facilitate these needs.

Utilizing leaders as identity entrepreneurs would require significant changes to training for leaders in emergency response; they would need to be taught how to notice identity faults arising and how to manage these. This could be difficult for certain leaders to adopt, as a fundamental trade off would arise regarding the amount of energy they exerted into managing identities compared to simply focusing on the task at hand. My research does suggest that identification concerns are a matter of criticality in determining whether or not a multiteam system will be successful or sub-optimal, and that this should perhaps become a leaders predominant focus. This is especially true considering the influence I have posited improved system-level communicative outcomes to have on collective cognition, coordination and general multiteam systems performance (see literature review for these proposed relationships). My research thus has some important practical implications for leaders in emergency response contexts.

7.5: Methodological contributions

Within this thesis, I utilized what is still considered a novel methodology, applying agent-based modelling and simulation techniques to understand how social identity processes influence system performance within emergency response. In doing so, I have been able to find outcomes that are insightful and counterintuitive that had not been garnered using traditional techniques. These insights can now be used as testable implications that, if validated in future empirical research, could provide guidance regarding the optimization of system outcomes in emergency response. This research thus helps prove how useful such a method can be.

Agent-based modelling and simulation techniques enabled me to conduct a large-scale study on an area that is hard to study utilizing traditional techniques. DeChurch and Mathieu (2009) suggested that scholars begin to use non-traditional methodological designs such as modelling due to the size of multiteam systems making “data collection cumbersome and sample sizes modest” (p. 286), however, to the best of the author’s knowledge, this is the first study of multiteam systems to utilize such a methodological design.

Agent-based modelling and simulation has allowed me to create and analyze an incredibly large data sample (a total of 75,600,000 data points across the three studies) and in so doing, made it possible to consider emergent properties across multiple levels of analysis and show tipping points and non-linearity's that would have been difficult to isolate using traditional quantitative designs.

Moreover, utilizing agent based modelling has allowed me to circumvent the issues that are characteristic of emergency response research. Buchanan and Denyer (2013) note that most theory developed in emergency response is developed from single idiosyncratic events and unique outlier events with small samples, and that the findings are then hard to generalize to other dissimilar incidents. Agent-based modelling has allowed me instead to consider the emergency response system regardless of the specific incident being faced, and the assertions made in this work are thus generalizable to any UK-based major incident.

Through this work, the benefits of agent-based modelling and simulation methods have thus been proven. It has allowed me to uncover findings that are valuable in their own right and enhance understanding of how social identity processes manifest throughout an emergency response system to produce optimal or sub-optimal communicative outcomes for the system. This thus evidences how agent-based modelling can provide a tool for theory building. The findings of this thesis will hopefully spur further theoretical and empirical attention to the role of social identity within emergency response systems and provide a solid basis from which future research can branch. With such benefits evident, other scholars within the fields of emergency response and multiteam systems should also consider utilizing such designs to enhance our ability to understand such complex systems.

7.6: Limitations and directions for future research

7.6.1: Limitations of computer modelling and simulation techniques

The limitations for this project are all caused by the choice of methodology. Whilst utilizing agent-based modelling provided a novel approach to the study of complex contextually based multiteam systems that avoided methodological and practical issues associated with other methodological techniques (see *Chapter 3: Methods* for an overview of the benefits of agent-based modelling), it is also burdened with its own set of limitations. Most notably, these limitations relate to the fact that a model is only a representation of real life and issues with validation.

In attempting to build a computational model, modellers face the challenge of balancing simplicity with veridicality (Carley, 2002). As stated in the model specification chapter, keeping models simple is a time honoured tradition in modelling work. However, this does lead to questions regarding the extent to which a model can represent complex human behaviour. As the research conducted within this programme of work was essentially explorative, in the sense that I was trying to investigate how theorised variables might influence the functioning of a specific system, my model erred on the side of simplicity. Whilst this simplification does help ensure parsimony, transparency and internal validity, it also means that my model is unlikely to have captured all the complexity of reality, and thus limits the generalizability of the findings. This is a typical problem faced by modellers, as computational models are inherently simplified versions of reality and create simulated data (Davis *et al*,. 2007). This means that, whilst interesting insights can be garnered, the applicability to real life should be “viewed through a conservative lens” (Dionne and Dionne, 2008, p.230). The implications of the model are only true of the specific parameter space that was experimentally examined within this work, and without further research to extend and validate the findings, should not be generalized outside of this specific experimental space.

However, Hughes *et al*. (2012) note that this limitation is not just restrained to computational models. As such reductionism and simplification is a factor of all models of human behaviour, variable-based research – the approach considered the gold standard in psychological science – also suffers from this limitation. Moreover, they argue that agent-based modelling methods can actually help generate more holistic models than other types of research, and should be considered as a complementary method to other techniques for understanding complex phenomenon. Computational models provide interesting insights in areas that are hard to study by other means, and are especially useful for use as in the current context as a theory building tool. The model and simulation results thus provide an initial examination of the process of social identity in emergency response multiteam systems, and raise a number of fruitful implications. However, simulation can only be one part of the process of understanding complex phenomena.

An additional issue raised in modelling research is robustness and validation of the model. Robustness refers to the extent to which the computer system is able to cope with errors during execution. In writing and running computer programmes, it is possible that programming errors (known as bugs) can occur. As noted by Harrison *et al*. (2007) these programming errors are hard to detect and yet can create spurious results, and thus it is critical that modellers are conscientious and check that their model is working correctly.

Within the models in this programme of work, I did all I could to ensure robustness of my model. The simulation programme utilized – NetLogo – has an in-built ‘check’ to ensure that code is written into the model in a manner that is logical to the programming software. If the code is written in a manner that makes no sense, the programme automatically raises this bug to the programmer’s attention, and will not run the model until this is resolved. Whilst this acts as an initial protection against obvious bugs, it cannot detect more complex programming errors, in which the code makes programming sense but is still incorrect in terms of how the modeller determined the model should run. To ensure no complex bugs were included in my model, every new mechanism or procedure that was added into the model was first created in a basic model without the other elements to check it was working as expected. Once I was sure the mechanism was working as I had planned, I then tested it in conjunction with other procedures from the full model in isolation, to ensure that when in conjunction with the additional elements the programme still worked correctly. This helped ensure that any findings from my model are caused by the planned systematic changes to my modelling variables, and are not a facet of bugs or programming errors within the model. However, the best test of robustness is whether other simulators can replicate the findings, and for this reason, I have included a copy of my code in the appendices to make this available for replication or extension.

Validation of models is also a significant issue for computational modellers. There are generally two forms of validation that can occur: validation of the micro-level assumptions at the individual level, and validation of the model findings at an aggregated level. This is required to show that the model has grounding in real life and has utility for making insights. Within this research project, the micro-specifications were theoretically grounded. However, validation of the outcomes of this model has yet to be conducted. Scholars have noted that such validation can be extremely challenging to gather. As agent-based models are simplified versions of reality, and the models themselves are based on dynamic and stochastic processes rather than the consideration of outcome correlations, traditional forms of validation are not applicable to these designs, and often there are no empirical estimates available for modellers to utilize (Fioretti, 2013; Harrison *et al.*, 2007; Hughes *et al*., 2012). Within this research for example, as the field for study is challenging to study utilizing traditional methodologies and the assertions made within this work, whilst theoretically grounded, are novel, there was no empirical data on which to validate the assertions that have been made.

Whilst a lack of empirical validation might be seen as a significant issue with modelling research, many scholars contend that modelling should be viewed as a complementary approach, providing additional perspectives that contribute to a comprehensive understanding of complex phenomenon (e.g. Dionne and Dionne, 2008; Hughes *et al*., 2012; Smith and Collins, 2009). Whilst one should be careful not to overstate the applicability of implications of modelling research to real world settings without further validation, they still provide a tool to gain traction in understanding areas where only ‘simple theory’ exists (Davis *et al*., 2007) and thus help guide future empirical study to pertinent aspects of the problem.

Moreover, some scholars contend that the requirement for validation depends on the aims of the model itself (Fioretti, 2013; Harrison *et al*., 2007). For example, Harrison *et al.* (2007) note that simulations created with the intention of prescription or prediction will require extensive grounding in real world data to ensure that the results produce useful implications. However, they also note that a typical use of modelling and simulation is for discovery and theory building, and suggest that in such instances model grounding is not essential. Similarly Fioretti (2013) contends that “to the extent that [agent-based models] are employed in theory building rather than theory testing, validation is at least as much an issue of social acceptance as a question of coherence with available data” (pp. 235-236).

The research within this project was conducted on exactly this premise: to understand an area that has not previously been considered in depth and thus generate interesting insights that can be treated as hypotheses for future empirical work. It is therefore not a limitation that this research has not yet been validated in the real world, as the theoretical and practical insights garnered are interesting and counterintuitive. This research should thus be considered as an initial theory building piece that should be further validated in the real world. Harrison *et al.* (2007) state that theoretical simulation work such as that conducted within this research project “should not be avoided simply because grounding is not available; it is still a legitimate scientific endeavour with the potential to make important contributions to management theory” (p. 1242). I therefore suggest that while validation of the model within this work has not yet been achieved, the findings still provide interesting insights that should not be omitted on this premise.

These inherent limitations of modelling based research have three main repercussions for future research needs. First, the model and findings presented within this work should be validated in real life settings. Second, further exploration of the current model should be conducted. Finally, extensions to the current model should be added.

7.6.1.1: Validation of the current model

Whilst the model in this programme of work was theoretically grounded and insights that are interesting in their own right have been garnered, it would still be fruitful to empirically test the findings of the model in the real world. Whilst it would be challenging to study emergency response multilevel multiteam systems in real world contexts (which was one of the original reasons for utilizing agent-based modelling: see *Chapter 3: Method*), the findings of this initial simulation research help relieve some of the challenge by guiding scholars towards specific facets of interest.

Specifically, it would be fruitful to use experimental techniques to investigate the whether fostering commitment to vertical categorizations can indeed help protect the system against sub-optimization. This could then be additionally checked with naturalistic studies such as in emergency response training exercises, taking measurements of individual's levels of commitment to certain identities, to understand whether multiteam systems that are successful in this context are indeed fostering high levels of vertical categorization, and whether there are any instances in which high horizontal categorization does not lead to system sub-optimization. This would help make clear whether the assertions made within this work are true in real world settings and consequently do present a suitable tool for practitioners to use to improve system functioning in emergency response.

Additional research considering how social identity influences the functioning of multiteam systems comprised of representative and/or integrative teams would be fruitful. I have suggested within this discussion that the reason that vertical categorization is beneficial for systems performance whilst horizontal categorization is detrimental is perhaps linked to the type of team this categorization belongs to. Further research to test whether this hypothesised reasoning is true should thus be conducted.

Furthermore, I have asserted above that it is possible that the different types of tasks that agents are involved in (i.e. whether these are creative problem solving tasks or more routine active tasks) might influence the degree to which enhancing commitment with vertical categorizations will benefit the system. I suggested that enhancing commitment to vertical categorizations might be more influential and important in the silver and gold commands as opposed to the bronze command level, due to the different types of tasks they conduct and forms of interdependence between agents required in each context. It would be interesting to test this proposition in real world contexts to gain a more in depth understanding of how increasing commitment to vertical categorizations differentially influences different types of teams that compose the multilevel multiteam system.

7.6.1.2: Further exploration of the current model

Not only should the assertions that come from the current model be validated through further research, but the model itself should be explored further. Within this single model, the scope of possible experiments that could be conducted is enormous, even before extending the model to include alternative elements. In order to ensure transparency of the model findings and keep the experimental runs to a number that was practical within the time periods for this research project[16], some of the alternative possibilities presented within the current model were suppressed. These could prove as interesting and fruitful lines of research for future studies, and might also be required to further check the robustness of the assertions made within this research. As noted by Dionne and Dionne (2008), different assumptions have the potential to lead to completely divergent results. The model findings presented within this work are thus restricted to the exact conditions presented within the model experiments run. Further investigation of the model under varying conditions that already exist within the model itself would thus be an important next step for research in order to test whether the current results remain robust, and to see if any other interesting outcomes can be garnered.

For example, within this research, the number of agents that comprised the system was kept constant at thirty-six agents, and their group composition remained the same throughout every study. Within this thesis, the aim was to understand how social identity processes manifest in a typical emergency response multiteam system, and thus the size of the system was not directly varied. However, I have argued above that distinguishing between forms of multiteam systems in research will be critical going forward, and have specifically noted that the size of the system likely results in divergent repercussions. Future research might thus be required to test whether the same outcomes are apparent when the size of the system is increased or decreased, and team sizes are also varied.

Another aspect that might have been explored further was the movement of individuals around the system. Agents within the models for this work were allowed to roam freely across the entire ‘world’ space. In real life however, each command level of response is located at one of three specific locations: bronze command at the scene, silver command in a special unit nearby, and gold command at a third location, usually the police station. As proximity based communication was included as a facet of this model, it is very

[16] A total of 252 conditions were investigated for this current programme of work. Any of the below mentioned explorations would have increased this number in an exponential fashion, and thus only the most pertinent aspects were included in this initial study

possible that limiting the movements of agents so they could not come into proximity with agents of dissimilar levels of command might have had an influence on the outcomes to this model. Furthermore, in real world emergency response systems, the bronze command and gold command are encouraged not to communicate directly but to always filter their communication through the silver level of command. Adding this in as a rule to the model might change the outcomes of my research, and would make an interesting potential avenue for further research.

For this research, I felt that this level of veridicality would have made the model too complex, and have limited the outcomes to the model specifically to emergency response arrangements rather than any multiteam system utilizing the multilevel design studied, and thus it was not included. Future research should however be conducted to assess whether the specific locations of agents and restrictions of their movements influences the robustness of the assertions made within this work.

Furthermore, the nature of categorization and intergroup biases could have been explored further within this model. Within the simulations studied here, changes to the levels of categorization or bias were made in a uniform manner across the entire system of agents[17]. Future exploration of this model could include making non-uniform changes to categorization and bias across the groupings of agents, such as having the agents within the police highly committed to this categorization whilst agents in the local authority had low commitment to their categorization, even though both of these are horizontal categorizations. As this was an initial investigation in this area, I felt it important to keep parameter changes simple and parsimonious to ensure clarity and gain some initial insights into how categorization and bias can influence system communication. However, changes in the level of uniformity of these parameters across the different agents might have made the model more realistic and true to real life, and further interesting findings might be

[17] Although some degree of stochasticity on these elements was built in

generated. It would thus be an interesting area of further research that could be conducted on the current model.

7.6.1.3: Extensions to the model

In addition to the further exploration of the current model, further extensions to the model are also possible. Whilst I believe that the processes that generate social identity are of extreme criticality in large-scale multiteam systems, there is little reason to believe that these are the only constructs relevant to the functioning of emergency response. In a real world context, a number of generative mechanisms would enact on a situation at any one time. The effects found within this programme of work could thus diverge when other additional mechanisms are also at play. It would thus be fruitful to consider extensions in terms of additional complexity within the current mechanisms included in the model, such as the forms of communication, the nature of information, and the conceptualization of social identity.

The communicative based mechanisms introduced within the model are in some ways limited in their current format. Communication of information was added into the system in a fairly one-dimensional form, with no distinctions between information type nor in communicative function. For example, the importance and utility of non-verbal communication was ignored, even though this is known to enhance communication, especially of tacit information (e.g. Nonaka and von Krogh, 2009). Williams and Mahan (2006) suggested that communication has four disparate functions within multiteam systems, specifically (1) controlling behaviour through norms, (2) motivating and teaching through feedback, (3) expressing emotions, especially in relation to conflict management, and (4) supplying information. Whilst it wasn't explicitly exclusive of the other functions of communication, my research only definitively considered this fourth function of communication. Different forms of communication might be fostered or inhibited by divergent mechanisms, and might also have disparate effects on multiteam system-level outcomes. Extending the model to consider different forms and motives for communication might thus be a worthwhile extension.

Additionally, some forms of information might benefit from certain communicative processes and outcomes, whereas others might require alternative processes outcomes for effective multiteam system functioning. For example, information regarding the evolving situation would conceivably be appropriate for high levels of propagation in order to allow for individuals and collectives to have the most up-to-date situational awareness possible (a facet posited by Seppänen, Mäkelä, Luokkala and Virrantaus [2013] to be an important requirement for effective emergency management). More specific information however, perhaps regarding the chemical compound found in containers near the scene of an explosion, is unlikely to be beneficially shared across all members of the system; in fact, such sharing could instead lead to issues of overload and consequent information processing difficulties (Sutcliffe and Weick, 2008). Instead, specific information would likely require timely deposition at the target agent in question who can utilize such specialised information for decision making. Thus, the distinction of different types of information might also provide an opportunity for fruitful future extensions of the model.

The above mentioned opportunities for extension of communication and information are only a suggestion of the possible studies that could be a conducted. Further research questions could also be asked through the development of these elements. Perhaps a consideration of information with different levels of importance in order to test what might happen when identities influence prioritisation of information in certain ways might have been an interesting additional facet to add into the model, or having information degrade as it is passed through numerous nodes as would be more realistic of real-world contexts in which information must be decoded, interpreted and recoded and disseminated by each agent that receives it. A number of important and interesting questions regarding the nature of communication and information types within multiteam systems could be asked within future research.

Additionally, the concept of identification could be developed and extended further. For example, within this programme of work, I did not consider the notion of shifting identities that might be important to how social identity influences multiteam systems (Connaughton *et al*., 2012). Identification with a given social identity is neither static nor compulsory. On the contrary, individuals might enact different identities at different times on the basis of which properties are made most salient in any given moment (Bruner, 1957; Fiske and Taylor, 1991; Hogg and Terry, 2000). Categories can, and often do, change in salience on the basis of positive and negative interactions with others classed as in-group or out-group members. Further research should consider the influence of shifting identities on the outcomes found within this research. Do changes in salience of identities during the simulation enhance or suppress some of the findings that emerged when such a process was not considered? Moreover, a superordinate identification could have been explicitly included into my model to allow for more direct comparison with some of the previous literature existing on multiteam system social identity dynamics to date. However, even without such enhanced considerations of identity, this body of work has been able to provide important theoretical and practical contributions.

7.6.2: Further consideration of the antecedents and consequences of social identity in emergency response

Within this programme of work, I only considered the mediating mechanisms of social identification facets and communicative outcomes for multiteam systems. The possible antecedents and a further explanation of multiteam system outcomes were excluded from this thesis in order to prevent dilution of important findings on the utility of these mediating mechanisms. Future work, however, should also consider some of the possible antecedents of both horizontal and vertical identification in order to provide further understanding of how individuals might manage these factors that have been empirically shown within this body of work to be important for the effective (or non-effective) functioning of emergency response multiteam systems. Moreover, the link between communicative outcomes and the other processes considered critical for emergency response success, namely cognition, coordination and decision making, should be examined in more detail.

A possible antecedent that should be considered is how leaders can control categorization and commitment within emergency response settings, and thus appropriately manage identity concerns to ensure optimal outcomes. Recent theoretical research has begun to consider how leaders can act as 'identity entrepreneurs' (Haslam *et al.,* 2011; Reicher and Hopkins, 2001, 2003), shaping social identities and their meaning through changing and managing the definitions of category prototypes, boundaries and content. In doing so, leaders become not only passive actors influenced by identity, but actually become "masters of identity" (p.162). Thus far, little research has been conducted on the topic of identity entrepreneurs (although for a noted exceptions to this, see Steffans, Haslam, Ryan and Kessler, 2013). Considering that this research project has shown social identity to be a factor that can determine whether an emergency response system sub-optimizes, further research on how leaders can act as identity entrepreneurs within emergency response settings could possibly be a very fruitful line of future research.

Research by Mischel and colleagues on situation strength could also provide important antecedents to the mediating mechanisms considered within this thesis and thus might be worthy of research (e.g. Mischel, 1968, 1999; Meyer, Dalal and Hermida, 2010). Mischel (1968) suggested that the level of situation strength influenced the degree to which individuals selected behaviours on the basis of external or internal cues to desired responses. If a situation is defined as strong, then the environmental and situational forces provide clear cues regarding the desirable behaviour, whereas if they are weak, individuals are more inclined to turn to their personality or other internally based directives in order to select the appropriate behaviours and actions. I would suggest that social identity facets are more likely to come to the fore, and to have a stronger determinate effect on multiteam system outcomes such as system-level communication, when situations are defined as weak. Empirically testing how situation strength interacts to moderate the influence of social identity processes on system performance would help advance our understanding of when and why social categorization and identification can influence performance outcomes.

Additionally, this research only considered communicative outcomes as the dependent variable. Whilst I have theoretically explained the connection between communication and other outcome variables (please see literature review for this breakdown), I have not shown these effects empirically. It would thus be a suitable advancement to this research to explicitly check whether my assertions regarding improved communicative performance leading to enhanced collective cognition, coordination, decision making and actual multiteam systems performance outcomes (non-communicative) are correct.

Moreover, I believe an interesting future avenue of research might be to consider how cognitive architectures such as transactive memory systems and social identity processes interact. Transactive memory has already been shown to benefit multiteam systems performance (Healey *et al*. 2009). However, within this research I have contended that social identity processes likely prevent the use of this cognitive architecture. This sentiment is echoed by Hinsz and Betts (2012) who stated that "because of the inherent nature of distrust, hostility, and ingroup favouritism among multiple teams working in concert, the exchange of information as part of a multiple-team transactive knowledge system may be hindered" (p.306).

However, when one considers Bunderson's (2003) notion of expertise recognition, it might be that social identity can actually in some way aid the creation of transactive memory systems. Bunderson suggests that attributes of expertise are informed by what he terms ‘specific’ (task-specific cues) and ‘diffuse’ (i.e. social category) status cues. Whilst diffuse status cues are not expected to have a strong correlation with group performance outcomes, they may provide a quick way to ascertain who might need certain aspects of information, thus allowing for early transactive memory systems development. Bunderson does suggest that such diffuse cues are more likely to be used to attribute expertise in groups that are centralised with short tenure, such as those utilized in emergency response. I believe an investigation into the way in which the social categories that exist in emergency response thus help or hinder the development of transactive memory systems through their influence on expertise recognition might be an interesting avenue to investigate through further research.

7.7: Summary

The main aim of this thesis was to illuminate in detail the effects of a generative mechanism proposed to explain the system sub-optimization that has been repeatedly found to occur in emergency response to large-scale civil emergencies: social identity processes. Through the utilization of novel agent-based modelling techniques, I was able to show that the proposed mechanism, social identity, does indeed help explain why sub-optimization may occur in systems utilizing multilevel multiteam system designs, such as in the UK emergency response context. However, the research also identified that some social identity processes (namely, high commitment to vertical categorizations) can negate the negative influence of social identity on systems communicative performance. This counterintuitive finding was theoretically surprising, yet provides explanation for other multiteam systems studies who found similar outcomes. Social identity processes therefore not only explain when and how the system may sub-optimize, as theorized in the literature review, but also instances in which social identity can be ‘cut through’ and not result in sub-optimal performance.

To explain these findings, I suggested that it was important to consider the type and size of the multiteam system under study, proposing that the inclusion of 'representative' teams within a large system may result in different dynamics being engendered, and thus suggesting that future work ought to consider such design characteristics when considering the generalizability of their findings across multiteam system types.

The findings and theorising of this research have numerous implications for literature and practice, most notably suggesting that alternatives to superordinate identification as an identity management technique not only exist but may be more fruitful within certain systems (such as the transient systems utilized in emergency response). I proposed that effective management of commitment to vertical categorizations may be a viable alternative within the system under study, and discussed the repercussions of this for the multiteam system, social identity and emergency response literatures. However, I also note the difficulties practitioners would likely face in utilizing such a technique. Additionally, I have called for further validation, replication and extension of the findings of this thesis and the theoretical inferences conceived.

Chapter 8: Conclusion

The aim of this research was to better understand why emergency response systems are repeatedly found to sub-optimize and to generate ideas to help prevent this sub-optimization from occurring in the future. In order to understand this problem, I conceptualized the emergency response system as a multilevel multiteam system and theorized that the key issue leading to system sub-optimization were breakdowns in communication between the different groupings that comprise the system. I then proposed a generative mechanism that I believe explains why such breakdowns in communication occur: social identity.

As little research has been conducted regarding the influence of social identity within this specific organizational design to date, and that that has been conducted is sparse and contradictory, I conducted this research in an exploratory manner. I aimed to glean how the theorised mechanism of social identity influenced the communicative functioning of multilevel multiteam systems. To do so, I deconstructed social identity into the generative processes of categorization (including the notion of commitment to categorizations) and intergroup bias, in order to understand how these processes individually and conjunctively influenced the system.

Due to its unique positioning as a tool for both theory-creating and theory-testing, I utilized agent-based modelling computer simulation techniques to explore how the theorised generative mechanism influenced system-level communicative outcomes. As a result of this, interesting and counterintuitive findings were garnered that have implications for theory and practice.

This research has shown that social identity is influential in emergency response multiteam system contexts, and lays the foundation for more research into these complex processes. It was found that social identity processes not only explain *when* and *why* the system may suboptimize, as theorised in the literature review, but also provides a potential mechanism for reducing this negative influence in the form of commitment to vertical categorizations, which can help explain why such fracture does not always occur and identity concerns can at times be 'cut through' to maintain an effective response.

This thesis therefore shows the utility and strength of taking a social identity approach when considering the functioning of emergency response multiteam systems. However, I would take this further, in so far as I believe that social identity is the *key* mechanism of criticality for multiteam systems functioning. Whilst other mechanisms impacting on between-team communication and collaboration have been presented in the multiteam systems literature, such as motivation and reward structures (Kanfer and Kerry, 2012), forms of exercising (Healey *et al.*, 2009), multiteam charters (Ascendio, Carter, DeChurch, Zaccaro and Fiore, 2012) and leadership (Bienfeld and Grote, 2014; DeChurch, *et al.*, 2011; DeChurch and Marks, 2006; Zaccaro and DeChurch, 2012), I argue that if social categorization and intergroup biases are not managed appropriately, all other efforts to encourage between-team working will also be compromised. For example, regardless of whether there are reward structures in place encouraging between-team working, or leaders and charters specifying how and why between-team working must be conducted, if during the actual event agents categorize strongly with their horizontal grouping and intergroup biases are allowed to manifest from this classification, agents will find between-team communication troublesome. This suggests that the predominant focus of multiteam systems research on these other facets (such as leadsership and mental models) is likely misplaced, and greater focus should instead be paid to the influence and management of identities.

Furthermore, a number of scholars contend that increasing training will enhance emergency response multiteam system performance (e.g. Ödlund, 2010; Waller, Lei and Pratten, 2014) as this will enhance familiarity with the system in which they work, the expected procedures they should follow, and how they should work with other teams within the system. However, if issues with social identity processes (i.e. high commitment to their horizontal categorization and intergroup biases stemming from this) occur during the response, then no amount of pre-incident training will help protect against this. A mechanism that leaders can thus enact ‘in flight’ to protect the system as the event is underway is thus more profitable.

In this research, I have proposed such a mechanism for in-flight management of identities to enhance communicative functioning between the various responders. Whilst this will require further validation, it is a huge step forward in our understanding of these complex systems. Previous research in emergency response has only briefly begun to note the influence of trust and relationships on system optimization, and failed to directly consider the psychological constructs that underpinned these aspects of human interaction. By bringing social identity into this context, I have been able to provide a more detailed and theoretically grounded understanding of why relational issues can appear during emergency response, how these may influence functioning, and how these issues may be relieved to prevent sub-optimal response. Moreover, the literature on social identity in multiteam systems was contradictory and confusing. This research has helped provide potential explanations for the divergence between empirical and theoretical work in this area, and provided greater clarity regarding how social identity processes may actually manifest throughout these complex systems.

The improved understanding of the key influence of social identity in emergency response systems also has clear ramifications for the selection and training of key emergency response personnel. As mentioned in the discussion, effective management of vertical categorizations to leverage performance will be a difficult process and require skilled leaders able to read the situation and ‘entrepreneur’ identities to get the best results. This suggestion also pushes leaders towards acting as facilitators, coordinators or connectors in line with recent trends in leadership research.

In general, this thesis can be summarized into five main contributions. First, this thesis furthers understanding of system sub-optimization in emergency response. My findings highlight that taking a social identity perspective can indeed help explain breakdowns in communication that have been found to occur in emergency response multiteam systems. This provides a new perspective to the emergency response literature that has not previously been considered, thus augmenting the current debates taking place within this literature stream. Moreover, this suggests emergency response practitioners and practitioners in other organizations adopting similar multiteam system designs should place greater focus on the role social identity plays in restricting their ability to be communicatively efficient and effective.

Second, I contribute to the literature of social identity in general and within multiteam systems specifically in proposing a viable alternative mechanism through which to manage identity. Specifically, I propose that increasing agents' commitment to the vertical grouping with which they categorize themselves can protect the system from sub-optimization. Predominantly, scholars contend that a superordinate or dual identity is required for effective system functioning. However, I argue that such an initiative is likely to be restricted in emergency response systems and have instead shown how the benefits believed to be achieved through these overarching identities can alternatively be achieved through the careful management of team identities. In systems in which a dual or superordinate identity might be too challenging to develop, this thus might present a viable alternative option. The concept that a team-based identity can protect the system from sub-optimization in intergroup settings is novel to the social identity literature. This therefore contributes to the literature in providing further understanding of how it might be possible to prevent social identities from causing sub-optimization and warrants further study.

Third, this thesis highlights the need for scholars to distinguish between different forms of multiteam systems, and to make these design characteristics explicit. In theorising why high commitment to vertical categorizations is found to be beneficial within this thesis, I suggested this could be due to the composition of the system in terms of whether it is comprised of integrative or representative teams. Moreover, I have argued that the reason for divergent findings regarding the influence of social identity in multiteam systems thus far is likely due to the size and compositional complexity of the multiteam systems under study. This suggests that divergent forms of multiteam systems are indeed likely to result in divergent outcomes, and thus might limit the generalizability of multiteam systems studies to only systems comprising similar designs. Additionally, I have developed the concept of a multilevel multiteam system. This design, comprised of a multiteam system with more than one overlapping team network structure, has never previously been considered in multiteam systems research before, and thus presents a contribution to the literature that merits further exploration.

Fourth, this work demonstrates the need to nuance our conception of social identity in future research. I have coined new terms to be used in social identity research in complex multiteam systems; namely, horizontal and vertical categorization. In nuancing social identity in this manner and studying these categorizations as separate concepts, my research has shown how categorization with these different groupings affects system-level outcomes in divergent ways. This illustrates how it is not just the processes of categorization and intergroup biases alone that cause communication issues within systems, but that this is specifically related to the grouping on which these processes are focused and the composition of these groups within the wider system. The breakdown of social identity within this context into such formulations has allowed me to show that even when mechanistically similar, social identity processes do not affect system-level outcomes in uniform ways, and thus taking such a nuanced and more complex view of social identity is important when considering identification research in complex multiteam systems.

Finally, I have utilized a novel methodology for this research, and in so doing, shown its utility for both multiteam systems research generally and emergency response research specifically. In using this methodology, I have been able to consider a contextually-based multiteam system that differs in design from those predominantly studied in multiteam systems research thus far. Most research in multiteam systems to date is conducted using ‘scaled world’ designs, in which the multieam system is reduced to only two or three teams composed of two members in each. In contrast, agent-based modelling allowed me to consider a system of thirty six agents organised across nine possible component teams. In so doing, I have been able to provide an explanation for some of the conflicting findings that currently exist within the literature and generated further insights into how social identity may manifest in emergency response. Additionally, this method has allowed me to systematically test the effects of a number of different manifestations of social identity and uncover non-linear relationships and tipping points that would have been difficult (if not impossible) to uncover using traditional methodological designs. Most notably these tipping points have been found in terms of the relationship between intergroup bias and communicative outcomes, suggesting that once bias reaches a certain threshold level, any further increases have dramatic negative influence on system-level communication. This research is thus an innovative example of how such a methodology can be utilized to study these complex systems, and scholars interested in these areas could also consider using computer simulation techniques in the future.

This thesis helps extend and develop our understanding of complex multiteam systems and emergency response; moreover, the findings may also be fruitfully adapted and utilized in other contexts. For example, multiteam system designs are not only used for emergency response systems, but are also utilized in areas such as new product design and large scale engineering projects. It would therefore be helpful to consider the extent to which social identity affects functioning in these environments. Additionally, the utility of vertical categorizations as a mechanism for managing identity issues could possibly be utilizable in contexts that do not strictly adhere to the multiteam system definition, such as matrix structure organizations or task forces. It would be worth extending research into vertical categorizations and social identity processes more generally into these contexts to see if similar effects are garnered.

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Appendices

Appendix 1: Code

```
breed [agents agent]
breed [informations information]

directed-link-breed [prox-links prox-link]
directed-link-breed [rules-links rules-link]
undirected-link-breed [inf-links inf-link]
undirected-link-breed [target-links target-link]

agents-own
[ K-values
  current-info
  rep1 ; repertoire for passed information
  rep2 ; repertoire for waiting to be dealt with information
  commwith
  Kofcurrent
  commdone?
  horizontal
  vertical
  value1
  value2
  source-for
  target-for
  source?
  target?
  H-level
  V-level
  J-level
  L-level
  H-amount
  V-amount
  N-amount
  J-amount
  L-amount
  potential
  J-match
  L-match
  accu
  percentaccu
  involvedinaccuracy?]

informations-own
[K-values
  number
  source
  target
  comm-list
  age
  at-target?
  info-age-when-target2]

target-links-own
[commnumlist
  firstcommnum
  lastcommnum
  meancommnum
  highestcommnum
  lowestcommnum
  countcommnum]

links-own
```

```
[whichinfo
  commthroughwho?1
  commnum1
  commthroughwho?2
  commnum2
  commthroughwho?3
  commnum3
  commthroughwho?4
  commnum4
  commthroughwho?5
  commnum5
  commthroughwho?6
  commnum6
  commthroughwho?7
  commnum7
  commthroughwho?8
  commnum8
  commthroughwho?9
  commnum9
  commthroughwho?10
  commnum10
  linknumber]


globals
 [N-list
  B-list
  S-list
  G-list
  po-list
  fi-list
  pa-list
  la-list
  c2a-list
  c2b-list
  mean-h-level
  mean-v-level
  info-age-when-target
  mean-J-level
  mean-L-level
  freq-h-0-0.2
  freq-h-0.2-0.4
  freq-h-0.4-0.6
  freq-h-0.6-0.8
  freq-h-0.8-1.0
  freq-h-1.0+
  freq-v-0-0.2
  freq-v-0.2-0.4
  freq-v-0.4-0.6
  freq-v-0.6-0.8
  freq-v-0.8-1.0
  freq-v-1.0+
  percentagecomm
  percentB
  percentS
  percentG
  percentPO
  percentF
  percentPA
  percentLA
  percentC2A
  percentC2B
  meaninfpercent
  meaninfpercentB
  meaninfpercentS
  meaninfpercentG
  meaninfpercentPO
```

```
  meaninfpercentF
  meaninfpercentPA
  meaninfpercentLA
  meaninfpercentC2A
  meaninfpercentC2B
  total-comm
  prox-comm
  rule-comm
  inter-agency
  inter-level
  inter-both
  intra-both
  mean-accuracy]

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;; to setup ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to setup
  clear-all
  reset-ticks

  set B-list [1 2 3 4 5]
  set S-list [6 7 8 9 10]
  set G-list [11 12 13 14 15]
  set po-list [16 17 18 19 20]
  set fi-list [21 22 23 24 25]
  set pa-list [26 27 28 29 30]
  set la-list [31 32 33 34 35]
  set c2a-list [36 37 38 39 40]
  set c2b-list [41 42 43 44 45]
  set N-list (sentence (B-list) (S-list) (G-list) (po-list) (fi-list) (pa-list) (la-list) (c2a-list) (c2b-list))
  set info-age-when-target []

  setup-agents

;  setup-plot

  ifelse H/V-selected?
  [setup1]
  [setup2]
end

to setup-agents
  create-agents 36
  ask agents
  [move-to one-of patches
    while [any? other turtles-here]
    [move-to one-of patches]
    set rep1 []
    set rep2 []
    set commwith []
    set current-info nobody
    set source-for nobody
    set target-for []
    set commdone? []
    set K-values []
    set target? false
    set source? false
    set H-level 0
    set V-level 0
    set J-level 0
    set L-level 0]

  ask agents with [who < 12]
  [set vertical "bronze"]
  ask agents with [who > 11 and who < 24] with [vertical != "bronze"]
  [set vertical "silver"]
  ask agents with [who > 23] with [vertical != "bronze"] with [vertical != "silver"]
```

```
  [set vertical "gold"]

  ask agents with [who = 0 or who = 1 or who = 12 or who = 13 or who = 24 or who = 25]
  [set horizontal "policemen"
    set color blue]
  ask agents with [who = 2 or who = 3 or who = 14 or who = 15 or who = 26 or who = 27]
  [set horizontal "firemen"
    set color blue - 2]
  ask agents with [who = 4 or who = 5 or who = 16 or who = 17 or who = 28 or who = 29]
  [set horizontal "paramedics"
    set color turquoise]
  ask agents with [who = 6 or who = 7 or who = 18 or who = 19 or who = 30 or who = 31]
  [set horizontal "la"
    set color green]
  ask agents with [who = 8 or who = 9 or who = 20 or who = 21 or who = 32 or who = 33]
  [set horizontal "cat2a"
    set color yellow]
  ask agents with [who = 10 or who = 11 or who = 22 or who = 23 or who = 34 or who = 35]
  [set horizontal "cat2b"
    set color yellow + 2]

  ask agents
  [if vertical = "bronze"
  [set value1 B-list]
  if vertical = "silver"
  [set value1 S-list]
  if vertical = "gold"
  [set value1 G-list]
  if horizontal = "policemen"
  [set value2 po-list]
  if horizontal = "firemen"
  [set value2 fi-list]
  if horizontal = "paramedics"
  [set value2 pa-list]
  if horizontal = "la"
  [set value2 la-list]
  if horizontal = "cat2a"
  [set value2 c2a-list]
  if horizontal = "cat2b"
  [set value2 c2b-list]]

end

;;;;;;;;;;;;;;;different setups depending on on/off switch parameters ;;;;;;;;;;;;;;;;;;;;

to setup1 ;if H/V-selected is on [first instance]
  ifelse J/L-selected?
  [setup3]
  [setup4]
end

to setup2 ; if H/V-selected is off [first instance]
  ifelse J/L-selected?
  [setup5]
  [setup6] ; would this just be setting up a total base model - version of setup5 - without J/L - them set to zero or
mid level - it will be a mix of setup 4 and setup 5
end

to setup3 ;if H/V is on and J/L is on
  ask agents
  [set h-level random-normal H-select 5
    set v-level random-normal V-select 5
    set mean-h-level mean [h-level] of agents
    set mean-v-level mean [v-level] of agents
    set-H-amount
    set-V-amount
    set-N-amount
```

```
    repeat k-amount [set-k-values2]

    set J-level random-normal J-select 5
    set L-level random-normal L-select 5
    set mean-J-level mean [J-level] of agents
    set mean-L-level mean [L-level] of agents
    set-J-amount
    set-L-amount]
end

to setup4 ;if H/V is on and J/L is off
  ask agents
  [set h-level random-normal H-select 5
    set v-level random-normal V-select 5
    set mean-h-level mean [h-level] of agents
    set mean-v-level mean [v-level] of agents
    set-H-amount
    set-V-amount
    set-N-amount

    repeat k-amount [set-k-values2]

 set J-level random-normal 25 5 ;; decided on default of 25 after J/L models show model does work at this
amount but also slightly influenced by identity matters.
    set L-level random-normal 25 5
    set mean-J-level mean [J-level] of agents
    set mean-L-level mean [L-level] of agents
    set-J-amount
    set-L-amount]
end

to setup5 ;if H/V is off and J/L is on
  ;;;;;; therefore H/V need to be random but J/L selected
  ask agents
  [repeat K-amount [set-K-values]
    set mean-h-level mean [h-level] of agents
    set mean-v-level mean [v-level] of agents

    set J-level random-normal J-select 5
    set L-level random-normal L-select 5
    set mean-J-level mean [J-level] of agents
    set mean-L-level mean [L-level] of agents
    set-J-amount
    set-L-amount]

    set freq-h-0-0.2 (count agents with [h-level <= 0.2])/(count agents) * 100
    set freq-h-0.2-0.4 (count agents with [h-level > 0.2] with [h-level <= 0.4])/(count agents) * 100
    set freq-h-0.4-0.6 (count agents with [h-level > 0.4] with [h-level <= 0.6000000000000001])/(count agents)
* 100
    set freq-h-0.6-0.8 (count agents with [h-level > 0.6000000000000001] with [h-level <= 0.8])/(count agents)
* 100
    set freq-h-0.8-1.0 (count agents with [h-level > 0.8] with [h-level <= 1.0])/(count agents) * 100
    set freq-h-1.0+ (count agents with [h-level > 1.0])/(count agents) * 100

    set freq-v-0-0.2 (count agents with [v-level <= 0.2])/(count agents) * 100
    set freq-v-0.2-0.4 (count agents with [v-level > 0.2] with [v-level <= 0.4])/(count agents) * 100
    set freq-v-0.4-0.6 (count agents with [v-level > 0.4] with [v-level <= 0.6000000000000001])/(count agents)
* 100
    set freq-v-0.6-0.8 (count agents with [v-level > 0.6000000000000001] with [v-level <= 0.8])/(count agents)
* 100
    set freq-v-0.8-1.0 (count agents with [v-level > 0.8] with [v-level <= 1.0])/(count agents) * 100
    set freq-v-1.0+ (count agents with [v-level > 1.0])/(count agents) * 100
end

to setup6 ;if H/V is off and J/L is off
  ;;;; therefore both need to be RANDOM
```

```
  ask agents
  [repeat K-amount [set-K-values]
    set mean-h-level mean [h-level] of agents
    set mean-v-level mean [v-level] of agents

    set J-level random 101
    set L-level random 101
    set mean-J-level mean [J-level] of agents
    set mean-L-level mean [L-level] of agents
    set-J-amount
    set-L-amount]

    set freq-h-0-0.2 (count agents with [h-level <= 0.2])/(count agents) * 100
    set freq-h-0.2-0.4 (count agents with [h-level > 0.2] with [h-level <= 0.4])/(count agents) * 100
    set freq-h-0.4-0.6 (count agents with [h-level > 0.4] with [h-level <= 0.6000000000000001])/(count agents)
* 100
    set freq-h-0.6-0.8 (count agents with [h-level > 0.6000000000000001] with [h-level <= 0.8])/(count agents)
* 100
    set freq-h-0.8-1.0 (count agents with [h-level > 0.8] with [h-level <= 1.0])/(count agents) * 100
    set freq-h-1.0+ (count agents with [h-level > 1.0])/(count agents) * 100

    set freq-v-0-0.2 (count agents with [v-level <= 0.2])/(count agents) * 100
    set freq-v-0.2-0.4 (count agents with [v-level > 0.2] with [v-level <= 0.4])/(count agents) * 100
    set freq-v-0.4-0.6 (count agents with [v-level > 0.4] with [v-level <= 0.6000000000000001])/(count agents)
* 100
    set freq-v-0.6-0.8 (count agents with [v-level > 0.6000000000000001] with [v-level <= 0.8])/(count agents)
* 100
    set freq-v-0.8-1.0 (count agents with [v-level > 0.8] with [v-level <= 1.0])/(count agents) * 100
    set freq-v-1.0+ (count agents with [v-level > 1.0])/(count agents) * 100


end

;;;;; When H/V is off (setups 5 and 6)

to set-K-values
  let values ["v1" "v2" "N"]
  let weights [1 1 1]
  let Kselect random-weighted values weights


  if Kselect = "v1"
  [set K-values lput one-of value1 K-values
    set v-level v-level + 0.2]
  if Kselect = "v2"
  [set K-values lput one-of value2 K-values
    set h-level h-level + 0.2]
  if Kselect = "N"
  [set K-values lput one-of N-list K-values]
end

;see 'used in both' section for random-weighted part of this mechanism

to set-J-amount
  let J-no J-level * 0.01
  set J-amount round (J-no * k-amount)
end

to set-L-amount
  let L-no l-level * 0.01
  set L-amount round (L-no * K-amount)
end


;;;;;;;; when H/V is on (setups 3 and 4)

to set-H-amount
```

```
  let H-no h-level * 0.01
  let H-amounta (H-no * k-amount)
  ifelse H-amounta = 0
  [set H-amount 0.1]
  [set H-amount H-amounta]
end

to set-V-amount
  let V-no v-level * 0.01
  let V-amounta (V-no * k-amount)
  ifelse V-amounta = 0
  [set V-amount 0.1]
  [set V-amount V-amounta]
end

to set-N-amount
  let HV-no V-amount + H-amount
  let N-amounta K-amount - HV-no
  ifelse N-amounta = 0
  [set N-amount 0.1]
  [set N-amount N-amounta]
end

to set-K-values2
  let values ["v1" "v2" "N"]
  let weights (list (V-amount) (H-amount) (N-amount))
  let Kselect random-weighted values weights


  if Kselect = "v1"
  [set K-values lput one-of value1 K-values]
  if Kselect = "v2"
  [set K-values lput one-of value2 K-values]
  if Kselect = "N"
  [set K-values lput one-of N-list K-values]
end

;;;;; used in both!

to-report random-weighted [values weights]
  let random-chance random-float sum weights
  let selector (random-chance)
  let running-sum 0

  (foreach values weights
    [set running-sum (running-sum + ?2)
      if (running-sum > selector)
      [report ?1]])
end

;;;;;;;;;;;;;;;;;;;; to go ;;;;;;;;;;;;;;;;;;

to go

  if count informations < info-drops
  [ask one-of agents
  [hatch-informations 1
    let thatinfo one-of informations-here with [source = 0]
    set source-for thatinfo
    set source? true
    ifelse current-info = nobody
    [set current-info thatinfo
      set kofcurrent [k-values] of current-info
      create-inf-link-with thatinfo]
    [set rep2 lput thatinfo rep2]
    ask thatinfo
    [set source myself
```

```
    set number count informations
    let targetagent one-of other agents with [source-for != myself]
    set K-values [K-values] of targetagent
    set target targetagent
    set age 0
    set at-target? false
    set info-age-when-target2 0
    ask targetagent
    [set target-for lput thatinfo target-for
      set target? true
      set-commdone?]]]]
```

;might want to make the information 'hide' and i dont think it actually needs to create the link.... but it is helpful for now to be able to see this.

```
 ask informations
 [set shape "sheep"
   set age age + 1
   ask source
   [set shape "circle"]
   ask target
   [set shape "square"]]

 ask agents
 [move]

  ask agents
 [if target? = true
 [if member? current-info target-for
 [let sharedinfo current-info
   set rep1 lput sharedinfo rep1
   set current-info nobody
   set kofcurrent 0
   set-commdone?
   create-target-link-with sharedinfo
   [set commnumlist []
     set firstcommnum 0
     set lastcommnum 0
     set meancommnum 0
     set highestcommnum 0
     set lowestcommnum 0
     set countcommnum 0
     set linknumber count target-links]
   ask target-link-with sharedinfo
   [set-targetcommnum]
   ask sharedinfo
   [set at-target? true]]]

   ask informations with-max [number]
   [set info-age-when-target n-of number [0 0 0 0 0 0 0 0 0 0]]

   ask informations
   [if at-target? = true
   [sort-info-age]]

  ifelse current-info != nobody
   [reset-J/L-match
     let Kofinfo [K-values] of current-info
     set kofcurrent kofinfo
     commbyprox
     commbyrules]

   [checkrep2]]

   ask inf-links
   [set color white]
   ask prox-links
```

```
    [set color violet]
    ask rules-links
    [set color magenta]
    ask target-links
    [set color yellow]

   set-percentagecomm
   set-commform

   let nonaccuagents agents with [current-info = nobody] with [not member? true commdone?]
   ask nonaccuagents
   [set involvedinaccuracy? false]

   let accuagents1 agents with [current-info != nobody]
   let accuagents2 agents with [member? true commdone?]
   let accuagents (turtle-set accuagents1 accuagents2)
   ask accuagents
   [set-accuracy]

    set mean-accuracy (sum [percentaccu] of agents with [involvedinaccuracy? != false] / sum
[involvedinaccuracy?] of agents)

    tick
end

to move
  rt random 360
  fd random 5
end

to set-commdone?
  set commdone? map [member? ? rep1 or member? ? rep2 or current-info = ?] (target-for)
end

to sort-info-age
  let index number - 1
  set info-age-when-target replace-item index info-age-when-target info-age-when-target2
end

to reset-J/L-match
  set J-match 0
  set L-match 0
end

;;;;;;;;;;;;;;;;;;;;;;;;;;;;; COMMUNICATION PROCEDURES ;;;;;;;;;;;;;;;;;;;;;;;;

to commbyprox
  let potential-share one-of other agents in-radius 3
  if potential-share != nobody
  [ask potential-share
    [set potential myself]]
  let sharedinfo current-info

  ask informations
  [create-inf-links-with agents with [not member? myself target-for] with [current-info = myself]]

  iterate-J
  iterate-L

  if J-amount < J-match and L-amount < L-match
  [if potential-share != nobody
  [if sharedinfo != nobody
    [if [member? sharedinfo target-for] of potential-share ; if you are the target, then it doesnt matter if you have
already received the information, you can still get it through proximity
      [ask potential-share
        [if member? sharedinfo rep1 = true or member? sharedinfo rep2 = true or current-info = sharedinfo ;; if
the info is in your repertoire
```

```
      [let num-of-links count in-link-neighbors
        create-prox-link-from myself
        [set whichinfo []
          set commthroughwho?1 []
          set commthroughwho?2 []
          set commthroughwho?3 []
          set commthroughwho?4 []
          set commthroughwho?5 []
          set commthroughwho?6 []
          set commthroughwho?7 []
          set commthroughwho?8 []
          set commthroughwho?9 []
          set commthroughwho?10 []
          set commnum1 0
          set commnum2 0
          set commnum3 0
          set commnum4 0
          set commnum5 0
          set commnum6 0
          set commnum7 0
          set commnum8 0
          set commnum9 0
          set commnum10 0
          set linknumber num-of-links + 1]
    ask in-prox-link-from myself
      [set whichinfo lput sharedinfo whichinfo
        set-whocomm]
    set commwith lput myself commwith
    create-target-link-with sharedinfo
    [set commnumlist []
      set firstcommnum 0
      set lastcommnum 0
      set meancommnum 0
      set highestcommnum 0
      set lowestcommnum 0
      set countcommnum 0
      set linknumber count target-links]
    ask target-link-with sharedinfo
    [set-targetcommnum]
    ask sharedinfo
      [set at-target? true]
    ask myself
      [set rep1 lput current-info rep1
        ask inf-link-with sharedinfo
          [die]]]]]]]

if J-amount < J-match and L-amount < L-match
[if potential-share != nobody
  [if current-info != nobody
    [ask potential-share
      [if member? sharedinfo rep1 = false and member? sharedinfo rep2 = false
        [ifelse current-info = nobody
          [ifelse empty? rep2
            [set current-info sharedinfo
              set kofcurrent [k-values] of current-info
              let num-of-links count in-link-neighbors
              create-prox-link-from myself
              [set whichinfo []
                set commthroughwho?1 []
                set commthroughwho?2 []
                set commthroughwho?3 []
                set commthroughwho?4 []
                set commthroughwho?5 []
                set commthroughwho?6 []
                set commthroughwho?7 []
                set commthroughwho?8 []
                set commthroughwho?9 []
```

```
      set commthroughwho?10 []
      set commnum1 0
      set commnum2 0
      set commnum3 0
      set commnum4 0
      set commnum5 0
      set commnum6 0
      set commnum7 0
      set commnum8 0
      set commnum9 0
      set commnum10 0
      set linknumber num-of-links + 1]]
  [set rep2 lput sharedinfo rep2
    let num-of-links count in-link-neighbors
    create-prox-link-from myself
    [set whichinfo []
      set commthroughwho?1 []
      set commthroughwho?2 []
      set commthroughwho?3 []
      set commthroughwho?4 []
      set commthroughwho?5 []
      set commthroughwho?6 []
      set commthroughwho?7 []
      set commthroughwho?8 []
      set commthroughwho?9 []
      set commthroughwho?10 []
      set commnum1 0
      set commnum2 0
      set commnum3 0
      set commnum4 0
      set commnum5 0
      set commnum6 0
      set commnum7 0
      set commnum8 0
      set commnum9 0
      set commnum10 0
      set linknumber num-of-links + 1]]
ask in-prox-link-from myself
[set whichinfo lput sharedinfo whichinfo
  set-whocomm]
set commwith lput myself commwith
if [member? sharedinfo target-for] of potential-share
[ask sharedinfo
  [set info-age-when-target2 age]
ask myself
  [set rep1 lput current-info rep1
    ask inf-link-with sharedinfo
    [die]]]]
[if current-info != sharedinfo
  [set rep2 lput sharedinfo rep2
    let num-of-links count in-link-neighbors
    create-prox-link-from myself
    [set whichinfo []
      set commthroughwho?1 []
      set commthroughwho?2 []
      set commthroughwho?3 []
      set commthroughwho?4 []
      set commthroughwho?5 []
      set commthroughwho?6 []
      set commthroughwho?7 []
      set commthroughwho?8 []
      set commthroughwho?9 []
      set commthroughwho?10 []
      set commnum1 0
      set commnum2 0
      set commnum3 0
      set commnum4 0
```

```
          set commnum5 0
          set commnum6 0
          set commnum7 0
          set commnum8 0
          set commnum9 0
          set commnum10 0
          set linknumber num-of-links + 1]
        ask in-prox-link-from myself
        [set whichinfo lput sharedinfo whichinfo
         set-whocomm]
        set commwith lput myself commwith
        if [member? sharedinfo target-for] of potential-share
        [ask sharedinfo
         [set info-age-when-target2 age]
        ask myself
         [set rep1 lput current-info rep1
          ask inf-link-with sharedinfo
          [die]]]]]]]]]]

ask agents with [potential = myself]
 [set potential nobody]

end

to commbyrules
 let potential-share one-of other agents
 if potential-share != nobody
  [ask potential-share
   [set potential myself]]
 let sharedinfo current-info

 ask informations
 [create-inf-links-with agents with [not member? myself target-for] with [current-info = myself]]

 iterate-J
 iterate-L

  if J-amount < J-match and L-amount < L-match
 [if potential-share != nobody
  [if sharedinfo != nobody
   [if [member? sharedinfo target-for] of potential-share
    [ask potential-share
     [if member? sharedinfo rep1 = true or member? sharedinfo rep2 = true or current-info = sharedinfo
      [let num-of-links count in-link-neighbors
        create-rules-link-from myself
        [set whichinfo []
          set commthroughwho?1 []
          set commthroughwho?2 []
          set commthroughwho?3 []
          set commthroughwho?4 []
          set commthroughwho?5 []
          set commthroughwho?6 []
          set commthroughwho?7 []
          set commthroughwho?8 []
          set commthroughwho?9 []
          set commthroughwho?10 []
          set commnum1 0
          set commnum2 0
          set commnum3 0
          set commnum4 0
          set commnum5 0
          set commnum6 0
          set commnum7 0
          set commnum8 0
          set commnum9 0
          set commnum10 0
          set linknumber num-of-links + 1]
```

```
          ask in-rules-link-from myself
          [set whichinfo lput sharedinfo whichinfo
            set-whocomm]
          set commwith lput myself commwith
          create-target-link-with sharedinfo
          [set commnumlist []
            set firstcommnum 0
            set lastcommnum 0
            set meancommnum 0
            set highestcommnum 0
            set lowestcommnum 0
            set countcommnum 0
            set linknumber count target-links]
          ask target-link-with sharedinfo
          [set-targetcommnum]
          ask sharedinfo
          [set at-target? true]
          ask myself
          [set rep1 lput current-info rep1
            ask inf-link-with sharedinfo
            [die]
            set current-info nobody
            set kofcurrent 0]]]]]]]

if J-amount < J-match and L-amount < L-match
[if potential-share != nobody
  [if sharedinfo != nobody
    [ask potential-share
      [if member? sharedinfo rep1 = false and member? sharedinfo rep2 = false
        [ifelse current-info = nobody
          ;true
          [ifelse empty? rep2
            [set current-info sharedinfo
              set kofcurrent [k-values] of current-info
              let num-of-links count in-link-neighbors
              create-rules-link-from myself
              [set whichinfo []
                set commthroughwho?1 []
                set commthroughwho?2 []
                set commthroughwho?3 []
                set commthroughwho?4 []
                set commthroughwho?5 []
                set commthroughwho?6 []
                set commthroughwho?7 []
                set commthroughwho?8 []
                set commthroughwho?9 []
                set commthroughwho?10 []
                set commnum1 0
                set commnum2 0
                set commnum3 0
                set commnum4 0
                set commnum5 0
                set commnum6 0
                set commnum7 0
                set commnum8 0
                set commnum9 0
                set commnum10 0
                set linknumber num-of-links + 1]]
            [set rep2 lput sharedinfo rep2
              let num-of-links count in-link-neighbors
              create-rules-link-from myself
              [set whichinfo []
                set commthroughwho?1 []
                set commthroughwho?2 []
                set commthroughwho?3 []
                set commthroughwho?4 []
                set commthroughwho?5 []
```

```
      set commthroughwho?6 []
      set commthroughwho?7 []
      set commthroughwho?8 []
      set commthroughwho?9 []
      set commthroughwho?10 []
      set commnum1 0
      set commnum2 0
      set commnum3 0
      set commnum4 0
      set commnum5 0
      set commnum6 0
      set commnum7 0
      set commnum8 0
      set commnum9 0
      set commnum10 0
      set linknumber num-of-links + 1]]
  ask in-rules-link-from myself
  [set whichinfo lput sharedinfo whichinfo
    set-whocomm]
  set commwith lput myself commwith
  ask myself
  [set rep1 lput current-info rep1
    ask inf-link-with sharedinfo
      [die]
    set current-info nobody
    set kofcurrent 0]
  if [member? sharedinfo target-for] of potential-share
  [ask sharedinfo
    [set info-age-when-target2 age]]]
;false
  [if current-info != sharedinfo
    [set rep2 lput sharedinfo rep2
      let num-of-links count in-link-neighbors
      create-rules-link-from myself
      [set whichinfo []
        set commthroughwho?1 []
        set commthroughwho?2 []
        set commthroughwho?3 []
        set commthroughwho?4 []
        set commthroughwho?5 []
        set commthroughwho?6 []
        set commthroughwho?7 []
        set commthroughwho?8 []
        set commthroughwho?9 []
        set commthroughwho?10 []
        set commnum1 0
        set commnum2 0
        set commnum3 0
        set commnum4 0
        set commnum5 0
        set commnum6 0
        set commnum7 0
        set commnum8 0
        set commnum9 0
        set commnum10 0
        set linknumber num-of-links + 1]
      ask in-rules-link-from myself
      [set whichinfo lput sharedinfo whichinfo
        set-whocomm]
      set commwith lput myself commwith
      ask myself
      [set rep1 lput current-info rep1
        ask inf-link-with sharedinfo
        [die]
        set current-info nobody
        set kofcurrent 0]
      if [member? sharedinfo target-for] of potential-share
```

```
          [ask sharedinfo
            [set info-age-when-target2 age]]]]]]]]

  ask agents with [potential = myself]
    [set potential nobody]

end

to checkrep2
  if rep2 != []
  [let info first rep2
    set current-info info
    set kofcurrent [k-values] of current-info
    set rep2 butfirst rep2]
end

to iterate-J
  let listA K-values
  let potential-share one-of agents with [potential = myself]
  if potential-share != nobody
  [let listB [K-values] of potential-share

  foreach listA
  [if member? ? listB
    [set J-match J-match + 1]]]

end

to iterate-L
  let listA Kofcurrent
  let potential-share one-of agents with [potential = myself]
  if potential-share != nobody
  [let listB [K-values] of potential-share

  foreach listA
  [if member? ? listB
    [set L-match L-match + 1]]]

end

to set-whocomm
  let mysource end1
  let previouslinks links with [end2 = mysource]  with [last whichinfo = [last whichinfo] of myself]
  let previouslink max-one-of previouslinks [linknumber]
  let num [number] of last whichinfo

  if num = 1
  [ifelse previouslink != nobody
    [let commthrough [commthroughwho?1] of previouslink
      if commthrough != 0 and commthrough != nobody
      [set commthroughwho?1 lput mysource commthrough]]
    [set commthroughwho?1 lput mysource commthroughwho?1]]

  if num = 2
  [ifelse previouslink != nobody
    [let commthrough [commthroughwho?2] of previouslink
      if commthrough != 0 and commthrough != nobody
      [set commthroughwho?2 lput mysource commthrough]]
    [set commthroughwho?2 lput mysource commthroughwho?2]]

  if num = 3
  [ifelse previouslink != nobody
    [let commthrough [commthroughwho?3] of previouslink
      if commthrough != 0 and commthrough != nobody
      [set commthroughwho?3 lput mysource commthrough]]
    [set commthroughwho?3 lput mysource commthroughwho?3]]
```

```
  if num = 4
  [ifelse previouslink != nobody
    [let commthrough [commthroughwho?4] of previouslink
      if commthrough != 0 and commthrough != nobody
      [set commthroughwho?4 lput mysource commthrough]]
    [set commthroughwho?4 lput mysource commthroughwho?4]]

  if num = 5
  [ifelse previouslink != nobody
    [let commthrough [commthroughwho?5] of previouslink
      if commthrough != 0 and commthrough != nobody
      [set commthroughwho?5 lput mysource commthrough]]
    [set commthroughwho?5 lput mysource commthroughwho?5]]

  if num = 6
  [ifelse previouslink != nobody
    [let commthrough [commthroughwho?6] of previouslink
      if commthrough != 0 and commthrough != nobody
      [set commthroughwho?6 lput mysource commthrough]]
    [set commthroughwho?6 lput mysource commthroughwho?6]]

  if num = 7
  [ifelse previouslink != nobody
    [let commthrough [commthroughwho?7] of previouslink
      if commthrough != 0 and commthrough != nobody
      [set commthroughwho?7 lput mysource commthrough]]
    [set commthroughwho?7 lput mysource commthroughwho?7]]

  if num = 8
  [ifelse previouslink != nobody
    [let commthrough [commthroughwho?8] of previouslink
      if commthrough != 0 and commthrough != nobody
      [set commthroughwho?8 lput mysource commthrough]]
    [set commthroughwho?8 lput mysource commthroughwho?8]]

  if num = 9
  [ifelse previouslink != nobody
    [let commthrough [commthroughwho?9] of previouslink
      if commthrough != 0 and commthrough != nobody
      [set commthroughwho?9 lput mysource commthrough]]
    [set commthroughwho?9 lput mysource commthroughwho?9]]

  if num = 10
  [ifelse previouslink != nobody
    [let commthrough [commthroughwho?10] of previouslink
      if commthrough != 0 and commthrough != nobody
      [set commthroughwho?10 lput mysource commthrough]]
    [set commthroughwho?10 lput mysource commthroughwho?10]]


    set commnum1 length commthroughwho?1
    set commnum2 length commthroughwho?2
    set commnum3 length commthroughwho?3
    set commnum4 length commthroughwho?4
    set commnum5 length commthroughwho?5
    set commnum6 length commthroughwho?6
    set commnum7 length commthroughwho?7
    set commnum8 length commthroughwho?8
    set commnum9 length commthroughwho?9
    set commnum10 length commthroughwho?10
end


to set-targetcommnum
  ;1 need to update their list by taking the commnum of the link that spoke to them
  let mysource end1
  let keyinfo end2
```

```
let previouslinks links with [end2 = mysource]  with [last whichinfo = keyinfo]
let previouslink max-one-of previouslinks [linknumber]
let num [number] of keyinfo


if num = 1
[if previouslink != nobody
  [let commnum [commnum1] of previouslink
    set commnumlist lput commnum commnumlist]]

if num = 2
[if previouslink != nobody
  [let commnum [commnum2] of previouslink
    set commnumlist lput commnum commnumlist]]

if num = 3
[if previouslink != nobody
  [let commnum [commnum3] of previouslink
    set commnumlist lput commnum commnumlist]]

if num = 4
[if previouslink != nobody
  [let commnum [commnum4] of previouslink
    set commnumlist lput commnum commnumlist]]

if num = 5
[if previouslink != nobody
  [let commnum [commnum5] of previouslink
    set commnumlist lput commnum commnumlist]]

if num = 6
[if previouslink != nobody
  [let commnum [commnum6] of previouslink
    set commnumlist lput commnum commnumlist]]

if num = 7
[if previouslink != nobody
  [let commnum [commnum7] of previouslink
    set commnumlist lput commnum commnumlist]]

if num = 8
[if previouslink != nobody
  [let commnum [commnum8] of previouslink
    set commnumlist lput commnum commnumlist]]

if num = 9
[if previouslink != nobody
  [let commnum [commnum9] of previouslink
    set commnumlist lput commnum commnumlist]]

if num = 10
[if previouslink != nobody
  [let commnum [commnum10] of previouslink
    set commnumlist lput commnum commnumlist]]


;2 need to use the list to work out each of the commnum statistics
ifelse commnumlist != []
[set firstcommnum first commnumlist
  set lastcommnum last commnumlist
  set meancommnum mean commnumlist
  set highestcommnum max commnumlist
  set lowestcommnum min commnumlist
  set countcommnum length commnumlist]
[set firstcommnum 0
  set lastcommnum 0
  set meancommnum 0
```

```
    set highestcommnum 0
    set lowestcommnum 0
    set countcommnum 0]

end

;;;;;;;;;;;;;;;;;;;;;;;;OUTPUT REPORTERS ;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to-report iscommdone?

  if ticks = 0
  [report false]

  ifelse all? agents with [target? = true] [not member? false commdone?]
  [report true]
  [report false]
end

to-report allfinished?
  ifelse iscommdone? = true and count inf-links = 0
  [report "finished"]
  [report "not finished"]
end

to-report h-min
  report [h-level] of one-of agents with-min [h-level]
end
to-report h-max
  report [h-level] of one-of agents with-max [h-level]
end
to-report v-min
  report [v-level] of one-of agents with-min [v-level]
end
to-report v-max
  report [v-level] of one-of agents with-max [v-level]
end
to-report J-min
  report [J-level] of one-of agents with-min [J-level]
end
to-report J-max
  report [J-level] of one-of agents with-max [J-level]
end
to-report L-min
  report [L-level] of one-of agents with-min [L-level]
end
to-report L-max
  report [L-level] of one-of agents with-max [L-level]
end

to-report meaninfoage
  ifelse info-age-when-target = []
  [report 0]
  [report mean [info-age-when-target2] of informations]
end

to-report mean-number-comm
 ; let targetcommnum values-from target-links [commnumlist]

  let v1 [commnumlist] of target-links with [linknumber = 1]
  let v2 [commnumlist] of target-links with [linknumber = 2]
  let v3 [commnumlist] of target-links with [linknumber = 3]
  let v4 [commnumlist] of target-links with [linknumber = 4]
  let v5 [commnumlist] of target-links with [linknumber = 5]
  let v6 [commnumlist] of target-links with [linknumber = 6]
  let v7 [commnumlist] of target-links with [linknumber = 7]
  let v8 [commnumlist] of target-links with [linknumber = 8]
  let v9 [commnumlist] of target-links with [linknumber = 9]
```

```
  let v10 [commnumlist] of target-links with [linknumber = 10]

  let targetcommnum (sentence (v1) (v2) (v3) (v4) (v5) (v6) (v7) (v8) (v9) (v10))
  ifelse targetcommnum != []
  [let targetcommnuma reduce sentence targetcommnum
  report mean targetcommnuma]
  [report 0]

end

to-report meanfirst
  ifelse not any? target-links
  [report 0]
  [report mean [firstcommnum] of target-links]
end

to-report meanlast
  ifelse not any? target-links
  [report 0]
  [report mean [lastcommnum] of target-links]
end

to-report meanhighest
  ifelse not any? target-links
  [report 0]
  [report mean [highestcommnum] of target-links]
end

to-report meanlowest
  ifelse not any? target-links
  [report 0]
  [report mean [lowestcommnum] of target-links]
end

to-report meancount
  ifelse not any? target-links
  [report 0]
  [report mean [countcommnum] of target-links]
end

to set-percentagecomm
  set percentagecomm (count agents with [not empty? rep1])/(count agents) * 100
  let percent1 (count agents with [member? information 36 rep1])/(count agents) * 100
  let percent2 (count agents with [member? information 37 rep1])/(count agents) * 100
  let percent3 (count agents with [member? information 38 rep1])/(count agents) * 100
  let percent4 (count agents with [member? information 39 rep1])/(count agents) * 100
  let percent5 (count agents with [member? information 40 rep1])/(count agents) * 100
  let percent6 (count agents with [member? information 41 rep1])/(count agents) * 100
  let percent7 (count agents with [member? information 42 rep1])/(count agents) * 100
  let percent8 (count agents with [member? information 43 rep1])/(count agents) * 100
  let percent9 (count agents with [member? information 44 rep1])/(count agents) * 100
  let percent10 (count agents with [member? information 45 rep1])/(count agents) * 100

  let percentness percent1 + percent2 + percent3 + percent4 + percent5 + percent6 + percent7 + percent8 +
percent9 + percent10
  let num2 [number] of one-of informations with-max [number]
  set meaninfpercent percentness / num2

  set percentB (count agents with [vertical = "bronze"] with [not empty? rep1])/(count agents with [vertical =
"bronze"]) * 100
  let percentB1 (count agents with [vertical = "bronze"] with [member? information 36 rep1])/(count agents
with [vertical = "bronze"]) * 100
  let percentB2 (count agents with [vertical = "bronze"] with [member? information 37 rep1])/(count agents
with [vertical = "bronze"]) * 100
  let percentB3 (count agents with [vertical = "bronze"] with [member? information 38 rep1])/(count agents
with [vertical = "bronze"]) * 100
```

```
  let percentB4 (count agents with [vertical = "bronze"] with [member? information 39 rep1])/(count agents with [vertical = "bronze"]) * 100
  let percentB5 (count agents with [vertical = "bronze"] with [member? information 40 rep1])/(count agents with [vertical = "bronze"]) * 100
  let percentB6 (count agents with [vertical = "bronze"] with [member? information 41 rep1])/(count agents with [vertical = "bronze"]) * 100
  let percentB7 (count agents with [vertical = "bronze"] with [member? information 42 rep1])/(count agents with [vertical = "bronze"]) * 100
  let percentB8 (count agents with [vertical = "bronze"] with [member? information 43 rep1])/(count agents with [vertical = "bronze"]) * 100
  let percentB9 (count agents with [vertical = "bronze"] with [member? information 44 rep1])/(count agents with [vertical = "bronze"]) * 100
  let percentB10 (count agents with [vertical = "bronze"] with [member? information 45 rep1])/(count agents with [vertical = "bronze"]) * 100

  let percentnessB percentB1 + percentB2 + percentB3 + percentB4 + percentB5 + percentB6 + percentB7 + percentB8 + percentB9 + percentB10
  set meaninfpercentB percentnessB / num2

  set percentS (count agents with [vertical = "silver"] with [not empty? rep1])/(count agents with [vertical = "silver"]) * 100
  let percentS1 (count agents with [vertical = "silver"] with [member? information 36 rep1])/(count agents with [vertical = "silver"]) * 100
  let percentS2 (count agents with [vertical = "silver"] with [member? information 37 rep1])/(count agents with [vertical = "silver"]) * 100
  let percentS3 (count agents with [vertical = "silver"] with [member? information 38 rep1])/(count agents with [vertical = "silver"]) * 100
  let percentS4 (count agents with [vertical = "silver"] with [member? information 39 rep1])/(count agents with [vertical = "silver"]) * 100
  let percentS5 (count agents with [vertical = "silver"] with [member? information 40 rep1])/(count agents with [vertical = "silver"]) * 100
  let percentS6 (count agents with [vertical = "silver"] with [member? information 41 rep1])/(count agents with [vertical = "silver"]) * 100
  let percentS7 (count agents with [vertical = "silver"] with [member? information 42 rep1])/(count agents with [vertical = "silver"]) * 100
  let percentS8 (count agents with [vertical = "silver"] with [member? information 43 rep1])/(count agents with [vertical = "silver"]) * 100
  let percentS9 (count agents with [vertical = "silver"] with [member? information 44 rep1])/(count agents with [vertical = "silver"]) * 100
  let percentS10 (count agents with [vertical = "silver"] with [member? information 45 rep1])/(count agents with [vertical = "silver"]) * 100

  let percentnessS percentS1 + percentS2 + percentS3 + percentS4 + percentS5 + percentS6 + percentS7 + percentS8 + percentS9 + percentS10
  set meaninfpercentS percentnessS / num2

  set percentG (count agents with [vertical = "gold"] with [not empty? rep1])/(count agents with [vertical = "gold"]) * 100
  let percentG1 (count agents with [vertical = "gold"] with [member? information 36 rep1])/(count agents with [vertical = "gold"]) * 100
  let percentG2 (count agents with [vertical = "gold"] with [member? information 37 rep1])/(count agents with [vertical = "gold"]) * 100
  let percentG3 (count agents with [vertical = "gold"] with [member? information 38 rep1])/(count agents with [vertical = "gold"]) * 100
  let percentG4 (count agents with [vertical = "gold"] with [member? information 39 rep1])/(count agents with [vertical = "gold"]) * 100
  let percentG5 (count agents with [vertical = "gold"] with [member? information 40 rep1])/(count agents with [vertical = "gold"]) * 100
  let percentG6 (count agents with [vertical = "gold"] with [member? information 41 rep1])/(count agents with [vertical = "gold"]) * 100
  let percentG7 (count agents with [vertical = "gold"] with [member? information 42 rep1])/(count agents with [vertical = "gold"]) * 100
  let percentG8 (count agents with [vertical = "gold"] with [member? information 43 rep1])/(count agents with [vertical = "gold"]) * 100
  let percentG9 (count agents with [vertical = "gold"] with [member? information 44 rep1])/(count agents with [vertical = "gold"]) * 100
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  let percentG10 (count agents with [vertical = "gold"] with [member? information 45 rep1])/(count agents with
[vertical = "gold"]) * 100

  let percentnessG percentG1 + percentG2 + percentG3 + percentG4 + percentG5 + percentG6 + percentG7 +
percentG8 + percentG9 + percentG10
  set meaninfpercentG percentnessG / num2

  set percentPO (count agents with [horizontal = "policemen"] with [not empty? rep1])/(count agents with
[horizontal = "policemen"]) * 100
  let percentPO1 (count agents with [horizontal = "policemen"] with [member? information 36 rep1])/(count
agents with [horizontal = "policemen"]) * 100
  let percentPO2 (count agents with [horizontal = "policemen"] with [member? information 37 rep1])/(count
agents with [horizontal = "policemen"]) * 100
  let percentPO3 (count agents with [horizontal = "policemen"] with [member? information 38 rep1])/(count
agents with [horizontal = "policemen"]) * 100
  let percentPO4 (count agents with [horizontal = "policemen"] with [member? information 39 rep1])/(count
agents with [horizontal = "policemen"]) * 100
  let percentPO5 (count agents with [horizontal = "policemen"] with [member? information 40 rep1])/(count
agents with [horizontal = "policemen"]) * 100
  let percentPO6 (count agents with [horizontal = "policemen"] with [member? information 41 rep1])/(count
agents with [horizontal = "policemen"]) * 100
  let percentPO7 (count agents with [horizontal = "policemen"] with [member? information 42 rep1])/(count
agents with [horizontal = "policemen"]) * 100
  let percentPO8 (count agents with [horizontal = "policemen"] with [member? information 43 rep1])/(count
agents with [horizontal = "policemen"]) * 100
  let percentPO9 (count agents with [horizontal = "policemen"] with [member? information 44 rep1])/(count
agents with [horizontal = "policemen"]) * 100
  let percentPO10 (count agents with [horizontal = "policemen"] with [member? information 45 rep1])/(count
agents with [horizontal = "policemen"]) * 100

  let percentnessPO percentPO1 + percentPO2 + percentPO3 + percentPO4 + percentPO5 + percentPO6 +
percentPO7 + percentPO8 + percentPO9 + percentPO10
  set meaninfpercentPO percentnessPO / num2

  set percentF (count agents with [horizontal = "firemen"] with [not empty? rep1])/(count agents with
[horizontal = "firemen"]) * 100
  let percentF1 (count agents with [horizontal = "firemen"] with [member? information 36 rep1])/(count agents
with [horizontal = "firemen"]) * 100
  let percentF2 (count agents with [horizontal = "firemen"] with [member? information 37 rep1])/(count agents
with [horizontal = "firemen"]) * 100
  let percentF3 (count agents with [horizontal = "firemen"] with [member? information 38 rep1])/(count agents
with [horizontal = "firemen"]) * 100
  let percentF4 (count agents with [horizontal = "firemen"] with [member? information 39 rep1])/(count agents
with [horizontal = "firemen"]) * 100
  let percentF5 (count agents with [horizontal = "firemen"] with [member? information 40 rep1])/(count agents
with [horizontal = "firemen"]) * 100
  let percentF6 (count agents with [horizontal = "firemen"] with [member? information 41 rep1])/(count agents
with [horizontal = "firemen"]) * 100
  let percentF7 (count agents with [horizontal = "firemen"] with [member? information 42 rep1])/(count agents
with [horizontal = "firemen"]) * 100
  let percentF8 (count agents with [horizontal = "firemen"] with [member? information 43 rep1])/(count agents
with [horizontal = "firemen"]) * 100
  let percentF9 (count agents with [horizontal = "firemen"] with [member? information 44 rep1])/(count agents
with [horizontal = "firemen"]) * 100
  let percentF10 (count agents with [horizontal = "firemen"] with [member? information 45 rep1])/(count
agents with [horizontal = "firemen"]) * 100

  let percentnessF percentF1 + percentF2 + percentF3 + percentF4 + percentF5 + percentF6 + percentF7 +
percentF8 + percentF9 + percentF10
  set meaninfpercentF percentnessF / num2

  set percentPA (count agents with [horizontal = "paramedics"] with [not empty? rep1])/(count agents  with
[horizontal = "paramedics"]) * 100
  let percentPA1 (count agents with [horizontal = "paramedics"] with [member? information 36 rep1])/(count
agents with [horizontal = "paramedics"]) * 100
  let percentPA2 (count agents with [horizontal = "paramedics"] with [member? information 37 rep1])/(count
agents with [horizontal = "paramedics"]) * 100
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  let percentPA3 (count agents with [horizontal = "paramedics"] with [member? information 38 rep1])/(count
agents with [horizontal = "paramedics"]) * 100
  let percentPA4 (count agents with [horizontal = "paramedics"] with [member? information 39 rep1])/(count
agents with [horizontal = "paramedics"]) * 100
  let percentPA5 (count agents with [horizontal = "paramedics"] with [member? information 40 rep1])/(count
agents with [horizontal = "paramedics"]) * 100
  let percentPA6 (count agents with [horizontal = "paramedics"] with [member? information 41 rep1])/(count
agents with [horizontal = "paramedics"]) * 100
  let percentPA7 (count agents with [horizontal = "paramedics"] with [member? information 42 rep1])/(count
agents with [horizontal = "paramedics"]) * 100
  let percentPA8 (count agents with [horizontal = "paramedics"] with [member? information 43 rep1])/(count
agents with [horizontal = "paramedics"]) * 100
  let percentPA9 (count agents with [horizontal = "paramedics"] with [member? information 44 rep1])/(count
agents with [horizontal = "paramedics"]) * 100
  let percentPA10 (count agents with [horizontal = "paramedics"] with [member? information 45 rep1])/(count
agents with [horizontal = "paramedics"]) * 100

  let percentnessPA percentPA1 + percentPA2 + percentPA3 + percentPA4 + percentPA5 + percentPA6 +
percentPA7 + percentPA8 + percentPA9 + percentPA10
  set meaninfpercentPA percentnessPA / num2

  set percentLA (count agents with [horizontal = "la"] with [not empty? rep1])/(count agents with [horizontal =
"la"]) * 100
  let percentLA1 (count agents with [horizontal = "la"] with [member? information 36 rep1])/(count agents with
[horizontal = "la"]) * 100
  let percentLA2 (count agents with [horizontal = "la"] with [member? information 37 rep1])/(count agents with
[horizontal = "la"]) * 100
  let percentLA3 (count agents with [horizontal = "la"] with [member? information 38 rep1])/(count agents with
[horizontal = "la"]) * 100
  let percentLA4 (count agents with [horizontal = "la"] with [member? information 39 rep1])/(count agents with
[horizontal = "la"]) * 100
  let percentLA5 (count agents with [horizontal = "la"] with [member? information 40 rep1])/(count agents with
[horizontal = "la"]) * 100
  let percentLA6 (count agents with [horizontal = "la"] with [member? information 41 rep1])/(count agents with
[horizontal = "la"]) * 100
  let percentLA7 (count agents with [horizontal = "la"] with [member? information 42 rep1])/(count agents with
[horizontal = "la"]) * 100
  let percentLA8 (count agents with [horizontal = "la"] with [member? information 43 rep1])/(count agents with
[horizontal = "la"]) * 100
  let percentLA9 (count agents with [horizontal = "la"] with [member? information 44 rep1])/(count agents with
[horizontal = "la"]) * 100
  let percentLA10 (count agents with [horizontal = "la"] with [member? information 45 rep1])/(count agents
with [horizontal = "la"]) * 100

  let percentnessLA percentLA1 + percentLA2 + percentLA3 + percentLA4 + percentLA5 + percentLA6 +
percentLA7 + percentLA8 + percentLA9 + percentLA10
  set meaninfpercentLA percentnessLA / num2

  set percentC2A (count agents with [horizontal = "cat2a"]  with [not empty? rep1])/(count agents with
[horizontal = "cat2a"]) * 100
  let percentC2A1 (count agents with [horizontal = "cat2a"]  with [member? information 36 rep1])/(count
agents with [horizontal = "cat2a"]) * 100
  let percentC2A2 (count agents with [horizontal = "cat2a"]  with [member? information 37 rep1])/(count
agents with [horizontal = "cat2a"]) * 100
  let percentC2A3 (count agents with [horizontal = "cat2a"]  with [member? information 38 rep1])/(count
agents with [horizontal = "cat2a"]) * 100
  let percentC2A4 (count agents with [horizontal = "cat2a"]  with [member? information 39 rep1])/(count
agents with [horizontal = "cat2a"]) * 100
  let percentC2A5 (count agents with [horizontal = "cat2a"]  with [member? information 40 rep1])/(count
agents with [horizontal = "cat2a"]) * 100
  let percentC2A6 (count agents with [horizontal = "cat2a"]  with [member? information 41 rep1])/(count
agents with [horizontal = "cat2a"]) * 100
  let percentC2A7 (count agents with [horizontal = "cat2a"]  with [member? information 42 rep1])/(count
agents with [horizontal = "cat2a"]) * 100
  let percentC2A8 (count agents with [horizontal = "cat2a"]  with [member? information 43 rep1])/(count
agents with [horizontal = "cat2a"]) * 100
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  let percentC2A9 (count agents with [horizontal = "cat2a"]  with [member? information 44 rep1])/(count
agents with [horizontal = "cat2a"]) * 100
  let percentC2A10 (count agents with [horizontal = "cat2a"] with [member? information 45 rep1])/(count
agents with [horizontal = "cat2a"]) * 100

  let percentnessC2A percentC2A1 + percentC2A2 + percentC2A3 + percentC2A4 + percentC2A5 +
percentC2A6 + percentC2A7 + percentC2A8 + percentC2A9 + percentC2A10
  set meaninfpercentC2A percentnessC2A / num2

  set percentC2B (count agents with [horizontal = "cat2b"] with [not empty? rep1])/(count agents with
[horizontal = "cat2b"]) * 100
  let percentC2B1 (count agents with [horizontal = "cat2b"] with [member? information 36 rep1])/(count agents
with [horizontal = "cat2b"]) * 100
  let percentC2B2 (count agents with [horizontal = "cat2b"] with [member? information 37 rep1])/(count agents
with [horizontal = "cat2b"]) * 100
  let percentC2B3 (count agents with [horizontal = "cat2b"] with [member? information 38 rep1])/(count agents
with [horizontal = "cat2b"]) * 100
  let percentC2B4 (count agents with [horizontal = "cat2b"] with [member? information 39 rep1])/(count agents
with [horizontal = "cat2b"]) * 100
  let percentC2B5 (count agents with [horizontal = "cat2b"] with [member? information 40 rep1])/(count agents
with [horizontal = "cat2b"]) * 100
  let percentC2B6 (count agents with [horizontal = "cat2b"] with [member? information 41 rep1])/(count agents
with [horizontal = "cat2b"]) * 100
  let percentC2B7 (count agents with [horizontal = "cat2b"] with [member? information 42 rep1])/(count agents
with [horizontal = "cat2b"]) * 100
  let percentC2B8 (count agents with [horizontal = "cat2b"] with [member? information 43 rep1])/(count agents
with [horizontal = "cat2b"]) * 100
  let percentC2B9 (count agents with [horizontal = "cat2b"] with [member? information 44 rep1])/(count agents
with [horizontal = "cat2b"]) * 100
  let percentC2B10 (count agents with [horizontal = "cat2b"] with [member? information 45 rep1])/(count
agents with [horizontal = "cat2b"]) * 100

  let percentnessC2B percentC2B1 + percentC2B2 + percentC2B3 + percentC2B4 + percentC2B5 +
percentC2B6 + percentC2B7 + percentC2B8 + percentC2B9 + percentC2B10
  set meaninfpercentC2B percentnessC2B / num2

end

to set-commform
  let totalcomm count prox-links + count rules-links
  set total-comm totalcomm
  ifelse total-comm > 0
  [set prox-comm count prox-links / totalcomm * 100
    set rule-comm count rules-links / totalcomm * 100
    let inter-agency-prox count prox-links with [[horizontal] of end1 != [horizontal] of end2] with [[vertical] of
end1 = [vertical] of end2]
    let inter-agency-rules count rules-links with [[horizontal] of end1 != [horizontal] of end2] with [[vertical] of
end1 = [vertical] of end2]
    let inter-level-prox count prox-links with [[vertical] of end1 != [vertical] of end2] with [[horizontal] of end1
= [horizontal] of end2]
    let inter-level-rules count rules-links with [[vertical] of end1 != [vertical] of end2] with [[horizontal] of end1
= [horizontal] of end2]
    let inter-both-prox count prox-links with [[horizontal] of end1 != [horizontal] of end2] with [[vertical] of
end1 != [vertical] of end2]
    let inter-both-rules count rules-links with [[horizontal] of end1 != [horizontal] of end2] with [[vertical] of
end1 != [vertical] of end2]
    let intra-both-prox count prox-links with [[vertical] of end1 = [vertical] of end2] with [[horizontal] of end1 =
[horizontal] of end2]
    let intra-both-rules count rules-links with [[vertical] of end1 = [vertical] of end2] with [[horizontal] of end1
= [horizontal] of end2]
    let inter-agency-true inter-agency-prox + inter-agency-rules
    set inter-agency inter-agency-true / totalcomm * 100
    let inter-level-true inter-level-prox + inter-level-rules
    set inter-level inter-level-true / totalcomm * 100
    let inter-both-true inter-both-prox + inter-both-rules
    set inter-both inter-both-true / totalcomm * 100
    let intra-both-true intra-both-prox + intra-both-rules
```

```
    set intra-both intra-both-true / totalcomm * 100]
  [set prox-comm 0
    set rule-comm 0
    set inter-agency 0
    set inter-level 0
    set inter-both 0
    set intra-both 0]
end

to set-accuracy
  set accu 0

  ifelse Kofcurrent != 0
    ;[A] kofcurrent isn't empty
    [let listA Kofcurrent
      let listB K-values

      ifelse member? true commdone?
      ;[B] if the agent has received the information they are the target for
      [foreach listA
        [if member? ? listB
          [set accu accu + 1]]
      set accu accu + k-amount
      set involvedinaccuracy? 2]

      ;[B] if they haven't got true in their commdone (i.e. either they are not a target or they havent received their target info yet)
      [foreach listA
        [if member? ? listB
          [set accu accu + 1]]
      set involvedinaccuracy? 1]]

    ;[A] Kofcurrent is empty but they are still the target and have the info
      [if member? true commdone?
        [set accu K-amount
          set involvedinaccuracy? 1]]

  set percentaccu accu / k-amount * 100

  end
```

Appendix 2: ANOVA tables

ANOVA tables for Study One: Horizontal and Vertical Categorization

Table I: Time Taken

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	17001495.594[a]	35	485757.017	25.118	.000
Intercept	120980748.296	1	120980748.296	6255.808	.000
H level	6121951.258	5	1224390.252	63.312	.000
V level	4810139.130	5	962027.826	49.746	.000
H level * V level	6308243.592	25	252329.744	13.048	.000
Error	70857908.325	3564	19338.949		
Total	208753138.000	3600			
Corrected Total	87859403.919	3599			

a. R Squared = .194 (Adjusted R Squared = .186)

Table II: Propagation

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3091723.374[a]	35	88334.954	517.655	.000
Intercept	263942531.427	1	263942531.427	1546738.623	.000
H level	1005102.947	5	201020.589	1178.008	.000
V level	1333450.734	5	266690.147	1562.840	.000
H level * V level	753169.693	25	30126.788	176.547	.000
Error	6143204.153	36000	170.645		
Total	273177458.953	36036			
Corrected Total	9234927.526	36035			

a. R Squared = .335 (Adjusted R Squared = .334)

Table III: Accuracy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	734936.480[a]	35	20998.185	76.150	.000
Intercept	248290405.705	1	248290405.705	900424.839	.000
H level	309162.912	5	61832.582	224.236	.000
V level	87586.175	5	17517.235	63.526	.000
H level * V level	338187.393	25	13527.496	49.057	.000
Error	9926930.288	36000	275.748		
Total	258952272.473	36036			
Corrected Total	10661866.768	36035			

a. R Squared = .069 (Adjusted R Squared = .068)

ANOVA tables for Study Two: Intergroup and Information-based Bias

Table IV: Time Taken

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	553679927.816[a]	35	15819426.509	826.111	.000
Intercept	1530318328.514	1	1530318328.514	79915.172	.000
J level	533427725.151	5	106685545.030	5571.255	.000
L level	6695898.415	5	1339179.683	69.934	.000
J level * L level	13556304.250	25	542252.170	28.317	.000
Error	68248048.670	3564	19149.284		
Total	2152246305.000	3600			
Corrected Total	621927976.486	3599			

a. R Squared = .890 (Adjusted R Squared = .889)

Table V: Propagation

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	35573704.914[a]	35	1016391.569	13798.246	.000
Intercept	46207334.763	1	46207334.763	627297.773	.000
J level	18576346.259	5	3715269.252	50437.450	.000
L level	12614147.471	5	2522829.494	34249.223	.000
J level * L level	4383211.185	25	175328.447	2380.210	.000
Error	2651793.332	36000	73.661		
Total	84432833.009	36036			
Corrected Total	38225498.246	36035			

a. R Squared = .931 (Adjusted R Squared = .931)

Table VI: Accuracy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	31507545.727[a]	35	900215.592	6482.000	.000
Intercept	112375965.607	1	112375965.607	809162.872	.000
J level	30498424.258	5	6099684.852	43920.766	.000
L level	561504.164	5	112300.833	808.622	.000
J level * L level	447617.305	25	17904.692	128.923	.000
Error	4999654.460	36000	138.879		
Total	148883165.794	36036			
Corrected Total	36507200.187	36035			

a. R Squared = .863 (Adjusted R Squared = .863)

ANOVA tables for Study Three: The interaction of Categorization and Bias

Time Taken:

Table VII: Horizontal Categorization and Bias Conditions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	504421311.240[a]	29	17393838.319	333.508	.000
Intercept	1292689963.901	1	1292689963.901	24785.917	.000
Bias Condition	484573189.354	4	121143297.339	2322.790	.000
H level	6118533.913	5	1223706.783	23.463	.000
Condition * H level	13729587.973	20	686479.399	13.162	.000
Error	937211169.858	17970	52154.211		
Total	2734322445.000	18000			
Corrected Total	1441632481.099	17999			

a. R Squared = .350 (Adjusted R Squared = .349)

Table VIII: Vertical Categorization and Bias Conditions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	779407145.824[a]	29	26876108.477	729.304	.000
Intercept	1292689963.901	1	1292689963.901	35078.149	.000
Bias Condition	484573189.354	4	121143297.339	3287.318	.000
V level	125597352.596	5	25119470.519	681.636	.000
Condition * V level	169236603.873	20	8461830.194	229.618	.000
Error	662225335.275	17970	36851.716		
Total	2734322445.000	18000			
Corrected Total	1441632481.099	17999			

a. R Squared = .541 (Adjusted R Squared = .540)

Table XI: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 1 – low intergroup bias, low information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8841422.242[a]	35	252612.064	22.461	.000
Intercept	43585523.738	1	43585523.738	3875.461	.000
H level	2337065.702	5	467413.140	41.561	.000
V level	1372283.376	5	274456.675	24.404	.000
H level * V level	5132073.164	25	205282.927	18.253	.000
Error	40082664.020	3564	11246.539		
Total	92509610.000	3600			
Corrected Total	48924086.262	3599			

a. R Squared = .181 (Adjusted R Squared = .173)

Table XII: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 2 – low intergroup bias, high information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8923798.430[a]	35	254965.669	33.350	.000
Intercept	47556195.210	1	47556195.210	6220.491	.000
H level	3016719.500	5	603343.900	78.919	.000
V level	1238674.067	5	247734.813	32.404	.000
H level * V level	4668404.863	25	186736.195	24.426	.000
Error	27247092.360	3564	7645.088		
Total	83727086.000	3600			
Corrected Total	36170890.790	3599			

a. R Squared = .247 (Adjusted R Squared = .239)

Table XIII: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 4 – high intergroup bias, low information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	165404589.520[a]	35	4725845.415	75.657	.000
Intercept	766348489.000	1	766348489.000	12268.635	.000
H level	3920227.127	5	784045.425	12.552	.000
V level	147373432.067	5	29474686.413	471.866	.000
H level * V level	14110930.327	25	564437.213	9.036	.000
Error	222621831.480	3564	62464.038		
Total	1154374910.000	3600			
Corrected Total	388026421.000	3599			

a. R Squared = .426 (Adjusted R Squared = .421)

Table XIV: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 5 – high intergroup bias, high information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	161988822.139[a]	35	4628252.061	70.195	.000
Intercept	800491962.801	1	800491962.801	12140.750	.000
H level	4568346.899	5	913669.380	13.857	.000
V level	140183824.686	5	28036764.937	425.223	.000
H level * V level	17236650.554	25	689466.022	10.457	.000
Error	234989887.060	3564	65934.312		
Total	1197470672.000	3600			
Corrected Total	396978709.199	3599			

a. R Squared = .408 (Adjusted R Squared = .402)

Propagation:

Table XV: Horizontal Categorization and Bias Conditions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	21992638.778[a]	29	758366.854	2592.298	.000
Intercept	1187461892.695	1	1187461892.695	4059058.471	.000
Bias Condition	19633246.105	4	4908311.526	16777.906	.000
H level	1624428.501	5	324885.700	1110.545	.000
Condition * H level	734964.172	20	36748.209	125.615	.000
Error	52702187.338	180150	292.546		
Total	1262156718.810	180180			
Corrected Total	74694826.115	180179			

a. R Squared = .294 (Adjusted R Squared = .294)

Table XVI: Vertical Categorization and Bias Conditions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	39180274.290[a]	29	1351043.941	6853.263	.000
Intercept	1187461892.695	1	1187461892.695	6023481.896	.000
Bias Condition	19633246.105	4	4908311.526	24897.747	.000
V level	12393054.905	5	2478610.981	12572.924	.000
Condition * V level	7153973.280	20	357698.664	1814.451	.000
Error	35514551.826	180150	197.139		
Total	1262156718.810	180180			
Corrected Total	74694826.115	180179			

a. R Squared = .525 (Adjusted R Squared = .524)

Table XVII: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 1 – low intergroup bias, low information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1260314.032[a]	35	36008.972	328.656	.000
Intercept	323753753.640	1	323753753.640	2954917.356	.000
H level	444931.784	5	88986.357	812.183	.000
V level	106888.449	5	21377.690	195.115	.000
H level * V level	708493.799	25	28339.752	258.658	.000
Error	3944318.479	36000	109.564		
Total	328958386.151	36036			
Corrected Total	5204632.511	36035			

a. R Squared = .242 (Adjusted R Squared = .241)

Table XVII: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 2 – low intergroup bias, high information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7809337.098[a]	35	223123.917	2110.177	.000
Intercept	186321765.295	1	186321765.295	1762123.177	.000
H level	68109.425	5	13621.885	128.828	.000
V level	7338285.411	5	1467657.082	13880.249	.000
H level * V level	402942.263	25	16117.691	152.432	.000
Error	3806535.002	36000	105.737		
Total	197937637.396	36036			
Corrected Total	11615872.101	36035			

a. R Squared = .672 (Adjusted R Squared = .672)

Table XVIII: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 4 – high intergroup bias, low information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1761851.127[a]	35	50338.604	191.766	.000
Intercept	274108308.067	1	274108308.067	1044223.997	.000
H level	522071.277	5	104414.255	397.769	.000
V level	766120.619	5	153224.124	583.712	.000
H level * V level	473659.232	25	18946.369	72.177	.000
Error	9449983.067	36000	262.500		
Total	285320142.262	36036			
Corrected Total	11211834.195	36035			

a. R Squared = .157 (Adjusted R Squared = .156)

Table XIX: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 5 – high intergroup bias, high information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	10776409.951[a]	35	307897.427	1579.433	.000
Intercept	158968780.371	1	158968780.371	815468.025	.000
H level	319177.241	5	63835.448	327.459	.000
V level	10002282.972	5	2000456.594	10261.816	.000
H level * V level	454949.738	25	18197.990	93.351	.000
Error	7017903.727	36000	194.942		
Total	176763094.049	36036			
Corrected Total	17794313.678	36035			

a. R Squared = .606 (Adjusted R Squared = .605)

Accuracy:

Table XX: Horizontal Categorization and Bias Conditions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	12080710.604[a]	29	416576.228	1448.466	.000
Intercept	1141417687.737	1	1141417687.737	3968793.605	.000
Bias Condition	11182472.203	4	2795618.051	9720.570	.000
H level	536696.438	5	107339.288	373.227	.000
Condition * H level	361541.963	20	18077.098	62.855	.000
Error	51810806.236	180150	287.598		
Total	1205309204.577	180180			
Corrected Total	63891516.840	180179			

a. R Squared = .189 (Adjusted R Squared = .189)

Table XXI: Vertical Categorization and Bias Conditions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	13954637.389[a]	29	481194.393	1735.935	.000
Intercept	1141417687.737	1	1141417687.737	4117726.192	.000
Bias Condition	11182472.203	4	2795618.051	10085.344	.000
V level	70360.123	5	14072.025	50.766	.000
Condition * V level	2701805.063	20	135090.253	487.345	.000
Error	49936879.451	180150	277.196		
Total	1205309204.577	180180			
Corrected Total	63891516.840	180179			

a. R Squared = .218 (Adjusted R Squared = .218)

Table XXII: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 1 – low intergroup bias, low information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	114017.326[a]	35	3257.638	9.830	.000
Intercept	242580353.469	1	242580353.469	731984.420	.000
H level	22555.795	5	4511.159	13.612	.000
V level	21418.655	5	4283.731	12.926	.000
H level * V level	70042.875	25	2801.715	8.454	.000
Error	11930435.240	36000	331.401		
Total	254624806.034	36036			
Corrected Total	12044452.565	36035			

a. R Squared = .009 (Adjusted R Squared = .009)

Table XXII: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 2 – low intergroup bias, high information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1203215.484[a]	35	34377.585	173.180	.000
Intercept	295067839.291	1	295067839.291	1486433.200	.000
H level	193811.344	5	38762.269	195.269	.000
V level	744653.915	5	148930.783	750.253	.000
H level * V level	264750.224	25	10590.009	53.348	.000
Error	7146262.753	36000	198.507		
Total	303417317.527	36036			
Corrected Total	8349478.236	36035			

a. R Squared = .144 (Adjusted R Squared = .143)

Table XXIII: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 4 – high intergroup bias, low information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1868373.091[a]	35	53382.088	221.755	.000
Intercept	162370451.745	1	162370451.745	674504.140	.000
H level	90474.337	5	18094.867	75.168	.000
V level	1643679.336	5	328735.867	1365.604	.000
H level * V level	134219.418	25	5368.777	22.302	.000
Error	8666123.620	36000	240.726		
Total	172904948.456	36036			
Corrected Total	10534496.712	36035			

a. R Squared = .177 (Adjusted R Squared = .177)

Table XXIV: Interaction of Horizontal and Vertical Categorizations in Bias Cluster 5 – high intergroup bias, high information-based bias

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	693639.539[a]	35	19818.273	68.436	.000
Intercept	204291109.730	1	204291109.730	705458.204	.000
H level	282234.012	5	56446.802	194.922	.000
V level	274827.105	5	54965.421	189.807	.000
H level * V level	136578.421	25	5463.137	18.865	.000
Error	10425110.818	36000	289.586		
Total	215409860.087	36036			
Corrected Total	11118750.357	36035			

a. R Squared = .062 (Adjusted R Squared = .061)