POLITECNICO DI TORINO

MASTER'S DEGREE COURSE IN ENGINEERING AND MANAGEMENT

Master's Degree Thesis

Flood Emergency Management

A case study of the use of a Decision Support System in the City of Gold Coast, Australia



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Abstract

This work wants to, in a first place, provide the readers a general picture of the analysed environment of Gold Coast, Australia, with its meteorological characteristics, therefore the needs to undertake a study on emergency flood management, and best practices in logistics during emergency situations put in place by NGOs and private companies. Furthermore, an inspection of differences and similarities between Business and Humanitarian Supply Chains is undertaken.

It is thus discussed the impacts that disasters, such as the 2010-2011 Queensland floods, may have on both infrastructures and communities; afterwards the consequent inferred challenges of achieving a suitable resilience for cities and buildings in the particular zone of Gold Coast (Queensland, Australia) is.

The last part of this work wants to holistically explore how simulation techniques such as prescriptive Agent-Based Models (ABM) can have a role in both the operational side of Emergency Management and in urban planning. In doing this, an ABM simulating the behavior of people during an evacuation has been developed on AnyLogic[®].

Contents

Li	st of	Figures	III
Li	st of	Tables	V
1	Intr	oduction	1
	1.1	Disaster Trends	1
	1.2	Hydro-Meteorological Disasters in Australia	4
	1.3	The Importance of Pre-emptive Cost Effective Actions	6
	1.4	Research aim	7
2	Hur	nanitarian Logistics and Disaster Management	8
	2.1	Emergency vs. Business Logistics	9
	2.2	The Role of Corporations in Disaster Relief Operations	11
	2.3	The Disaster Management Cycle	14
	2.4	Disaster Impact and Country Logistics Performance	17
3	Nat	ural Disasters and their Impacts on Communities	19
	3.1	The Costs of Natural Disasters	19
	3.2	The 2010-2011 Queensland Floods	20
		3.2.1 Impacts on Communities	23
		3.2.2 Concluding Remarks	27
4	The	Challenges of Disaster Resilience	29
	4.1	The benefits of building resilience	30
	4.2	Four points for a safer community	31
		4.2.1 Physical and Community measures	33
	4.3	Flood Emergency Management	33
		4.3.1 Flood risk	34
		4.3.2 Best practice in Flood Emergency Management	35
	4.4	The case of the Gold Coast, Australia	38
		4.4.1 Flood Emergency Decision Support System (DSS)	39
		Ι	

5	Agent-Based Modeling and Evacuation Plan					
	5.1	Introd	luction	49		
	5.2 The Agent-Based Modeling Approach					
		5.2.1	ABM as a Method to Understand the Complexity and Dy-			
			namics of Evacuation Planning	52		
		5.2.2	The Software: $AnyLogic^{\mathbb{R}}$	5^{2}		
	5.3	The N	Iodel Framework	56		
		5.3.1	The Agents	5'		
		5.3.2	Simulations	69		
		5.3.3	Limitations	76		
6	Cor	nclusio	ns	7'		

List of Figures

1.1	Number of disasters per continent	2
1.2	Number of disasters per subgroup	3
1.3	Number of disasters per type	3
1.4	Gold Coast's flooded road	5
2.1	Lee's supply chain matched strategies. Source: «Aligning Supply	
	Chain Strategies with Product Uncertainties»	10
2.2	Coca-Cola for the 2004 tsunami	12
2.3	Wal-Mart for the 2005 Hurricane Katrina	13
2.4	Disaster Management Cycle (Safran, 2003)	16
3.1	2015-2050 Forecast of the total economic cost of natural disasters. $% \left({{{\cal L}_{\rm{c}}}} \right)$.	20
3.2	Impacts of natural disasters. Source: The economic cost of the social	
	impact of natural disasters	21
3.3	Cyclone Yasi near peak intensity.	22
3.4	Wesley Hospital (Brisbane), January 2011	22
3.5	Satellite image an inundated Brisbane, 13 Jan. 2011	23
3.6	Eagle Terrace, Fri. 14 Jan. 2011 at 05:22 vs Sun. 13 Feb. 2011 at	2.4
~ -		24
3.7	Milton Road on Wed. 12 Jan. 2011 at 15:59 vs Sun. 13 Feb. 2011 at 08:34. Source: The 2010-2011 Floods and Queensland (Australia).	25
3.8	Ann Street during 2010-11 floods.	26
3.9	South Bank on Thu 13 Jan 2011 at 10.03 vs Sat 12 Feb 2011	
0.0	Source: The 2010-2011 Floods and Queensland (Australia)	27
4.1	Elements of flood risk	35
4.2	Chevron Island in Surfers Paradise, Gold Coast, Australia	38
4.3	Predicted Flooding in Gold Coast	45
4.4	Gold Coast catchments boundaries.	46
4.5	Flood Management Decision Support System Structure	47
4.6	IFD Design Rainfall Depth (mm) against Duration	48
5.1	Structure of an agent-based model	51

5.2	Three simulation approaches	5
5.3	Different simulation methods and level of abstraction	6
5.4	The Main	0
5.5	Map properties	1
5.6	Model's Agents	1
5.7	Flood agent properties	2
5.8	Person Agent Properties	4
5.9	Person Agent Statechart	5
5.10	ArcMap snapshot	8
5.11	Screenshot Simulation Scenario 1	2
5.12	Screenshot Simulation Scenario 2	3
5.13	Screenshot Simulation Scenario 3	5

List of Tables

5.1	List of Agents.	57
5.2	Evacuation Centers Capacitites	59
5.3	PC System	69
5.4	Parameters Scenario 1	70
5.5	Results Scenario 1	70
5.6	Analysis Scenario 1	71
5.7	Parameters Scenario 2	71
5.8	Results Scenario 2	71
5.9	Analysis Scenario 2	71
5.10	Parameters Scenario 3	74
5.11	Results Scenario 3	74
5.12	Analysis Scenario 3	74

Listings

initEvacuationZones Function	58
Flood Function	62
Evacuating Function	66
initProperties Function	67
	initEvacuationZones FunctionFlood FunctionEvacuating FunctioninitProperties Function

Chapter 1 Introduction

Although the last two decades have seen a decrease in the raw number of both natural and man-made disasters in the world, this should be set in the context of a significant upward trend over the last 60 years of data. Furthermore, practitioner forecasts would suggest that the impact of trends such as urbanization and climate changes are likely to lead to a substantial growth in the incidence level over the long term and there is, thus, a clear need to develop a robust relief and rebuilding capability (Cozzolino, 2012; Haavisto et al., 2016). In parallel, according to the United Nations (UN), the world is dealing with the largest humanitarian crisis since the end of Second World War with more than 20 million people across four countries (Yemen, South Sudan, Somalia and Nigeria) facing man-made disasters in the form of starvation and famine (United Nations, 2017b). The resultant demand for humanitarian aid and, consequently, the logistics and supply chain management to support it delivery is also growing. It is unsurprising, therefore, that recent estimates would suggest that some 60-80% aid agencies' expenditure is on logistics. Assuming that the overall annual expenditure of such agencies is of the order of 20US\$ billion, the resultant logistic spend is around 15US\$ billion, and this provides a huge potential area for improvement, and consequential benefit to those affected by such disasters (Tatham and Christopher, 2014).

Indeed arguably the importance of achieving an effectiveness and efficient humanitarian supply chain is significantly underestimated when compared to fundraising activities - not least as it can represent the difference between a successful and a failed operation (Kovács and Spens, 2012).

1.1 Disaster Trends

As noted in one of the seminal contributions to the early research in the logistic field, a 'disaster' means

a disruption that physically affects a system as a whole and threatens

its priorities and goals

(Van Wassenhove, 2006). As mentioned in the introductory paragraph, it is possible to distinguish between natural and a man-made disasters, whilst in parallel, it is also possible to distinguish between those that take place suddenly and those that can be characterised as 'slow-onset'.

Such disasters reflect vast ecological breakdown in the relations between man and his environment and thus they can be both natural (earthquakes, floods, hurricanes) and man-made (terrorist attacks, chemical leakages, engineering failures).

Given the impact of such natural disasters, there is an obvious implication of a continuous increase in the need for humanitarian aid and for the logistics and supply chain management activities needed to support its delivery.

Although the definition of a disaster differs between countries and the accuracy of the data collected varies across the globe and through time, the general trends are highlighted in Fig. 1.1, which shows the total number of disaster per continent. It should be noted that, for a disaster event, in order to be recorded into the EM-DAT data base (from which Fig 1.1, 1.2, 1.3 are abstracted), it must fulfill at least one of the following primary criteria:

Deaths: 10 or more people dead,

Affected: 100 or more people either affected, injured or homeless,

Declaration/international appeal: Declaration by the country of a state of emergency and/or an appeal for international assistance.



Figure 1.1: Number of disasters per continent





Figure 1.2: Number of disasters per subgroup

Whilst, as discussed earlier, the total number of such events shows a significant increase from 1960 onwards - albeit with a dip over the last decade - and what is most apparent is that the majority are hydro-metereological, with floods being the most common and widespread of all natural disasters, as shown in Fig. 1.3.



Figure 1.3: Number of disasters per type

1.2 Hydro-Meteorological Disasters in Australia

The financial and emotional burden of natural disasters in Australiais significant and the costs of extreme weather events continue to rise, for example, the damage bill in the aftermath of the 2010/11 flooding that impacted much of the country's East coast (and Queensland in particular) has been estimated at AU\$5 Billion (Queensland Floods Commission of Inquiry, 2012). Protecting lives and property is an enduring issue for all Australians and there is a continuing need to develop and maintain a national, long-term preventative approach to managing natural disasters and protecting local communities. Over the first 4 years of this decade, natural disasters around Australia including the Black Saturday bushfires in Victoria during 2009, Cyclone Yasi in Northern Queensland, and widespread flooding across Queensland, Victoria, Tasmania and NSW in 2010-2011 have claimed more than 200 lives and directly affected hundreds of thousands of people (Deloitte Access Economics, 2017).

Floods are part of the Australian landscape and they occur in many parts of the country, with their severity varying widely between locations and over time, and this reflects both their multiple causalities and the associated human activities. These phenomena have both positive and negative impacts. Positive impacts include inflows to water supplies, sustaining flood-dependent ecosystems and improving soil moistures and fertility for farming. Negative effects mainly occur due to human occupancy of the floodplain, without which there would be no flood risk to the community. These negative effects include human fatalities and injuries, as well as economic damage, disruption of individuals' lives and communities' function, and environmental damage. Furthermore, damage from flooding is greater than that of any other natural hazard. However, it is also the most manageable disaster, because its behaviour and location can be estimated and considered in pre- and post- disaster decision making.

Historically, most of Australia's towns and cities were located on floodplains for reasons that were principally associated with water supply, transportation, waste disposal, amenity or recreation Such locations were suitable points for river crossings or to act as service centres for surrounding rural areas. Regular flooding improves agricultural land by increasing soil moisture, recharging groundwater and depositing fertile silts. These benefits mean that a significant proportion of Australia's extensive agricultural output is produced on floodplains.

On the other hand, and in addition to the loss of lives, floods cause damage to houses, industries, public utilities and property resulting in huge economic losses. Thus, although it is not possible to control the flood disaster totally, by adopting suitable structural and non-structural measures the flood damage can be minimised. It follows, therefore that in order to plan any flood management measures, reliable, accurate and timely information is required¹.

Flooding occurs most commonly from heavy rainfall when natural watercourses are overwhelmed and do not have the capacity to carry the excess water. However, floods are not always caused by heavy rainfall. In coastal areas, water inundation can be caused by a storm surge as a result of a tropical cyclone, a tsunami or a high tide coinciding with higher than normal river levels. A further cause is the failure of a dam - due for example, to structural deficiencies -, the downstream area will flood, even in dry weather conditions.

In the extensive flat inland regions of Australia, floods may spread over thousands of square kilometres and last several weeks, with flood warnings sometimes issued months in advance. In contrast, in the mountaineous and coastal regions of Australia, flooding can happen rapidly with a warning of only a few hours in some cases. While riverine flooding occurs in relatively low-lying areas adjacent to streams and rivers. Disaster experts classify floods according to their likelihood of occurring in a given time period. A hundred-year flood, for example, is an extremely large, destructive event that would theoretically be expected to happen only once every century. In reality, this classification means there is a one-percent chance that such a flood could happen in any given year. But over recent decades, possibly due to global climate change, such hundred-year floods have been occurring worldwide with frightening regularity.



Figure 1.4: Gold Coast's flooded road

¹In this context satellite remote sensing plays an important role.

The Gold Coast has more than 55 kilometers of coastline and over 260 kilometers of navigable waterways. These natural and man-made features present significant challenges and opportunities for managing flooding that is predicted to occur with climate change. The city has, indeed, experienced more than 45 floods since 1925 with past events having caused moderate to extensive damage to private property, community buildings, bridges and roads. Such events not only incur short term costs in terms of managing the impact of disaster, but they also have long-term impacts on the wellbeing of communities and individuals.

1.3 The Importance of Pre-emptive Cost Effective Actions

When devastating natural disasters occur, new mitigation measures are often accelerated. Yet efforts remain heavily focused on post-disaster recovery rather than pre-disaster prevention and preparedness. In many ways this is unsurprising as no-one, least of all local government authorities, like paying an insurance policy.

In recent years, awareness of disaster risks and impacts has significantly increased (and this may be one of the causes of the decrease in the total number of disasters over the last decade noted in Figure 1.1) and it is increasingly recognised that a whole-of-nation approach is needed to build resilience. Yet different parts of Australia are affected in different ways, each faces its own risk profile and has differing capabilities to withstand, adapt to, or avoid impacts. The mechanisms for building resilience, inevitably, differ between each state and territory, as does their motivation to become more resilient. Each faces its own exposure and vulnerability, fostered by disaster risks, demographics, infrastructure and other local circumstances. Approaches vary, yet there remains a common imperative to reduce exposure to natural disasters. Several opportunities exist to share best practice and drive greater coordination; despite between 2009 and 2013, \$11.0 billion was spent on disaster recovery, while only \$225 million was spent on mitigation (Deloitte Access Economics, 2016).

As recognised in the Australian National Strategy for Disaster Resilience (NSDR), the task of building more resilient communities is complex and requires greater collaboration between government, business and community. The opportunity exists for Australia to design a more sustainable and comprehensive national approach to make communities safer and more resilient, and the budgetary impact of responding to and recovering from natural disasters could potentially be significantly reduced through carefully considered and directed investment in pre-disaster resilience.

1.4 Research aim

As will be appreciated from the above introduction, tackling the complex challenges inherent in flood events requires consideration of a number of key themes:

- Prioritisation of **mitigation** and investment options based on appropriate economic value and risk assessment.
- Higher quality planning **standards** required of local government, to ensure no further development is allowed in areas of unacceptable risk and that building standards reflect the need to protect property, as well as lives.
- A zealous effort to coordinate and update existing **data**, natural resource mapping and assessments that may exist across government departments needs to be prioritised and integrated into land use planning. This will enable the government to provide a more informed and consolidated approach to **planning** decisions and land management
- Commitment to recurrent funding of **education and awareness** programs aimed at helping people to adapt to living with the threat of disaster to promote long term behavioural change.

The overall aim of this research is, therefore, to highlight both the opportunity and need to develop a broad, long-term approach to managing natural disasters, through a coordinated and collaborative response. Importantly, the policy response and strategy to build Australian's resilience to natural disasters must focus on **prevention**.

Chapter 2

Humanitarian Logistics and Disaster Management

As stated by United Nations, 2017a, in its framework of response and recovery there is a large difference between the terms emergency and disaster. An **emergency** is an event that can be responded to using the resources available at hand, implying that there is no need to request external assistance. A **disaster**, on the other hand, is characterized by impacts that overwhelm the capacities of local responders and place demands on resources which are not available locally. Hence, an event is declared as a "disaster" when there is a need for external assistance to cope with its impacts. A national government declares a state of disaster or national calamity as a way to request international humanitarian assistance and the support of the international community to cope with the impacts of the disaster. It follows that not every emergency will become a disaster. Rather, it is the interaction between the event itself (the flood, or fire, or pandemic), a community's exposure to that event and its level of vulnerability to the event that dictates whether the event will become disaster. Sometimes, however unavoidable, catastrophic disasters will occur - and - for the most part, our resultant choices and actions to prevent, prepare for, respond to and recover from an emergency will influence whether or not it becomes a disasters or how severe the disaster is.

Disasters, therefore, result in massive demands that often outstrip resources. The process of planning, managing, and controlling the flow of those resources to provide relief to affected people is called emergency (or humanitarian) logistics (Caunhye et al., 2012).

According to Thomas and Fritz, 2006, logistics planning during the 2004 Indian Ocean tsunami, the largest relief effort in history, was conducted manually without the presence of logistics experts. This event raised many issues relating to largescale humanitarian disasters, including the level of preparedness for such events and ow best to manage logistics and supply chain activities in such volatile conditions. The event made tragically clear that the countries in the region completely lacked the communication infrastructure to provide the knowledge, capacity and capability to deal with the aftermath of such an event.

The serving of physical links such as roads and railways is made much worse if communication tools are also fractured, or if the area to be covered is so large that communities are unable to link up and present a common response (Pettit et al., 2014). The outcome of the tsunami was a dramatic situation in which the delivery of basic humanitarian aid was out of balance with requirements: while in the immediate aftermath of the disaster aid was scarce and, as the crisis continued, the lack of coordination meant that there often was either oversupply of certain items, or supply of those that were not suitable to the on-ground conditions (BBC, 2005).

Whilst, arguably, the situation has improved since, the 2004 tsunami serves to highlight many of the issues and difficulties in the preparation and response to such disasters and, in particular, highlights the importance of determine the most appropriate balance between planning for, and responding to, large-scale events.

2.1 Emergency vs. Business Logistics

To many observers, the challenges set by recent large-scale catastrophic events, such as the above cited tsunami or the hurricanes that devastated much of the Southern United States in 2005, have had the potential to be, at least in part, mitigated through the application of consolidated tools and techniques that have been proved beneficial in a commercial context (Tatham and Christopher, 2011, 2014). However, the fundamental basis for supply chain design is the development of strategic supply chain objectives that include efficiency and effectiveness. For example, if an organisation's goal is to achieve differentiation in the market is by offering reliable and fast deliveries, then the operational design is likely to prefer truck deliveries over rail. However, if low cost is the primary objective, management might choose the cheaper, but slower, rail or ship transport modes. A valuable framework which assist in the choice of the most suitable supply chain strategy based on the nature of the supply and uncertainties of different products, is provided by Lee, 2002, and is well summarized in Fig.2.1.

Whilst, in principle, the emergency logistics challenge aims to achieve the same generic outcomes of the '5 Rights' (Right Place, Right Time, Right Quantity, Right Quality, Right Cost), the overall process has a number of peculiar aspects that differentiate this from those of the commercial world (Kovács and Spens, 2012):

1. The **massive level of uncertainty** (unusable routes, safety issues, changing facility capacities, demand uncertainties) and, hence, unpredictability surrounding in particular rapid onset event, since timing and location of such events is difficult to forecast with any degree of confidence;

Low (Stable Process) Efficient supply chains Responsive supply chains High (Evolving Process) Risk-hedging supply chains Agile supply chains

Figure 2.1: Lee's supply chain matched strategies. Source: «Aligning Supply Chain Strategies with Product Uncertainties».

- 2. The challenge of a **de-coupling of financial and material flows**¹;
- 3. Complex communication and coordination lines which often reflect physical damage to the system from the event, involvement of many third parties, government, and civilians, and the inability to access accurate realtime demand information;
- 4. Limited resources which are often overwhelmed by the scale of the situation (supply, people, transportation capacity, fuel).
- 5. A logistic failure that can lead to loss of life and/or unnecessary suffering, rather than simply reduced profits (Christopher and Holweg, 2011).

That said, the growing degree of unpredictability is increasingly a peculiar feature of modern supply networks - both in commercial world as well as in humanitarian area - as demand can no longer be easily predicted and supply conditions have become more volatile in almost every industry. So the question becomes one of what lessons can be learnt from the management of commercial supply chains that can be applied to a humanitarian one - albeit with some adjustments to reflect the differences between the contexts.

That said, it is argued that humanitarian organizations lag behind their private sector counterparts who realized some time ago the importance of using efficient

¹Aid agencies are therefore placed in the challenging situation of having to second guess the needs of the beneficiaries, who are often just focused on the goal of staying alive, and at the same time, agencies must satisfy the increasingly demanding governance requirements of the donor community (Tatham and Christopher, 2014).

supply chains, particularly given the increasing opportunities to 'go global'. At least in part, this reflects the challenge faced by humanitarian logistician in obtaining recognition for their contribution to the disaster response. This has resulted in something of a vicious circle in which a lack of understanding of the logistics function and its importance has resulted in a lack of inclusion in planning and budgetary processes which, in turn, has resulted in logistics requirements not being met (Van Wassenhove, 2006).

Another fundamental difference reflects the fact that those affected are frequently unable to make their needs known in the same way as in the commercial context where a person can go to a shop and select items from the shelf – in effect creating the demand for a replacement item to be shipped up the supply chain. In a emergency/disaster context, it is often the case that the impact of the event itself (which may destroy roads, bridges and communcation systems) means that the logistician has to guess the answer to the 6W Problem of "Who Wants What Where When and Why" noting that the requirements differ between old and young, male and female, and between religions (to name but a few variables).

In short, immediately after a disaster, humanitarian organizations are likely to face significant problems of transporting large amounts of many different commodities including food, clothing, medicine, medical supplies, machinery, and personnel from multiple origins to multiple destinations. The resultant transportation of supplies and relief personnel must be done as quickly and efficiently as possible in order to maximize the survival rate of the affected population and minimize the longer term cost of such operations.

More recently, humanitarian organizations have shown greater interest in the resources, expertise, processes, and technologies that business possess. At the same time, the business sector has become more aware of many advantages that derive from cooperation with humanitarian organizations (Cozzolino, 2012), and this will be discussed further in the next section.

2.2 The Role of Corporations in Disaster Relief Operations

Several corporations have become deeply involved in the disaster relief effort with some having established relationships with aid agencies well before the 2004 tsunami struck. Coca-Cola, for example, had for many years maintained relationships with the Red Cross and other aid agencies in multiple countries. Working with local subsidiaries, Coca-Cola converted its soft-drink production lines to bottle huge quantities of drinking water and used its own distribution network to deliver it to relief sites. Similarly, British Airways, UPS, FedEx, and DHL have all worked with their existing aid agency partners to furnish free or subsidized transportation for relief cargo . Nevertheless, the response to the 2004 tsunami marked a turning point in the involvement of the corporate sector in humanitarian relief. In its aftermath, corporations and aid organizations alike examined ways in which they could collaborate most fruitfully with one another. Researchers such as Thomas and Fritz, 2006, suggest that effective partnerships are possible if corporations understand the dynamics of the aid sector.



Figure 2.2: Coca-Cola operating in the disaster relief after the 2004 tsunami

Of course, such involvement is not entirely altruistic with many companies participating in humanitarian response efforts because they have seen impact of financial losses inflicted when disasters interrupt the flow of business - thus - working to alleviate the economic impact of such disruptions makes good business sense. In addition, firms feel increasing pressure from consumers and employees, as well as a growing segment of the investment community to demonstrate good corporate citizenship.

Working with the established community of aid agencies makes a good sense. Humanitarian aid agencies have decades of experience on the front lines of disasters and in long-term development initiatives. They have cultivated expertise in various intervention strategies. Their networks, relationships, and know-how reaches into the most remote parts of the world. Importantly, they do not differentiate between highly visible disasters and unpublicized ones; rather they are guided by the four core principles of humanity, impartiality, neutrality and independence, which afford them legitimacy. Their brands generate trust and respect, which facilitate their ability to solicit donations.

However, as the number of large-scale disasters increases, aid agencies are struggling to keep up with burgeoning demand. Critically, because their funding mechanisms require them to devote almost all their resources to frontline assistance services, funds to develop backroom infrastructure and processes are limited. Technology is fragmented and having multiple, incompatible information systems is not unusual. As a result, information exists in silos, preventing agencies from collecting organizationwide metrics. There are no clearly defined career paths, professional associations, or communities of practice for people who work in the backroom areas of logistics, technology, finance, and human resources at these agencies. Because each project is funded separately, field staff turnover is very high, sometimes as much as 80%. Therefore, the tacit knowledge of aid workers is often lost at the end of a major operation.



Figure 2.3: Wal-Mart for the 2005 Hurricane Katrina

When it comes to efficiency of supply deliveries, the modeling and optimization techniques established in commercial supply chain management have clear relevance. For instance, some of the swiftest emergency assistance to the victims of hurricane Katrina did not come from the American Red Cross or the US Federal Emergency Management Agency (FEMA), it came from Wal-Mart. Millions of affected or displaced people waited for days as agencies struggled to provide assistance. Wal-Mart moved faster than traditional emergency aid groups mainly because the retail giant had mastered the fundamentals of logistics and supply chain management.

It follows, therefore, that aid organizations and corporations have much to gain from working together. Companies can reinforce their reputations with customers, demonstrate their good intentions, and attract employees who want to work for responsible corporate citizens. Aid agencies can become more efficient at alleviating suffering and enhance their relationships with donors by more clearly demonstrating their impact. But if the mutual benefits are extensive and important, so are the challenges of forming truly effective private-public partnerships.

2.3 The Disaster Management Cycle

In a disaster context, the aim is of course to ensure efficient and effective delivery, such that the appropriate commoditites and people reach those affected. However, optimizing the logistics performance requires that all the relationships among the actors involved are managed through an integrated approach that eliminates redundancy, and maximize integration along the entire emergency supply chain.

The logistics strategy of humanitarian organizations facing disasters events must be developed under a set of principles capable of creating a swift and effective response because time saved means lives saved. Therefore, as a response to this growing uncertainty, organizations have typically developed an 'agile' approach that is designed to help business excel in a turbulent environment.

According to multiple works from the literature, the agile principle has been linked to emergency and humanitarian operations as a reflection of the uncertainty found in this context (Cozzolino et al., 2012). Agile supply networks differ from lean ones which aim at the elimination of *anything* that does not add value and only work on what is absolutely needed to be achieved at a given moment in time. This implies that they work best in a relatively steady supply and demand environment – and can thus be contrasted with agile networks that are designed to operate in conditions of uncertainty. However, the two principles of *agility* and *leaness* are not mutually exclusive, rather, they can operate within the same overall supply chain at different moments or in different elements (upstream vs downstream) (Christopher, 2016). Thus, as the focus moves from the immediate relief effort through to eventual reconstruction, the nature of the supply chain response will need to change from an 'agile' model which, aims at maximizing the responsiveness, to a 'leaner' one in favour of a greater level of cost effectiveness (Tatham and Christopher, 2014).

The biggest hurdle facing humanitarian logistics teams has been the complexity of the operating conditions within which they had to work in order to supply aid to those affected. For example, as mentioned earlier, the physical impact of the event can mean that bridges are destroyed and roads blocked with the result that the regular transport of goods to/from a location is severly impacted.

As a result, humanitarians need robust equipment that can be set up and dismantled quickly enabling them to be extremely adaptable and prepared for the unexpected as circumstances can change very quickly from one moment to the next. Unfortunately, logisticians in this sector often have to work with fragmented technology and poorly defined manual processes. They often work under high levels of uncertainty in terms of demand, supply and assessment to which as mentioned must be added the pressure of time which, in this context, is not just a question of money but a difference between life and death.

A further level of complexity comes from that fact that, unlike private sector logisticians, humanitarians often have to contend with *many stakeholders*, including large numbers of uncoordinated and disparate donors, the media, governments, the military not to mention the final beneficiaries. At any one time, there can be as many as several hundred humanitarian organizations at the scene of a disaster, and they frequently do not act in a coordinated fashion reflecting their different political agendas, ideologies and religious beliefs, together with their desire to obtain media and donor attention (Tatham and Christopher, 2014). Thus one of the greatest challenge in a humanitarian response is that of integrating the responding agencies without compromising their mandates or beliefs.

Another difference with the private sector, where the financial bottom line motivates the constant need to measure performance and invest in improvement, is that the humanitarian sector operates without the market forces of demand and supply regulated through price. In the private sector, performance is rewarded by the market (e.g. stock market, higher revenues and profits) and internal incentive schemes such as bonuses, stock options and so on, which feeds a culture of continuous improvement - but none of these mechanisms feature in the emergency logistics context.

As discussed earlier, the overall process of disaster management is a key factor that drives successful execution of relief efforts, and it begins with strategic process design (Tomasini and Van Wassenhove, 2009). It is often described as a process composed of several stages, even though there is disagreement among authors as to exact the structure and nomenclature of the stages. However, for the most part, the literature indicates the existence of the following phases:

- Immediate Relief,
- Recovery,
- Prevention.

This can be depicted by a cyclical model as shown in Figure 2.4. It highlights the shortness of the immediate impact phase where immediate relief is urgently



Figure 2.4: Disaster Management Cycle (Safran, 2003).

required and then shows the extended time periods of the transition, recovery and prevention stages. These phases comprise various elements as shown, for example in the recovery stage to incorporate the restoration, rehabilitation and reconstruction phases.

Whilst Safran's model does not depict specific timelines nor does it show that the developmental aid, prevention and preparedness activities are ongoing and link to the resilience of the immediate relief and recovery phases, nevertheless this early cyclical model a linear model is devised to highlight the transitional areas and their importance - albeit these are sometimes portrayed in a linear fashion (Barber and Heaslip, 2013). The work of these latter authors distinguishes between the immediate aftermath of the disaster (48-72 hours), and the rest of the transition stage, which typically lasts about a month after the disaster's occurrence, before it is possible to start the process of returning to a semblance of normality, namely recovery phase.

2.4 Disaster Impact and Country Logistics Performance

Every country in the world has a different level of logistics performance as evidenced by, for example, the World Bank Logistic Performance Index (The World Bank, 2016), and this affects a whole range of areas including, for example, the country's trade competitiveness. In addition, however the pre-existing logistic capabilities are fundamental in the determining the country's ability to respond logistically to a disaster, and hence the likelihood that there will be a requirement to seek external assistance (Haavisto, 2012).

In the first 72 hours the affected country is most likely to have to handle the impact of the disaster by itself. Thereafter, in the case of an event where immediate relief is needed, humanitarian organizations generally aim to reach the affected area within 72 hours of the disaster occurrence. However, even when they have done so, they still rely heavily on the resources in the country - for example, airports, docks, warehouses, trucks and road networks.

Country's logistics performances vary and there are several different measurements in use for determining them. There are variations in the level of infrastructure and large ones as well in country specific policies and procedures which in the commercial sector affect the trade competitiveness. A country's trade competitiveness has in empirical studies been found to have a statistical link with the country's logistics performance. The link has been found between transport cost and trade flows, and between the quality of the infrastructure and transport cost (Hausman et al., 2005). The logistics performance of a country could be linked to the timelinesss and cost in a humanitarian response operation in a similar manner it is linked to trade competitiveness. The logistics performance in a country might even have a larger significance for the humanitarian sector than for the commercial, since a disaster is determined by time and place uncertainty and the outcome of the operations is measured in lives (Kovács and Spens, 2007). In a relief operation the logistics performance of the affected country might therefore be crucial in successfully accessing and aiding the affected population.

Logistics performance has been proven to have an impact on trade competitivenes; the commercial supply chain can be seen as a process of managing the flow of goods, information and finances from the source to final customer. Similarly, to commercial logistics operations, disaster logistic response struggles with conflicting interests of stakeholders and with unpredictable demand.

Disaster response is characterized by numerous factors of uncertainty which don't exist in the commercial sector. In most cases, the beneficiaries, their location and their needs are unknown. A relief operation is therefore characterized by demand uncertainties in the form of location, type and volume. This uncertainty and unpredictability leads to the relief operations being reactive rather than proactive, which would mean that the response operations are seldom prepared for (Beamon and Balcik, 2008). Planning and preparing for a disaster are even more important than they are for the commercial sector.

Thus, the lack of impact of a disaster is not simply due to its lack of predictability, is also reflects the reality that many countries do not have the capability in the 'peacetime' pre-disaster state to develop and improve their logistic infrastructure and this has a further negative impact of the timeliness of the response. Indeed, there is a further perspective here in that there is a link between the per capita Gross Domestic Product (GDP) and the post-disaster casualty rates (Kahn 2005) so that countries in the low/middle income bracket (LMIC) are impacted both ways – higher casualty rates and poorer infrastructure to support the response.

Chapter 3

Natural Disasters and their Impacts on Communities

3.1 The Costs of Natural Disasters

Australia has a long history of natural disasters, from catastrophic bushfires to flooding rains and they have incurred billions of dollars in costs to individuals, businesses and governments. As reported by Deloitte Access Economics, 2017, Queensland has been Australia's most disaster-prone state over the past decade and incurred a total economic cost of AU\$11 billion per year. Furthermore, these costs are expected to double by 2030 and to rise to an average of AU\$23 billion per year by 2050, even without any consideration of the potential impact of climate change (ibid.). Each year an estimated amount of AU\$560 million is spent on post-disaster relief and recovery by the Australian Government compared with an estimated consistent annual expenditure of AU\$50 million on pre-disaster resilience: a ratio of more than AU\$10 post-disaster for every AU\$1 spent pre-disaster (Deloitte Access Economics, 2016).

Clearly comprehensive information on all costs of natural disasters is required to understand the full impact of natural disasters on Australian communities and their economies and thereby, to understand the extent to which expenditure on mitigation and resilience actions is effective. However, the outcomes arising from natural disasters are interconnected in a complex web, as represented in Figure 3.2, at page 21, and these outcomes can be quantified in terms of human costs, general costs and/or economic efficiency losses.

Furthermore, according to the Deloitte report introduced above, the long term economic cost of natural disasters may be underestimated by more than 50% with the less visible *intangible costs* are estimated to be as high as the *tangible costs* (ibid.). In this respect, such costs are typically grouped into tangible and intangible costs, as follow:



Figure 3.1: 2015-2050 Forecast of the total economic cost of natural disasters. Source: The economic cost of the social impact of natural disasters

- Direct tangible costs are those incurred as a result of the hazard event and have a market value such as damage to private properties and infrastructure.
- Indirect tangible costs are the flow-on effects that are not directly caused by the natural disaster itself, but arise from the consequences of the damage and destruction such as business and network disruptions.
- Intangible costs capture both direct and indirect damages that cannot be easily priced such as death and injury, impacts on health and wellbeing.

Given the all these categories of costs relating to extreme weather events are expected to continue increasing over time, there is an even greater need for a coordinated development of emergency management processes and operations across government, businesses and the not-for-profit sector.

3.2 The 2010-2011 Queensland Floods

The Australian continent was subjected to widespread rainfalls during the summer 2010-2011, especially in the north-eastern state of Queensland. Between the end of November 2010 and January 2011, nearly 75% of Queensland was affected by some major flooding, representing a surface area comparable to France, Germany, Netherlands, Belgium, Denmark and Norway combined. Both large-scale flooding and flash floods took place causing substantial loss of life.

Prolonged and extensive rainfall from November 2010 to early February 2011 led to extensive flooding in Queensland. This was followed soon after by Cyclone



Figure 3.2: Impacts of natural disasters. Source: The economic cost of the social impact of natural disasters.

Yasi (Figure 3.3) on 3rd February, 2011. Yasi made landfall as a category 5 cyclone in Far North Queensland, an area which had just recovered from Cyclone Larry.

On Thursday 13th January 2011 Brisbane, the state capital of Queensland, Australia, experienced its second highest flood since the beginning of the 20th Century. Major flooding occurred throughout most of the Brisbane River catchment, where numerous record flood heights were experienced. The flooding caused the loss of 23 lives in the Lockyer Valley and one in Brisbane, and an estimated 18,000 properties were inundated in metropolitan Brisbane, Ipswich and elsewhere in the Brisbane River Valley.



Figure 3.3: Cyclone Yasi near peak intensity.



Figure 3.4: Wesley Hospital (Brisbane), January 2011.

The flood of the Brisbane River in its lower valley was the result of a combination of high-impact factors hailed from the continuous and heavy rainfalls of 7, 8, 9, 10 and 11 January, which soaked some of the bordering catchments of the area, such as Bremer and Brisbane River catchments. All these factors led to the development of a major flood in the lower Brisbane River valley on 11, 12, 13 and 14 January 2011. The peak flood in Brisbane took place on 12 January afternoon and 13 January morning, Figure 3.5.



Figure 3.5: Satellite image an inundated Brisbane, 13 Jan. 2011, (NASA, 2011)

3.2.1 Impacts on Communities

In a survey on the effects of the floods, 47% of respondents reported that their own home, homes in their suburb, or their family home had been damaged or destroyed. People from disadvantaged socio-economic backgrounds and in outer regional and remote areas were more seriously affected more in a number of ways, such as distress and feeling terrified, helpless or hopeless, or having reduced incomes.

Deaths and Injuries

Thirty-six people died in the floods, including three who were missing and later declared deceased. Major flooding occurred throughout most of the Brisbane River



Figure 3.6: Eagle Terrace, Fri. 14 Jan. 2011 at 05:22 vs Sun. 13 Feb. 2011 at 08:34. Source: *The 2010-2011 Floods and Queensland (Australia)*.

catchment, most severely in the catchments of Lockyer Creek, which caused the loss of 19 lives. Based on the average life expectancy in Queensland and the average age of people affected by the floods, the lifetime cost of deaths and injuries is estimated at around \$320 million (net present value in 2015 dollars).

Mental health issues

Adults of working age and residents of regional, remote and socioeconomically disadvantaged areas, were disproportionately more likely to report emotional impact caused by the floods. Of a sample of more than 6,000 Queensland residents exposed to the floods, 14.3% reported feeling 'terrified, helpless or hopeless', and 3.9% thought they might be 'badly injured or die'. Up to five months after the disasters, 7.1% were 'still distressed' and 8.6% were 'worried about how they might manage'. Likely, Turner et al., 2013 found that residents whose homes were directly affected by the Brisbane flooding were more likely to report poorer physical and mental health.



Figure 3.7: Milton Road on Wed. 12 Jan. 2011 at 15:59 vs Sun. 13 Feb. 2011 at 08:34. Source: *The 2010-2011 Floods and Queensland (Australia)*.

According to researches conducted and reported in Queensland Health, 2011, mental health issues were the largest impact of the floods.

Risky or high-risk alcohol consumption

Mental health-related behaviours such as substance use (alcohol and smoking) have been documented following natural disasters. Alderman et al., 2013 surveyed a sample of 3,000 residents (aged 18 years and over) in flood-affected areas in the greater Brisbane region. Of the 960 respondents, 10.6% reported some form of direct flood impact. The group affected directly by the floods were 5.2 times more likely to increase their alcohol use, and 4.5 times more likely to increase their tobacco use.



Figure 3.8: Ann Street during 2010-11 floods.

Family violence

Increased rates of family and gender violence after natural disasters is qualitatively well-documented. Stress is often cited as the key reason for increased violence against women during a post-disaster. Anecdotal evidence from domestic violence service providers such as the Ipswich Women's Centre Against Domestic Violence reported a spike in cases of family violence after the 2010–11 floods. It was documented that the underlying problems many families were facing were heightened in the aftermath of the disaster. An additional exacerbating factor was the shortage of crisis accommodation due to the floods for people affected by domestic violence.

Short-term unemployment

Natural disasters have negative effects on employment and disposable income, which in turn affects consumer confidence. Commonwealth Bank of Australia, 2011 analysed the effect of natural disasters on personal income and the disruption to living arrangements when disasters hit. The analysis used the Australian Government's Disaster Income Recovery Subsidy as a proxy for unemployment. It found the number of people applying for the Newstart Allowance rose dramatically following the floods. Importantly, repeated flooding events in North Queensland prior to the 2010–11 floods appeared to have made people vulnerable to loss of income. Between the North Queensland flood in 2009, the South West Queensland flooding



Figure 3.9: South Bank on Thu. 13 Jan. 2011 at 10:03 vs Sat. 12 Feb. 2011. Source: The 2010-2011 Floods and Queensland (Australia).

in 2010 and the 2010–11 floods there was a consistent decline in the proportion of Queenslanders receiving a salary and an increase in the proportion relying on the Newstart Allowance (the main income support payment for unemployed) as their only source of income.

3.2.2 Concluding Remarks

In December 2010 alone, many places in Queensland received more than six times the expected average December rainfall (Honert and McAneney, 2011). Between November 2010 and January 2011, the wet summer season caused some widespread flooding across most of the State, in particular in Central, Western, Southern and South-East Queensland. While major floods are a relatively common occurrence in tropical and sub-tropical Queensland, the extent and magnitude of the 2010-2011 floods were unprecedented in many places and a number of record water levels were observed. Both large-scale floods and flash flooding were occurred. Large-scale flooding took place in the Fitzroy River and Condamine-Balonne River systems
in particular. Some deadly flash floods occurred in the Toowoomba Range and Upper Lockyer Valley. In Brisbane, some people were taken by surprise by the Brisbane River flood on Tuesday 11 January evening and Wed. 12 January 2011, although the maximum water elevation was 1 m below the 1974 flood level of the Brisbane River. Many assumed improperly that the Brisbane River flood would be mitigated by the Wivenhoe Reservoir and did not understand that the floodwaters of the Bremer River and Lockyer Creek are un-controlled (Chanson, 2011).

Chapter 4

The Challenges of Disaster Resilience

While some progress has been made in building resilience and reducing losses and damages in Queensland, it is clear form the literature that achieving a substantial reduction of disaster risk requires perseverance and persistence, with both a more explicit focus on people and their health and livelihoods, and regular follow-ups.

Community organisations play a critical role in supporting people, especially in areas experiencing poverty and disadvantage who struggle to manage everyday adversity and are therefore even more challenged in times of crisis. The role of such organisations in supporting communities to recover from disasters and emergencies is increasingly recognised by the communities themselves, as well as by governments and emergency services.

However, such organisations are generally not well prepared for disasters and emergencies, reflecting the overall challenge that such events occur relatively infrequently and so not only is knowledge easily lost, but also the context can change through, for example, a change in land usage from farming to housing, etc. A key risk from being poorly prepared is that in the aftermath of a disaster or emergency, community organisations will be unable to provide services to their communities at a time when they are needed most. It is argued, therefore, that community organisations need to step up to their role in building organisations and communities that are resilient in the face of disasters and emergencies.

Stepping up is consistent with having a risk management framework, but in practice many organisations' risk management frameworks do not identify or address the risks related to disasters and emergencies. This shortfall has the potential to become even more frequent and challenging, and are likely to disproportionately impact those who are experiencing poverty and disadvantage.

In short, further investment in disaster resilience is essential to lessen the forecast increase in costs. This includes physical measures, such as resilient infrastructure, and community measures, such as preparedness programs. Such investment in disaster resilience yields a double dividend. First, it helps to mitigate the impacts of disasters when they occur. And secondly, it provides a number of co-benefits such as employment opportunities, improved service reliability, greater business confidence and incentives for innovation. Such co-benefits support economic growth and social capital in Australian communities. This double dividend is a crucial part of the business case for well-designed resilience investment and is particularly relevant in Australia, which is currently investing in infrastructure to service its growing and urbanising population (Council of Australian Governments, 2011), and these projects could exploit the net benefits of the double dividend by integrating resilience into early planning.

State and local governments play a major role in how a community responds to natural disasters. As well as emergency management and disaster recovery, they influence prevention and preparedness through data collection and its subsequent provision, infrastructure and land use planning, building codes and community initiatives. However, when it comes to prioritising resilience, leveraging investment, demonstrating its net benefits and integrating resilience more broadly across portfolios, governments face common barriers.

State and territories are looking to better understand resilience in order to appreciate how best to integrate it across land use planning, building and infrastructure decisions. To this end, each has recently completed state-wide **disaster risk assessments** to improve baseline information (Deloitte Access Economics, 2017), guided by the principles and outcomes of *Sendai Framework for Disaster Risk Reduction 2015-2030*, reporting against its indicators, they aimed at the improvement of awareness of state level as well as national trends and impacts of disasters. In this respect, the Sendai framework was adopted at the Third United Nations World Conference on Disaster Risk Reduction, held from 14 to 18 March 2015 in Sendai, Miyagi, Japan. It aims to guide the multihazard management of disaster risk in development at all levels as well as within and across all sectors (United Nations Office for Disaster Risk Reduction, 2015). However, as noted in the Framework, the realization of substantial reduction of disaster risk and losses in lives and livelihoods, requires the strong commitment and involvement of political leadership in every country at all levels in the implementation of the Framework.

4.1 The benefits of building resilience

Investments in resilience have the potential to have two kinds of benefits, which have both to be considered when assessing the Net Present Value of the investment.

The first benefit is, self-evidently, the reduction in future costs inflicted by the impact of a natural disaster. Simplistically, the higher the level of resilience, the higher the costs and losses avoided.

The second sphere of advantage gained, are the **co-benefits** introduced in the

previous section. These benefits are achieved even in the absence of a natural disaster through their contribution to economic growth, social development and capital in Australian communities. They may, among others, include:

- Regional growth associated with investments,
- improved business and consumer confidence,
- short and long term employment,
- more reliable services,
- more cohesive communities,
- accrue technical skills and competences in human capital.

The nature of such co-benefits varies with respect of the investment's scope; for example, looking at the case of decreasing the threat of flooding, it can improve business confidence in a region. Investments in more resilient telecommunications platforms can improve service reliability.

According to Infrastructure and Development, 2017, Australian governments are currently investing in a significant way in new infrastructure to service the growing urbanising population. As a demonstration of that, over 10 years, \$75 billion have been committed on transport infrastructure.

4.2 Four points for a safer community

State governments need to work collaboratively with local governments, which are responsible for local planning, assets and services. Better collaboration will also help the States to better understand and address local vulnerability. State governments should also leverage private sector and community expertise to drive solutions and create safer communities.

To this aim, four recommendations have been proposed by Deloitte Access Economics, 2017, p. 9-10:

1. Include resilience across all aspects of policy and decision-making

By increasing coordination and resilience policy and planning, state governments can mitigate the forecast increase in natural disaster costs. Disaster resilience is built through a broad set of mitigation measures and policies. States should take the opportunity that exists to mainstream resilience across portfolios beyond emergency management. Addressing resilience in planning, land use and building controls presents the biggest opportunity to embed resilience.

2. Prioritise resilience investments by considering the broader co-benefits resulting

Shifting the funding balance from recovery to resilience involves smarter planning and investment. The process of prioritisation should consider an investment's potential to deliver 'co-benefits', including economic growth and community connectedness. Resilience investment must be prioritised to where it can be most effective. A double dividend includes an investment's 'cobenefits', such as improved business and consumer confidence. Co-benefits are more difficult to measure and, as such, have rarely been adequately factored in to decisions. However, they are crucial to local economies and communities and should be evaluated as such. The benefits of resilience measures should be considered in full and reviewed on a case-by-case basis so investment can be better prioritised and the value of both physical and community measures can be better communicated.

3. Improve understanding of disaster risks and costs to society

Consistent and publicly available data on disaster risks, costs, impacts and on public investment in recovery and resilience would improve awareness and planning. There has been significant improvement in data for some hazard types in recent years, such as state-wide flood maps in Queensland and NSW, and bushfire mapping in Victoria. However, there are still limitations associated with the availability, consistency and usability of data relevant to natural disaster risks.

4. Collaborate and coordinate to build resilience to natural disaster

Governments, business, community and not-for-profit groups need to work together to drive resilience and reduce the socioeconomic impacts of natural disasters. The impacts of natural disasters are felt by individuals, businesses, governments and communities – and across government portfolios. Thus, a cross-sector collaborative process is needed to mitigate the impact of natural disasters. Leveraging local knowledge can lead to more targeted and better-informed infrastructure and planning decisions, as well as more effective awareness, education and engagement programs. Engaging business, community and not-for-profit groups in local emergency management resilience planning should be fostered. It drives collective buy-in, innovation, sustained resourcing and accelerates change to ultimately make communities safer.

It is also argued that greater economic benefits result from considering resilience in development phases of Safran's Disaster Cycle (see Fig. 2.4), rather than retrofitting after a disaster event has occurred. State, district and local emergency management committees are well placed to drive the required collaborative approach and responsibilities should be clearly outlined by these committees to help ensure that resilience is integrated, and these levels of authority use all the levers at their disposal to mitigate disaster impacts.

4.2.1 Physical and Community measures

A key opportunity to build resilience is through the building or adaption of physical structures such as levees or drainage channels.

That said, whilst physical resilience measures can significantly reduce disaster impacts, they cannot always stop them from happening. The remaining impacts, however, can be lessened by **community measures** which include awareness activities that enable individuals, businesses and governments (including emergency services), to be better prepared when a disaster occurs, such as:

- Early warning systems,
- community education session,
- emergency and evacuation planning and distribution of emergency kits.

The majority of these measures are relatively inexpensive (compared to the physical investments in infrastructures) and are often sustained by volunteers. However, because their benefits are indirect and grow with respect to time and topic's knowledge, they are more difficult to measure. Nevertheless, such community measures are particularly beneficial in either high-risk areas or in areas with swiftly growing levels of urbanization or where there has been an influx of new residents who may not be familiar with appropriate responses to natural disasters - as is, for example, the case of Gold Coast City, the population of which has grown from 515,202 in 2011 to 571,722 in 2017, a rise of over 10% in just 6 years (Population Australia, 2018).

4.3 Flood Emergency Management

Flooding can take many different forms, but in general terms can be categorised into two main groups, namely, **regional** and **flash floods**. Regional floods occur when water spills over rivers, creeks, man-made canals, lakes, the ocean and result in inundation of surrounding land. Regional floods can be sub-grouped based on the source of water spillage which can be as a result of:

- heavy rainfall (generally long duration, see section 3.2),
- storm tide (as a result of cyclone activities),
- sea level rise;

• Tsunami.

Flash floods, on the other hand, occur when overland flow (resulting from heavy short-duration rainfalls) cannot be effectively drained (generally through man-made drainage system) into the area of receiving water (including rivers, creeks, man-make canals, lakes and ocean).

Whilst, from a resident's perspective there is little difference in the source of the flooding, there are important differences on how the emergency efforts associated with each type of flood should operate (Mirfenderesk, 2009).

With this in mind, it has also to be considered that, in the area of resilience against flooding, flood studies are expensive and time consuming; they will be justified only when their results can be used to inform land planning and emergency management decisions that affect a large number of people. It is not therefore best practice to conduct a flood study for an urban area alone or even for a local government area. The performance of individual flood studies for cities and towns can lead to different or imperfect information being used and inconsistencies in predicted flood levels at local government boundaries. A flood study should be completed over a whole catchment to encompass the hydrology and hydraulics of all relevant waterways¹.

4.3.1 Flood risk

Flood risk exists when all the components of risk, i.e. harzard, vulnerability and exposure overlap (Mirfenderesk, Carroll, et al., 2016). According to researches undertaken by both practitioners and academics (Mirfenderek et al., 2011), flood risk management focuses on mitigating all three components of risk as shown in Figure 4.1, which has been adapted from the Gold Coast's Sustainable Flood Management Strategy.

Exposure to a hazard in this context means the presence of people and/or properties in areas subject to ptential flooding, while vulnerability reflects the lack of resistance and preparedness of the community itself. Thus, in this sense, it is a measure of a community resilience and its ability to cope with and recover from the impact of a flood event.

However, there is a limit to the extent that hazard and exposure can be mitigated. The risk that a flood overwhelms all the protective measures and inundates cities is always possibile; this is called **Flood Residual Risk** = Hazard * Exposure * Vulnerability, and is managed through emergency management (Mirfenderesk, Carroll, et al., 2016). With this in mind, the concept of flood emergency

¹The two concepts of the expense of a flood study and the fact that it would ideally be conducted for a whole catchment, lead to some difficulty in determining the areas for which flood studies should be initiated.



Figure 4.1: Elements of flood risk. Source: Gold Coast City Council, 2010.

management is not just limited to operations only during the flood incidents, but it also will also covers the post flood activities that are needed to help the community to recover from the disaster as quickly as possible.

The residual risk therefore has a symbiotic relationship with floodplain management. Floodplains are strategically managed for the sustainable long-term benefit of the community and the environment, and to improve community resilience to floods. A good flood warning system and flood emergency management operations are essential for the reduction of residual flood risk. Such measures warn people of an impending threat and assist them to protect life and minimise flood damage.

Emergency management is a complicated task and requires solving a multitude of non-structured, semi-structured and ill-structured problems in a very short period of time. These problems include but are not limited to, regular forecasts of the flood situation, detection of at-risk people and assets, assessment of available response time and identification of aid delivery mechanisms (Mirfenderesk, Carroll, et al., 2016).

4.3.2 Best practice in Flood Emergency Management

Best practice requires the consideration and management of flood impacts in relation to existing and future development within the community. It aims to improve community flood resilience using a broad risk management hierarchy of avoidance, minimisation and mitigation to:

- limit the health, social and financial costs of occupying the floodplain
- increase the sustainable benefits of using the floodplain

• improve or maintain floodplain ecosystems dependent on flood inundation;

It also promotes understanding of flood behaviour so that the full range of flood risks to the community can be understood, effectively communicated and, where practical and justifiable, mitigated. It facilitates informed decisions on the management of this risk, and economic investment in development and infrastructure on the floodplain. However, the degree of effort required, and approaches used, to understand flood behaviour will vary depending upon the complexity of the flood situation, and the information needs of government and the community to understand and manage the flood risk.

Flood risk management efforts may be prioritised in relation to the scale of the potential growth in risk, primarily due to new developments in the floodplain, and the scale of existing flood risk to the community. This may promote sustainable urban and rural land use planning practices that are fully cognisant of flood risk, and limit growth in this risk to acceptable levels. It may also facilitate the treatment of the risk (where practical, feasible and cost-effective) to limit the exposure of the existing community to flooding to more tolerable levels. Treatment may involve a combination of flood mitigation, emergency management, flood warning and community awareness – together with infrastructure design, and strategic and development scale landuse planning that considers the flood situation and associated hazards.

The following sections describe key principles of a best practice approach to flood risk management, upon which the emergency management strategic decisionmaking should be based.

- A cooperative approach to manage flood risk. Decision makers at all levels need to be aware of their duty of care for decisions made with respect to the use of the floodplain, and for developing and implementing plans to manage flood risk.
- A risk management approach. A risk management approach enables investment to be focused on understanding and managing flood risk where it is needed most. Studies and management effort can be targeted considering the current knowledge, the scale of flood risk to existing development, and the potential for growth in flood risk through increased development within the floodplain.

Plans to manage risk are 'live documents' and need to be regularly reviewed to ensure that they are current, able to be implemented and consider lessons that have been identified from any recent flood events.

A proactive approach. A proactive approach involves actively managing the risks of occupying the floodplain. This involves considering the full range

of flood risks early in the process of developing strategic land-use plans and in managing risk to the existing community and to infrastructure.

- An informed approach. Knowledge and experience of previous flood events is a starting point for understanding flood risk. However, using this information without understanding the potential range and severity of flood events at a given location can result in poor management decisions leaving the community unsustainably exposed to risk. Information from historic flood events can be improved using investigative techniques and more sophisticated modelling to increase understanding of these events, facilitate extrapolation to provide a greater understanding of the range of flood behaviour and risk, and enable assessment of treatment options to inform management decisions.
- **Supporting informed decisions.** It is important that flood information is readily accessible to government (including decision makers, flood risk managers, land-use planners, emergency managers), non-government entities (including infrastructure providers, insurers) and the community as a whole to provide the basis for informed decisions on investing in floodplains and managing flood risk.

The effort required to achieve best practice will vary depending upon the area of interest and current flood risk management practice. It begins with bringing together current knowledge of flood risk and its management, and communicating this to decision makers, risk managers and the community. Where necessary, it then identifies and fills gaps in knowledge and management practices, so that risk can be better understood and managed.

The degree of sophistication necessary to improve knowledge and inform management will vary depending upon the current level of knowledge, the complexity of the flood behaviour in the area and the exposure of the community to flood risk. Improvements in knowledge and management of flood risk are likely to occur over time, depending on need and available resources. Efforts are likely to be concentrated on where flood problems are known to exist and need management, where knowledge is insufficient to understand and manage risk, where exposure is high, or where growth of exposure due to future development is likely to be high.

Managing flood risk to the community requires cooperation across all levels of government, and between the government and non-government sector. States and Territories have a shared responsibility with all levels of government for managing flood risk. They do this through administrative arrangements, which vary between jurisdictions. It is important for State and Territory policy frameworks to clearly delineate responsibilities and linkages across all necessary prevention, preparedness, response and recovery functions.

4.4 The case of the Gold Coast, Australia

The Gold Coast is Australia's fastest growing regions, and it is estimated that the population may exceed 700,000 by 2026 (up from 500,00 in 2010) and will potentially exceed one million by 2061 (Gold Coast City Council, 2011). Its population lives within five main catchment areas (Figure 4.4):

- Pimpama River catchment,
- Coomera River catchment,
- Broadwater catchment,
- Nerang River catchment ,
- Tallebudgera and Currumbin Creeks catchments.



Figure 4.2: Chevron Island in Surfers Paradise, Gold Coast, Australia

The Gold Coast has experienced more than 45 floods since 1925 (Australian Government Bureau of Meteorology, 2018), with cyclones passing over the region having triggered many of the floods. Historical records indicate that more than 40 cyclones have passed the Gold Coast region over the last 120 years, with the last major flood (1974) being triggered by Cyclone Wanda, which led to the evacuation of 1500 people (Gold Coast Bulletin, Tuesday 29, 1974 p3). In this respect, the area avoided much of the impact of the 2010/2011 flooding which was mainly confined

to the inland regions of the State and the length of Brisbane River following the emergency opening of the Wyvenhoe dam.

Nevertheless, the Gold Coast has long been rated as one of the most vulnerable areas subject to flooding in Australia (Smith and Handmer, 2002). Like many other coastal cities it has been developed on floodplains and as a result managing flood risk plays an important role in its long term sustainability - particularly in light of the growing concern about climate change impacts, the increased frequency and severity of storms and changes in the rate of urbanization, discussed in Chapter 1. Thus, future floods could potentially overwhelm existing protection measures, exposing communities to higher risks.

The rise in the level of vulnerability is mainly due to the fact that exposure to flood hazard (as a result of population growth in flood affected areas) has been growing faster than adaptive capacity. According to a research from Mirfenderesk and Abbs, 2008, this pressure is expected to increase over the next 10 years, as a result of climate change impacts. As indicated earlier, the Gold Coast comprises 7 major catchments (Figure 4.4). Some of these catchments such as Tallebudgera, Currumbin and Broadwater have time of concentrations as low as 3 hours, making them highly susceptible to short duration local flooding (Mirfenderesk, 2009). By contrast, catchments such as Nerang, Coomera and Logan-Albert can have time of concentration² between 3 and 92 hours, making them susceptible to regional scale long duration flooding, in addition to short duration local ones.

These facts clearly demonstrate that Gold Coast is prone to long and short duration riverine flooding, to flooding emanating from storm times, as well as flash flooding - all of which pose significant risks to the city's community and economy.

Unsurprisingly, finding swift solutions to understand the potential impact of a flooding event requires the processing a huge amount of data in a short period of time and also needs the use of an effective and robust **Decision Support System** (**DSS**).

4.4.1 Flood Emergency Decision Support System (DSS)

Emergency decision support systems have been used by flood emergency managers for decades. In the 1980s and 1990s these systems were usually presented in the form of hard copy flood maps, graphs, tables and other documents. Advancements in computer technology since the 1990s have, however, enabled developers to enhance the capabilities of these systems by incorporating computer flood models in the DSS.

²Time of concentration is a concept used in hydrology to measure the response of a watershed to a rain event. It is defined as the time needed for water to flow from the most remote point in a watershed to the watershed outlet (Wikipedia, 2018).

Due to limited computer speed at that time, these models were limited to point forecasting - meaning that they were restricted on the prediction of water levels at a few critical locations in a given catchment area (Caddis et al., 2015). The shortcomings of this approach have been partly addressed through interpolation of the point forecasts and using historical flood maps as a surrogate for surface forecasting. However, this approach has a number of limitations as it:

- lacks acccuracy,
- is limited to the maximum flood surface,
- lacks information about the timeline of flooding and its temporal and spatial evolution throughout the flood event.

It follows that a more effective flood emergency management system would be better served by surface forecasting, i.e. predictions of water level, flow speed, and a time history of variations of these parameters at every location of risk within a catchment.

In parallel, computer technologies advancement and the development of Graphics Processing Units (GPUs), have significantly reduced solution computations times, providing unique opportunities for developers of DSS. In terms of communication, flood emergency DDS have also benefitted from advances in information and communication technology (ICT) with a proliferation of web-based applications coinciding with the availability of ever-increasing Internet bandwidth which has enabled DSS developers to communicate the outputs more effectively and to an increasing number of stakeholders (Caddis et al., 2015; Smythe et al., 2015).

Looking at the case of the City of Gold Coast, The Council has been building a sophisticated Flood Emergency Decision Support System, capable of model-based surface forecasting. The development of such a system brings together more than 20 years of hydrologic and hydraulic modelling into a platform which can be integrated, as needed, with spatial databases on the community, properties, infrastructure and the environment.

The project has been led by Dr. Hamid Mirfenderesk, Coordinator Natural Hazards, and his team, whose main purpose is to assist emergency managers in tactical and strategic decision-making during a flood emergency (Mirfenderesk, Carroll, et al., 2016).

The development of such a DSS started with understanding and subsequently breaking down of the following stakeholders' needs:

Ability to generate timely warnings

A warning should be well-timed and issued only when an action is required. Furthermore, the scope of warning should be limited to the area of interest as regularly providing status reports of river conditions over large areas that do not necessitate any intervention, has the potential to distract the efforts of emergency managers.

Comprehensiveness

The information should be complete and answer three fundamental questions

- 1. Who needs help?
- 2. How much time is there?
- 3. How the help can be provided?

This requires the identification of:

- the assets that will be affected,
- the inundation level and its timeline,
- the roads connecting with the affected assets,
- any roads that are cut offs,
- high velocity flows.

Accuracy

Provide accurate information to emergency managers and to the community is paramount. An underestimation of a threat can result in high cost damages and the possibility of loss of life, while an overestimation, instead, has the potential to degrade community trust and cause public complaints.

Speed

In order to be effective, a DSS needs to be able to quickly respond to any type of question placed by emergency managers, who are, of necessity, dealing with extreme time critical tasks.

Flexibility

This feature allow strategists to map out scenario planning to anticipate future needs and preparing for multiple potential futures.

Ease of Construction and Maintenance

The general limitation of resources, may not allow local governments to be adequately equipped to deal with complex systems, which can generate highly overhead costs for their operation and maintenance, becoming often too costly. A partial solution is the need for shared systems to promote the ease of maintenance through the integration with local corporate systems.

Effectiveness of user interface

The user interface should allow the user to interact with the system in a non-complex way.

Whilst these needs may appear to be easy manageable if taken singularly, tradeoffs amongst them must not be underestimated.

The flood emergency DSS developed by the Gold Coast City Council, is endowed with a structure which is composed of **four tiers** (see Figure 4.5) with each tier of operation being triggered by the previous one and as long as the output information go throughout the system, their comprehensiveness increases. The system uses two module of forecast:

- Data-driven, operating in Tier 1;
- Model-driven, which operates in Tiers 2 and 3.

While a communication-driven module, used in Tier 4, facilitates the information flow between the system and its users.

Tier 1

This data-drive module is a Rainfall Analysis with inputs of rainfall measured at alert stations and the rainfall predicted by the Bureau of Meteorology. The module interrogates more than 80 alert rain gauges across the city and then undertakes a frequency analysis of the measured data and compares it to historical statistical data by using Intensity-Frequency-Duration³ (IFD) curves for each gauge location (Figure 4.6 shows a typical example of such curves). As a parallel task, the system downloads rainfall forecasts from the Bureau of Meteorology website and generates catchments-based IFD curves for each catchment in the city. It then analyses both sets of curves and, if the measured and predicted rainfalls cross the threshold values, it automatically sends warning messages to emergency managers.

This first module responds to the critical question of whether or not to undertake mobilization.

³IFDs are Intensity–Frequency–Duration design rainfall intensities (mm/h) or design rainfall depths (mm) corresponding to selected standard probabilities, based on the statistical analysis of historical rainfall. They are used in the design of infrastructure including gutters, roofs, culverts, stormwater drains, flood mitigation levees, retarding basins and dams. They can also be used to assess the severity of observed rainfall events (Bureau of Meteorology, 2016).

⁴The main terms used to describe design rainfalls are:

[•] Exceedances per year (**EY**): is defined the number of times an event is likely to occur or be exceeded within any given year.

[•] Annual exceedance probability (**AEP**) is the probability or likelihood of an event occurring or being exceeded within any given year, usually expressed as a percentage.

Tier 2

The second tier is a model-driven module and is triggered by the first tier, once it latter has issued a flood warning. The fundamental question that tier is considering is whether the consequences of an impending flood are sufficiently high to require actions such as an evacuation. This module comprises two main elements:

- 1. A data-driven control centre, comprising of a set of computer programs which have two roles:
 - To provide an effective user interface to test what-if scenarios.
 - To control the data flow between the different modules. For instance by importing the real-time rainfall and water level gauge data and preparing them to be used as inputs, as necessary, into the hydrodynamic modelling (Tier 3).
- 2. An integrated, model-driven, hydrological model which generates two outputs:
 - Point water level forecasts at critical control points (generally in the upper points of the catchments, such as dam walls). This provides decision-makers the ability to assess the capacity of the city's dam storage to absorb the flood and the potential downstream impact.
 - Point forecasts of flood flows at input points for incorporation into hydro-dynamic models of the city's floodplains.

Tier 3

This module is aimed at providing emergency managers with all the flood's consequence - related information they will need for decision-making and informed actions, such as evacuation and rescue operations. Similar to the previous one, this model-driven module is made up by two registers:

- 1. A suite of detailed two-dimensional hydrodynamic models for all the city's catchments.
- 2. A suite of computer programs operating within the Council Information and Communication Technology (ICT) systems for the analysis of the models' outputs.

As this tier generates the timeline of rising and falling flood levels based on two-dimensional hydro-dynamic model results, it enables the system to be used in post-disaster recovery.

Tier 4

This last communication-driven tier is designed to facilitate decentralised decision-making. The system allows the exchange of information throught

a set of freely available web-based applications such as Google Earth^{\mathbb{M}} and Google Maps^{\mathbb{M}} via KML⁵ files, which can be easily shared through e-mail to decision-makers and displayed using Google Earth^{\mathbb{M}}.

This case study clearly demonstrates that computing technology has reached a level where swiftly generating comprehensive model-based forecasts and quickly communicating the outputs to decision-makers is no more an abstract concept.

The working prototype of flood emergency decision support system described above was developed by Dr. Mirfenderesk and his team, is currently in operation in the Gold Coast supporting both tactical and strategic decision-makers during a flood emergency.

These actions have undoubtely contributed to the management of flood risk on the Gold Coast, however, in light of changing climate indicators, new technologies in assessment, planning and construction of mitigation options, and changing adaptive capacities of the community, a constant review and re-evaluation is prudent.

⁵Keyhole Markup Language is an open standard officially named the OpenGIS®KML Encoding Standard (OGC KML). It is maintained by the Open Geospatial Consortium, Inc. (OGC) (Open Geospatial Consortium, 2018).



Figure 4.3: Predicted Flooding in Gold Coast. Source: Coastal Risk Australia, 2018



Figure 4.4: Gold Coast catchments boundaries. Source: Loders Creek and Bigger Creek Catchments



Figure 4.5: Flood Management Decision Support System Structure. Source «New generation flood forecasting and decision support system for emergency management»



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Figure 4.6: IFD Design Rainfall Depth (mm) against Duration⁴. Downloaded by Australian Government Bureau of Meteorology, 2018

Chapter 5

Agent-Based Modeling and Evacuation Plan

5.1 Introduction

In the words of Borshchev and Filippov, 2004, p. 25-29:

The "agent-based approach is more general and powerful¹ because it enables the capture of more complex structures and dynamics. The other important advantage is that it provides for construction of models in the absence of the knowledge about the global interdependencies: you may know nothing or very little about how things affect each other at the aggregate level, or what the global sequence of operations is, etc., but if you have some perception of how the individual participants of the process behave, you can construct the agent-based model and then obtain the global behaviour".

Agent-based models (ABMs) are used to simulate complex and heterogeneous systems such as infrastructures and they can be applied in a vast range of fields like biology, business problems, ecology, social science, technology, earth science, network theory (Cimellaro et al., 2018).

Mass evacuation planning in large geographical areas is a very complex and difficult task. The complexity lies in the fact that a sound evacuation plan would have to take account of a number of concomitant factors. These factors include:

- 1. the nature of the disaster in question,
- 2. the unique geography and transportation infrastructure in a given area,

¹than System Dynamics, Dynamic Systems or Discrete Event Simulation.

- 3. the anticipated human behavioral patterns in the evacuation process,
- 4. the population distribution in the area,
- 5. the population dynamics over different time periods, and
- 6. the special needs of different population groups,

to name a few.

Unfortunately, it is difficult if not impossible for any community to fully understand how these factors would affect each other unless the community had previous experience of a similar disaster. Nevertheless, in order to better prepare for a given type of disaster within a vulnerable community, it is clearly advantageous for community leaders to have a better understanding of the human and geophysical characteristics of the community in order to be able to anticipate possible outcomes of different response and evacuation strategies under different situations, inform the general public, and develop a set of evacuation plans. In order to achieve this goal, evacuation managers in a community can use computer modeling techniques to simulate different 'what-if' scenarios and then, use the results from these simulations to inform the public, and to generate different evacuation plans to meet different circumstances.

The complexity associated with evacuation planning in an urban environment requires a computer modeling framework that can incorporate all the above factors into the modeling process. Agent-based modeling (ABM) provides such a general approach that can be used to account for these factors in the modeling and simulation process. To achieve this, an ABM approach decomposes a complexity system into individual components (agents) and then seeks to understand the behaviors of the entire system based on the behavior of individual agents in the system and the interactions between these agents.

Using ABM in the context of a flood event in the Gold Coast area has two potential benefits:

- 1. it is able to estimate estimate the evacuation time for the GC area.
- 2. it improves our understanding of the dynamics of the flood event and how these dynamics would affect evacuation planning and disaster preparedness in evacuating certain populations groups.

5.2 The Agent-Based Modeling Approach

In ABM, an agent is the software representation of some entity that completes an action or takes a decision through which it interacts with its environment. The agent may represent an actor in a social network (e.g. a human being, an operator



Figure 5.1: Structure of an agent-based model

deciding to shut down a pumping station, or a consumer who buys tomatoes). Beyond this level of granularity, an agent may also represent an organisation, for example an electric utility company deciding to build a new nuclear plant or a government deciding on new policy to ensure drug safety. The agent paradigm aligns with the concept of systems composed of multiple interacting social entities and technical subsystems. As such, it is the premier candidate with which to model socio-technical systems and explore the dynamics and structural change ensuing from the interactions within and between the social and the technological networks.

Agent-based concepts generally are the best means by which to model complex systems, as long as the following conditions are satisfied:

- The problem has a distributed character and thus each actor is, to some extent, autonomous.
- The subsystems (agents) operate in a highly dynamic environment.
- Subsystem interaction is characterised by flexibility: it can result from a reactive or pro-active attitude, from a propensity to co-operate or to compete, or it can be the result of social interaction (including, for example, trust or empathy).

Essentially, in the agent paradigm, everything is a "thing that interacts with other things". All things together make up the system and so, in an agent-based model, we model the "things" and their interactions. These can be either technical objects, such as production installations, electric vehicles, gas pipelines or control systems, or social entities including individuals, organisations or parts thereof. For any agent-based simulation model, we thus need to capture the relevant behaviour and applicable interactions. Once this has been accomplished, we can encode them into a simulation model and determine or generate the starting condition. Upon pressing "run" the agents will begin to interact and form linkages, and we can watch the system evolve. As a matter of course, apart from the behaviour and interaction, we can also track all kinds of characteristics of the agents and visualise them in respect of each agent or system component or in terms of the evolved system.

Agent-based modeling is a type of microsimulation modeling technique that addresses the disaggregated characteristics of constituent units in a complex system and the dynamic interactions between these individual autonomous entities. As traffic is dynamic and disaggregate in nature, agent-based modeling is well suited for modeling and simulating traffic and transportation systems.

In contrast to macrosimulation, ABM has advantages in better representing realistic situations during, in this scenario, evacuations. It also provides greater flexibilities and capabilities to assess different scenarios under emergency situations. Therefore, agent-based modeling can help us better understand the outcomes of different options in evacuation planning and disaster management and gain insights about the dynamics of an evacuation that usually cannot be achieved through traditional macroscopic modeling approaches. In addition, the capability of agentbased modeling in capturing the fine details of traffic movements can also help us better communicate with a general audience about the complexity of an evacuation.

In the case of the application of ABM to a traffic problem, vehicles are represented as individual entities, with the movements of individual vehicles are captured based on the characteristics of individual drivers and certain rules (such as car folowing or lane changing) that govern the interactions between individual drivers. Typical rules include car-following and lane-changing rules. Because evacuations, particularly large-scale evacuations, usually involve a large number of vehicles over large transportation networks, it is a computationally very intensive task to model and simulate traffic at the individual vehicle level, but advances in computer technology and computing power since the 1990s has made ABM and simulation of large scale evacuations possible.

5.2.1 ABM as a Method to Understand the Complexity and Dynamics of Evacuation Planning

Whilst ABM is widely used to analyze behaviors of stakeholders under implementation of urban policies, especially in the events of natural disasters, the difficulty of

creating a model embracing all the aspects of a cummunity (e.g. social, behavioural and cognitive) lies in the fact that there is very limited knowledge about how these spheres would interact during an actual evacuation. Because it is very costly and almost impossible to test-run an evacuation in a given area, one possible approach for community disaster managers to understand the complexity and dynamics related to an evacuation is through modeling and simulation. The ABM approach, focusing on the behaviors of individual participants in an evacuation and the collective system level behaviors resulting from the interactions of the individuals, and can be used to model and simulate an evacuation in a community and help disaster managers better prepare for potential tragedies. Chen and Zhan (2006) have provided examples of how an evacuation process can be parameterized and simulated, and these demostrate how ABM can provide answers to a set of 'what-if' scenarios so that community leaders can better prepare for possible outcomes under different circumstances during an evacuation. Community leaders can use the simulation results to inform the public about the safest actions with respect to different ground situations during an evacuation. The real power of ABM and simulation is its potential to reveal some counterintuitive collective system level behaviors when all individuals appear to make rational decisions at the individual level. This type of counterintuitive system level behavior may differ from one location to another, and vary from one culture to another.

Emergency management has historically focused on the immediate and urgent aspects of an incident (i.e. response and post-disaster recovery). However, there is a growing awareness that emergency management is much more complex and comprehensive than traditionally perceived. Although the primary function of emergency services is to protect life and property, a comprehensive approach to emergency management involves more than just reactive responses to incidents as they unfold. It also entails development of methods to avoid incidents in the first place and preparing for those that will unavoidably occur at some point in the future.

Agent-based modelling has a number of major advantages as a support for the resultant policy making. First, the basic idea is accessible and easy to grasp, even for those who are unfamiliar with the approach. As explained earlier, ABM consists of a number of 'agents' represented in a computer program. Each agent corresponds to a real person (or organisation firm, department or other group) in the real world. These agents are programmed to interact in the same ways as the real actors do and to experience the same constraints and have access to the same knowledge. This one-to-one correspondence between what we see in the policy world and what is represented in the model makes it easy to grasp what the agent-based modelling approach is about, especially in these days of computer games.

A good agent-based model can be relatively 'transparent' to inspection by decision makers. For example, one can try out what happens in the model when agents are given certain attributes, or are allocated particular behavioural rules, and can check that the model behaves in a plausible fashion. If data are available, then the model outcomes can be compared with what actually happened. A third advantage of agent-based modelling is that it can deal with complexity. It is increasingly being realised that the social world has to be understood as a complex adaptive system, meaning that the interactions between its parts are non-linear and multi-level. These aspects can be simulated in a natural way with agent-based models. Moreover, it will be appreciated that, when one is dealing with questions of infrastructure, one has to contend not with just a social system, nor with just a technical or physical system, but also with the complex interactions between these two.

5.2.2 The Software: $AnyLogic^{\mathbb{R}}$

The model presented in this research is aimed at understanding the complex behaviour of people during an evacuation in the area of the City of Gold Coast. It tries to capture as accurately as possible the dynamics of the evacuees in the case of a flash flood, and measure the times for evacuation strategies that, under stochastic assumptions, would be necessary were the evacuation to be undertaken. To achieve this, the architecture integrates both: an agent-based simulation model and a geographical information system (GIS) data bases.

The selected software for the model implementation is **AnyLogic**^(R) which is a multimethod simulation modeling tool developed by The AnyLogic Company (former XJ Technologies).

The tool was named AnyLogic, because it supports all three well-known modeling approaches, namely system dynamics, discrete event simulation and agent-based modeling, and any combination of them within a single model.

AnyLogic includes a graphical modeling language and also allows the user to extend simulation models with Java code. The Java nature of AnyLogic lends itself to custom model extensions via Java coding as well as the creation of Java applets which can be opened with any standard browser. These applets make AnyLogic models very easy to share or place on websites. In addition to Java applets the Professional version allows for the creation of Java runtime applications which can be distributed to users. These pure Java applications can be a base for decision support tools.

System dynamics and discrete event are traditional simulation approaches, agent based is a newer one. Technically, the system dynamics approach mainly deals with continuous processes whereas "discrete event" and agent based models work mostly in discrete time, i.e. they jump from one event to another. System dynamics and discrete event simulation historically have been taught at universities to very different groups of students, namely management and economy, industrial and operations research engineers. As a result, there are two distinct practitioners' communities, with ABM being, until recently, mainly a purely academic topic. However, the



Figure 5.2: Three simulation approaches.

increasing demand for global business optimization caused leading modelers looking at combined approaches to gain a deeper insight into complex interdependent processes which have very different natures. It has only been within the last decade that the state of the art has advanced to the point where it has become possible to enlarge the scope of ABM to encompass more applied and policy-oriented topics. This was a result of a gradually improving understanding of the strengths and limitations of agent-based models, together with huge improvements in the supporting infrastructure: much better development environments and much faster computers, which made larger and more complicated models feasible to develop and test (Van Dam et al., 2010).



Figure 5.3: Different simulation methods and level of abstraction.

5.3 The Model Framework

The basic model developed for this research simulates the advent of a flash flood along the GIS route of the Nerang River (see Figure 5.4), and thus the movement of the citizens in the areas of Bundall, Surfers Paradise and Broadbeach to, the active evacuation centers. To achieve this, the ABM integrates (see Figure 5.4):

- the Geographical Information System (GIS) map with its relative navigation toolbar,
- the control panel used to setup the parameters for the specific simulation (Table 5.4),
- the output graph representing the number of people warned, evacuating and evacuated in relation to time, and
- the set of variables, parameters, agents and functions using within the model.

AnyLogic provides a GIS map tile layer, which is a part of a GIS map that contains a tiled map. A tiled map is a map that is downloaded in real time from special online map services, such as OpenStreetMap. Such maps are called "tiled maps" because they are downloaded as tiles, which are small, usually square, images that are placed seamlessly side-by-side to construct the maps.

In this context, the routing method is chosen as *Fastest* (rather than *Shortest*), and a *Foot* road type (see Fig. 5.5).

5.3.1 The Agents

The agent is the smallest element of an agent-based model, the atomic element of a generative theory, and some would even say that the "agent is the theory". An agent is able to perform actions on itself and other agents, receive inputs from the environment and other agents, and behave flexibly and autonomously because, as shown in Fig. 5.1 adopted from Van Dam et al., 2010, an agent consists of both states and rules.

Agents are:

- 1. Encapsulated, meaning that they are clearly identifiable, with well-defined boundaries and interfaces;
- 2. Situated in a particular environment, meaning that they receive input through sensors and act through effectors;
- 3. Capable of flexible action, meaning that respond to changes and act in anticipation;
- 4. Autonomous, meaning that they have control both over their internal state and over their own behaviour; and
- 5. Designed to meet objectives, meaning that they attempt to fulfill a purpose, solve a problem, or achieve goals.

In the model presented, the agents, as showed both in the snapshot Fig. 5.6 and in Table 5.1, are:

Evacuation Zones
Flood
Sensor
Properties
People

Table 5.1: List of Agents.

Evacuation Zone

The Evacuation Zones are considered as an agent type and the capacity is therefore added as a parameter. They are initiated through the following function *initEvacuationZones*:

Listing 5.1: initEvacuationZones Function

```
String [] EvacZoneName = \{
"evacuation_zone_1",
"evacuation_zone_2"
"evacuation_zone_3"
};
int [] EvacZoneCapacity = {
50000,
10000,
20000
};
double [] Lat={
-28.001487,
-27.9709203,
-28.0357642
};
double [] Lon={
153.416248,
153.41414529999997,
153.42411518096924
};
for (int i = 0; i < 3; i++) {
EvacuationZone = add evacuationZones();
e.name = EvacZoneName [ i ];
e.capacity=EvacZoneCapacity[i];
e.setXY(Lat[i], Lon[i]);
}
  which takes as inputs
```

1. the total number of Evacuation Zones,

- 2. their coordinates, and
- 3. their capacities expressed in number of people.

The area of Gold Coast counts a number of 35 potential primary evacuation centres. In the area analyzed in the model, the centers considered are *The Arts Centre Gold Coast, 135 Bundall Road, Surfers Paradise* and the *Southport Community Centre, 6 Lawson Street, Southport* (Table 5.2).

Evacuation Center	Capacity
1	50.000
2	10.000
3	20.000

Table 5.2: Evacuation Centers Capacitites



60

🔲 Properties 🔀		₫ ▽ 🗖		
🏐 map - GIS Map				
Name: map Visible: 💿 yes	Visible on upper l	evel 🗌 Lock	^	
Tiles				
▼ Routing				
Routes are:	 Requested from OSM server Loaded from PBF file Straight lines 			
Routing server:	AnyLogic 🗸			
Routing method:	Fastest 🗸			
Road type:	Foot 🗸			
If route not found:	 Create straight route Show error dialog 			
Search				
Shapefiles				
 Center and scale 				
Latitude, deg: -28.00315 Longitude, deg: 153.40543				
Scale: 1:	50000 🗸			
Appearance				
Position and size				
Advanced				
Description				

Figure 5.5: Map properties.

0	evacuationZones []
0	flood
0	sensor
0	properties []
0	people []

Figure 5.6: Model's Agents.

Flood

As said above, the Flood here represents a flash flood occurring in the main path of the Nerang River, following the route created in the GIS map and having an initial default speed, included as a property in the Main (see Figure 5.7).

Icod - Floo	d					
Name:	flood Show name	lgnore				
Single agent ○ Population of agents						
▼ Movement						
Initial speed: =	FloodingSpeed kilometers p	er hour \vee				
 Initial location 						
Place agent(s):	 at the agent animation location in the latitude/longitude in the node in the first result of map search 					
Node:	= 💡 gisPoint 👻 🔀					
Routing:	= 🕅 network 🗸 🖫					
Statistics						
Advanced						
Description						

Figure 5.7: Flood agent properties.

The agent has been designed in order to follow the following *floodFunction*:

```
Listing 5.2: Flood Function

//this line defines point1

point1 =

new GISPoint( map, true, y1, x1, 0, null, null, 1.0,

LINE_STYLE_SOLID, "" );

//this line adds pont1 to the pointsCollection

pointsCollection.add(point1);

x2=flood.getLongitude();

y2=flood.getLatitude();

//this line defines point2
```

y1=y2; point1=point2;
Person

This agent represents the people involved in the evacuation dynamics, therefore, the size of this agent will not be limited to one as in the *Flood* agent's case, yet a population of agents (Figure 5.8).

🔲 Properties 🛛			\bigtriangledown		
people - Person					
Name:	people Show name Ignore				^
⊖ Single agent ● Po	pulation of agents				
Population is:	Initially empty				
	 Contains a given number of agenes Loaded from database 				
minPrepTime:	=				
maxPrepTime:	=				
warnningReceivedRate	: = 1				
▼ Movement					
Initial speed: 📑 🛛	uniform (PeopleSpeedMin,PeopleSpeedMax) kilometers pe	r hour	~]	
▼ Initial location					
Place agent(s): at in in in 	the agent animation location the latitude/longitude the node the first result of map search				
Routing: = [Default 🖌 🔀				
Statistics					
Advanced					
Description					

Figure 5.8: Person Agent Properties.

The speed of people will follow a uniform distribution,

$\mathcal{U}(PeopleSpeedMin, PeopleSpeedMax)$

with values in a range that can be set up before starting the simulation.



Figure 5.9: Person Agent Statechart.

Figure 5.9 shows the statechart for the agent Person; with the use of warningReceivedRate it is assumed that the warning is issued to all people in the community, but not all receive it at the same time. It has been moreover implemented a resistance to evacuation, which means that a certain portion of people evacuate while a counterpart decides to not, but as things get worse people who decide to evacuate

increase, creating a loop that goes on till everyone is evacuated. During the evacuation phase, people will behave by reaching the closest evacuation center trough the following:

Listing 5.3: Evacuating Function

Property

This population of agents represent the inhabited buildings in the area. The coordinates of the centroid of such buildings have been extracted by a public accessible dataset provided by the Council of the City of Gold Coast, 2018 in a Shapefile ESRI (.shp) format (Fig. 5.10), using the open source project *GeoPandas* in *Python*; this allowed to have a final *.csv* file composed by three columns representing the (1) properties' ID, (2) Latitude and (3) Longitude. Similar to the Evacuation Zones, they are initiated by the following function *initProperties* in the Main, which reads the cited *.csv* file and initiates the buildings in the GIS Map of the model:

```
Listing 5.4: initProperties Function
int maxcolumns = 3;
String cols[] = new String[maxcolumns];
int[] skip = \{0, 0, 0\};
while (properties File.canReadMore())
ł
while(propertiesFile.getLineNumber() <= 1)
propertiesFile.skipTokens(1);}
System.out.println
("Parsing_line:_" + propertiesFile.getLineNumber());
int id = propertiesFile.readInt();
double lat = propertiesFile.readDouble();
double lon = propertiesFile.readDouble();
Property p = add properties (id, lat, lon);
p.setXY(lat, lon);
for (int i=0; i \ll random FamilySize; i++)
Person pe = add people();
p.members.add( pe );
pe.jumpTo( lat , lon );
}
int pos = 0;
while (pos < maxcolumns)
ł
if (skip[pos] = 1) {
propertiesFile.skipTokens(1);}
pos += 1;
}
}
```



5.3.2 Simulations

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Simulations have been run on a laptop PC Lenovo ThinkPad-X1Carbon with characteristics listed in the following Table 5.3.

Operative System	Microsoft Windows 10 Pro
Processor	Intel [®] Core [™] i5-3427U CPU @ 1.80GHz
RAM	4,00 GB (3,70 GB usable)
System Type	64 bit

Table 5.3: PC System

In order to explore different scenarios, a modular interface with the possibility to pre-set the parameters listed in the tables below, has been modelled. Due to the computational effort and time required by an even though simple agent-based model as this is, the approach to study three different scenario has been considered as the most suitable.

As a first step, has been analysed a standard scenario with a medium level of "resistance" to receive the command to evacuate (*warningRate*) and a considerable lower time to prepare in order to start the evacuation phase.

Parameters	Value Scenario 1
randomFamilySize	uniform_discr $(1,4)$
distance To River	$100 \mathrm{m}$
\min Prep	$2 \min$
$\max Prep$	$15 \min$
warningRate	2
FloodingSpeed	$10 \mathrm{~m/s}$
PeopleSpeedMin	$1 \mathrm{m/s}$
PeopleSpeedMax	$5 \mathrm{m/s}$

5 – Agent-Based Modeling and Evacuation Plan

Table 5.4: Parameters Scenario 1.

Simulation n.	Evacuation Time (min.)	Number of People
1	112.71	27897
2	139.76	15892
3	160.17	24702
4	147.41	14813
5	136.62	17069
6	123.02	18093
7	104.59	31292
8	109.85	28056
9	109.35	35436
10	100.50	26151
11	127.26	21162
12	128.84	16356
13	119.57	37664
14	110.55	29154
15	113.10	21006

Table 5.5: Results Scenario 1.

AVRG Evac. TimeSD Evac. TimeAVRG Number of People $\mu_{t,1} = 122.89$ $\sigma_{t,1} = 17.1$ $\mu_{p,1} = 24316$

Table 5.6: Analysis Scenario 1.

Parameters	Value Scenario 2
randomFamilySize	uniform_discr $(1,4)$
distanceToRiver	200 m
$\min Prep$	$3 \min$
\max Prep	20 min
warningRate	3
FloodingSpeed	10 m/s
PeopleSpeedMin	$2 \mathrm{m/s}$
PeopleSpeedMax	6 m/s

Table 5.7:	Parameters	Scenario	2.

Simulation n.	Evacuation Time (min.)	Number of People
1	163.92	50655
2	175.71	64460
3	193.79	46593
4	235.73	34302
5	212.11	35332
6	195.03	46318
7	194.88	37831
8	207.08	34698
9	220.08	49893
10	192.42	70420
11	230.44	32682
12	214.30	49551
13	233.95	48519
14	154.40	35698
15	170.16	35684

Table 5.8: Results Scenario 2.

AVRG Evac. Time	SD Evac. Time	AVRG Number of People
$\mu_{\rm t,2} = 199.65$	$\sigma_{\rm t,2} = 25.63$	$\mu_{\rm p,2} = 44842$

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Table 5.9: Analysis Scenario 2.





73

Parameters	Value Scenario 3
randomFamilySize	uniform_discr $(1,4)$
distanceToRiver	$300 \mathrm{m}$
$\min Prep$	$5 \min$
maxPrep	$30 \min$
warningRate	5
FloodingSpeed	$10 \mathrm{~m/s}$
PeopleSpeedMin	$2 \mathrm{~m/s}$
PeopleSpeedMax	$7.5 \mathrm{~m/s}$

Table 5.10: Parameters Scenario 3.

Simulation n.	Evacuation Time (min.)	Number of People
1	456.59	89224
2	256.08	89323
3	316.13	85864
4	309.72	96166
5	266.92	85141
6	314.92	91034
7	409.52	95465
8	421.47	84441
9	462.55	82748
10	335.10	78656
11	345.70	85697
12	321.96	95614
13	399.48	90050
14	261.78	89073
15	290.63	80000

Table 5.11: Results Scenario 3.

$$\begin{tabular}{|c|c|c|c|c|c|} \hline AVRG Evac. Time & SD Evac. Time & AVRG Number of People \\ \hline $\mu_{\rm t,3}=344.57$ & $\sigma_{\rm t,3}=69.05$ & $\mu_{\rm p,3}=87899$ \\ \hline \end{tabular}$$

Table 5.12: Analysis Scenario 3.



75

5.3.3 Limitations

Screening the model, are many the limitations that even a superficial reader might take on.

Among the most important ones, the lack of a defined human behavior framework to be included in it, as recently developed in works such as from Cimellaro et al., 2018. In an emergency situation, the variable which affect the most its stochasticity is indeed the human aspect, driven by emotions and not taking into consideration the irrational factors.

A second aspect, whilst not irrelevant, is the reliability of fluido and hydrodynamics representation of the flood. The model tends to oversimplify the complexities of interactions that will almost certainly verify in case of a flooding onset.

Chapter 6 Conclusions

The determinant events of Hurricane Katrina (2005) and the Tsunami caused by the 9.1 magnitude earthquake off the coast of Sumatra (2004) had the potential to show the tremendous bottleneck present in the competences and capabilities of Logistics and Supply Chain Management applied to humanitarian operation and emergency management.

Analysing the nature of humanitarian supply chains, the research wanted to investigate the best practices and approaches to this peculiar context. Defining *agility* as the capacity to quickly respond to rapid onset changes from both side of demand and supply in order to handle possible disruptions (Lee, 2002), the same has been identified as the most suitable and aligned to the essence and needs of humanitarian and emergency supply chains.

Relatively new simulation approaches like agent-based model, have the potential to simulate situations that would be extremely impossible to replicate in normal conditions.

Despite the aforementioned computational effort took by the computer in running the presented simulations, this relatively simple model's aim was never meant to be the study of crowd's behavior during the strike of events, yet to explore how nearly modern kind of simulation approach may have on defining strategies to operate in uncontested situations, as well as helping urban planning decision makers to reach a sustainable level of resilience in cities and building they operate in.

In the specific case of the model proposed in the research, despite the very strong assumptions made, almost trivially the biggest source of complexity was given by the number of people to be evacuated and it has showed three main areas of highly densed crowd trying to reach the evacuation centers. Here, policy makers and disaster manager should mostly pose their attentions.

Further development for the work, might be integrating more complicated and closer to reality functions to replicate the behaviour of flood, as well as having a more suitable function to simulate the spreading of a warning alarm and the effectiveness reaching out the citizenship. Moreover, the model assumes the houses to be built on one floor, without considering the interaction that may occur and the obviously growth of randomness caused by having multi-floors habitations to manage.

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