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Investigating the flood evacuation behaviour of older people: A case study of a rural town in Japan

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A R T I C L E I N F O

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A B S T R A C T

Japan is an ageing society where rural areas suffer from the out-migration of young people resulting in many older people not having family support nearby. Evacuation to safe places in a timely manner is a global challenge to community leaders and authorities when faced with natural hazards. However, there is little research focusing on older people's travel evacuation patterns. In this research, the evacuation behaviour in a rural town of Japan (Manno town, Kagawa prefecture) is simulated taking into account the older cohort of the population. The town (population 18,377 in 2015) is located in a hilly and rugged inland district. At a time of heavy rain in July 2018, an evacuation order was issued to all residents of Manno and subsequently landslides occurred in several areas. Evacuation procedures and the protocols of evacuation orders are described. Based on discussions with local government officials, an agent-based model was developed to simulate evacuation behaviours using the July 2018 rainfall situation. Evacuation times are estimated for 6 different scenarios. The challenges in managing the mobility needs of older people in a disaster situation are discussed along with recommendations to local government. Suggestions for future research into agent-based simulation are outlined.

1. Introduction

The challenges of ageing population structures confront many societies: their governments have become more mindful of tailoring policies targetted to this segment of the electorate and this includes the transport sector. One of the global challenges for community leaders and authorities in an ageing society is disaster management and evacuation, especially given the pressures of climate change. Japan is an ageing society where the sustainability of rural areas suffers also from the out-migration of young people resulting in many older people not having family support nearby. Enabling all residents and visitors to evacuate to safe places in a timely manner is a general problem that has been widely addressed in the literature but there is limited research focusing on the travel evacuation behaviour of older people.

The problem addressed by our research is how, at the time of a flood event and in a situation where evacuation management is needed, can authorities best address the specific needs of older people in rural parts of Japan? A case study was developed. Kagawa prefecture is located in the driest part of Japan where a number of reservoirs were built for irrigation purposes because of systemic drought impacting on agricultural productivity. Manno town has about 500 reservoirs that were constructed before the Edo era (1603–1868). These ageing infrastructures are at risk of collapse during heavy rains because of the lack of maintenance (most of the reservoirs are privately owned). From 5 July to 8 July 2018 Manno recorded 366 mm of rain and dykes were breached on two rivers that run through the town, roads were extensively damaged and five landslides occurred (Kagawa Prefecture, 2018). Evacuation orders were issued to all areas of the town, but, surprisingly, only 41 people (out of a population of approximately 18,000) evacuated their homes.

In the absence of authentic data on the traffic implications of a full-scale evacuation in Manno, we focused on the simulations of various hypothetical situations based around: the use of cars and walking as the main transport modes; the capacity of the road network; and the location of emergency shelters. Agent-based modelling (ABM) is applied to address the challenges of simulating the evacuation behaviour of residents with particular reference to the elderly. The simulations were developed on the NetLogo platform - a high-level platform for simulating complex and stochastic phenomena together with its GIS extension that allows the creation of ABM using map data and the visualisation of the results.

The significance of the findings for this small, rural town is not only

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the simulation results of the total time to safely evacuate all households but also the successful demonstration of an ABM methodology suitable for any local government authority in the planning and management of disasters. Whereas the road-network model representation of escape routes is a mature area of transport engineering (Black, 1981; Blunden, 1967, 1971; Plummer, 2006; US Department of Transportation, 2009) that uses nodes and links (analogous to graph theory) and network link capacities, the way that traffic on this network is represented by agent-based models is relatively new. To date, the visualisation of any traffic assignments on the transport network, from aggregate travel demand models, has been enhanced by geographical information systems developed in the 1990s (Black et al., 1997). The representation of individual vehicles or people (agents) flowing through transport networks is a more recent innovation (Horni, Nagel, & Axhausen, 2016).

The paper is organised in the following way. There are a substantial number of research articles on the travel behaviour of people during evacuations: Section 2 is a review of this material and how researchers have applied both theoretical concepts and empirical data on travel-time departures as inputs to mathematical models of disaster evacuations. With respect to the travel decisions made by older people we draw attention to the lack of behavioural data. Any evacuation behaviour in the real world is conditioned by the context so it is necessary to describe the emergency planning and management policies of all levels of government and relevant stakeholders, and the degree of community preparedness for disasters after discussions with town officials, as in Section 3 for the case of Japan. Section 4 describes the characteristics of the Manno case study area and the setting up of the simulation model based on discussion with town officials and local data. Section 5 presents the results from the agent-based simulation model on total times to evacuate and the distribution of evacuation times, whereas Section 6 is a discussion about the overall findings from the research and implications for policy. The conclusions also identify areas where further research would be valuable.

2. Flood evacuation literature and issues of older people

2.1. Policy context for modelling

There are many complex and interdependent behavioural issues when formulating evacuation management plans, especially those related to heavy rain and flooding (Opper, Cinque, & Davies, 2010). Emergency authorities need an operational model that indicates the scale and timing of peak flooding and identifies those high-risk areas - informed by weather forecasts and hydrological models. These comprehensive data sets allow authorities to formulate robust evacuation plans for areas within the geographical boundaries of the maximum expected flood.

Important underpinnings for such plans are mathematical models of evacuation behaviour. Such emergency planning (US Department of Transportation, 2009) is accomplished by applying a range of mathematical simulation models. One vital component of this human behaviour is in the evacuation process itself. The importance of this process needs to be emphasised by those advising governments and emergency service authorities in the planning of emergency evacuation routes, especially the capacities of the roads to handle the vehicular traffic demands (given the scientific predictions on flood heights and inundation) and the location of emergency evacuation centres, and other places, where people seek safe havens. In most developed countries the motor vehicle is regarded as the dominant mode for escape purposes.

Mathematical models are constructed using data, whether collected during evacuations or by asking people what they did when evacuating or what they plan to do when a natural disaster occurs. Inherent in people's response to disaster warnings is knowledge of prior events, combined with how they interpret messages, and how they behave in such extreme situations – what they do rather than what they say they will do (Alsnih, Rose, & Stopher, 2005). In the economic rational choice literature this is the distinction between revealed preferences and stated preferences, respectively (Makinoshima, Abe, Inamura, Machida, & Takeshita, 2017).

2.2. Evacuation behaviour and models

At the time of an emergency evacuation, modellers conceptualise that peoples' behavioural responses – the decisions they take - are represented in four distinct stages (Mesa-Arango, Hasan, Ukkusuri, & Murray-Tuite, 2013; Pel, Bliemer, & Hoogendoorn, 2012; Troncoso Parady & Hato, 2016), whilst acknowledging that there are interactions amongst the stages (sometimes handled by model feed-back loops). These steps are: (1) decision on whether to evacuate or not; (2) departure time choice (if evacuating); (3) destination choice; and (4) route/transport mode choice.

Pre-departure behaviour involves the psychological reaction of individuals including their perception of the threat and knowledge/experience of evacuation procedures. Both the availability and accuracy of information affect the behavioural response. Residents decide whether or not to evacuate based on physical conditions, location and knowledge of shelters, local roads and conditions, and knowledge of procedures. The time taken to make a decision and prepare is called milling time (Mas, Suppasri, Imamura, & Koshimura, 2012; Wang, Mostafizi, Cramer, Cox, & Park, 2016). There is accumulated evidence that some residents disobey evacuation orders (Keys, 2015).

There is a high degree of simplification in the mathematical representations of people's departure times following warnings and evacuation orders. Recently, Urena Serulle and Cirillo (2017) have reviewed the literature on the mathematical form of departure distributions. Early approximations of evacuation departure time frequency distributions have been based, variously, on empirical evidence, stated intention surveys, professional judgement (see, for example, the linear rate of leaving a flooded area in Hissel et al., 2014) and simulations of the diffusion of messages (Southworth, 1991). According to Murray-Tuite and Wolshon (2013) the S-shape of the evacuation departure time curves (evacuees start to depart within a certain time and the percentage of departed evacuees reaches 100% in an S-shaped curve) is based on numerous hurricane evacuation events as published by the US Army Corps of Engineers with typical fast, medium and slow evacuation response rates. Rayleigh distribution, Uniform distribution, Poisson distribution, sigmoid curve and Weibull distribution have all been used to represent this response function (Pel et al., 2012).

There is only a modest amount of empirical data against which to compare these assumed departure time frequency and cumulative distributions. For example, empirical data from the Hurricane Lili evacuation revealed a departure time distribution that is more complex than the one described in Murray-Tuite and Wolshon (2013) because departure times were determined by time of day as well as the elapsed time following receiving a warning. The case of hurricane Ivan is another interesting example where data were collected from 3200 households as part of the post-storm assessment (Mesa-Arango et al., 2013). These data do allow some useful generalisations to be made. The cumulative frequency distribution of departure times appears to follow an S-shape, but on closer examination the frequency distribution is approximately normal, giving rise to a linear cumulative frequency distribution. A similar shaped cumulative frequency is found in another empirical study, although the evacuation time was only 2 h (Ng, Diaz, & Behr, 2015). More importantly, this study identifies a vulnerable group in the evacuating population: the 'medically-fragile'.

2.3. Transport mode choice

In the vast majority of the literature reviewed (for example, Dixit & Wolshon, 2014; Lim & Wolshon, 2005; Mahmassani, 2017; Renne, 2005), the authors consider evacuation by private vehicles on public roads where the important factor is lane capacity because an under-supply of road space may lead to congestion and people being trapped (with associated risk to life) by rising water levels (Dawson, Peppe, & Wang, 2011). In general, people will want to evacuate the flooded area by the fastest possible means. In developed countries (where most of the research has been conducted) the majority of evacuees take their own private transport (motor vehicles, some hauling trailers, caravans and horse boxes) whilst those without a vehicle, or older people living in aged-care facilities, require an offer of a ride or the use of public, or community, transport. In countries in the developing world, there is often no alternative but to walk. Even in a developed country, such as Japan, consideration has been given to bicycles as a way of escaping tsunamis (Takada, Ikeda, Aoki, Murakami, & Koyama, 2017). However, in the case of floods or typhoons, this travel mode is especially dangerous.

2.4. Agent-based models (ABM) and the evacuation behaviour of older people

Agent-based modelling (ABM) has been applied as one of the most suitable methods to address the challenges of simulating the complex evacuation behaviour of residents and visitors when confronted by natural hazards such as floods, coastal inundations (tsunamis) and fires (Horni et al., 2016). It enables analysts to capture the interactions of diverse agents and their dynamic responses (Chen, Meaker, & Zhan, 2006; Crooks, Castle, & Batty, 2008; Dawson et al., 2011). There is an expanding literature that applies ABM to flood and tsunami evacuation modelling (for example, Dawson et al., 2011; Mostafizi, Wang, Cox, Cramer, & Dong, 2017) but there are few studies from our search on keywords that focus directly on older people and evacuations.

Older people are particularly vulnerable when it comes to evacuation because of their mobility issues, as covered comprehensively by Cahalan and Renne (2007). Pre-existing health conditions are an important factor for the elderly during disasters (Cohen & Mulvaney, 2005). They must bring medication and take extra clothing and blankets in case there is insufficient supply in the shelters (Tuohy & Stephens, 2012). It is apparent from the testimonials of survivors of the North East Japan earthquake and tsunami of 2011 that older people require more time to prepare and get into cars, especially if they are reliant on walking-frames or wheel-chairs (Editorial Office of The Ishinomaki Kahoku A Daily Newspaper of Sanriku Kahoku Shimpo, 2014; Muramatsu & Akiyama, 2011).

This implies the need for extra time to prepare for evacuation. Older people who do not have cars need to be picked up by family or neighbours (Rosenkoetter, Covan, Cobb, Bunting, & Weinrich, 2007). Usman, Murakami, Dwi Wicaksono, and Setiawan (2017) applied an agent-based model to determine the distribution of evacuation times given various scenarios on the location of emergency shelters for access on foot in Indonesia. The walking behaviours of older people were handled explicitly by them following evacuation paths with the least gradients. Smith, Tremethick, Johnson, and Gorski (2009) have identified some of the common challenges that emergency management professionals face in planning to meet the needs of the frail elderly during and after disasters. Characteristics of the frail elderly in independent living environments may include: declining health and increased chronic diseases; limitations in vision; hearing and mobility restrictions; limited access to healthcare resources; relative poverty due to fixed incomes; and limited social networks.

In summary, we have found relatively little information from the literature review component of our research methodology that can be used to form assumptions in our agent-based model where the needs of older people are included. Factors that are well established for model building include: the extra 'milling' time for preparations to evacuate (and the distribution used to represent the milling time); the reliance of older people on others to drive them to evacuation shelters; and that walking is a feasible evacuation mode providing distances to emergency shelters are short.

3. Disaster management and preparedness – case of Japan

Japan's disaster management system covers all of the phases of natural hazards - from prevention through to recovery and rehabilitation - and has been progressively strengthened in the post-Second World War era following practical experience during and after disastrous events. The Ise-wan typhoon of 1959 caused immense damage that led to the enactment of the Disasters Countermeasures Basic Act in 1961 that has been subsequently updated (Government of Japan, 2011, p.10). This disaster management system sets out the respective roles of the public and private sectors at the national, prefectural and local government levels. Recent revisions include a Community Disaster Management Plan that is established jointly on a voluntary basis by local residents and local businesses (Government of Japan, 2015, p.11). Town councils produce guidelines but apparently they are not particularly effective in rural areas. In general, and according to our Japanese sources in local government, residents do not perceive that flood risks are serious and are hesitant to evacuate from their homes (Mas, Suppasri, et al., 2012).

In many of the disasters that have affected Japanese communities, including both metropolitan cities and rural villages, most of the victims of storms and floods were older people aged 65 years and over, primarily because they were unable to escape by themselves in a timely manner. The Cabinet Office established a framework whereby neighbours should support and assist older people and the disabled. It formulated 'Guidelines for Evacuation Support of People Requiring Assistance During a Disaster' in March 2005 and 'Measures for Supporting Persons Requiring Assistance During a Disaster', a guidebook filled with case studies from disasters, in March 2007 (Government of Japan, 2011, p.18). Responding to the increasing number of serious natural hazards, local governments are hurrying to make a list of people (mostly older and disabled people) who need assistance for evacuation. The list also requires the elderly to nominate a person (family in most cases) who are in charge of providing assistance. However, local governments are struggling to complete the list due to the lack of people who can provide assistance[1].

As noted in Section 2, it is the behavioural responses of people impacted by disasters that represent challenges in disaster management, and knowledge dissemination and community awareness are strategies adopted by governments to influence these responses. The Government of Japan has designated the 1st day of September as 'Disaster Preparedness Day'[2] and the week that includes this day as 'Disaster Preparedness Week'. Various events to raise awareness and readiness about disasters, such as disaster drills and 'disaster reduction campaigns', are held annually in various parts of the country (Government of Japan, 2015, p.42).

4. Case study area and ABM of flood evacuation

Whilst the disaster management system is comprehensive, and the respective responsibilities of governments, stakeholders and the community are clear, the question is 'does this management system work effectively in rural Japan, especially in areas where the population is ageing?' Already, we have noted the problem of keeping a register of older residents. To answer this question we resort to a case study methodology (Yin, 2003) which is suitable where the observer has access to an unexplained phenomenon (in this case, evacuation behaviours of people in a rural town that has significant ageing population). The case study in our research is used to develop new ideas to cope with the challenges emerging from the case through an enhanced

[1] Based on discussions with officials of Kagawa prefecture and representatives of neighbourhood associations during 2018–9.

[2] In memory of the 1923 Great Kanto earthquake which claimed the lives of over 100,000 people in the Tokyo region.

Fig. 1. Location of Manno Town, Kagawa Prefecture, Japan (Source: Authors).

understanding of evacuation processes. An agent-based micro-simulation model is applied to simulate evacuation behaviour to observe dynamic responses of evacuees and to identify challenges for decision makers.

4.1. Manno study area – characteristics

The study area on Shikoku Island, Japan, is Manno town, Kagawa prefecture (Fig. 1). The town's area is about 194 km^2 and its population in 2015 was 18,377. As of 2015, the proportion of the population over 65 was 35.5% and over 75 was 20.1% (Statistics Bureau, 2015). Fig. 2 shows the trend of percentages of youth, productive-age population, older people (65–74 years old) and people over 75 years old of the past 35 years. It shows that the ratio of older people has been increasing while the ratio of the productive-age population has been decreasing, which has implications on the capacity to raise local revenues. It is also understood that the ratio of the older age population is above the national average in Manno town.

The decrease in the productive-age population is caused by an out-migration of young people moving to big cities for education and employment - a typical trend that is seen in many Japanese rural towns (Muramatsu & Akiyama, 2011). It is projected that the proportion of older people in the Japanese population will keep increasing and will be about 40% by 2045 (National Institute of Population and Social

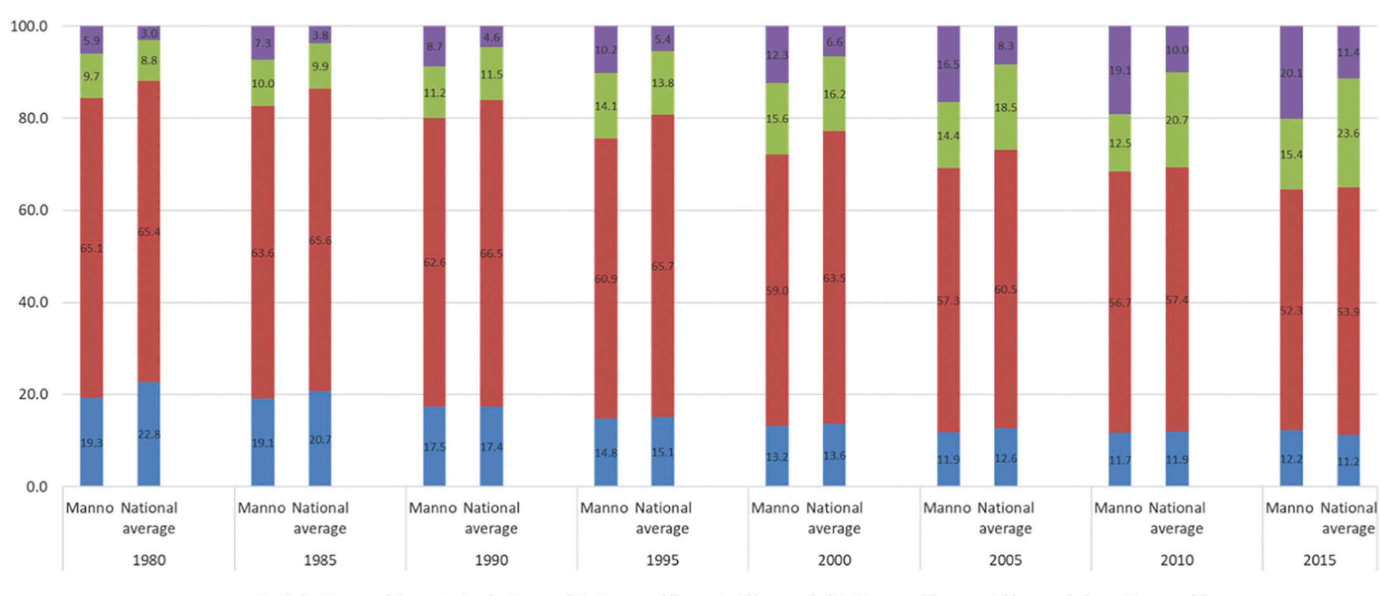

Fig. 2. Trend of age cohorts in Manno Town compared with national average, Japan (Source: 2015 Population Census, Statistics Bureau).

Security Research, 2018). Manno town's older population already exceeds 50% of the population and it will keep increasing. The town is now one of the most sparsely populated areas in Kagawa prefecture with a higher ranked index of depopulation.[3]

Kagawa prefecture is located in the driest area in Japan and, in the past, a number of reservoirs were developed for irrigation purposes. The area has been suffering drought that impacts on agricultural and farming productivity. Manno town has about 500 reservoirs including the biggest reservoirs in Japan - 'Manno Pond' - believed to have been built during 701–704 CE. Most reservoirs in Kagawa prefecture were built before the start of the Edo era (1603). In recent times, these ageing infrastructure reservoirs are in risk of collapse during heavy rains because of the lack of maintenance and the advancing age of their owners (most of the reservoirs are privately owned) (Shikoku Newspaper, 2018). Limited mitigation strategies are in place. Manno town has prepared hazard maps of the major reservoirs and disseminated these to residents. The hazard maps include information on the expected flood water level around the reservoirs. The town has also developed and disseminated a hazard map of landslides, noting the fact that the town is located in hilly terrain.

Manno town has not experienced many disasters compared to other towns in Kagawa prefecture (based on our analyses of the Shikoku Disaster Archives, n.d.). Even during the 2004 typhoons that flooded the capital city of Kagawa, residents were not affected, although some small dykes were damaged. Rather, historical records show that the town has suffered more from droughts than floods, which justifies the number of ponds that had been developed in the town and explains why older residents fail to understand the potential risks of flooding.

4.2. Vulnerability and awareness of disasters

The vulnerability of Manno town is explained by the impact of recent heavy rain that affected extensive areas of western Japan in July 2018. The record-breaking precipitation during the period from 28th June to 8th July claimed the lives of more than 220 people in west Japan. More than 30,000 houses were flooded and 11,000 houses entirely, or partially collapsed. In addition, there was severe damage to infrastructure. Kagawa prefecture was less affected with no casualties, compared to neighbouring prefectures. However, in Manno town, 366 mm of rain was recorded in the period between 5 July and 8 July. One residential house was damaged. Dykes of two rivers that run through the town were damaged and roads were also extensively damaged, causing one major road to be closed. In addition, five landslides (one case is shown in Fig. 3) were recorded (Kagawa Prefecture, 2018). Evacuation orders were issued to all areas of the town. Surprisingly, the total number of people who evacuated was only 41.

The authors conducted fieldwork in September 2018, two months after the flood. After visiting the damaged/landslides sites, we conferred with officials of Manno town in order to understand residents' awareness of disaster risks and current challenges in evacuation.[4] The study area was revisited in July 2019 with the main purpose of determining with local officials the location of potential emergency shelters and the perceptions of residents on evacuation as they entered the typhoon season. The residents, in general, do not have a high degree of risk awareness. Mountains surround the town and these block the approaching typhoons that are the prime cause of flooding and landslide disasters in the region. In fact, there has never been a major disaster that has caused loss of lives and major damage to infrastructure. Even at the time of the July flood in 2018, residents still did not think it would seriously affect Manno.

When an evacuation order was issued, the town council opened shelters for residents. The council encouraged residents to come to shelters by issuing warnings using the local wireless network before the rain became heavier. However, very few people came to the shelters. It is assumed that some people felt that they might have been safer somewhere in their neighbourhood, or they stayed upstairs in their houses because of the long travel distance to the limited number of shelters on offer in the town. It is also assumed that residents thought that travelling to shelters was itself more dangerous than staying at home, because of the hilly terrain and the narrow roads. The council officer also noted that some people, went home after spending only a little time in a shelter, because they were worried about the state of their houses as the rain became heavier. 'Luckily, nobody was affected - but this is a risky behaviour', the officer confirmed.

In summary, Manno is highly vulnerable to heavy rain because of its topographical characteristics and the existence of a number of reservoirs. If residents do not evacuate well before it gets dark or the hazard becomes more serious, it could become more dangerous for them to travel to shelters because most of the feasible evacuation routes are hilly and narrow. Also, the number of shelters is inadequate for the size of the population and some residents need to travel relatively long distances. This problem is compounded because residents' awareness is not high. As the recent storms confirm, residents tend to stay in their home/immediate neighbourhoods even when evacuation orders have been issued. However, staying home is not recommended because, if roads were closed due to landslides and floods, the supply of emergency goods could not be delivered, including medication that is a critical necessity for many older people. For this reason, and to raise awareness of the potential risks to residents and also to inform the council, we have applied an agent-based simulation model to quantify the implications of six evacuation scenarios.

4.3. Agent-based micro-simulation

In our research design an ABM has been developed with the necessary input data and assumptions and is applied more narrowly to the Chunan area of Manno town. In this study, we have set six scenarios. For all scenarios, simulation was developed based on the situation at the time of the July flood of 2018. The evacuation order was issued at midnight on 7th July. Therefore, for the simulation, it is assumed that residents would evacuate their homes. Based on the literature, older people take more time to prepare to depart (Editorial Office of The Ishinomaki Kahoku A Daily Newspaper of Sanriku Kahoku Shimpo, 2014). Therefore, the delay in departure time, and the probability of later departure, are considered by using a Rayleigh distribution (Mostafizi et al., 2017; Wang et al., 2016 see Appendix A).

In the literature on evacuation behaviour and agent-based models the specification of road-lane capacity is an important input but in rural Japan this is not an issue in simulation modelling. There are three major roads that connect the area with other parts of town. These roads are administered by the prefectural government and all have one lane in each direction. Minor roads have been developed in the road network model to connect houses with these three roads. Fig. 3 is a screenshot of the simulation model that shows all routes relevant to evacuations.

The town officer confirmed that traffic congestion does not occur in the Chunan area. However, for some scenarios (3 and 4 below), reduced speeds of 8 km/h and 5 km/h (from 30 km/h) are considered, respectively, because in an emergency situation, cars are expected to depart almost simultaneously. This base speed (30 km/h), and the reduction of speed, were confirmed as being relevant when the authors drove around the town in the rain (in September 2018 as Typhoon 24th was approaching).

4.4. Scenarios modelled

The Chunan area has a population of 4097 (1587 households, as of

[3] Based on discussions with officers of Manno town.

[4] It also informed the agent-based simulation model which is described in the following sub-section. Several discussions were held and feedback on the simulation results was also provided.

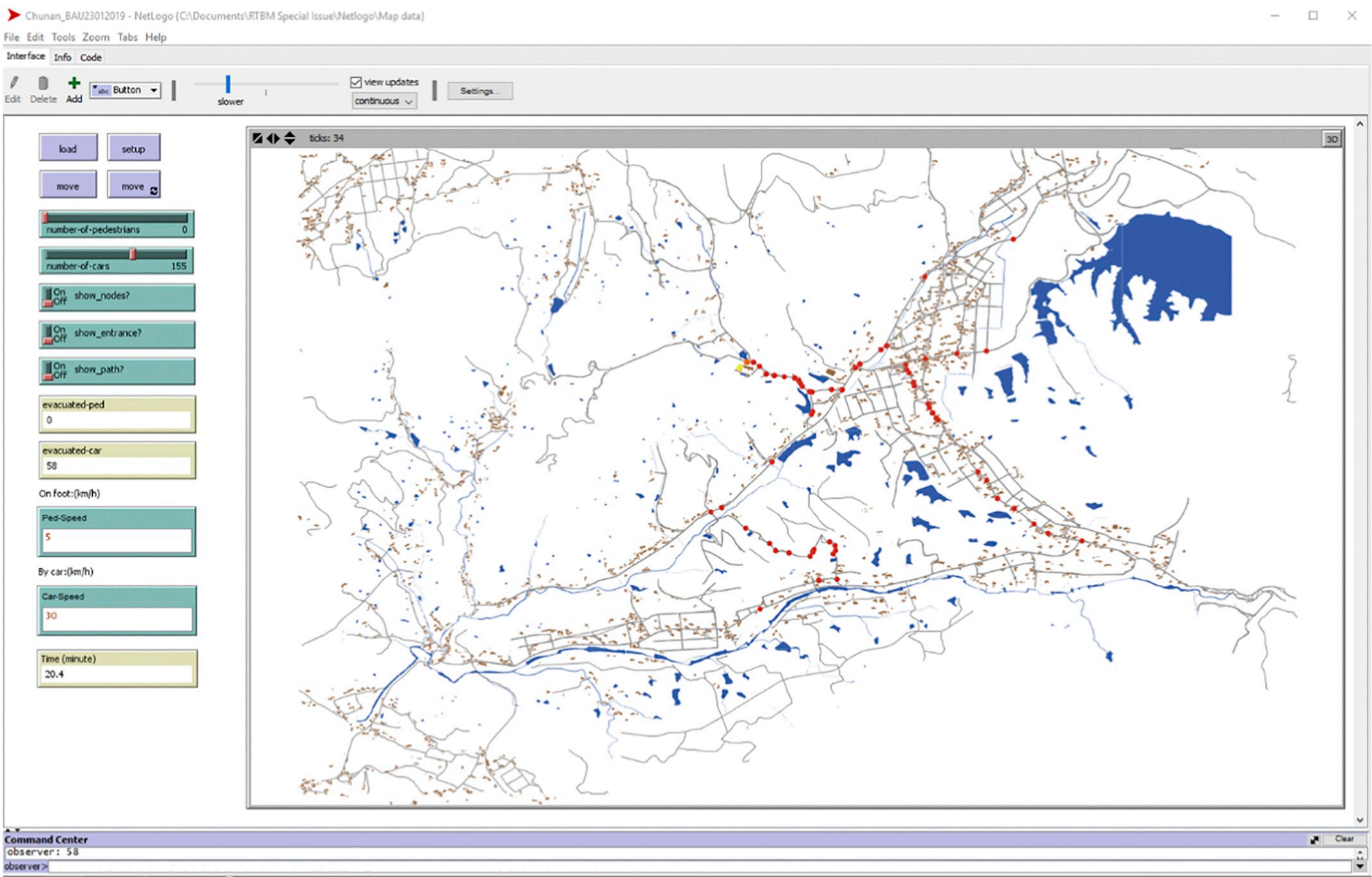

Fig. 3. Screenshot of simulation GUI on NetLogo Platform (BAU Scenario) (Source: Authors).

Fig. 4. Landslide at the rear of a house in the Chunan District (A tarpaulin sheet is covering the hillside behind the house) (Source: Photo taken by the authors in September 2018).

2017) in an area of about 19.4 km^2. Chunan was the most affected of the three areas of the town by the floods of July 2018 (Fig. 4 provides an example of the destruction). The area has only one evacuation centre (Chunan Community Centre). The northern part of the area is relatively flat and the southern part includes more mountainous areas. Residential houses and agricultural fields are scattered across the area.

The simulation setting for each scenario is shown in Table 1. The travel mode is the motor car for scenarios 1–5 with only one or two shelters (i.e. a community centre) dedicated for evacuation. Because it is regarded as unrealistic to walk to the shelters, which are relatively far from most of the residential dwellings, the car is used in these scenarios. Scenario 6 was based on the most recent discussions with the town officers in mid 2019. The rationale for this scenario where walking is the dominant mode is that the location of the shelter in scenarios 1–5 are too far away for most residents and, as such, older residents hesitate to evacuate. Allowing residents to use small community facilities that are dispersed across the area allows residents to walk to the closest one. At the time of the July flood in 2018, only a few people evacuated to the one shelter. However, in this 6th simulation, it is assumed that 10%[5] of households evacuate as in all other scenarios.

The BAU scenario assumes one car per household (i.e. 155 cars in total). The remainder of the population is assumed to remain on the higher levels in their homes. The BAU scenario does not consider the milling time. The second scenario considers milling time, taking into account the ratio of older people (over 75 years old), based on census data. In this scenario, 20% of cars have older passengers. The third scenario considers the risks of landslides that represent a situation similar to the July 2018 flood. In this case, the available routes for evacuation are more limited (based on the landslide hazard map) and the congestion effect of traffic is therefore considered. The fourth scenario is one where more residents evacuate than in the base case scenario: 230 cars (assuming 15% of households evacuate) are simulated to move to shelters. Congestion effects are also considered. The fifth scenario is where there is one additional shelter in the study area. Only having one shelter was raised as a concern by residents who responded to our questions. The sixth scenario is a case in which residents walk to

[5] The rationale for this is derived from the experience of the 2004 typhoon disasters that impacted on many residential areas of Kagawa Prefecture, where 10% of houses were inundated.

Table 1
Simulation setting for each scenario.

Scenario	Number of agents	Speed
1. Business as usual (BAU)	155 cars	30 km/h[a]
2. Business as usual (BAU) (20% car with older people)	155 cars	30 km/h[a] with milling time considered
3. Limited routes (landslide)	155 cars	30 km/h[a] as max with congestion effect
4. More cars (1.5 times more cars)	230 cars	30 km/h[a] as max with congestion effect
5. Two shelters	155 cars	30 km/h[a]
6. Evacuate to nearby community facility	30 cars	30 km/h
	80 older people (over 75 years old)	3.2 km/h[b]
	180 adults	4.5 km/h[b] milling time is considered for all agents

[a] The progression of vehicles through this network was set with a relatively slow mean speed of 30 km/h for scenarios 1, 2 and 5, taking into consideration that there are some steep roads in the area and there is the (hypothetical) situation of heavy rain falling whilst the evacuation is underway.
[b] Walking speeds are based on data collected by Takabatake, Shibayama, Esteban, Ishii, and Hamano (2017).

the closest small community facility. There are 15 community facilities identified for this scenario and all are theoretically available to all residents. Even with this scenario, some residents need assistance to evacuate. Therefore, we have set 30 cars that are specifically allocated for this purpose. Here, milling time is considered for all agents.

The dedicated shelter for the Scenarios of BAU, 2, 3 and 4 is located following instructions from town officials to residents. The second shelter set for Scenario 5 was chosen from those public facilities that are accessible from major roads and where there is no risk of a landslide. The 15 community facilities for scenario 6 were chosen from the hazard map provided by the town council (see Appendix B for a location of shelters). These facilities are unlikely to be affected by landslides.

For all scenarios, the evacuating agents were randomly generated and assigned to home locations. Shortest paths were found using the A* algorithm which is commonly used in evacuation modelling (Mas, Imamura, & Koshimura, 2012). The simulation is developed on the NetLogo platform, which is a high-level platform for simulating complex and stochastic phenomena, commonly used for evacuation simulations. The advantage of using NetLogo is its GIS extension, which allows for the creation of ABM using map data.

We are confident that the road network model is an accurate one for the purposes of our simulation. The geographic data provided through Open Street Map (OSM) was consistent with the data published by the Geospatial Information Authority of Japan. Therefore, the OSM road network data was loaded into the NetLogo GUI. Data for buildings/houses were downloaded from the website of Geospatial Information Authority of Japan and re-loaded onto the NetLogo GUI. For all scenarios, the mean time to evacuate was calculated from a simulation of 10 runs, to account for randomness in generating the evacuating agents onto the road network.

5. Results

The mean evacuation time for each scenario calculated from the ABM simulations is shown in Table 2. This calculated time is the total time taken for all cars to arrive at the shelter from when they started to move from their original location. For scenarios 1, 3, 4, and 5, the time calculated is for evacuation travel only. The milling time (time taken to decide whether to evacuate or not) and the preparation time are not included in these scenarios. Also, the time taken to park cars at the evacuation shelter car park and to walk to the facility is not considered in any scenarios. This additional time at the destination end of a car trip is unlikely to be of much consequence because of the ample capacity of the car park and surrounding streets, and, in any case, walking times would be similar under all scenarios.

Table 2
Simulation results by scenario – mean evacuation times.

Scenario	Mean evacuation time (minutes)
1. Business as usual (BAU)	58.0
2. Business as usual (BAU) (20% car with older people)	60.5
3. Limited routes (landslide)	59.5
4. More cars (1.5 times more cars)	66.7
5. Two shelters	55.9
6. Evacuate to nearby community facility	80.1

For the business-as-usual (BAU) scenario, the majority of cars finish their journey to the shelter within 40 min although the mean evacuation time is 58 min. The skewed longer travel times are because of the topography and therefore the evacuation of all cars takes around one hour. Discussions about our results with the town officer confirm that this mean time is a highly plausible result based on local knowledge.

For scenario 2, 50% of the cars start moving after 7.4 min and 95% start moving after 9.9 min. The majority of cars without older people as occupants arrived within 40 min. Cars with older people arrived during the 40 to 60 min period, as a result of their delayed departure. This reflects the additional time needed for departure preparation.

For Scenario 3, the limited route options for drivers forced evacuees to choose from a limited number of roads in the east, north and south side of the area (Fig. 5). This caused some traffic congestion in the simulation model. It was observed that the cars often reduced speed (decelerated) while travelling, resulting in a modest 90-second increase in the mean evacuation time over the BAU scenario.

For scenario 4, the increased number of cars on the road (unusual in this study area) caused traffic congestion and cars often reduced their speed (decelerated) whilst travelling. This caused evacuees to take more time to complete their journeys to the shelter by adding almost 9 min to the mean evacuation time when compared with the base case (BAU).

In Scenario 5, evacuees have two options for their shelter destination. In the simulation model, it is assumed that evacuees head towards the nearest shelter. Unsurprisingly, the mean evacuation time of scenario 5 is the shortest time amongst the scenarios 1–5 at approximately 56 min.

For Scenario 6, although the mean evacuation time is the longest at 80.1 min because of the high incidence of walking, the majority of agents arrive at a shelter within 60 min.

Given the spatial distribution of residences it is obvious that there will be a distribution of travel times on arrival. Fig. 6 shows this temporal distribution of time of arrival at the safe haven for each of the six scenarios. It is worth noting that under Scenarios 1–5, about 25% of cars arrive within 20 min of departure. It is equally obvious from this graph that the limited route scenario causes a slower arrival of cars at the shelter.

Fig. 7 presents a summary of the simulation results in a slightly different way. The focus is now on each ten-minute time interval each showing the percentage of all agents arriving in that interval. More cars arrive early when there are ‘two shelters’, whereas, when the routes are restricted and more cars and older passengers are involved, cars arrive

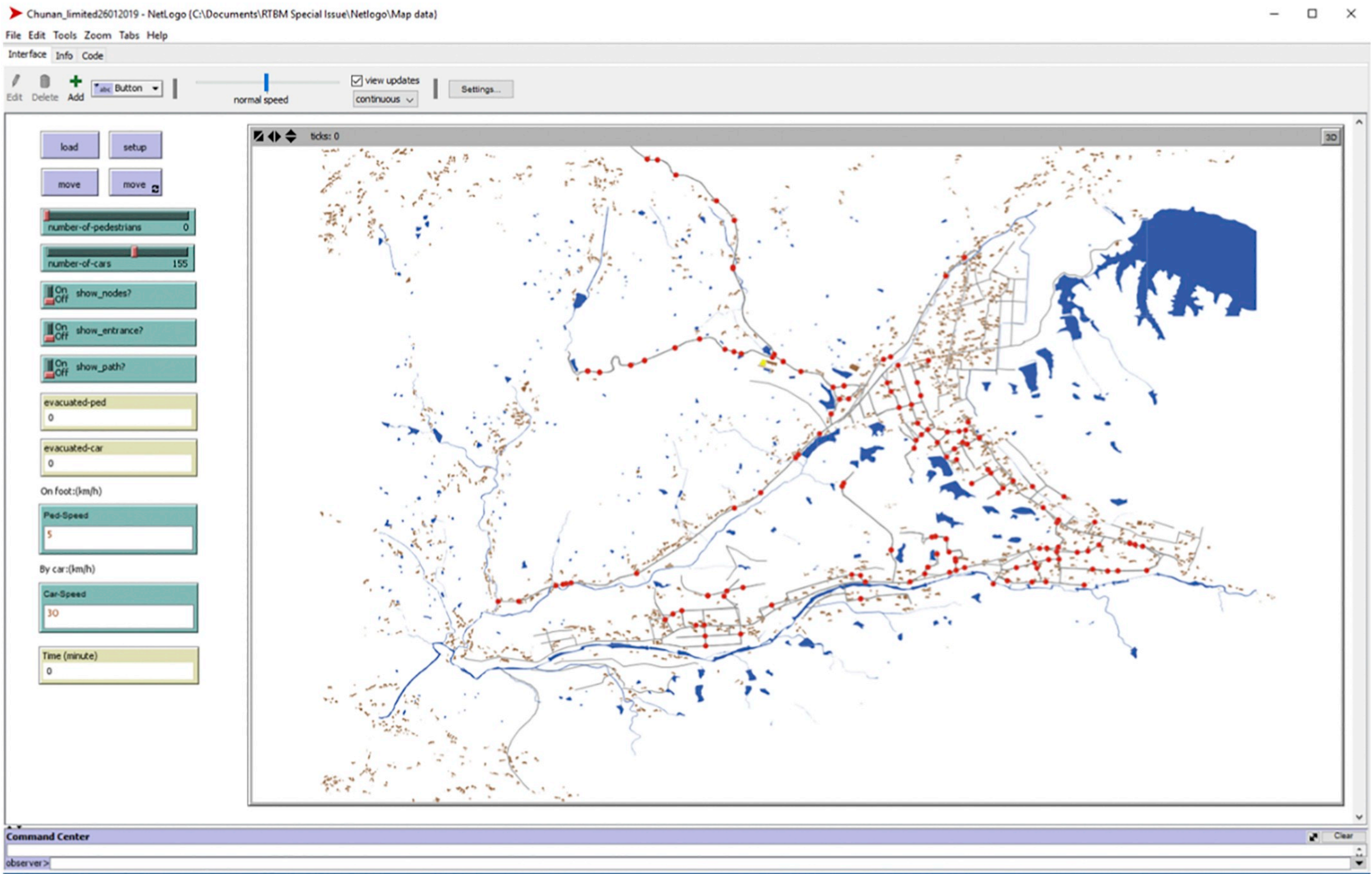

Fig. 5. Screenshot of simulation GUI on NetLogo Platform (Scenario 3) (Source: Authors).

later. The result of scenario 6 indicates that the walking older agents arrive at shelters earlier than those using cars (scenario 2) in the first 20 min.

The findings summarised in Figs. 6 and 7 show the ‘two shelters’ scenario results in a higher proportion of cars arriving early. The BAU, ‘limited route’ and ‘more cars’ scenarios demonstrate slower arrival of cars. For Scenario 3, the majority of cars arrive at a shelter within 40–50 min compared to the majority of cars arriving within 40 min under the BAU scenario. For Scenario 4, the majority of cars take 50 min to reach a shelter. In the ‘two shelters scenario’, two-thirds of cars finish their journey within 30 min. BAU with older people also show a slower arrival: the majority arrive in 30–40 min. For scenario 6 over 70% of older people finish evacuating their homes within 40 min.

6. Discussion

This study simulated evacuation behaviours at the time of a flood event in a rural town of Japan, where older people occupy a significant part of population. In this case study, it was assumed that 10% of households evacuated, using one car per household (i.e. 155 cars in

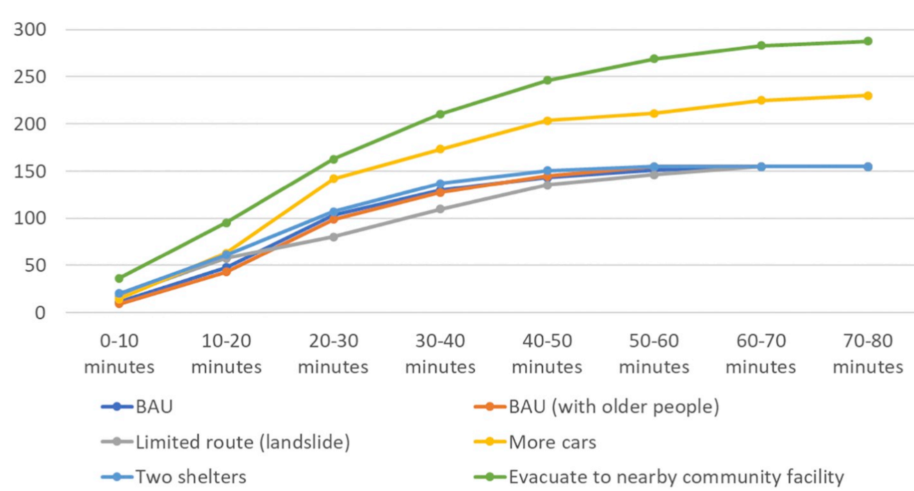

Fig. 6. Number of agents arriving at a shelter by time in the six scenarios, Manno Town (Source: Authors).

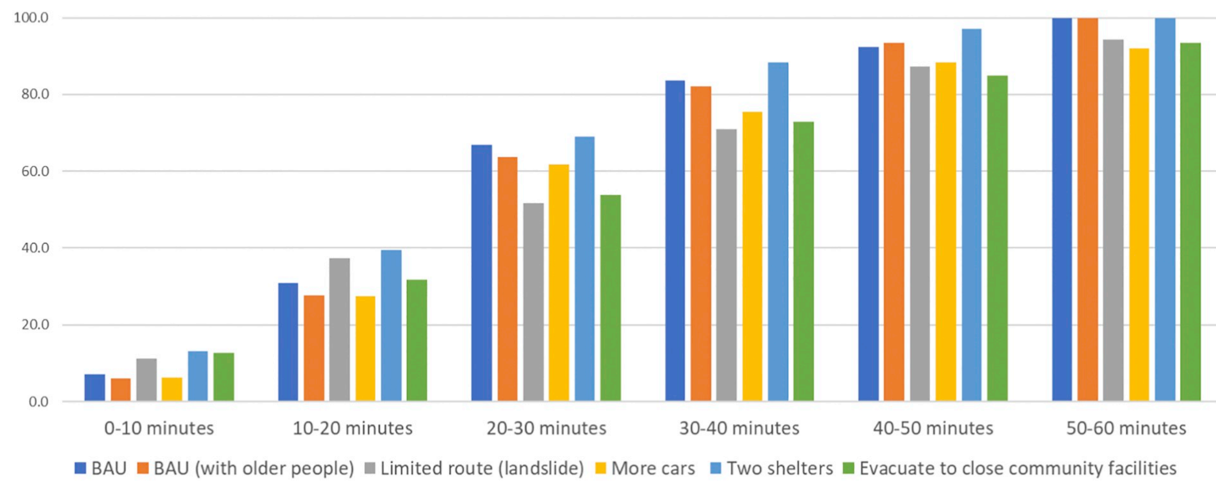

Fig. 7. The percentage of agents arriving by ten-minute time interval in the six scenarios (Source: Authors).

total) as the business as usual (BAU) scenario. We set this base case based on discussions with the Manno town officer. Other scenarios tested included: 20% of cars with older passengers; road closures due to landslides; more traffic on the evacuation road network; and the addition of an extra shelter. A sixth scenario provided more community shelters and this allowed us to simulate walking to the nearest shelter. The simulations were assumed to take place at night when everyone was more likely to depart from their home.

The result of Scenario 2 indicates that preparedness to evacuate is critical for older people, because delay in departing homes could result in significant loss of time to reach safety. Results of Scenarios 3 and 4 are closely related to the road capacity of this rural town, which is restricted as is the case in most areas of Japan. The result of Scenario 5 suggests that even one more shelter could ease traffic congestion, hence reducing travel times. Scenarios 1–5 considered the car as the only travel mode option for all evacuees as private transport is the most preferred mode for all journeys.

The mean evacuation time by car at night is around 1 h, whilst most cars arrive at a shelter within 40–50 min. However, this can be regarded as the shortest time possible because the (modest) time for parking at the shelter location and walking to the shelter are not considered in the simulation. Assisting older (and disabled) people to walk from the car park to the shelter entrance requires time, in particular when there is heavy rain falling. Considering this, the authors think that a realistic, yet conservative, planning time for all evacuation processes to be completed might be in the order of 80 min after departure. This was discussed with town officers who thought our simulation results were reasonable. As each minute is critical for evacuation, reducing this time is an immediate challenge for the community.

In fact, many older people are reluctant to drive when it is dark and in heavy rain. The result of Scenario 6 provides some useful information in considering how the local council could best manage evacuation transport to minimise the pressure on older people, including the choices of travel mode and destination. Fig. 8 shows the arrival time of each agent in the Scenario 6 simulation. Although the mean travel time (shown in Table 2) is 80.1 min, Fig. 8 shows that nearly 80% of older people reach safety within 40 min, which is even faster than the result of Scenario 2, where cars with older people arrived during a 40–60 min period. This implies that, rather than driving older people to a shelter which is far from their home, it may be better to ask those who are relatively fit to walk to their nearest shelter by themselves. As shown in Fig. 8, half of older people complete their evacuation from home within 30 min. It would be necessary to organise evacuation drills regularly to develop confidence amongst older people so that they can evacuate relatively easily by themselves. This would allow the local council more time to focus on people who need assistance.

Policy implications of the research findings with regard to emergency transport management are threefold. First, in order to make the evacuation process smoother and safer for ageing Japanese in rural towns, there is a need for a detailed evacuation plan and a manual for officials to follow during an emergency. Ideally, qualified people should be dispatched to each neighbourhood to assist older people to prepare and get into cars. Our simulation (Scenario 2) confirmed that preparation time is critical at the time of evacuation for older people. If the provision of dispatching personnel to assist older people is unrealistic given the limited resources of most Japanese rural towns, the appropriate training of town officers/fire brigade members becomes imperative. The detailed evacuation plan needs to be developed with a clear indication of the people who assist, the destinations and the suggested routes to these destinations.

Under national directives local governments are hurrying to list people (mostly older and disabled people) who need assistance with evacuation. However, they are struggling to find enough people who can provide assistance. Considering the fact that local councils are under huge pressure with limited resources, national government could support them by bringing in experts. This could also assist in complementing the necessary knowledge and skills within local governments, where officers are rotated to duties in different areas of government every 3–5 years. This rotation has resulted in a lack of experienced experts who have implicit knowledge of disaster management in their jurisdiction.

The town council could organise minibuses to collect older people from their homes (the optimisation of this 'dispatch problem' can also be solved by agent-based models). It is preferable that all older residents evacuate considering the potential health impact on them, their vulnerability without medical support, and the isolation that older people may feel if they stayed at home. However, evacuating all older people (in the case of our study area, the estimated number of people is 819) is difficult because some need assistance to evacuate but they often do not have family or friends nearby. Looking towards the future when driverless autonomous vehicles (AV) enter the vehicle fleet, agent-based models can be designed by local government to optimise pick-up and delivery routes.[6]

The second policy suggestion relates to the road system. The evacuation routes (there are only three major roads in the study area) require more capacity and evacuation signage, as suggested by the results of Scenarios 2–3. Currently, the roads have one carriageway in each

[6] Our discussion with town officers informed that at this stage, it is unrealistic for town council to organise minibuses to pick up all older people who are dispersed in the town, due to its limited financial resources.

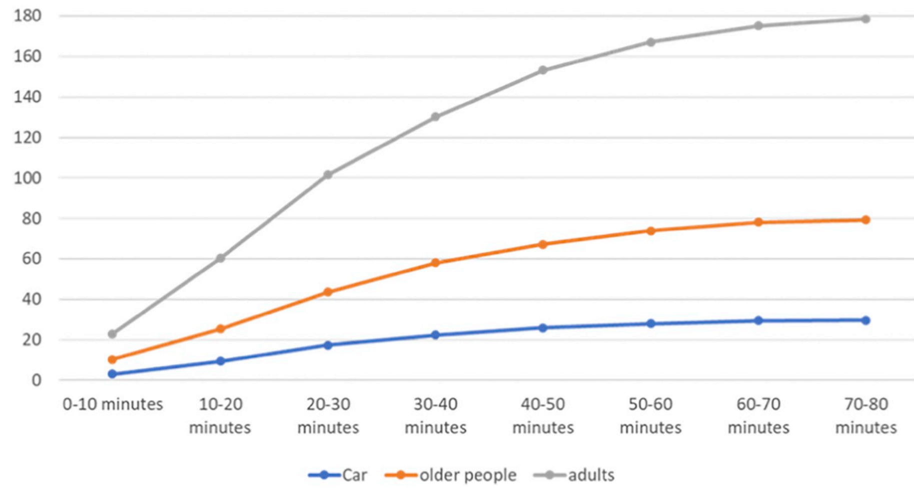

Fig. 8. Number of agents arriving at a shelter by time (Scenario 6).

direction but widening them to two lanes in each direction is difficult from both a physical and a financial perspective. Although roads are highly unlikely to be congested in normal circumstances, the simulation demonstrates that congestion effects occur at the time of evacuation and car speed reduces because of limited road capacity. Despite evacuation flows occurring in one direction, the on-coming lane must be retained for emergency vehicles and supply vehicles. However, making one extra passing lane, where feasible, would add to road capacity and reduce overall evacuation time. In Japanese rural towns, the so-called 'overtaking' lane is rarely seen but policies to upgrade road capacity need to be considered and funded to reduce congestion at the time of evacuation. In addition each evacuation route needs clear directional signage to be installed, based on the approved Japanese signage standards. Given some drivers' preference to follow a familiar route to a shelter it would be necessary to test the location and visibility of signs in a driving simulator (as has been done recently by the NSW Government in Sydney).

Thirdly, as demonstrated by the simulation, having only one shelter in a relatively wide geographical area is a constraint. Not only does it take time for residents to evacuate, but if the scale of disaster is large, one shelter may no longer be appropriate/safe (as seen in some areas of North East Japan at the time of the 2011 tsunami). It is recommended that councils arrange options for shelters that are located in safe areas. Our scenario 6 simulation demonstrated that providing more options for shelters allows older residents to independently evacuate within a relatively reasonable time. Older people tend to hesitate to evacuate if evacuation distances are long and they cannot drive, or they do not have the confidence to drive in heavy rain or when it is dark, so shelters located conveniently and within walking distance could give them greater reassurance. The results of the scenario 6 simulation show that providing more facilities with easier access for older people would reduce the stress of evacuation since they could reach shelter at much the same time as those being collected and driven to the one or two community shelters.

Discussions with town officials confirmed the value of nearby shelters from a different perspective. Because many older people feel uncomfortable staying somewhere unfamiliar and far from their homes, they may feel more comfortable in a nearby shelter because they know they will be with their familiar neighbours. This option could potentially reduce the concerns of older people and hence avoid returning home in a heavy rain. In hilly rural terrain, as in Manno, finding a safe public facility may be difficult. In this case, local government could ask whether privately-owned property owners have appropriate space and capacity that could be used as short-term, emergency shelters.

In addition to the policy implications above, we would also like to discuss the potential of agent-based simulation and its practical application in emergency planning and management. Throughout the world there has been a long history of typhoons and flood disasters and such events are expected to become more frequent and intense as weather patterns are affected by climate change (Climate Central, 2018; Esteban, 2009). In addition, the trauma of those people who experience flooding and survive has lasting mental health impacts (Fernandez et al., 2015). In many of the disasters that have affected Japanese communities, including both metropolitan cities and rural villages, most of the victims of storms and floods were older people aged 65 years and over, primarily because they were unable to escape by themselves in a timely manner. Whilst natural hazards cannot be eliminated communities can be better prepared. In the case of Japan this process began with the Disasters Countermeasures Basic Act of 1961 and has been regularly updated (Government of Japan, 2011, p.10). This disaster management system sets out the respective roles of the public and private sectors at the national, prefectural and local government levels.

Recent revisions of the Basic Act include a Community Disaster Management Plan established jointly on a voluntary basis by local residents and local businesses (Government of Japan, 2015, p.11). The Cabinet Office also established a framework whereby neighbours should support and assist older people and the disabled (Government of Japan, 2011, p.18). However, at the local level there are still many problems in implementing these policies. First, town councils produce guidelines but apparently they are not particularly effective in rural areas according to the interviews that we have conducted in our case study area. Secondly, post-disaster reviews (Keys, 2015) and media reports from many different countries highlight the fact that a proportion of residents disobey orders to evacuate. For example, in Manno Town, at the time of the July flood in 2018, only a few people evacuated to the community shelter. Low levels of awareness is one factor.

Computer simulations can help in enhancing residents' understanding of risks and improving community preparedness by the visualisation of results from various weather patterns and predicted flood levels. These are helpful tools which demonstrates to residents the importance of timely evacuations to prevent potential loss of life in dangerous events. As reviewed in Section 2.2 of this paper, the modelling of travel behaviour is complex and all evacuation models – whether strategic and macro or operational and agent-based micro-simulations – require input data that is often in the form of assumptions. Unfortunately, when searching for keywords on the behaviour of the older cohorts in the community when evacuating from homes we identified a paucity of specific information. Therefore, as with many model building exercises reported in the literature we had to make a series of assumptions with the assistance of the local council. We have made the assumptions as realistic as possible by obtaining local knowledge through interviews in the community and with town officials in Manno Town. Our simulations are based on the real situation at the time of the July flood of 2018.

Agent-based modelling is not beyond the capability of local government officers. Once the model was set up and the data loaded, it took approximately 4 h to prepare and run each scenario. The significance of this research lies in its demonstration of how agent-based models of evacuation can be applied readily across towns in rural Japan where resources for planning evacuations are limited. The visualisations generated by the model could provide a valuable resource in community education and disaster preparedness. Given data on the location of older residents in any study area, the model could be extended to focus on the needs of them and the role that neighbours can play in the evacuation process (Bankoff, Frerks, & Hilhorst, 2004).

The simulations were assumed to take place at night but in the case of a day-time evacuation, the behaviour of evacuees becomes more complicated, as evidenced by the case of the 2011 earthquake and tsunami disaster (Editorial Office of The Ishinomaki Kahoku A Daily Newspaper of Sanriku Kahoku Shimpo, 2014) because residents are out and about. Parents (or grandparents) would pick up children from their school/childcare, often travelling from their work, then arrive home, prepare for evacuation, get into the car again and head off to shelters. This already includes many processes and journeys that require significant time even before evacuees head off to the community shelters. Our simulations do not include this process, but, even in a small town, it might add nearly 1 h to the simulated times for evacuation in the day when compared to those simulations at night. Applying this model to other Japanese rural towns will give varying estimates of evacuation times.

The immediate challenge of the simulation, integrating more realistic route choices for evacuees, needs to be considered. According to a questionnaire survey that the authors conducted in the same prefecture in 2018, residents prefer to use their familiar routes to a shelter rather than the shortest possible route. This is an understandable choice but representing the complexity of each agent's route choice is a challenge for researchers. Furthermore, Table 2 reported only on the mean travel times during an evacuation scenario but the appropriate measure of social impact is calculated from these mean times multiplied by the total number of vehicles evacuating in each scenario. Such information would be important when establishing the costs and benefits of any policy interventions such as increasing the number of community shelters available.

For a practical and effective use of simulation, we suggest that an inter-sectoral (university, government and industry) and inter-governmental (prefecture, city and town) taskforce needs to be constituted and meetings convened on a regular basis (4–5 per annum). Currently, there is a lack of communication between these stakeholders. Whilst governments are continuously lacking resources, researchers are accumulating outputs that are not sufficiently applied in practice. Also, to make research output more applicable, researchers need to understand place and locality and the needs of residents. Japanese universities have developed disaster prevention research centres to address the problem of increasing risks from natural hazards. It is suggested that there should be stronger leadership and a system in place that enable research outputs to be utilised by governments/practitioners (in particular local councils in rural areas) by complementing the knowledge gained from each other.

7. Conclusions

Managing evacuation of residents to safe places in a timely manner is a global challenge to community leaders and authorities in an ageing society. The literature review has confirmed that there is little research focusing on older people's evacuation. Evacuation procedures and the protocols of evacuation orders in Japan have been described. Discussions with local government officials in the case study town of Manno (population 18,377 in 2015) led to the identification of current challenges to the management of transportation in emergencies: in particular, with issues in relation to the travel of older people and the need to offer more community shelters.

An agent-based simulation model was developed to predict evacuation behaviour using the July 2018 rainfall situation in the case study area. The simulation was developed on the NetLogo platform. Its applicability was demonstrated based on the estimated evacuation times of six different scenarios. The simulation results of around 1 h for five of the scenarios, together with our recommended 80 min to complete all aspects of the evacuation, were shared with the town officers. An additional scenario was discussed with town officials where more community shelters were provided, allowing elderly people to evacuate on foot. Older people tend to hesitate to evacuate if distances are long, or they do not have the confidence to drive in heavy rain and when it is dark. Shelters located conveniently within walking distance can give greater reassurance to older people during emergencies.

This paper has demonstrated that agent-based models of evacuation can be applied readily across towns in rural Japan which often lack the resources to engage consultants. Once the model was set up and the data were loaded, it took approximately 4 h to prepare and run each scenario. The research and policy implications have been discussed. Although these implications are specific to the case study area, the trend of ageing and the challenges that older people face at a time of natural hazard and evacuation, are common to wider international communities. At the time of Hurricane Katrina (2005), people who were 75 years old and older were the most affected population cohort (Brunkard, Namulanda, & Ratard, 2013). In many developed countries, regional/rural areas have similar issues with older people, who often do not own a motor vehicle and rely on their family or a community service for their mobility. The case study described in this research has revealed that the mobility issues of older people in a rural area are more critical at a time of disaster when travel becomes essential for survival.

We suggest that agent-based simulation is a useful tool in facilitating a discussion in the community on how collectively – local authorities and residents – they can best manage evacuation, by considering specific, local characteristics of terrain, topography and the demographics of residents. Whilst we have demonstrated the utility of an agent-based model for flood evacuation behaviour, an obvious extension of the research would be to test, on an identical road network, other open-source ABM platforms such as MATSim (Horni et al., 2016). Such a model evaluation would cover such criteria as software functionality, computational speed, software documentation, visual representations and so on. In this way, potential users of such evacuation models can be informed of the advantages and disadvantages of each ABM platform. As further behavioural research into the evacuations of older people becomes available in the literature then ABM assumptions can be further refined.

Postscript

As we were checking our revised manuscript, Typhoon the 10th was approaching Kagawa Prefecture on 15-16 August 2019. During the afternoon of the 15th August 2019 Takamatsu City Council (and Kagawa Prefecture) issued an evacuation warning to some communities concerning the risks of storm surge as high tide was approaching. About 160 people evacuated in Kagawa Prefecture at a peak time. One person was injured in Manno. The behaviour during this evacuation confirmed what we had previously discussed at community workshops in June this year: although people do not evacuate from their homes, they move their cars to higher grounds (e.g. parking at a shopping mall where the City Council has negotiated an agreement) so as to avoid their cars being submerged (lessons from 2004 storm surge). And then they walk home. Guidance on where to move cars was issued by the City Council on 14th August. In Manno Town, only 4 people evacuated and despite the fact that evacuation advice (one level lower than an evacuation order) was issued during the day and not at night. Awareness of risk still seems low.

Acknowledgements

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Appendix A

Probability of action using a Rayleigh distribution with a scale parameter δ is given as

$$p(t) = \begin{cases} 0, \text{ if } 0 < t < \tau \\ 1 - e^{\frac{-(t-\tau)^2}{2\delta^2}}, \text{ if } t > \tau \end{cases}$$

where, τ is delay time (Wang et al., 2016).

Appendix B

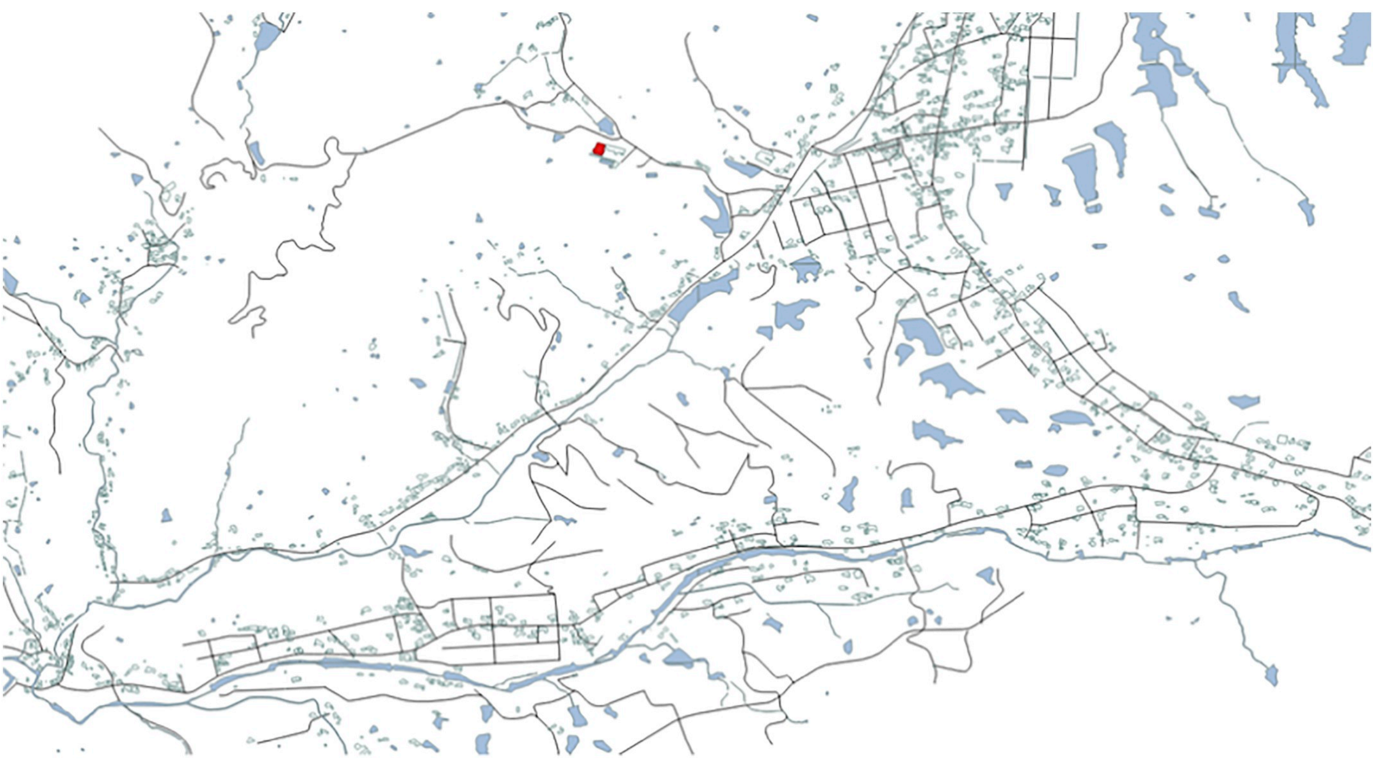

Fig. B.1. Location of shelter (Scenarios 1–4) (one shelter, highlighted in red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

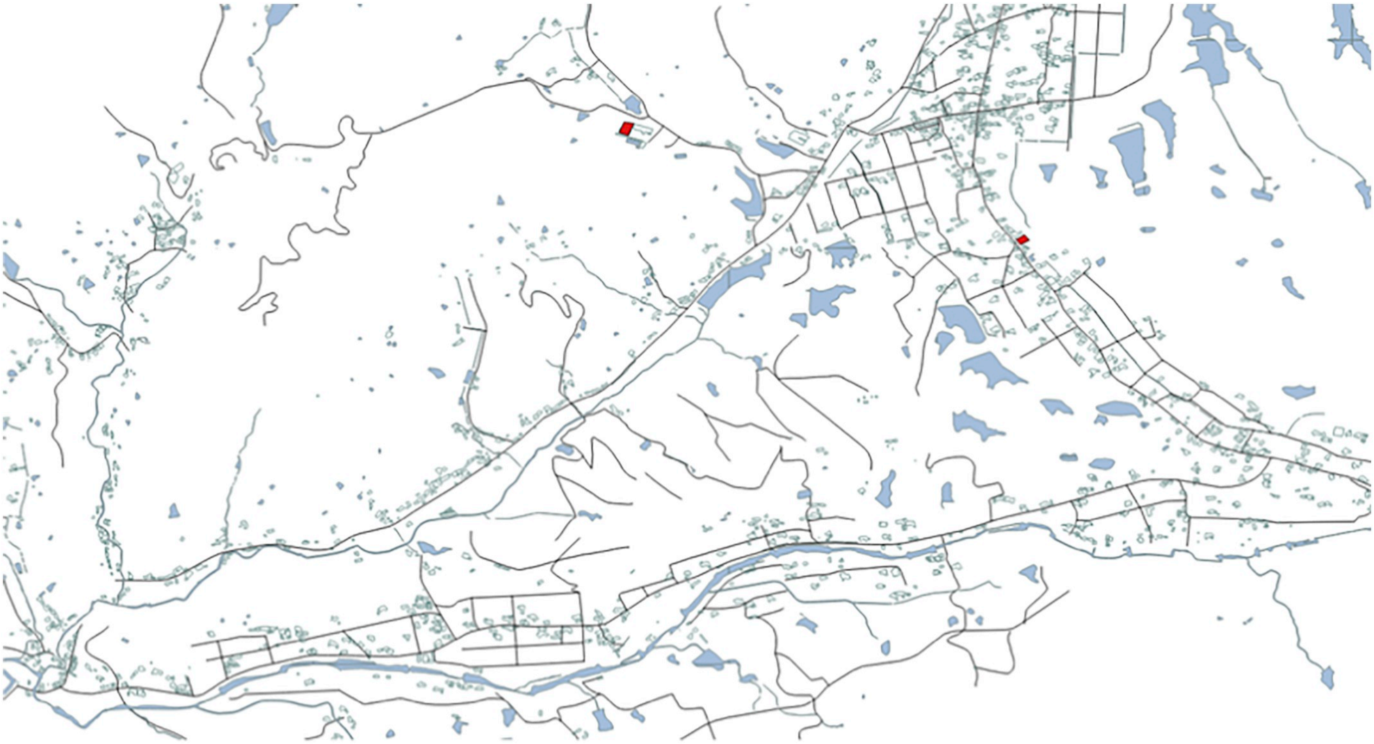

Fig B.2. Location of shelter (Scenario 5) (two shelters, highlighted in red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

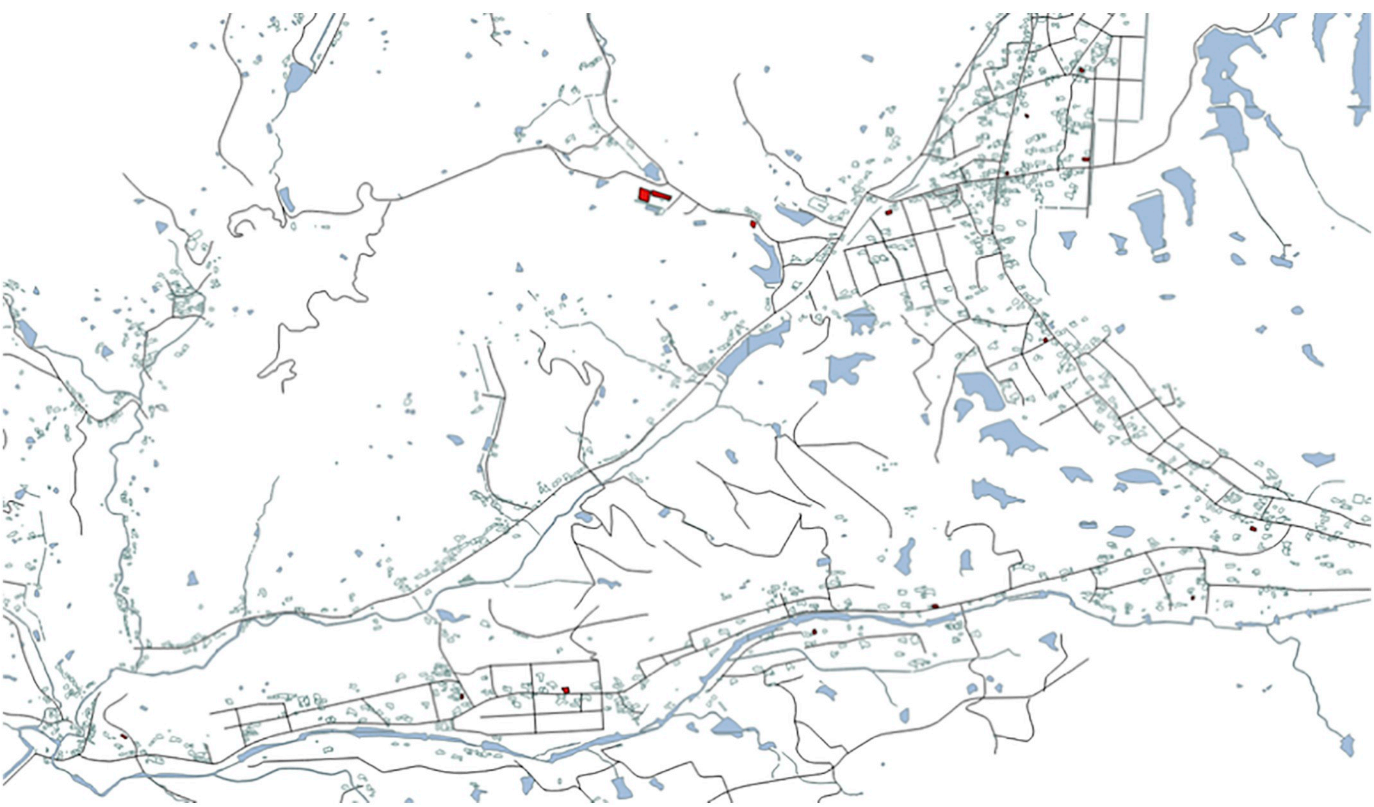

Fig. B.3. Location of shelters (Scenario 6) (fifteen shelters, highlighted in red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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