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Evacuation Simulation of the Elderly: Data Collection and Model Validation

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Abstract – The inclusion of human behaviour in fire engineering design increasingly utilizes egress modelling software to demonstrate the time required for evacuation in the case of a fire emergency. These models are being developed to incorporate aspects of social influence, account for variations in pre-evacuation times, and movement speeds. However, in order for these models to accurately represent an egress scenario, they rely on having access to a range of data, covering a variety of situations, populations and constraints. These models must also be validated to show that they can accurately represent possible human movement and behaviour. This paper critically examines a fire drill performed in 2016 at a retirement home in Canada and provides insights and guidance into modelling elderly populations, both in general and situations specific scenarios.

Keywords: Aging Populations, Fire Drills, Retirement Homes, Egress Modelling Software

1. Introduction and Background

Changing demographics, particularly aging populations, are creating new societal demands in global contemporary building design. Among this is a surge in the creation and retrofitting of purpose built homes for the aged. There are two types of these homes which are under consideration in the theme of aging populations: retirement homes and long term care (LTC) homes. In both types of homes, the elderly populations have various degrees of autonomy. Their populations are generally vulnerable in the sense that the residents have a reduced ability to avoid fire risk situations [1]. Based upon this increased risk, these homes are staffed with care takers whom have various degrees of responsibility to respond in emergency situations such as fire.

The demographics of each type of home are unique, and it is often common to lump the two as one in the same by many, however, they are distinct. LTC homes are typically reserved for residents whom require significant nursing and general care in regards to their mobility and generalized day to day tasks. Retirement homes may involve residents whom are at the initial stages of requiring significant levels of care from assisting care-taker staff. Both house aged populations, whereas the LTC homes include significant populations for those whom have advanced physical and/or cognitive impairments. A fire safe design and staff response has to accommodate these population diversities.

Within the last 15 years there have been numerous global fires which have resulted in life loss of the elderly in these types of homes for the aged. The foremost care home fire considered in literature and media has been Rose Park in the UK which resulted in 14 deaths in 2004 [2]. That fire was said to be influenced in break downs in procedure and staff response to the fire (details of which can be found elsewhere [2]). Within Canada the recent L'isle-Verte fire in 2014 highlighted over 30 deaths of residents and the deaths of

2 staff. In Canada alone in the last three years, there have been five fires in care and retirement homes, three of which resulted in loss of life [3].

At Carleton University, in collaboration with research partners, a recent study has been underway to develop a baseline for the behaviour and actions of elderly people during the pre-evacuation and movement stages of emergency egress situations. To date, preliminary results of four emergency drills have been provided by these authors elsewhere [3, 4]. These drills have seen a diverse range of staff participation, yet limited involvement of actual residents of the care homes, necessitating an extension of the work to consider movement baselines of residents. The drills suggested that the role of staff was significant in the adequate employment of evacuation procedures. Among previous observations these drills had highlighted: a limited communication between staff inside and outside the fire zone, generalized uncertainty among staff, and limited time spent checking for residents. The authors have previously critiqued the realism of these drills, and whether the prime objective of these drills were being met or if they were instead reinforcing flawed behaviour for the staff – particularly in the absence of realistic resident participations [3,4]. Additionally, previous work attempted rudimentary modelling using basic software which did not account for specific behaviours that residents of these homes would be known to display. Moving forward, it was hypothesized that for developing data which could competently inform the verification and validation of egress modelling software, future drills were needed with higher resident participation. This paper explores these research themes.

2. Methodology

2.1. Interviews and Fire Drill Observation

As part of an earlier research project, 14 LTC and retirement homes were contacted and asked if an interview with a senior staff member could be conducted regarding fire safety practices and procedures. The four interviews conducted at LTC homes and the initial interview conducted at the participating retirement home have been detailed elsewhere [3].

After the first interview, an inquiry was made to see if one of the retirement home's mandatory fire drills could be observed by the research team. The contact agreed and it was decided that a drill would be observed in mid-June of 2016. In May, a second meeting was held in preparation for the planned fire drill observation. This drill was to be the mandated annual drill observed by city fire protection officers. Ontario provincial law in Canada requires that this drill represent the worst case scenario for a fire emergency to take place, and requires that all residents in the fire zone evacuate (or have a staff stand in place of a resident if extenuating circumstances occur). As in previous drill observations there had been very little resident participation [3,4], this drill was chosen to ensure that resident data could be collected. For this retirement home, the worst case scenario involved three participating staff members (number of staff on the night shift), and took place on the floor of the home dedicated specifically to the care of residents with dementia as these residents would require the most assistance to evacuate.

On the day of the drill observation, four members of the research team met with the retirement home contact, fire protection officers, and participating staff members half an hour prior to the scheduled drill time. As residents could not give consent to be recorded due to their mental state, cameras were not used. Instead, the four research team members were present in the fire zone during the drill and recorded all observations by hand. The observation positions in the zone had been pre-determined after a critical analysis of the floor plan so as to minimize the impact the observers would have on the drill while maximizing the amount of data able to be collected. The team entered the fire zone along with one fire prevention officer, two supervising staff members and two participating staff members just prior to the drill commencing. Once the drill finished, the research team joined all drill participants (except residents) for a debriefing during which the details of the drill were discussed. Following this, the research team asked the three participating staff if they would be willing to answer a set of questions about the drill. All staff agreed.

To maximize the integrity and amount of information collected during the drill, the observations made by the research team were compared and compiled in a post-drill meeting. Due to the method of observation and data recording, it is acknowledged that not all elements of the drill were collected and a degree of variability exists. Alternative methods of data collection and observation are being explored for future drills.

2.2. Evacuation Modelling Validation Methodology

The data collected during the fire drills has been used in comparison with associated evacuation modelling results using the software MassMotion [5] as a validation case study. This comprised of performing three different types of evacuation trials using the software. The first trial was used to represent the evacuation observed during the drill. To do this, input parameters of the model were defined based on data recorded. This represents an informed validation test case where information from a trial has been used to configure the model. The second trial set was used to compare the data collected during the drill with existing data relating to similar population groups, namely, aging populations and care-type facilities based on data within standard fire design guidance. This represents a blind validation test case where only basic prior information of the drills is utilised within the initial model configuration i.e. occupancy numbers and location. Subsequently this represents a test case more akin to that which a fire safety engineer may choose to utilise during an evacuation analysis of such a situation. For this case a best, mean, and worst case scenario were simulated using range of values available within standard fire design guidance to identify the range of results using such data. The third trial consisted of incorporating a range of pre-evacuation and movement times as distributions within the software from the standard fire design guidance data which were randomly sampled. Consequently 10 repeat simulations of the evacuation scenario were conducted in order to produce a range of results of the randomly sampled input parameters. Analysis of all trial results were then used to explore the current challenges and limitations of evacuation modelling retirement homes.

Prior to observing the fire drill and running the above trials, the dimensions of the hallway in the retirement home were taken along with the depth of the resident rooms. These dimensions were used in correlation with a simple floor plan of the building provided by the home to create a SketchUp model of the fire zone. This model was then imported into MassMotion and used as the base geometry for the trials.

3. Discussion of Findings

3.1. Fire Drill Observation

A day prior to the drill, the residents and staff in the home had been informed that a drill would be taking place the following day. In general, it is the home's policy that notification be given to all residents before a drill that will include the fire alarm takes place (as opposed to a silent drill). In this specific case, this notification was also necessary to inform everyone that the drill was meant to test a specific situation (night shift, second floor) as opposed to a standard afternoon drill. This ensured that only the three staff participating in the drill would respond to the drill as opposed to the standard response with staff assisting from other floors.

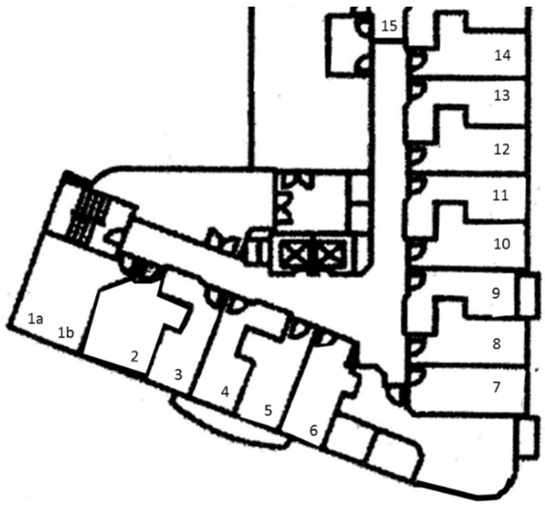
Though the drill took place during the afternoon, two of the three participating staff members normally worked on the night shift. They came in to partake in the drill as it was the night shift staffing level that the drill was simulating. The third staff member was also supposed to be from the night shift but due to unforeseen circumstances, a staff member from the day shift stepped in at the last minute.

During the pre-drill discussion, the fire prevention officers went over the retirement home's fire safety plan, and verified what was supposed to happen during the drill. As the officers were evaluating the home's ability to meet the time requirements and execute the steps depicted in the safety plan, the drill was more scripted than it would otherwise have been.

The fire drill took place on the floor of the retirement home dedicated to the care of residents with early on sets of dementia. Dementia results in a broad range of cognitive impairments of a person which can include inhibition of a person's to think, speak, interpret cues the surrounding environment and recall information. As such the residents involved in the drill depended heavily on staff during the evacuation which is described in further detail below.

The floor of the evacuation area was split into two compartments by a set of mag-lock fire doors. The drill observed was a horizontal evacuation during which the residents on the "fire" side of the doors were evacuated to the "safe" side of the doors. Three members of the nursing staff participated in the drill. Their role involved locating the fire; prompting, assisting and guiding residents to the safe zone; and ensuring that the fire zone was fully evacuated. In addition to the four members of the research team, three city fire prevention officers and two senior staff members observed the drill.

The fire zone was comprised of 14 resident rooms, a dining room, a sitting lounge and a nursing station. The designated fire room housed two residents and was located at the end of the hall, farthest away from the fire doors. Ten residents participated in the drill along with three staff stand-ins taking the place of particularly vulnerable or un-cooperative residents. Of the 14 resident rooms in the fire zone, two were vacant at the time of the drill. The mobility level of the participating residents, along with the location of the fire room, the safe zone and the occupied rooms can be seen in Figure 1 below.



Legend: Occupant Details and Mobility

Fire Room: 1a, 1b
Safe Zone: 15
Vacant Rooms: 11, 12
Residents with a Walking Aid: 1b, 3, 6, 8, 9, 10
Residents in a Wheelchair: 1a, 14
Residents without a Walking Aid: 2, 5
Staff Stand-In: 4, 7, 13

Fig. 1: Fire Zone Floor Plan

The drill ended 13 minutes and 33 seconds after the alarm first sounded. The alarm stayed on for roughly 5 minutes after which the drill continued without the use of the alarms. According to the general manager of the home, this was done to prevent causing further stress to the participating residents, as well as to cause less of a disturbance to the residents in the rest of the building. During the drill, three residents exhibited information seeking behaviours, either exiting their rooms or opening their room doors to observe. The one resident who left her room walked to the fire door after asking one of the participating staff what to do. This resident stood at the fire doors without exiting them for 20 seconds, and was then escorted back into her room by a staff member who was participating in the drill. This resident was then evacuated approximately three minutes later when one of the participating staff members prompted and walked with her to the fire doors. This prompting and guidance on the part of the staff was seen in all of the resident evacuations. Even the residents who were physically able to move on their own did not evacuate until a staff member went to their rooms, prompted them to leave, and walked with them to the fire doors. The one exception was the resident mentioned above who initially left her room by herself. As the goal of the drill observation was to collect movement times and behavioural data, the research team recorded a specific set of time stamps. These included when: the staff entered the resident rooms, the staff left the resident rooms, the residents left their rooms, and when the residents reached the fire doors and exited the fire zone. The latter two of these time sets are presented in Table 1 below, along with the overall travel times. From this table it can be see that it took the residents between 20 and 63 seconds to travel from their room to the fire doors. One note to be made is that Resident 1b exited the room 19 seconds before Resident 1a, and exited the fire zone 7 seconds after Resident 1a. However, as both residents moved down the hall together with a staff member, the time it took the residents to reach the fire doors was taken to be 39 seconds.

Table 1: Resident Travel Times

Room	Time Exiting Room	Time Exiting Fire Zone	Overall Travel Time (seconds)
1a 1b	4:06 3:45	4:45 4:52	39 39 (67)
2	2:34	3:17	43
3	10:16	11:19	63
5	5:17	5:37	20
6	6:07	6:42	35
8	6:45	7:18	33
9	5:17	5:37	20
10	8:01	8:27	26
14	8:50	9:05	15

The fire room was located at the end of the hall farthest away from the fire doors and as such the residents were meant to be evacuated sequentially, starting with those in the fire room and then moving on to rooms closest to the fire room and so forth. This was generally the order which was observed during the drill, with a few exceptions. The most notable of these exceptions was that the resident in Room 3 was not evacuated from the room until 10:16, after all other residents had been evacuated from the fire zone, despite being two rooms over from the fire room. A staff member had been noted going into the room at 3:30, and remaining inside the room for 23 seconds before exiting without the resident. This same staff member entered the room again at 9:27 and left with the resident 49 seconds later. Upon leaving the room with the resident, the staff member was heard telling the resident that she was not supposed to hide in the bathroom.

As per the retirement home's fire emergency procedures, the resident rooms were to be checked a second time after the initial sweep and evacuation of the rooms. During this second check the staff were supposed to hang a sign on the resident door handle to show one of two things: that either the resident was no longer in the room, or that assistance was needed and a resident was still inside. This check was completed predominantly by one staff member, staring roughly 9 minutes into the drill. A second staff member also began to check rooms at roughly 3 minutes later. In these secondary room checks, the staff member went into or looked into each room for between 3 to 10 seconds. This staff member checked all rooms in this way with the exception of one. In this case, the staff member just hung an all clear sign on the door handle and moved to the next room. While all other rooms checked by this staff member had already been evacuated, a resident and staff member were in the unchecked room. As discussed earlier, this was the resident who had not been evacuated during the first room sweep. The all clear tag was hung on the door at 9:58, and the resident and staff member within left at 10:16.

3.2. Data Validation and Egress Modelling

The first trial run using MassMotion simulated what occurred during the observed fire dill, with the exception that agents representing the staff were not included. As the resident egress was almost exclusively dependant on the interaction between the residents and the staff, a set of purely resident-based pre-evacuation times and walking speeds were unable to be collected. However, given the specific time stamps that were recorded (staff entering rooms, residents and staff leaving the rooms, residents exiting the fire zone), a ***situation specific*** set of pre-evacuation and movement times could be defined. To determine the pre-evacuation time of each resident, the time it took for a staff member to enter the resident's room, and the time that the staff member was in the room with the resident before leaving the room with them were combined. The walking speeds of the residents were calculated using the time it took the residents to travel from their rooms to the fire doors and the distance each resident travelled. This distance was calculated by measuring the path deemed most likely traversed using the created floorplan. Once the pre-evacuation time and walking speed for each resident was determined, these values were used directly create a scripted trial representative of the actual drill. A visual depiction of this can be seen in Figure 2 below. The trail was run and the overall evacuation time for each resident was compared to the time observed. The overall evacuation times for each room determined by the trail were similar to those seen in the actual drill, with minor variations. The times predicted by the trial tended to be longer than the observed times. The main reason for this is most likely due to the fact that the times from the observed drill were recorded when the resident left the room, whereas in the model, the agents start on a portal at the back of the resident room. Therefore, more time is required in the model because the agents must travel from the portal to the exit of the room as well. It was decided that the portals be placed at the back of the rooms as continuity between the three trial sets was required for comparisons and this placement made the most sense overall . The time discrepancies could also have resulted from the fact that the path chosen by the agents in the model may not have been the same as the paths taken by all of the residents during the drill (as was observed during the drill observation). See Figure 2 below.

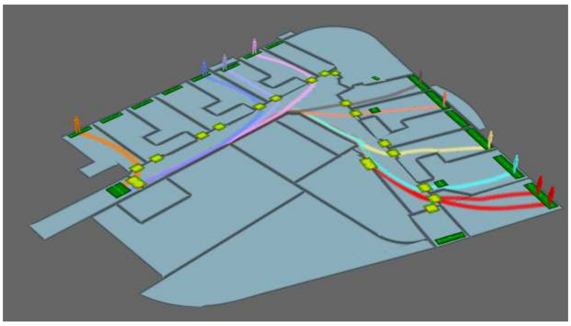


Fig. 2: MassMotion First Trial Set Simulation

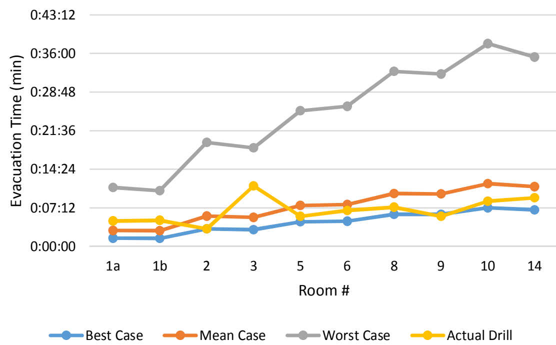


Fig. 3: Evacuation Timeline Comparison for Second Trail set

The second test set consisted of three different trials, representative of a worst, mean, and best case scenario. The data used for this was chosen from 2015 SFPE Handbook [6]. A number of data sets within the handbook were considered, and it was decided that for the pre-evacuation times, the data from Gwynne et al.'s paper [7] was the most appropriate for comparison, and for walking speed, Boyce et al.'s data [8] was the most appropriate. The first data set was deemed most appropriate as it involved staff and patients at an outpatient hospital and therefore most closely represented the interaction and dependency of residents on staff. The second data set was determined to best represent the data as it dealt with people with physical handicaps and/or movement aids, which was seen in the retirement home. The first data set proved a range of pre-evacuation time for staff (Mean: 50.8 seconds, Range: 30-66 seconds) and outpatients (Mean: 44.1 seconds, Range: 16-91 seconds) in an outpatient hospital. The second data set comprised a range of walking speeds for people with various mobility aids. The speeds for people moving with a walking frame was chosen to be most representative (Mean: 0.57 m/s, Range: 0.10-1.02 m/s) as 60% of residents observed in the drill used a walking frame. As each data set provided a range of times/speeds, as well as a mean time/speed, the three cases were created as follows: the worst case used the longest staff and outpatient pre-evacuation times from the first data set, and the slowest walking speed from the second data set. The other two tests were created in the same manner only using the mean values, and lastly, the shortest pre-evacuation times and fastest walking speeds. As the evacuation situation observed during the drill was very much dependant on the staff walking with the residents, these three trials were scripted to represent what would happen if you had two staff members evacuating all of the residents, moving down the hall away from the fire room. Therefore, the pre-evacuation time for the fire room included the staff pre-evacuation time and the resident pre-evacuation time; for the all subsequent rooms, the pre-evacuation time included the time required to evacuate all rooms preceding the room in question in addition to the time required for a staff member to walk back from the fire doors to the room. The walking speed chosen for the staff when walking without a resident was kept constant during each of the three trials and was set to 1.35 m/s, the default walking speed in MassMotion (representative of the average walking speed of the general populous). Once the three trials in the second set were run, they were compared to the first trial set representing the observed drill. The comparison was made showing the times of when each resident evacuated the fire zone and can be seen in Figure 3 above. It was found the times observed in in the drill fell predominantly between the best case and mean case scenarios. There were a few exceptions, the most notable being the room in which the resident was initially missed (see Section 3.1). The evacuation of the fire room was also outside of this range, however to a lesser degree. The technical difficulties which delayed locating the fire room most likely contributed to this. It should be noted that the large difference in times between the worst case scenario and the mean and average case scenarios is in part due to the set-up of the trials. Because the trials were scripted to represent a sequential evacuation and the pre-evacuation time of each room was dependant on how long it took to evacuate the previous rooms, the much slower walking speed, 0.10 m/s second played a large role in the overall evacuation times.

The third set of trials set out to show what could and could not be modelled given the current information known and MassMotion's software's capabilities. The study serves as a preliminary analysis to identify the extent to which the software is capable of representing key aspects of the evacuation process with little configuration utilising prior information from the drills. Using the same sets of pre-existing data from the 2015 SFPE Handbook that was used in the second set of trials, a scenario was created which incorporated a range of pre-evacuation and movement times for each agent, allowing for variability within the outcome. As the previous set of trials had shown that the actual drill fell predominantly between the mean and best case times, these were the sets of data used to create these ranges. The upper bound of the range for each room was determined assuming that all rooms prior to the one in question had taken the average time to evacuate (using the mean pre-evacuation time and mean walking speed). The lower bound was determined assuming that all previously evacuated rooms took the least amount of time to evacuate (shortest pre-evacuation time, fastest walking speed). As in the second set of trials, the staff walking speed when not accompanied by a resident was set to be 1.35 m/s and this was used to determine the time required to walk from the fire doors to each room and was incorporated in the pre-evacuation time. This method of using a range of possible times was required to allow for the variability that would need to be accounted for when trying to use egress modelling software to model what might happen in such a scenario. Without this, the model would be scripted much like the two earlier trial sets. However, this method does create a scenario where the range of pre-evacuation times and walking speeds for each resident increases as you move farther away from the fire room due to the growing difference between the upper and lower bounds. In order to have a more accurate depiction of a scenario such as this, the software needs to be able to account for situations where the behaviour and movement of one agent is dependent upon the behaviour and movement of another. This third test scenario was run ten times so as to have a variety of evacuation times for each room. The average evacuation time for each resident was calculated from the trials and compared to the times from the first trial. This can be seen below in Table 2. It is apparent from this comparison that there is a degree of variability between what the model predicted and what was observed during the drill. Similarly to the second trial set, the comparison also shows that the behavioural anomalies which were observed during the drill (technical difficulties, not evacuating a resident during the first room sweep), can play a large role in the outcome of the duration of an evacuation. It is also important to note that the compatibility of the data that the actual drill was being compared to also affect the validity of the model's output.

Table 2: Trial Three Data Comparison

Room	Average Evacuation Time (minutes)	Actual Drill Evacuation Time (minutes)	Time Difference (minutes)
1a	2:09	4:45	2:36
1b	2:16	4:52	2:36
2	4:25	3:17	1:08
3	6:19	11:19	5:00
4	8:03	5:37	2:26
6	9:56	6:42	3:14
8	11:28	7:18	4:10
9	13:29	5:37	7:52
10	14:09	8:27	5:42
14	15:43	9:05	6:38

4. Conclusions and Further Work

Having observed four LTC home fire drills and now one at a retirement home, a number of comparisons can be drawn. As noted in the LTC home drills where a large number of staff participated, there seemed to be a general sense of confusion about what to do. In contrast, while only three staff members participated in the retirement home drill, the process of the evacuation ran more smoothly, with the staff seeming to know how to respond. This brings in to question the belief that more staff members are better and raises the thought of finding an optimum number of staff responders; one which ensures there are enough staff to evacuate residents in a safe period of time, but also realizes that too many staff can be the cause of confusion if not appropriately trained/organised. A second point to be made is the importance of checking resident rooms thoroughly. It had been previously observed that time spent by staff going into and ensuring that rooms were vacant did not seem long enough to ensure that residents would not be missed if hiding. This too was observed in the latest drill and its importance became all the more apparent as a resident was indeed missed during the first sweep of the rooms. Lastly, this retirement home drill was specifically chosen by the research team as, given the provincial requirements, more resident participation than seen in previous drills would be almost guaranteed. This was important as the previous drills had provided little data on the actual resident behaviour and movement, and instead gave more insight into the staff behaviour. However, despite having 10 residents participate, most of the information was collected about the staff yet again as the residents did not evacuated until prompted and guided by the staff. While this data is very useful for the purpose of understanding what happens during an evacuation in a LTC or retirement home, it's applicability for use of understanding the behaviours and movement of aging populations in a more general sense is very limited. This is due not only to the fact that the resident behaviour and movement was dependant on staff, but also because the residents observed had some form of dementia.

From the modelling trials executed in this project, it can be seen that further work is required both on the modelling and available data side of things. As shown by the preliminary tests in the last trial set, modelling an evacuation in a LTC or retirement home is very challenging at the moment, and if it is attempted, a large amount of variability and uncertainty will exist. This is due to the fact that the software cannot currently create a model where the pre-evacuation times and movement times of an agent/s are directly dependant on that of other agents. This type of scenario, where the actions of some directly determine the actions of others is a concept not only relevant LTC and retirement homes, it is also important in places such as schools, museums, hospitals, restaurants, etc. While the software cannot currently model these types of interactions, steps are being taken to move in this direction.

Heading forward, the research team is in the process of finding ways to collect more data about aging populations when not directly influenced or dependent upon staff, looking at both emergency and non-emergency situations. Further information about resident behaviour in LTC and retirement homes is continuing to be collected to further inform designers so that when modelling software reaches the point where it can more accurately model such environments, they can make informed decisions about what might happen outside of what can be modelled.

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