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Evaluating Transport Technologies for Mitigating the Impact of Emergency Events: Findings from the SAVE ME Project

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Abstract

The EU FP7 SAVE ME project investigated the potential for innovative technological systems to initially detect and categorise disaster events in transport infrastructures, before supporting quick and efficient mass evacuation guidance of travellers as well as optimising actions of rescue teams. This paper presents the results of two evaluation tasks which assessed the desirability of having such systems in place. The first task involved professionals from a range of industrial sectors who undertook a multi-criteria analysis of six key SAVE ME components with respect to seven individual criteria; our results indicate that intelligent tools to assist rescue personnel and operators were deemed most desirable. The second task applied a series of analytical frameworks to ascertain how members of the general public (who took part in the pilot trials) found using the technologies developed in SAVE ME. Here our results indicate that under actual emergency situations, people would be cautious about putting their full trust into technology and would want simple, easy-to-understand and dynamic information to help them self-evacuate as quickly as possible.

Keywords: *Safety and Security; Intelligent Evacuation Guidance; Evaluation; AHP*

1. Introduction: Developing Safe and Secure Transport Networks

Transportation networks across the world are used by millions of people on a daily basis and are vital to national economies. However, these networks can be subject to disruptions, either from natural disasters or from incidents caused by human actions, be they deliberate or erroneous. The main weak points in transport networks can be identified in 'closed' areas, such as a metro station or long highway tunnels as within these critical infrastructures there are many individuals in close confinement who have access to a limited range of exit options [1]. If an incident does occur at these points, minimising the time taken to evacuate can mean the difference between life and death, but this requires rapid recognition of the situation, appropriate response and evacuation strategies by all individuals. [2].

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1.1. Transport Incidents and their Aftermath

Collisions in road tunnels, particularly those which result in fires, can have significant consequences not only during the incident but longer-term through disruptions to the wider transport system. A chronology of road tunnel collisions from 1979-2012 [3] illustrates the variety and scale of incidents that can occur. Whilst most road tunnel incidents involve a small number of individuals and vehicles, there have been some notable incidents, such as in the Mont Blanc Tunnel (1999) where a fire in the engine of a truck carrying flour and margarine burnt for 53 hours, reaching temperatures of almost 1000oC causing support structures in the tunnel to collapse. As a result, 39 people died and the wider economic impact totalled €200million as the tunnel could not re-open to traffic until March 2002. A collision in the Gotthard Tunnel (2001) between two trucks caused a fire in which 11 people died – some of whom remained in their vehicles and were overcome by smoke and fumes – with a total repair bill of around €12 million.

In light of these (and other) events, EU Directive 2004/54/EC [4] entered into force on 30 April 2004 which requires all tunnels longer than 0.5km on the Trans European Road Network to meet minimum safety requirements. An over-arching objective of this EU directive is to prevent accidents endangering human life, the environment and the physical tunnel installations. Furthermore, the EU directive has a specific aim of improving self-rescue conditions for people involved in serious incidents, to which this paper will return in a later section.

Transport networks, and in particular Public Transport systems, are also key targets for terrorist activities [5] as they are open systems which provide easy access and escape options for the terrorists who can subsequently intersperse into congregations of strangers to provide anonymity. Large crowds in densely packed environments are highly vulnerable to both conventional explosives and unconventional weapons, and a solo attack in one location can cause alarm and disruption across an entire transport network which can paralyse a whole city. Even the implied threat of an attack can be enough to cause significant problems whilst the threat is assessed and necessary actions taken.

Recent terrorist attacks have caused multiple fatalities as well as having strong political and societal consequences, especially if they are not rapidly dealt with in the most appropriate manner. The July 7th 2005 attacks in London illustrated just how important robust communications are in minimising the wider impact of a terrorist attack. A subsequent report produced by the ‘7 July Review Committee’ [6] criticised poor communication between emergency workers in the aftermath of the attacks. The report found that there were failures of communication both between and within the individual emergency services, whilst rescuers above ground level could not contact colleagues working underground as there were no systems in place which would have enabled communication below ground level. There was also an over-reliance on mobile telephones when it was widely recognised that mobile networks often become congested after a major incident occurs.

1.2. Incorporating User Needs into Disaster Mitigation Strategies

Transport incidents can have catastrophic consequences and enhancing self-evacuation through appropriate training and guidance has been shown to be one of the most effective means of mitigating the impacts [7] - however this solution is only directly applicable to those individuals who can do so. During an emergency incident, there are many users with specific needs which have to be taken into consideration when determining optimal rescue and recovery strategies. For example, older people are typically slower to react, slower in their movements and can be easily disoriented; disabled travellers face specific issues if they need to rely upon accessible escape routes which may not be in the same direction as routes used by the general masses, and may have to get to a safe refuge point to await rescue [8].

Children also fall into this ‘vulnerable users’ category as they may become separated from their families or guardians during an incident and as “[c]hildren under 18 usually constitute at least 50 per cent of the population affected by an emergency… any response which does not take into account children’s issues fails a substantial proportion of the affected population” [9]. The specific needs of these vulnerable users should therefore be integrated into any disaster mitigation system from the outset, including specific behavioural and movement limitations which can impede their escape.

1.3. Managing and Mitigating Transport Incidents

Effective mitigation of incidents is about having the right people in the right place at the right time, which is difficult to achieve at times of uncertainty and confusion. Previous research [10] has also identified that different emergency services do not always collaborate effectively during an incident as this could lead to uncertainty and asymmetries in operational practice and, somewhat surprisingly, did not happen due to a lack of incentives (*e.g.*, lack of personal recognition for efforts, fear of appearing incapable in an emergency). Nevertheless, efficient communication is recognised as a valuable rescue tool that will increase safety, save time and more importantly save lives [11-13].

Another important tool for rescuers is effective guidance systems to reach travellers in greatest need of assistance and rescue. Eliminating the need to both find and authenticate isolated people greatly reduces the direct personal risk to rescuers, thus helping to take the ‘search’ element out of ‘search and rescue’. Environmental monitoring is of crucial importance, as an accurate assessment of all hazards (actual and potential) may not be possible as they may not be immediately obvious or identifiable. Rescue personnel may be selecting erroneous protective measures due to limited information yet having access to correct and accurate information through Knowledge Management Systems has been shown to greatly improve the efficiency of responses to natural disasters [14] and the same can be said for mitigating emergency incidents occurring in critical transport infrastructures.

2. The SAVE ME Project

To begin addressing some of the aforementioned issues relating to uncertainty in transport incidents and improving the mitigation processes, SAVE ME [15] was a three-year (2009-2012) research and development project co-ordinated by Newcastle University involving 11 partners from six individual EU countries, funded under the EU FP7 Sustainable Surface Transport programme.

As illustrated in Figure 1, the key focus of the project was to understand how different technologies and applications could be integrated to support the evacuation process during a transport emergency. The overarching aim of SAVE ME was to save the lives of the general public, giving particular emphasis to the most vulnerable travellers, whilst also ensuring rescue operations were prioritised and thus carried out efficiently.

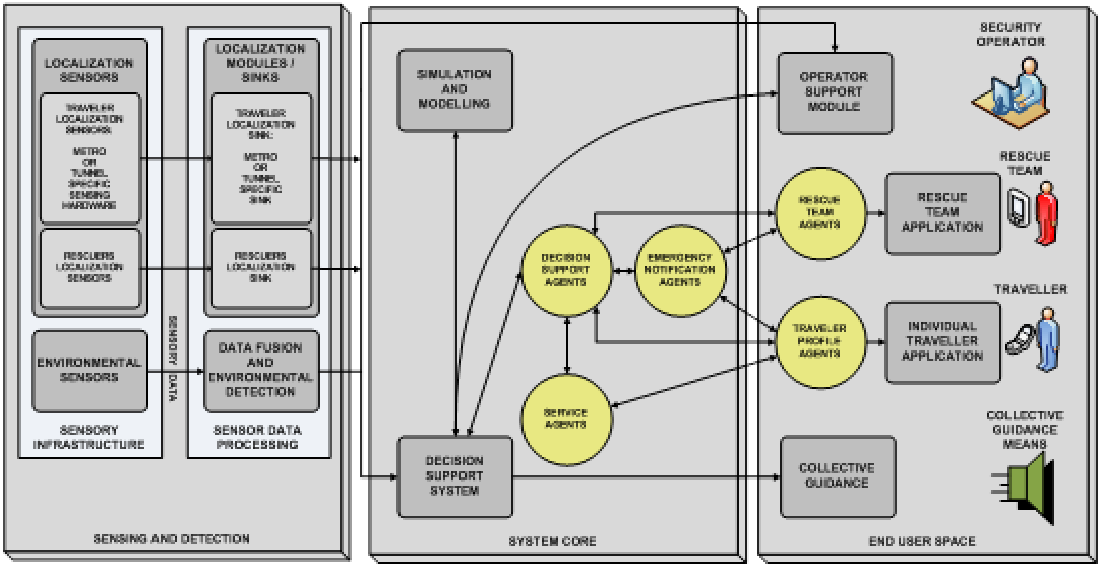

Figure 1. SAVE ME System Architecture

3. Industry Professionals' Evaluation of the SAVE ME System

To help identify the potential desirability of the SAVE ME system, a multi-criteria analysis of six key SAVE ME components with respect to seven criteria was carried out utilising the Analytic Hierarchy Process (AHP), a methodology originally proposed and developed by Thomas L. Saaty in the 1970s. AHP is a valuable tool in decision making, especially where a range of options are available, multiple criteria are involved and many people are concerned in reaching a unanimous decision, yet all may have differing views, opinions and objectives on the task in hand. Instead of determining which potential option is the 'correct' decision per se, the application of AHP produces a conclusion which best suits all goals based on the understanding of each individual about the task in hand.

The AHP methodology is based on three key principles, namely: 1) construction of the hierarchy, 2) allocation of relative weightings and 3) checks for logical consistency. For further information, Saaty goes into great detail on the mechanisms behind the entire AHP process [16]; this paper sets out to provide a high-level overview of the AHP process, with descriptions of the adaptations made specifically for the purpose of simplifying the inputs for respondents in an online data gathering exercise.

3.1. The Analytic Hierarchy Process (AHP) in Transport

As AHP offers a suitable framework for almost any decision making activity it has been applied in many different ways within the transport domain, such as infrastructure, future planning or purchasing decisions [17], operations management [18] and the evaluation of future transport strategies [19,20]. Previous work has applied AHP specifically for the application of decision making pertaining to safety-related projects, for example to prioritise ISA policies [21], understand underlying factors affecting road traffic safety [22] and to prioritise railway maintenance actions [23]. Perhaps of closest relation to the work undertaken by SAVE ME was the ADVISORS project [24] which utilised AHP for prioritising ADAS options to address an evaluative objective very similar to that required of the SAVE ME project.

3.2. Constructing the Hierarchy

AHP hierarchies typically have three main levels, although nested models can also incorporate sub-levels where desired. In terms of the SAVE ME exercise, the overall goal (top level of hierarchy) was to identify the individual SAVE ME components which would potentially be the most desirable/effective across seven individual criteria (middle level of hierarchy) as defined by expert advisors to the project. These criteria were:

A) Efficiency of emergency response unit, defined as the time (in seconds) in detecting a trapped person and in providing support to this person; B) Safety and security of the emergency response unit, defined as the probability of the emergency response unit becoming trapped or injured/fatally injured during the evacuation operation; C) Safety and security of all travellers, defined as the probability of a trapped traveller becoming trapped or injured/fatally injured during the evacuation operation; D) Safety and security of vulnerable travellers, defined as the probability of vulnerable travellers, i.e. older, mobility impaired or children being trapped or injured/fatally injured during the evacuation operation; E) Efficiency of supervising operators, defined as the time needed by the operators to locate a trapped person then dispatch and guide the emergency unit accordingly; F) Enhancement of use of PT due to higher public trust, defined as an increase in the number of journeys per person, and/or total annual increase of journey tickets through greater safety awareness; G) Jobs and revenue creation, defined as defined as the number of jobs or percentage of GDP expected to be created annually.

There were six individual SAVE ME components considered in the AHP exercise (bottom level of hierarchy): 1) Decision Support System (DSS), the central core of the system which determines appropriate mitigation strategies based on a variety of data inputs; 2) Operator support module (OpSuM), which assists the control room in managing the incident; 3) Rescuers guidance module (ReGuM), which helps the emergency response team navigate their way to trapped travellers and return to safety; 4) Individual guidance module (InGuM), a mobile-based system designed to assist self-evacuation through personalised information based the individual's location and physical limitations; 5) Collective guidance module (CoGuM), a screen-based system designed to provide evacuation guidance on a more generic level; 6) Training tools, scenarios and curricula (TTS&C), methods and materials required to help individuals learn how to use and apply the relevant SAVE ME modules described above.

3.3. Allocation of Relative Weightings: A Revised Approach

Once all criteria and alternatives had been identified and the hierarchy constructed, the next stage in the process was to assign relative weights to the criteria, which is usually achieved by applying pairwise comparisons. Traditionally, these comparisons are based on the scale given in Table 1, whereby the relative importance of criterion A is ranked against criterion B, C, D, … X, then criterion B is ranked against criterion C, D, E … X and so on. Each alternative is then ranked against the other alternatives with respect to their relative importance/contribution towards each individual criterion in turn, *i.e.*, 'for criterion A, how much more important is alternative 1 thought to be compared to alternative 2?'

Key criticisms directed at this approach are that such comparisons are potentially subjective, in particular for qualitative items which are often found in transport projects [25]. For those completing the weighting, there are $\{n(n+1)/2\}$ comparisons to be made which becomes a cumbersome task when $n>5$ and might not produce a consistent set of weightings, which is critical for the validity of the overall AHP result [26].

Table 1. Relative Weighting Scores Typically used in AHP Exercises

Score	Definition
1	Both criteria are equally important
3	Criterion A is moderately more dominant relative to the other criterion
5	Criterion A is strongly more dominant relative to the other criterion
7	Criterion A is very strongly more dominant relative to the other criterion
9	Criterion A is extremely more dominant relative to the other criterion
2,4,6,8	Intermediate values, when a compromise is required
1/n	Reciprocal values are used when Criterion B…X is more important than A

As SAVE ME utilised seven individual criteria and six separate SAVE ME components as alternatives, it would require a total of 147 individual comparisons to be made using the traditional approach. It was clearly going to be an arduous task for anyone to complete the various tables effectively and consistently, which is important for the validity of AHP output to be determined. It was therefore decided that a different approach would be needed in order to allow respondents to provide valid weightings but without being overwhelmed by the size of task asked of them.

For the weighting of the criteria, an importance scale from 0-100 was established. Participants were asked to initially consider all criteria and determine which one they felt to be most important and score this out of 100. They were then asked to identify their second most important criterion and score this out of 100, repeating this process until all seven criteria had been addressed. If two criteria were of equal importance, participants were permitted to given identical scores.

For the weighting of the individual SAVE ME components w.r.t. each criterion, participants were asked to follow a similar exercise where they considered how important each SAVE ME component would make in meeting the first criterion and provide a score from 1 (No Contribution) through to 10 (Critically Important Contribution). This was repeated for each subsequent criterion until all had been assessed and the output from all comparisons were converted into a corresponding value on the original pairwise comparison scale using a look-up table (Table 2). For the individual criteria comparisons, this was achieved by subtracting the corresponding scores. For the comparison of alternatives w.r.t. each individual criterion, the relative ranking scores were multiplied by 10 and the difference between the two was then taken.

The benefit of this approach was that participants were still considering the relative importance of each criteria or alternative, but by returning one list of importance scores they did not have to go through the repetitive task of comparing all combinations which had the advantage of ensuring consistent comparisons between individual criteria and alternatives.

Table 2: Weighting Scores Conversion Table used in SAVE ME AHP Exercise

Value of (A-B)	AHP Pairwise Score	Value of (A-B)	AHP Pairwise Score
-100 to -88	1/9	-10 to +10	1
-87 to -77	1/8	+11 to +21	2
-76 to -66	1/7	+22 to +32	3
-65 to -55	1/6	+33 to +43	4
-54 to -44	1/5	+44 to +54	5
-43 to -33	1/4	+55 to +65	6
-32 to -22	1/3	+66 to +76	7
-21 to -11	1/2	+77 to +87	8
		+88 to +100	9

3.4. Calculation of Priorities for the Criteria and Alternatives

Once all AHP matrices were completed, the next stage was to calculate the relative priorities of each criterion, and each alternative w.r.t. each individual criteria, using eigenvectors and eigenvalues. A robust approximation of this approach is achieved through the calculation of the geometric mean for each row within a matrix, then normalising the values within the resulting vector to give the overall priorities for each item within the matrix [27]. This process generates relative priorities but these can be questionable if the decisions made are not consistent *i.e.*, if A > B, and B > C, then A must be > C.

In AHP, a check on the consistency of the pairwise comparisons is made using matrix algebra to calculate a value, max, and from this a Consistency Ratio (CR) can then be determined. If the resulting CR value was > 0.1, values in the matrix are revisited to check for any errors, and then pairwise comparisons are assessed to identify where the inconsistency(ies) appear. As the process utilised for the SAVE ME AHP involved a single list of ranks based upon a prioritised list instead of the typical pair-by-pair process, consistent decisions were almost guaranteed, thus reducing the risk of erroneous AHP outputs.

3.5. Final Calculation of Overall Priorities

The final step in the AHP calculation is to combine all priority vectors from each matrix to produce the overall priority vector. The resulting vector is the overall priority weighting vector, representing the relative importance of each alternative when taking into consideration the relative weightings of all criteria, as well as the contributions each alternative makes to these criteria.

4. Results from the SAVE ME AHP Exercise

Following the 2nd International SAVE ME workshop in June 2012, respondents were sought from the list of workshop attendees, thus ensuring they had familiarity with SAVE ME and the individual system components. An online survey was set-up to gather the inputs needed for an AHP calculation and the URL was distributed to selected workshop attendees. Nine valid responses were received covering the views from a wide breadth of sectors, including emergency service personnel (police), industrial research organisations, public transport providers, professional industry forum and local authorities (resilience planning units), thus giving a diverse set of views and opinions about the relative merits of the SAVE ME system and its components.

The aforementioned AHP methodology was applied to all responses and the geometric mean was taken to generate the final values reported in the following sections. This aggregation across the entire set of respondents is recommended [28] to ensure all viewpoints are accounted for in the final outputs without incurring any bias. Although the final priority vector is the ultimate output from an AHP exercise, the priority vectors from each matrix are also of importance and will be discussed here.

4.1. Relative Importance of Individual Criteria

As shown in Figure 2, ‘Safety & Security of All Travellers’ ranked highest (0.195) which is encouraging as this supports the overall rationale of the SAVE ME project. ‘Safety & Security of Vulnerable Travellers’ was found to be less important (0.164), and respondents did question whether vulnerable travellers should actually be treated any differently to ‘ordinary’ travellers in an emergency. This raises an interesting debate on definitions of traveller categories during an emergency event: if an able-bodied person or ‘normal’ traveller becomes injured or trapped, thus becoming a ‘temporary’ vulnerable traveller, should their immediate needs take less of a priority than someone who has a permanent impairment and would always be categorised as a vulnerable traveller?

The criterion in second place (0.175) was the efficiency of the Emergency Response Unit (ERU) and not the safety of these personnel, which only ranked fifth (0.148). One thought here is that although the safety of personnel is clearly of importance to the overall rescue operation, they are highly trained experts in their field who have a critical and professional role to play in successfully managing and mitigating an emergency situation. In the context of the SAVE ME project, enhancing efficiency is potentially of greater value as this would have the advantage of reducing the time emergency personnel are exposed to dangerous and uncertain situations, thereby also improving their personal safety

Efficiency of operators (0.149) was thought to be of medium importance, possibly related to the fact that operators often hand-over control of emergency situations to the rescue services and so would have less overall responsibility. ‘Enhancement of use of PT due to higher public trust’ (0.123) and ‘Jobs and revenue creation’ (0.045) were of least importance; for the former, it can be said that some people have no choice but to use Public Transport services so improving safety perceptions might only have a slightly positive impact on their trust in the system. For the latter, it was very clear that the creation of jobs and revenue through a SAVE ME system is not a priority and that the safe and successful mitigation of an emergency must take priority.

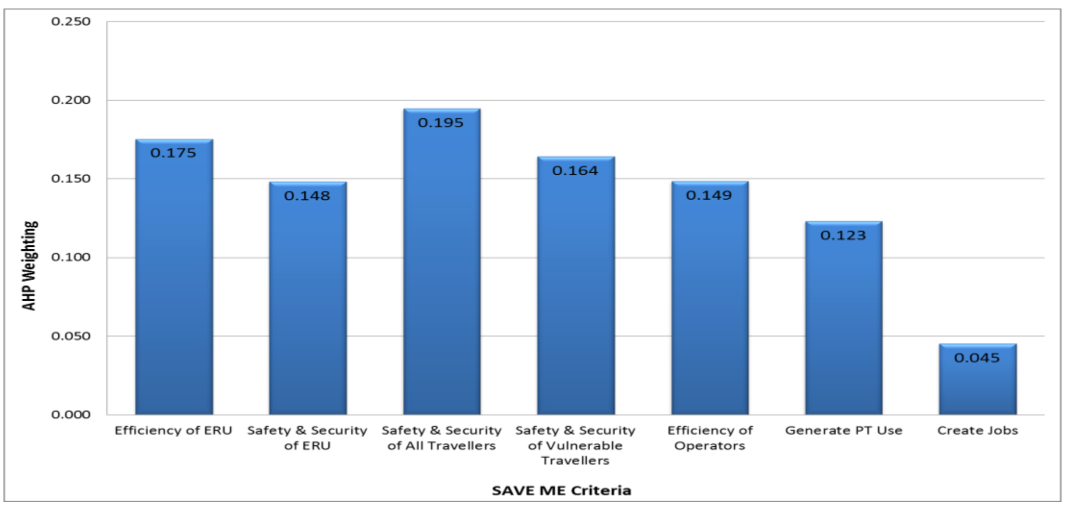

Figure 2. Relative Weighting of SAVE ME Criteria

4.2. Efficiency of the Emergency Response Unit (ERU)

Of the six SAVE ME components, the Rescuer Guidance Module (ReGuM) was thought to have the greatest contribution (0.236) to the ERU Efficiency, which is perhaps to be expected given it is the module which ERU personnel would rely upon the most. One key added value of the SAVE ME system was noted by rescue personnel who participated at the trials. An improvement in their work in terms of further reducing overall evacuation time, and saving the lives of trapped travellers in greatest need was identified.

As illustrated in Figure 3, another component which also makes a strong contribution is the Training Tools, Scenarios and Curricula (TTS&C) (0.215), which indicates that whilst new technologies and systems can deliver improved performance and safety levels, personnel need to be trained in a proper way to ensure they can derive maximum utility from the system.

These findings build upon previous work [29] which called for a greater flexibility and improvisation in emergency response operations, and the modules developed in SAVE ME could facilitate such actions in the future.

The Operator Support Module (OpSuM) (0.199) also scored relatively highly; it is reasonable to conclude that the operators can play a useful role in an emergency by providing a second layer of monitoring, support and information to the individuals directly at the scene of the emergency. Interestingly, the Individual Guidance Module (InGuM) scored very low (0.058) here, despite its potential ability for assisting users in self-evacuation, thereby saving rescuers valuable time and prioritising their operations to assist those in greatest need. However this was clearly viewed as a minor direct benefit to the ERU personnel.

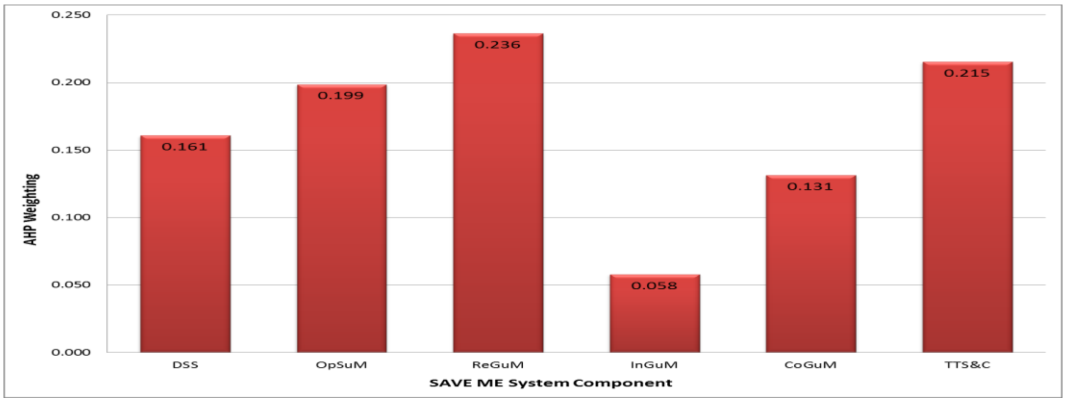

Figure 3. Relative Weighting of SAVE ME Components for ERU Efficiency

4.3. Safety & Security of the Emergency Response Unit (ERU)

Figure 4 shows how the ranking of results for ensuring the Safety and Security of ERU personnel are very similar to those found for the Efficiency of the ERU, with the ReGuM (0.223) followed by TTS&C (0.214) ranking first and second. This finding further supports the finding that the provision of correct and appropriate training materials for the SAVE ME system will be very important in order for the rescuers to make the most effective use of the new technologies and information streams available through the SAVE ME system.

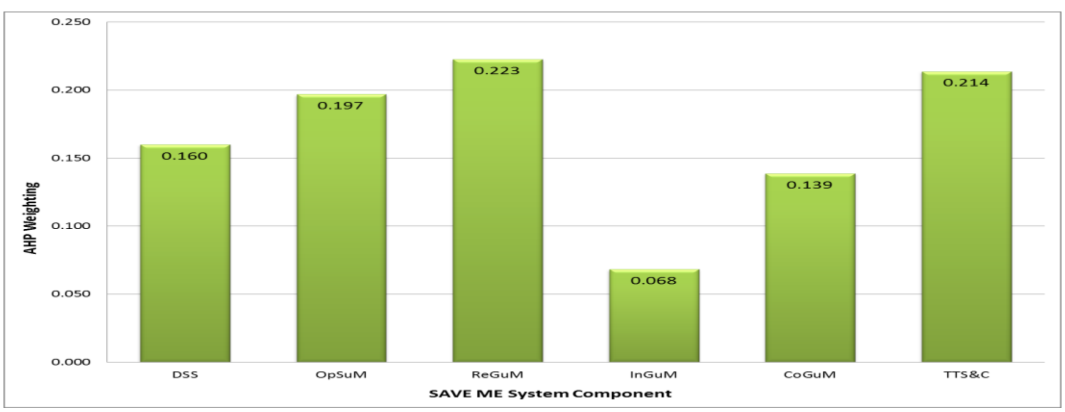

Figure 4. Relative Weighting of SAVE ME Components for Safety & Security of ERU

4.4. Safety & Security of All Travellers

When considering the needs of all travellers, as illustrated in Figure 5, it was felt that the Collective Guidance Module (CoGuM) would be far more effective (0.227) than the Individual Guidance Module (InGuM) (0.164). Post-processing and analysis of log-files from the trials found that SAVE ME could reduce the evacuation time of the generic population by 2% to 20% in supporting more travellers who are slower both in deciding what actions to take and when moving towards the right exit.

Here, the DSS features as the second most important (0.177) SAVE ME component, which indicates that the provision of accurate and reliable information streams from a central DSS is a key factor in enabling the self-rescue of individuals and thus their overall safety. What is interesting to note here is that the modules intended for supporting operators (OpSuM) and rescuers (ReGuM) received lower scores (0.162 and 0.149 respectively), which could imply that their direct impact on the safety of travellers is not as immediate as originally envisaged. This supports the notion of self-evacuation of travellers as being an effective means of mitigating the impacts of an incident.

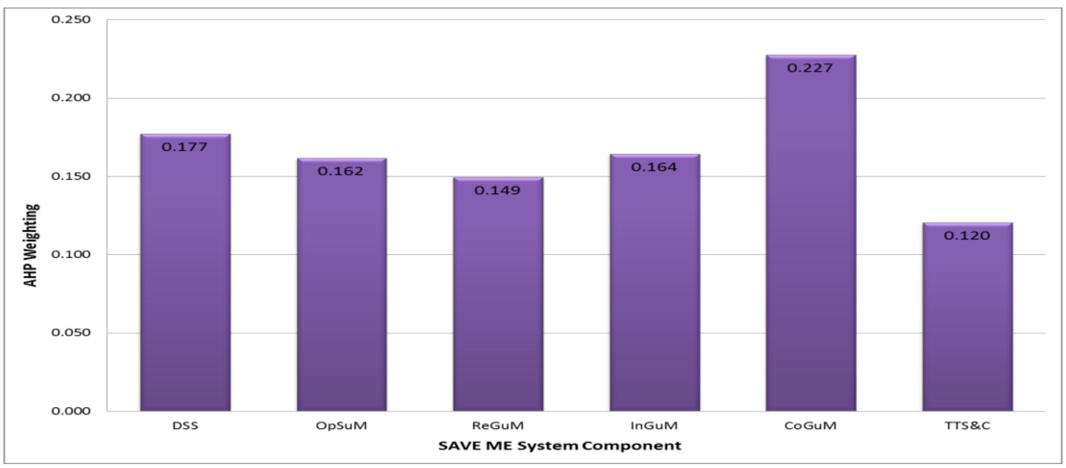

Figure 5. Relative Weighting of SAVE ME Components for the Safety & Security of all Travellers

4.5. Safety & Security of Vulnerable Travellers

Valuable comparisons can be made with the results shown in the previous section (Safety & Security of All Travellers, shown in Figure 5), as for vulnerable travellers it was clearly felt that the provision of personalised information via the InGuM was the most desirable SAVE ME component (0.221) followed by the CoGuM (0.174), as indicated in Figure 6.

The implication here is that for general traveller guidance, there is little perceived utility in trying to do so at a personalised level via mobile devices. This statement is supported on a technological level by the findings in a separate SAVE ME Market Research report, and on a user-level by comments provided by pilot trial participants in the post-trial questionnaires (discussed more in Section 5 of this paper).

Instead, these findings suggest there is merit in providing personalised information via the InGuM to those travellers who cannot follow ‘standard’ exit routes along with the general masses. For these travellers, they would therefore need to be directed to a safe refuge point, via the InGuM, perhaps along a different route to other people to await rescue, where they would be prioritised by the DSS to ensure that they were rescued as quickly as possible. Additional post-processing and analysis of log-files from the user trials indicates that SAVE ME is expected to have a much greater benefit in assisting vulnerable travellers as a reduction of 38% in overall evacuation time was calculated for wheelchair users.

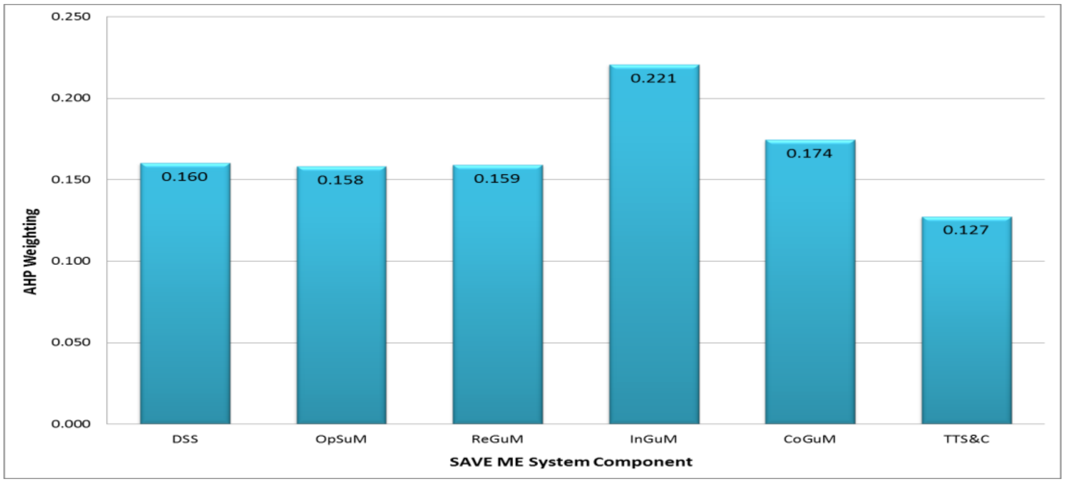

Figure 6. Relative Weighting of SAVE ME Components for the Safety & Security of Vulnerable Travellers

4.6. Efficiency of Operators

As shown in Figure 7, for improving the Efficiency of Operators, there were two SAVE ME components which stood out – the OpSuM (0.266) and TTS&C (0.228) *i.e.*, the most relevant components which would be used directly by these individuals.

However, unlike for the 'Efficiency of Rescuers' where the corresponding OpSuM scored relatively well, the remaining components, including the corresponding ReGuM, scored much lower here. This gives an indication that, with respect to the specific needs of the operator, they may not derive significant utility from having the other SAVE ME components to hand.

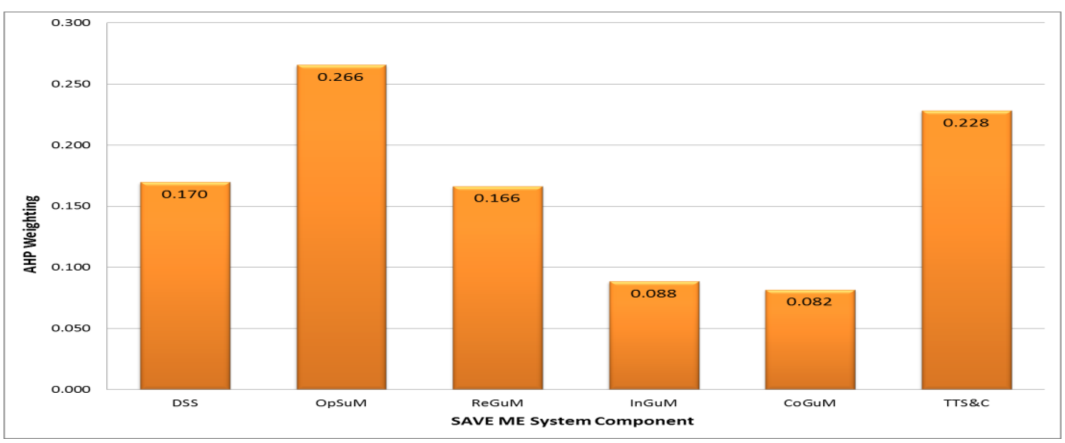

Figure 7. Relative Weighting of Save Me Components for the Efficiency of Operators

4.7. Enhancement of Use of Public Transport Due to Higher Public Trust

This criterion scored second lowest in the ranking of the individual criteria, but the findings further support the notion that the CoGuM is a preferable SAVE ME component, as shown in Figure 8, it scored highest (0.232) in terms of enhancing trust. Despite the apparent shortcomings of the InGuM, this component scored second highest (0.201) in terms of enhancing trust. It is interesting to see that the two SAVE ME components which would be publicly available are thought to be the ones which would instil the highest trust, which merits further investigation. This finding is supported by results from previous work also utilising AHP [30] which identified that protection/safety systems requiring direct activation and interaction were more effective than passive systems.

It may also be possible that there is a deeper psychosomatic factor pertaining to the possession of real-time, location-specific, context-aware information which, even if the system was never actually used, acts as a psychological ‘safety blanket’. This idea is notionally supported by the post-trial comments provided by the participants: some mentioned how the SAVE ME system would make them feel more confident, more secure and give them a heighted awareness when travelling, so that they would not panic (as much) if caught up in an actual emergency situation.

Aside from the two traveller components, respondents to the AHP task thought that the OpSuM (0.172) would have a greater impact on public trust in PT compared to the ReGuM (0.121) which actually scored the lowest for this particular criterion. One possible explanation here is that the public are likely to engage with operator personnel on a more regular, and perhaps informal, basis than they would with a member of the emergency services, who would only be on hand during an incident.

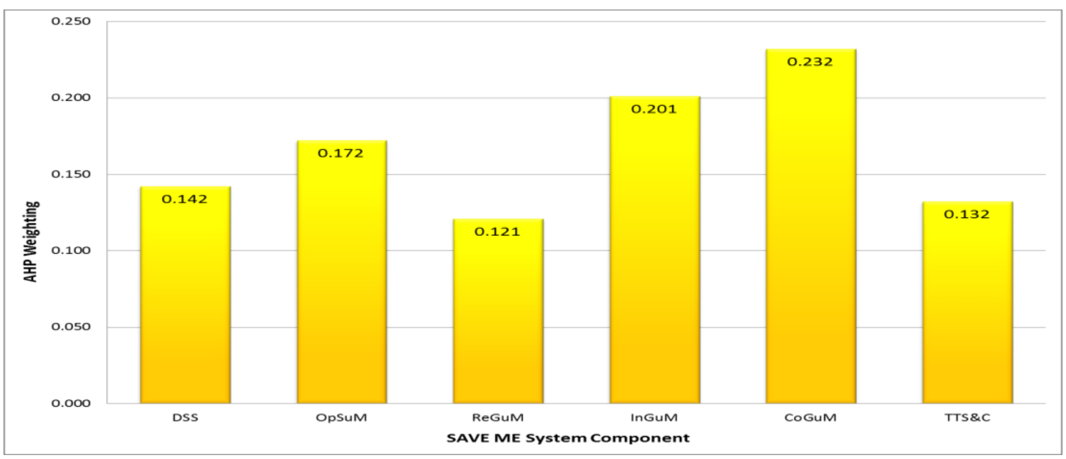

Figure 8. Relative Weighting of SAVE ME Components for Enhancing Use of Public Transport Due to Higher Levels of Trust

4.8. Jobs and Revenue Creation

This criterion was ranked lowest priority out of the seven criteria included in this AHP exercise however, as illustrated in Figure 9, it was thought that the InGuM would have the greatest potential (0.207) for creating new jobs and generating revenue. One potential avenue that could be explored here is the licencing of an official SAVE ME application across different mobile platforms (iOS, Android, Symbian etc.)

The OpSuM (0.174) and DSS (0.171) also stood out as potential components which could contribute towards the creation of jobs and revenue; here, the specialist nature of these components and the integration into existing safety monitoring systems by dedicated ICT companies, could provide one feasible avenue for this purpose.

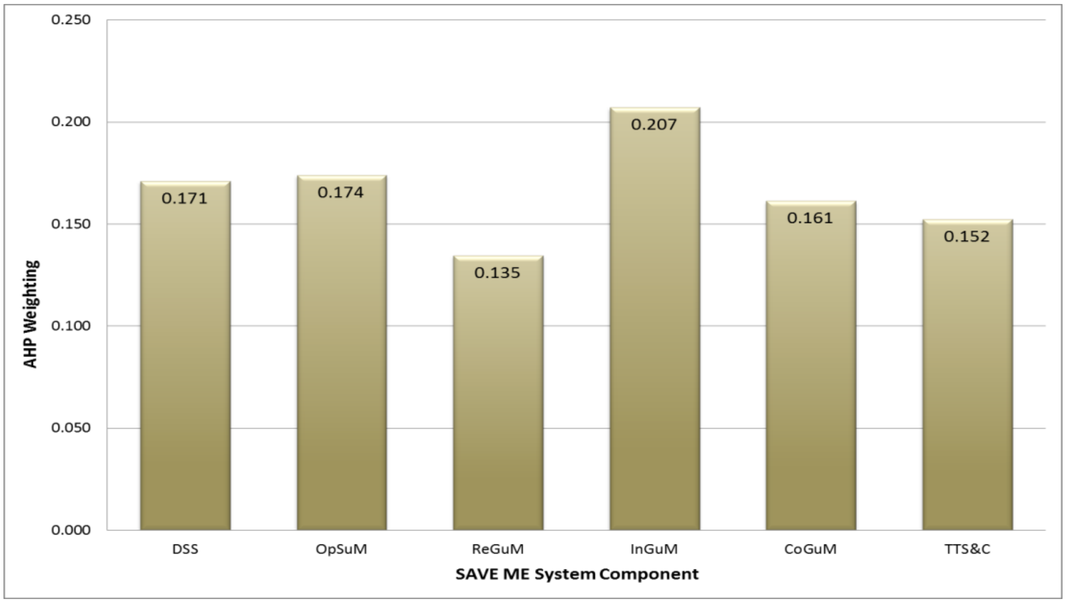

Figure 9. Relative Weighting of SAVE ME Components for Jobs and Revenue Creation

4.9. Overall Result of the SAVE ME AHP Process

Returning to the initial purpose of the AHP exercise, the ultimate objective is to help identify which of the six SAVE ME components would be the most desirable across all of the given criteria. The combination of all the results (using the approach described in Section 2) provides a final overall ranking of the six SAVE ME components, as shown in Figure 10.

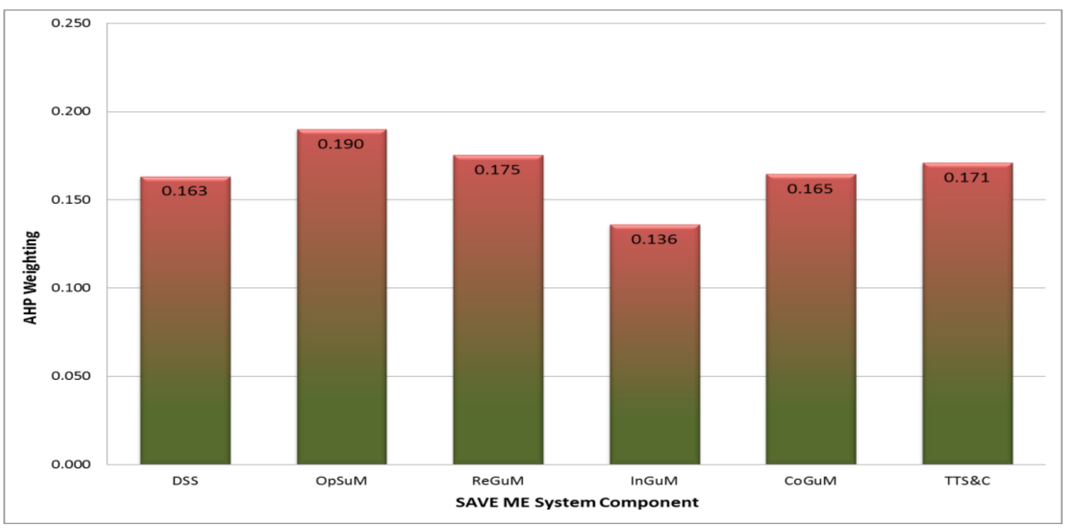

Figure 10. Combined Weighting of all SAVE ME Components in the AHP Exercise

It is the non-traveller modules, *i.e.*, the OpSuM (0.190) and ReGuM (0.175) components, which were thought to be the most preferable of the SAVE ME components, supported by robust TTS&C (0.171). With respect to the traveller-specific modules, the CoGuM (0.165) is more preferable to the InGuM (0.136), which is as expected, based on the discussion of the individual criterion results. At the central point of the whole system lies the DSS, which consistently remained in the middle of the rankings for every criterion. In the overall AHP exercise the DSS (0.163), placed fifth out of the six components, but was not too far behind the scores given to the CoGuM and TTS&C.

Finally, it is worth noting that individual scores are reasonably close, suggesting that all respondents were mindful of the fact that SAVE ME is designed as a system comprising a number of modules. Whilst this exercise sought to identify the most desirable module(s), an individual module would have little value as a standalone product. However components developed in SAVE ME could perhaps be retrofitted into existing safety monitoring systems to further enhance their functionality, and the results discussed here could help prioritise decisions on such developments.

5. Feedback from the General Public on the SAVE ME System

The results from the previous section indicate that modules designed for direct use by rescue personnel and system operators (*i.e.*, non-members of the travelling public) were viewed as being more desirable by industrial professionals compared to those systems designed for use by the traveller. Whilst this finding is important to consider when taking a holistic view of the SAVE ME system's future potential, such conclusions drawn must be tempered by the fact that the cohort of respondents to the AHP exercise did not include any members of the general public, who are the end users of a significant proportion of the SAVE ME system which would not necessarily be used by the industry professionals.

To address this discrepancy, such views and opinions were captured through a post-trial questionnaire administered to all participants from both SAVE ME pilot trials. The first trials took place in late May 2012 at the Colle Capretto Road Tunnel (CCRT) near San Gemini on the SS3bis Autostrada, about 70km south from Perugia, Italy. This was followed by a second series of trials in late June 2012 at Monument (MMT) Metro Station, located in the centre of Newcastle upon Tyne, UK. The final user questionnaire comprised a range of questions utilising scales originally developed and validated independently of the SAVE ME project. These were used to obtain quantitative data for a number of metrics (explained in full in the following sections) with a predefined target for each metric corresponding to a score of 70% on the respective scale used.

The main analysis reported in this section is based on the combined sample (n=33) of adult participants who had first-hand experience in using the SAVE ME systems under trial conditions in a real-world setting. However, as with most large-scale pilot trials involving novel and complex technological systems at the early stage of development, there were some technological issues encountered during the trials which affected the functionality of the individual guidance systems (in particular at the CCRT).

The project team undertook as much pre-planning, testing and fine-tuning of the system as was feasibly possible under the given circumstances, however it is important to give consideration to the fact that these unforeseen issues may have negatively influenced the scores given by some participants. To account for any potential differences between the two trial sites, all metrics were initially analysed separately for each pilot site to identify if there were any notable differences that could be attributed to these technological factors. To then provide a more measured evaluation of the SAVE ME system, scores from all participants were combined to give an overall grand score for each metric.

5.1. System Functionality

The Van Der Laan Acceptance (VDLA) scale [31] was employed to assess the perceived usefulness of, and user satisfaction with, the SAVE ME system. The VDLA scale is based on a simple nine-item, five-point Likert scale, initially developed with the specific intention of evaluating acceptance of new driver assistance technologies from the user perspective.

Five items in the VDLA scale load onto a scale for 'usefulness', whilst the remaining four items load onto a scale for 'satisfaction'. Both return a single value between -2.00 and +2.00 and so based on the target of 70%, the perceived usefulness target score was +0.80 whilst the user satisfaction target score was +0.75.

Table 3. Results of the VDLA Usefulness Scores

Pilot Site	Usefulness		
	Minimum	Median	Maximum
CCRT	-2.00	-0.60	+1.20
MMT	-1.40	+0.60	+2.00
Combined	-2.00	+0.40	+2.00

There is a large range in the scores for the usefulness metric but it is apparent that the technological issues could have influenced these scores: some CCRT participants gave a -2.00 (0%) rating whilst some MMT participants gave a +2.00 (100%) usefulness rating. A Mann-Whitney U-test indicates there is a significant difference between the usefulness ratings given by the CCRT and MMT participants ($U = 55.5$, $n1 = 13$, $n2 = 20$, $p = 0.0064$). Overall, a grand median value of +0.40 (which is equivalent to 60%) is perhaps an outcome to be expected for a system which still at the relatively early stages of technological realisation.

Table 4. Results of the VDLA Satisfaction Scores

Pilot Site	Satisfaction		
	Minimum	Median	Maximum
CCRT	-2.00	-1.25	+0.25
MMT	-0.50	+0.50	+1.50
Combined	-2.00	+0.00	+1.50

For the satisfaction metric, there was also a wide range of ratings. As some participants in the CCRT trials did not experience the SAVE ME system in its fully functioning form during the trials, a score of -2.00 (0%) for their satisfaction was the only reasonable outcome to be expected. However, higher scores from the MMT trials do reflect the fact that these trials were relatively more successful and experienced fewer problems, therefore participants were likely to be more satisfied with how the system performed. A Mann-Whitney U-test indicates a significant difference between the median satisfaction ratings of the CCRT and MMT participants ($U = 20.0$, $n1 = 13$, $n2 = 20$, $p = 0.0001$) whilst a grand median value of 0.00 (equivalent to 50%) can be said to be a favourable indication of the future potential of a commercialised SAVE ME system, when installed and calibrated for the specific conditions of a facility. Overall, the results from the VDLA scale show trial participants did see some utility in the SAVE ME system, despite the problems encountered.

5.2. System Usability

The System Usability Scale (SUS) [32] was adopted to measure how usable the SAVE ME system was during the trials. The SUS is one of the most commonly applied usability scales, and although it is acknowledged by its originator as a 'quick and dirty' approach and has its critics as a result, it has been applied extensively for many different evaluation activities. An empirical analysis of numerous studies employing SUS [33] has shown strong reliability and validity of using this approach.

The SUS itself is a ten-item, five-point Likert scale (from 1 to 5), although some items have their scale reversed compared to other items. All ten items are then combined and factored by 2.5 to return a final usability score on a scale between 0 and 100; therefore, the target score for this metric was an overall average of 70.

Table 5. Results of the SUS Scores

Pilot Site	Usability		
	Minimum	Median	Maximum
CCRT	22.5	62.5	85.0
MMT	27.5	62.5	77.5
Combined	22.5	62.5	85.0

It is interesting to note here that despite the differences between pilot sites in the usefulness and satisfaction ratings, participants at both sites thought they would be able to use the (fully functioning) SAVE ME system in the future. The median SUS score was 62.5 at both pilot sites - thus not statistically different - and although the average target score of 70 was not quite achieved, there were participants from both pilot sites who returned usability scores greater than 70. One notable finding is that despite the CCRT trial experiencing greater technical issues, the maximum usability score from the CCRT participants was 7.5 marks higher compared to that from the MMT participants. Looking ahead, these results imply that there is strong future potential for the SAVE ME system and that the technical issues may not have had a negative impact on the overall perception of what a SAVE ME-type system could indeed deliver.

Finally, an additional seven-point Likert item was added to the traditional SUS [34] to address the overall user-friendliness of the SAVE ME system. The responses to this extra item are also typically correlated with the SUS scores (per respondent).

Table 6. Correlation of the SUS Scores with User-Friendliness Scores

Pilot Site	Overall User-friendliness		
	Average	Median	Correlation with SUS Scores (r2)
CCRT	4.46	4	0.59
MMT	4.75	5	0.61
Combined	4.63	5	0.59

The results from this question show that, in general, respondents believed the SAVE ME system to be user-friendly: a grand median score of 5 indicates a user-friendliness rating of 'good'. The correlation between the individual SUS scores and the user-friendliness was medium-positive ($r2 \approx 0.60$), thus supporting the earlier conclusions. The combination of results suggest that whilst the current SAVE ME system is seen to be usable, there would be merit in undertaking further design and testing work to improve the system's overall usability and appearance.

5.3. Trust in the System

The final metric to be assessed was the degree of trust participants would put into the SAVE ME system's capabilities to help them evacuate in an emergency. This was achieved by adopting the 'Solutions for Human Automation Partnerships in European ATM' (SHAPE) Automation Trust Index (SATI) [35], originally designed for evaluating air-traffic control systems, and amending the wording to fit into the context of the SAVE ME trials. The SATI scale is a six-item, seven-point scale (0-6) which returns a combined overall trust score from 0-6. The equivalent 70% target score was 4.2.

Table 7. Results of the SHAPE Automation Trust Index (SATI) Scores

Pilot Site	SATI Score		
	Minimum	Median	Maximum
CCRT	0.0	2.5	4.7
MMT	1.2	3.75	4.8
Combined	0.0	2.8	4.8

As the table above shows, the grand median level of trust in the SAVE ME system was just under 3, which equates to a general rating of 'would possibly trust' the system. The individual median trust score from MMT was greater than that from the CCRT by 1.25 marks, however this difference was found to not be statistically significant ($U = 81.0$, $n1 = 13$, $n2 = 20$, $p = 0.0739$).

When looking across the range of individual scores, it was clear that opinions on trusting technology were divided. One participant from the CCRT trial did not trust the system, giving a score of 0 to each item on the SATI scale, but it could be argued that this is perhaps an extreme case and has been influenced by the aforementioned technological issues that occurred. Nevertheless, this score does highlight the fact that there will always be some who have an inherent mistrust of technology no matter how advanced the system may be. This could be further compounded by the fact that no technological system can ever be 100% reliable at all times and so people should only ever perceive SAVE ME-type systems as an aid and continue to utilise other means of gathering evacuation information. Conversely, the maximum trust scores for both trial sites were very close to 5 out of a possible 6, indicating that there are some who would be more willing to put a lot of their trust into technology, such as that developed in SAVE ME, to help them evacuate from a transport emergency.

5.4. Impact and Future Use

Following on from the measurement of usefulness, satisfaction, usability and trust, the trial participants were asked to give their views on the SAVE ME system's potential impact in the future. They were initially asked to state if they believed the wider implementation of a SAVE ME-type would change how people would behave in future transport emergencies, and also if they would change their own behaviour having experienced the SAVE ME system first-hand.

Table 8. Would SAVE ME Implement a Change in Future Behaviours?

Pilot Site	In General		Personally	
	Yes	No	Yes	No
CCRT	77%	23%	85%	15%
MMT	95%	5%	60%	40%
Combined	88%	12%	70%	30%

What is encouraging from these findings is that the majority of participants from both trials were of the opinion that a SAVE ME-type system would be able to implement a change in behaviours, not only in themselves having had direct experience with using the system, but they could also see how beneficial SAVE ME would be for other people.

Despite the positive behaviour implications for a SAVE ME system, there would be little value in investing in a new system if people were not willing to use it. Therefore, a follow-up question asked participants if they believed people like themselves would consider using a SAVE ME system in the future, with a caveat that further development and testing work would take place where necessary. Instead of a strict Yes-Maybe-No scale, ratings were returned on a 0-10 scale where 0 = definitely would not use and 10 = definitely would use.

Table 9. Potential Use of a SAVE ME-type System in the Future

Pilot Site	Would General Public Use SAVE ME in the Future?		
	Minimum	Average	Maximum
CCRT	2/10	7.2/10	10/10
MMT	2/10	6.2/10	9/10
Combined	2/10	6.7/10	10/10

A grand average score of 6.7/10 gives an indication that people would possibly be willing to use the SAVE ME system in its current configuration and design, and comes very close to meeting the 70% target. Further comments indicated that there would need to be an enhanced level of reliability, in particular the mobile application for individual guidance, in order to increase the likelihood of people using the SAVE ME system.

Whilst such developments would be accounted for in any future iterations, there was evidence that certain modules of the overall SAVE ME architecture would merit greater attention. A number of participants reflected upon the fact that during a real emergency situation, amongst all the potential chaos and confusion (*i.e.*, when SAVE ME is specifically designed to assist), they believed people would be likely to revert to "what they know" and rely upon their natural 'flight' instincts to get to a place of safety as quickly as possible. In this respect, many participants were of the opinion that fixed screens providing dynamic information based on the on-going situation (used as part of the Collective Guidance system in SAVE ME) would be highly preferable in supporting these natural instincts, as they could follow such information whilst still actively moving towards an exit.

In contrast, and supporting the industry professionals' results from the AHP exercise, trying to follow bespoke information on the smaller screen of a mobile device was less desirable: it may require individuals to be stationary, albeit momentarily, in order to decipher the information given to them, whilst others around them kept on moving. Whilst this finding may seem somewhat counterintuitive given that mobile devices are designed to be portable and used on the go, many felt people would generally not be as confident in using such applications under real emergencies, especially as they could not be trusted to be 100%

reliable all of the time. A number of participants from the MMT trials explicitly stated that even if they had Individual Guidance available through their mobile device, they would not use it and would be more reassured by the presence of the dynamic screens instead.

6. Conclusions

This paper has presented two separate evaluation tasks to help quantify the potential value of the modules and supportive tools developed through the SAVE ME project.

First, the Analytic Hierarchy Process was successfully implemented to help identify which of the individual SAVE ME components may be the most useful and/or desirable from the perspective of industrial professionals. Here, six individual SAVE ME components have been assessed across seven separate societal and operational criteria to produce a quantitative judgement as to which of the SAVE ME components may have the greatest future potential. The results of this exercise have revealed two key findings: 1) The SAVE ME components which assist and train professional personnel (operators and rescuers) are likely to deliver the greatest benefit across all the criteria considered. 2) Simplicity and clarity is essential when considering the provision of guidance information to travellers in emergency situations.

Second, a series of evaluation frameworks were applied through a questionnaire administered to participants in the SAVE ME pilot trials. Whilst there is a degree of uncertainty about the usefulness and satisfaction of the system in its current prototypical format, participants could clearly appreciate the future potential that a fully developed SAVE ME-type system would bring, not only to them but to the general travelling public. In particular, there was strong support for the provision of simple, dynamic information via large screens whilst there was less enthusiasm for having bespoke guidance provided on a mobile device, especially under stressful emergency situations.

Our findings from both exercises can be used to help the development of future technological systems and inform relevant policies in areas such as providing advanced information systems for passengers with specific needs and the procurement of assistive technologies for rescue personnel and infrastructure operators.

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