Modelling behaviour during a large-scale evacuation
A latent class model to predict evacuation behaviour

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Abstract

In a study for the Swiss Federal Office for Civil Protection (FOCP) the IVT (ETH Zurich) investigates the responses to large-scale evacuations (with evacuation zones of a minimum diameter of 1.5 kilometres). Evacuations are simulated using an expanded agent based micro simulation tool (MATSim). To obtain reliable results, the simulated agents have to be modelled based on observed and stated humans' behavioural patterns in such situations. A Swiss wide stated choice survey study aimed to collect data on evacuation behaviour.

A latent class multi nominal logit model is estimated to quantify people's responses to an evacuation order. The analyses offer insights into which attributes either increase or decrease the likelihood of an immediate evacuation, later evacuation or no evacuation at all.

The paper contributes to evacuation planning in several ways. During an evacuation, people respond to an exceptional event. The estimated models describe behavioural parameters, which are needed for the simulation. Estimating a detailed model on empirical data on stated evacuation response results in a more reliable input for the simulation. In this sense the paper presents highly necessary work.

Keywords

Latent class model, evacuation modelling, BIOGEME

1 Introduction

The Institute for Transport Planning and Systems (IVT) of ETH Zürich is currently focussing on large-scale evacuation events in Switzerland. On behalf of the Swiss Federal Office for Civil Protection (FOCP) the team employs a simulation tool to analyse such events. For an more accurate description of events, the simulated agents' behaviour should be similar to what could be expected in a real scenario.

The project is divided in three successive stages. The expanded agent based travel demand simulation tool MATSim, which is used to simulate evacuation events, made it necessary to first develop extensions for the simulation framework (for details on MATSim see Balmer, 2007). Implementing these extensions changed MATSim into an appropriate tool for evacuation events. Within this first stage agents' behaviour was fixed according the assumptions of Homo Economicus. As a result it was shown that evacuations are feasible within a reasonable time (see Dobler and Axhausen, 2010).

In the second phase information on evacuating populations were collected and analysed. This aimed to develop and implement a more realistic behavioural model for the simulated agents. Data collection employed a triangulation methodology including a literature review, expert interviews, and a survey. The literature review looked at the literature on evacuating populations' behaviour. As most papers focussed on events (e.g. floods, hurricanes, nuclear accidents) within specific environmental settings, the comparisons were limited. However, the literature review resulted in a first set of hypotheses on evacuation behaviour (for details on the review see Kowald *et al*., 2011). Employing guided expert interviews aimed to validate, correct, and extend the list of hypotheses on evacuation behaviour. Between September 2011 and February 2012 we interviewed twelve persons with expertise in evacuation planning, emergency management, or the field of evacuation research. In combination with previous knowledge from the literature research these interviews resulted in a detailed set of hypotheses of influential factors on peoples' evacuation behaviour (for details on the expert interviews see Kowald *et al*., 2012). Third step of the triangulation was a Swiss wide survey to check whether the hypotheses hold for the population of Switzerland and to quantify the assumed effects. In the final stage of the project the behavioural model from the triangulation will be implemented in MATSim to allow new simulations of evacuation events under more realistic assumptions.

This paper presents a decision model based on the stated preference experiment, which was a part of the population wide survey. It tests the influences on peoples' evacuation behaviour. In this sense it tests the hypothesis set generated in the expert interviews and quantifies their influences. The paper is organized as follows: Section two provides a brief description of both survey strategy and protocol. It also analyses the response rate of the data and compares the survey population to the Swiss population to allow a judgement on the representativeness of the data. The hypothesis set is presented in section three. Model methodology and development are described in section four followed by the model and its interpretation in section five. Finally, concluding remarks can be found in section six.

According to existing emergency plans in Switzerland evacuation areas are of at least three kilometres in diameter (see ENSI, 2009; Schweizerischer Bundesrat, 2003). In contrast to existing definitions of evacuation, this project exclusively focusses on a population that leaves the threatened area. In addition, it is of interest where evacuees search for shelter. However, we do not consider any decisions relating to a possible re-entry.

2 Description of data

The survey of evacuation behaviour was conducted in Switzerland in Decemer 2011 – February 2012. The survey was answered by 1008 respondents. Questions were grouped into items on: (1) the overall evacuation behaviour, (2) stated preference questions based on different evacuation scenarios, and (3) socio-demography. The first group asked general questions about where people seek shelter and which mode they choose in terms of both a short distance and a longer distance evacuation. In the stated preference part of the survey, respondents were presented with combinations of different disaster and respondent conditions. In each decision situation they were asked to make a choice, if they would evacuate or not. If respondents were willing to evacuate they had to specify if they would leave the threatened area immediately or pack a few things first and leave later. The last part of the survey focused on socio-demographic aspects such as civil status, age and income, which allow checking the representativeness of the respondents against the Swiss population. In addition it asked for locations were the respondents and their household members are normally located at midnight, 9am, and 5pm to place them in relation to each other.

2.1 The stated choice experiment: Combination of attributes

In the stated choice part of the survey instrument four different evacuation reasons were presented: A flood, a nuclear accident, a chemical accident, and a fire and resulting toxic gases. One of these threats was the basis for each situation while further characteristics which varied between different situations were given: The source of the initial evacuation warning, the source of warning confirmation (human beings always try to validate information), the status of the household (whether the household is united and in one place or not), the available time span to leave the evacuation zone, the distance to the cause of the evacuation, and the distance to the area outside the danger zone. These attributes were known from both literature research and expert interviews as being important for evacuation behaviour.

The number of possible combinations of attributes was reduced by logical considerations and an experimental design. According to the literature research and expert interviews there are only small probabilities for evacuations of more than seven kilometres in radius for natural, and chemical disasters, as well as threats related to fire and toxic gasses. So, these evacuation reasons were limited to two levels of variation in terms of distance to both evacuation reason and border. Furthermore, the combination of five kilometres distance to both reason and border was excluded, which resulted in a maximum evacuation radius of seven kilometres or more for these three scenarios. In terms of time for the evacuation the 16 hours time frame was excluded for chemical accidents. Those events often occur spontaneously, e.g. in explosions after train derailments or accidents in factories, which made time frames of more than eight hours unrealistic. The same thoughts, but even more restricted, can be made for fire and resulting toxic gasses. Here, the eight hours possibility was excluded as well, leaving nuclear accidents and natural disasters being the only threats with an available evacuation time of up to 16 hours. In addition, evacuations after nuclear accidents are the only ones that can have a radius of up to 20 kilometres. These considerations reduced the full factorial design from 1944 to 810 combinations. An overview on the attribute combinations is provided in table 1.

Second step in designing the experiment was blocking the combinations left. This was done by allowing for calculations of first order interaction terms between evacuation reason, available time, distance to evacuation reason, and distance to evacuation border. Assigning situations to blocks was done with a random mechanism whereby each situation was included in several blocks. In total the 810 combinations were distributed randomly between 250 blocks with each block containing 9 situational settings.[1] Assuming 1000 respondents and a non-biased answer behaviour this would result in 9000 choices including around eleven answers on each of the 810 original choice settings.

[1] Designing the experiment was done with algorithms implemented in the AlgDesign-package for the open source statistic software R (see Wheeler, 2009 and 2011; R Development Core Team, 2010).

Table 1 Attributes and alternatives of the stated preference experiment

Attributes	Reason of evacuation			
	Flood	Chemical accident	Nuclear accident	Fire, toxic gasses
Source of initial warning	1. Siren			
	2. Mass media (Radio & TV)			
	3. Social contacts			
Source of warning confirmation	1. Rescue teams (Police & fire fighters)			
	2. Mass media (Radio & TV)			
	3. Social contacts			
Status of household community	1. Members are joint			
	2. Members are divided			
Time to evacuate	1. Immediately	1. Immediately	1. Immediately	1. Immediately
	2. 8 hours	2. 8 hours	2. 8 hours	
	3. 16 hours		3. 16 hours	
Distance to source of evacuation	1. 2 kilometres	1. 2 kilometres	1. 2 kilometres	1. 2 kilometres
	(2. 5 kilometres)	(2. 5 kilometres)	2. 5 kilometres	(2. 5 kilometres)
			3. 10 kilometres	
Distance to evacuation border	1. 2 kilometres	1. 2 kilometres	1. 2 kilometres	1. 2 kilometres
	(2. 5 kilometres)	(2. 5 kilometres)	2. 5 kilometres	(2. 5 kilometres)
			3. 10 kilometres	
Choice	1. Immediate evacuation			
	2. Later evacuation			
	3. No evacuation			

Respondents were randomly recruited in the German and French speaking part of Switzerland. The Italian speaking area was excluded as only a substantially smaller part of the population, around 4.3%, lives in canton Ticino (BFS, 2005). Furthermore, this region is geographically segregated from the rest of Switzerland by the Alps. In terms of survey protocol all potential respondents received an introductory letter together with the paper-based questionnaire. This first contact was followed by a motivation call. Finally, all people that agreed to participate during the phone call got, if they did not answer within next three weeks, a remainder letter accompanied by a new questionnaire.

2.2 Response rate, –burden, (item) non-response behaviour

Employing a rating system from commercial survey research Axhausen and Weis (2009) found a nearly linear relation between response burden and response rate for earlier IVT surveys. This relationship can be used to predict the expected response rates of a given survey instrument. In case of the questionnaire on evacuation behaviour response burden was calculated at 323 points. In combination with the survey protocol, that is sending questionnaires without prior recruitment, providing no incentive but employing a motivation call, the rating system estimates the response rate being around 35%. However, the response rate obtained was lower, around 25% as shown in figure 1. In comparison to studies with prior recruitment this is a clear hint that motivation calls after sending a survey instrument are not as efficient as showing efforts to get the respondent's agreement before sending an instrument.

The questionnaire used examples to show respondents how questions can be answered. It showed only minor problems with item non-response, usually less than 10% of missing values. However, there are some larger shares of incomplete answers in terms of questions asking for sensitive private information like whether respondents are disabled or how much income their household has available. In addition, item non-response is higher in case of high burden answers like addresses of working and home location (questions 30 and 32). A summary of respondents' answer behaviour can be found in figure 2 (questions are numbered according their numbers in the questionnaire which can be found in the appendix).

Figure 1 The relation between response burden and -rate

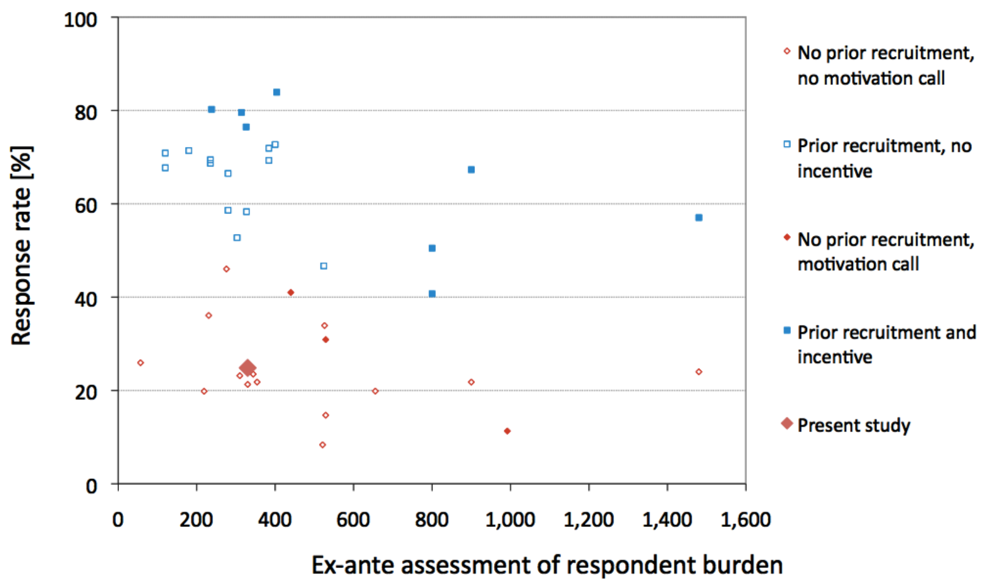
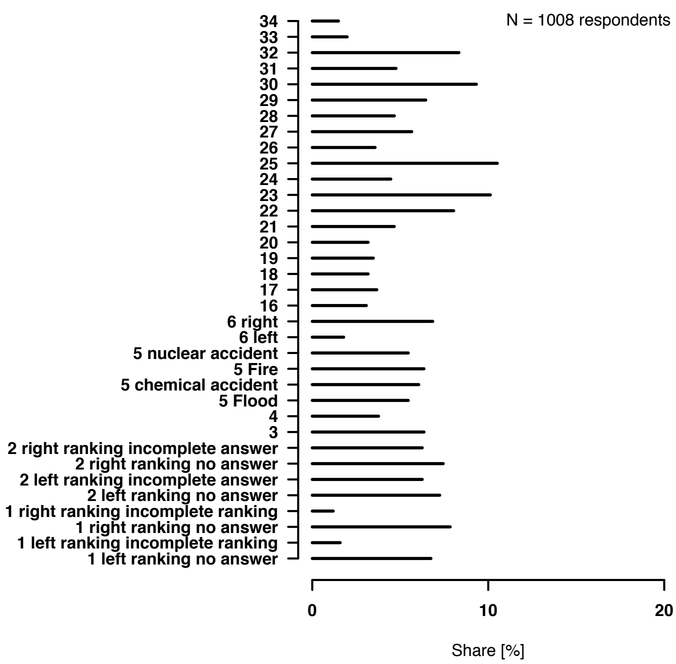
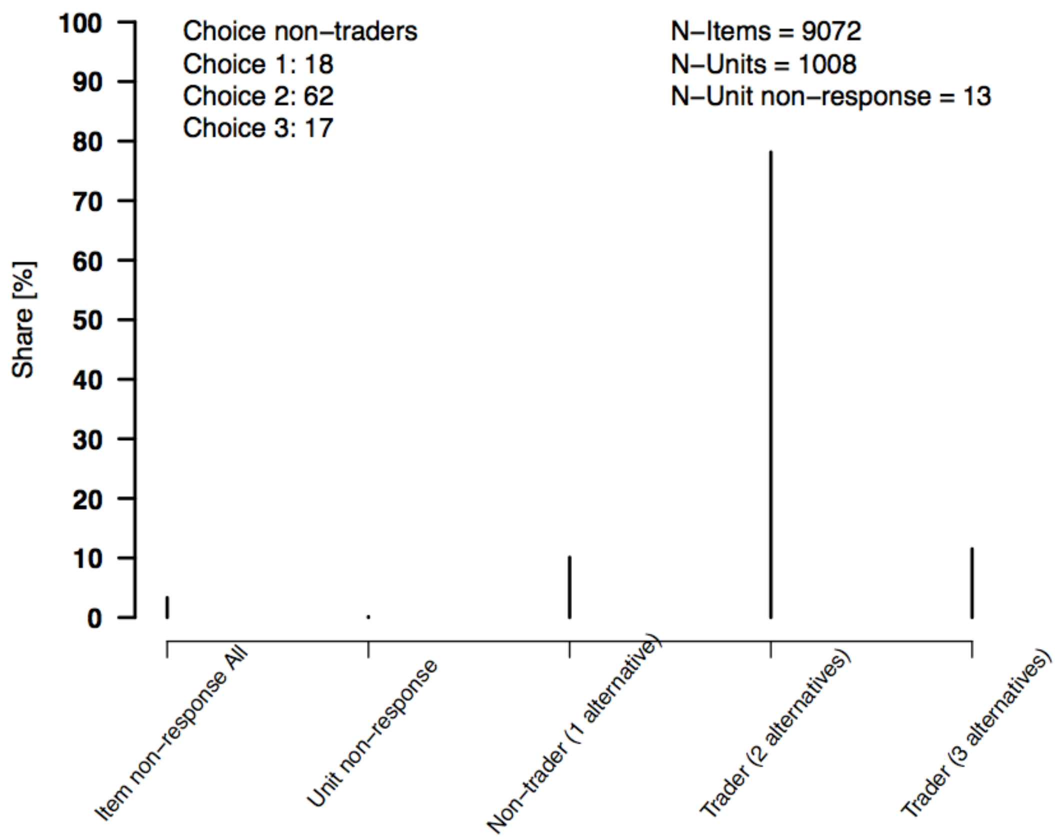


Figure 2 Missing values in attitudes and socio-demographics



In terms of the stated choice situations there was only little item non-response behaviour observed. Most respondents chose between two, some even between all three alternatives. Focussing on non-traders, a term describing respondents that always choose the same alternative independently from the descriptive attributes of the situation shows most of them always choosing a later evacuation followed by persons that always choose to evacuate immediately or always choose to refuse evacuation. This artefact results from the stated choice experiment design and can, at least in part, be explained by concerning that an ‘later evacuation’ is an imprecise description of a behaviour that can be understood in many ways (later can mean 15 minutes as well as an inexplicit time span in the sense that people are waiting until the last household member has dropped in to allow for a joint evacuation). Figure 3 gives an overview on answer quality in the stated choice experiment.

Figure 3 Missing values in the stated choice experiment



2.3 Representativeness of data

To assess whether survey respondents were representative for the population of Switzerland, we compared their characteristics with those of the whole of Switzerland, using the Microsensus data of 2005 (ARE and BfS (2007). The population turned out being quite representative, with some small exceptions. A larger share for females can be observed in the Microcensus data, but not in the survey data, where male overrepresented by a few per cent.

Focusing on civil status show married and divorced persons are overrepresented, whilst singles and widowed are underrepresented. The variable age is shown in two ways. For each category its share in terms of the overall population is analysed as well as the average age within the category. Because the survey only asked adults above 18 years, we excluded the people with an age below 18 from the Microcensus. Focusing on the average age per category shows the distribution within each category fitting well. The monthly household income is presented using three income groups. These characteristics show respondents with lower than average incomes as being strongly underrepresented whilst those with average or higher incomes are overrepresented. The relative share of citizenship differs slightly. The survey included approximately 11.1% more Swiss people and less French, Italian and other nationalities. The German nationals share is almost equal. In addition, the survey includes the availability of a driver license. People with a driver license are overrepresented in the survey. Table 2 compares the survey population to the target population using the Swiss Microcensus (ARE and BfS, 2007).

Within the Swiss cantons the population was covered well with only minor cases of over- or under sampling. Also the distribution between the German and French speaking part is sufficient. Therefore a data re-weighting in terms of geographical distribution or regarding socio demographics is not necessary.

Table 2: Comparison of survey data and Census data

	Attribute	Survey data	Microcensus Switzerland
Sex [%]	Male	50.3	49.7
	Female	49.0	51.3
Civil status [%]	Single	25.3	29.9
	Married	58.1	54.5
	Divorced	11.0	7.60
	Widowed	3.6	6.6
	Living separated	2.0	1.4
Age [% of people in class | Ø age within the class]	0-20	0.7 | 19.3	0.05 | 19.0
	21-40	29.7 | 31.7	28.9 | 31.4
	41-60	43.7 | 50.4	31.0 | 50.0
	61-80	25.8 | 67.7	18.5 | 69.4
	81+	0.1 | 84.0	2.8 | 84.6
Household income	<8000	57.9	73.0
	8001 – 12000	28.2	19.1
	>12.000	13.9	7.9
Citizenship	Swiss	91.9	80.0
	German	2.6	2.3
	French	0.4	1.3
	Italian	1.2	4.6
	Other	4.0	11.8
Drivers license	Available	91.8	80.7
	Not available	8.2	19.3

3 Hypotheses on evacuation behaviour

The literature research and expert interviews are summarized in a list of hypotheses concerning human behaviour in large-scale evacuations. Empirical modelling techniques aim to verify the supposed influences and quantify their importance, which is done in chapter 4. Table 2 provides an overview on the hypotheses. It also shows the magnitude of the expected influence (for a detailed interpretation of the hypotheses see Kowald *et al.*, 2012).

Table 3 Hypotheses from literature research and expert interviews

Hypotheses: Participation…	Influence
…increases for ‘life-threatening’ evacuation reasons	+++
…decreases for natural disasters	++
…decreases if time span is too large or to narrow	+
…decreases with available information from reliable sources	++
…increases if people have to care for others	+++
…increases for people without emotional relations	++
…increases when family is united	+++
…decreases for old people and young adults	+++
…decreases for people from ‘isolated’ sub-groups	+++
…decreases for people with high value private property	+++
…decreases for males	+
…is likely for most people	+++
…is often done in own car	+++
…is done in a pro-social way of behaviour	+
…includes that most people find private accommodations	++
…depends on an interaction between reason and information	++

4 Model specification

4.1 The latent class multi nominal logit model

The hypothesis are quantified and tested with a latent class multi-nominal logit (MNL) model, based on Walker and Ben Akiva (2002). The MNL model and its variations have been used extensively in transportation for the last several decades to model discrete choices (Hensher and Greene, 2003). These models rely on the economic principle of utility maximization. The applied random utility choice model assumes that the probability that alternative i is chosen by decision maker n is given by

$$P_n(i) = Pr\left(U_{in} \geq U_{jn}, \forall j \in C_n\right) \quad (1)$$

$$P_n(i) = P_r\left[V_{in} + \varepsilon_{in} \ \geq \ \underset{j\in C_n, j\neq i}{MAX} \left(V_{jn} + \varepsilon_{jn}\right)\right]$$

$U_{in} = V_{in} + \varepsilon_{in}$ represent the unknown utility for choice alternative i and for individual n (i = 1, 2, ..., N). V_{in} is the systematic observable component of choice alternative i and for individual n. ε_{in} is the random error component associated with choice alternative i and individual n. The choice probability for alternative *i,* according to observed utility is than given by:

$$P_n\ (i) = \frac{e^{V_{in}}}{\sum_{j\in C_n} e^{V_{jn}}} \quad (2)$$

We assume the random error components to be independently and identically distributed for all $i\ \in C$ with Gumbel-distribution that has a scale parameter $\mu > 0$. We also assume V_{in} and V_{jn} to be linear in their parameters. Let X_{in}, X_{jn} be explanatory variables (vectors of observable characteristics of individuals and attributes of alternatives) and the equation becomes:

$$P_n\ (i) = \frac{e^{\mu\beta' X_{in}}}{\sum_{j\in C_n} e^{\mu\beta' X_{jn}}} \quad (3)$$

The parameter β quantifies the impact of the explanatory variables on the utility of alternative i. The MNL model implies that the error terms ε_{in} are independently and identically distributed (iid). In this way, the MNL model does not allow sensitivity (or taste) variations to an attribute or across individuals. As a solution, a mixed or latent class MNL model can be estimated. In the continuous mixed MNL model, this distribution is continuous, while in the latent class context a finite number of classes are used to express the heterogeneity (Hess *et al.*, 2011).

A latent class MNL model considers discrete segments of decision-makers, which are not immediately identifiable from the data. These latent classes use the same framework of utility maximization, with different parameters per latent class. The inclusion of latent classes has a potential in improvements of the explanatory power of the generic models (Boxall *et al.,* 2002). During the data analysis, nested, cross-nested and mixed forms are also tested. The nested and cross-nested models were not as successfully as the Latent Class model. The mixed logit model has a similar share of explained variance, but needed very long computations time. Moreover, the expert interviews and literature study already indicated different possible classes (Kowald *et al*., 2011). We preferred the latent model to the mixed MNL model for this reason.

4.2 Factor analysis

To get a first idea of the potential segmentation, an explanatory factor analysis was carried out. Generally a factor analysis is used to assign multivariate data into classes of similar responses. This helps to examine how underlying constructs influence respondents answers. The factor analysis has two main goals (1) to identify the number of common factors influencing a set of measures and (2) to identify the strength of the relationship between each factor and each observed measure. The framework of Costello *et al.* (2005) is used to perform the factor analysis stepwise. The first step explores in variables in terms of communality. Variables with a low communality are excluded. The final factor model consists of two factors. The basis for imputing a label on these factors is the factor loading. The factor loadings are the correlation coefficients between the observed variables and the unobserved factors. More specific, the squared factor loading is the percentage of variance in the variable, explained by a factor. Table 4 presents the outcomes of the factor analysis.

Table 4 Factor loadings (Values with absolute smaller than 0,1 are not displayed)

Variable	Factor 1 (Care takers)	Factor 2 (Assistance needy)
Children	0.67	
Partner	0.52	
DriverLic	0.18	-0,48
PublicTransport	-0.18	0.27
Student		0.15
Age > 60	-0.27	
Income_High	0.24	-0.12

As the factor loadings show, decision-makers with children in the household, who have a partner, a driver license and are in the highest income group, define the first factor. Furthermore, the table presents a negative value for public transport. People with a driver license are less likely to use the public transport. Because of the high loadings for partner and children and a high income, we label them as 'care takers'. People without driver license, who take the public transport, define the second factor. This class has lower incomes. They have a negative value for driver license, which makes them dependent on public transport. The people may be single parents, students and elderly people. In this sense, they can be interpreted as group which needs evacuation assistance. In the following we refer to this group as the 'assistance needy'-group.

4.3 Model

Next step in the model specification is the definition of the utility functions where the results from the factor analysis are used to define the two classes. Since the estimated model will be used as a behavioural input model in the agent based simulation, a balance between simplicity and explorative power is extraordinarily important here. Defining the classes with many indicators, or a mixed form, where many draws are needed is therefore not optimal.

In the specification of the estimation model, the "care takers" class is defined by the existence of children in the household and the availability of a driver license. The partner indicator would have been also an option since the factor analysis shows a high loading on this factor too. In modelling, this partner factor was not successful. The second class is defined as (1-probability independent family). Two utility functions are estimated for both latent classes, resulting in four input equations. The equations are displayed below.

Class Care takers:

$$V_{imm} = ASC_{imm} + \beta^1_{atom} * d_{atom} + \beta^1_{chemie} * d_{chemie} + \beta^1_{fire} * d_{fire} + \beta^1_{time8} * \left(1 + \beta^1_{hhunit1} * hhunit\right) * d_{time8} + \beta^1_{time16} * \left(1 + \beta^1_{hhunit2} * d_{hhunit}\right) * d_{time16} \tag{4}$$

$$V_{lat} = ASC_{lat} + \beta^2_{atom} * d_{atom} + \beta^2_{chemie} * d_{chemie} + \beta^2_{fire} * d_{fire} + \beta^2_{time8} * (1 + \beta^2_{hhunit1} * hhunit) * d_{time8} + \beta^2_{time16} * (1 + \beta^2_{hhunit2} * d_{hhunit}) * d_{time16} \tag{5}$$

Class Assistance needy:

$$V_{imm} = ASC_{imm} + \beta^1_{atom} * d_{atom} + \beta^1_{chemie} * d_{chemie} + \beta^1_{fire} * d_{fire} + \beta^1_{time8} * d_{time8} + \beta^1_{time16} * d_{time16} + \beta^1_{age30} * d_{age30} + \beta^1_{age60} * d_{age60} \tag{6}$$

$$V_{lat} = ASC_{lat} + \beta^2_{atom} * d_{atom} + \beta^2_{chemie} * d_{chemie} + \beta^2_{fire} * d_{fire} + \beta^2_{time8} * d_{time8} + \beta^2_{time16} * d_{time16} + \beta^2_{age30} * d_{age30} + \beta^2_{age60} * d_{age60} \tag{7}$$

Three kinds of variables appear in the equation: alternative-specific constants (ASC), attributes of the evacuation and socio demographics of the decision maker. The “no evacuation” alternative is considered as the reference alternative. Which alternative is chosen as the reference alternative has no effect on the model except to shift the values of the estimated constants, keeping their differences constant. An alternative-specific constant reflects the mean of the difference of the disturbances when everything else is equal. In addition, main effects as well as interaction effects are considered. A main effect is the impact of different levels of a variable. An interaction between two or more variables occurs when the impact of a variable level depends on the levels of other variables. In the explanatory phase, the models are tested with a wide range of possible interaction effects. However, only the interaction between time and spatial distribution (joined or devised) of the household members during an evacuation is considered as important for the final model.

The first parts of the equations are similar. It contains dummy variables that represent the cause of the accident (*d_atom*, *d_chemie* and *d_fire*), with the case of a flood used as a reference category. Besides the reason of the accident, the timespan for evacuation is found as an influential factor. The utility of time is different for the two classes. For the first class, represented in equations 4 and 5), an interaction effect between time and a joined or devised household is estimated. The perception of time available for evacuation is influenced by the spatial situation of the household members. When people are not together, time availability will have an other impact on the decision to leave immediately, later, or not, than when the household members are all together (see hypothesis in table 3). The second class (equation 6 and 7) consists of people who do not live with family. The spatial distribution of other people in the household is not applicable, and thus the interaction effect is not estimated. Furthermore, in the second class, the age coefficient is estimated. People who are older are expected to behave different than the average mid-age decision maker. Since the old people, or very young people are not expected in the family class, this attribute is only relevant for the second class.

It would have been possible to estimate different parameters for the different classes. In this way, heterogeneity in the perceptions for reason and time for different classes can be captured. However, the models estimated in this way showed no significant heterogeneity. We conclude that for both classes this perception is the same and therefore used the same parameter.

5 Estimation results

The unknown parameters are estimated using maximum likelihood estimation. The software BIOGEME (Bierlaire 2003, 2008) is used for this estimation. The estimated parameters and t-values of the basic MNL-model (without latent classes) are shown in table 5, the descriptive statistics in table 6.

Table 5: Parameters MNL-model Rho^2 0.365

Parameter leave immediately	value	t-test	Parameter leave later	value	t-test
ASC_{imm}	2.93	14.55	ASC_{lat}	2.19	9.40
β^1_{chemie}	1.40	3.33	β^2_{chemie}	0.89	2.14
β^1_{atom}	1.72	8.70	β^2_{atom}	0.60	3.11
β^1_{fire}	0.54	1.57*	β^2_{fire}	0.29	0.82*
β^1_{age30}	-0.36	-3.63	β^2_{age30}	-0.00	-0.00*
β^1_{age60}	-0.60	-3.88	β^2_{age60}	-0.00	-0.00*
β^1_{time8}	-1.44	-5.87	β^2_{time8}	0.55	2.26
$\beta^1_{hhunit1}$	-0.43	-2.32	$\beta^2_{hhunit1}$	-0.62	-1.24*
β^1_{time16}	-1.71	-6.97	β^2_{time16}	0.39	1.63*
$\beta^1_{hhunit2}$	-0.48	-3.34	$\beta^2_{hhunit2}$	0.12	0.16*

The alternative specific constants for leaving immediately and leaving later have both positive signs. This indicates positive preference for immediate and later evacuation, compared to no evacuation, with all the rest remaining constant. Compared to a flood, a nuclear accident has the largest difference in utility for leaving immediately, followed by chemical accidents and fire. On the other side that means that people have a larger chance of not evacuating in case of natural disasters. The hypothesis regarding the cause of the accident mentioned that natural disasters are often perceived as less dangerous than industrial accidents. Contrarily, evacuations due to chemical or nuclear accidents have a higher chance for participation than fire and flood. Besides, the hypothesis suggested evacuations resulting from threats that are perceived being 'real' and 'life-threatening' have a higher participation rate. Clearly, on the one side all employed threats can be of a life threatening quality. However, chemical and nuclear accidents can be seen as more abstract than fire and flood. The high positive parameter results for chemical and nuclear accidents show that people are careful when being confronted with industrial disasters. Possible explanations might be that they rely on experts to get aware of the danger and that the Fukushima nuclear disaster (2011), which got a lot of media attention, was only few month ago at the time the questionnaires were sent out.

As expected, the coefficients for age are negative. When decision makers are older, they are less likely to evacuate immediately as well as leaving later. One could state that older people rather not evacuate. Remarkably, this is not only the case for old people, also people in the age class of 31 to 60 years have less chance for evacuate than the youngest group. Even when the model is estimated with more tightly defined age groups, with e.g. bins including 15 years, this effect remains visible. Clearly, it could be that people of 31 years and older are those who have families. They possibly prefer joint evacuations that need coordination and are more time consuming.

The time coefficient (time-span available for evacuation) is negative for leaving immediately. Since time is a dummy, the values should be compared with the reference category of an evacuation time span of one hour. Thus, people are less likely to evacuate immediately when the timespan of an evacuation is larger. For a later evacuation the estimated sign for the time coefficient is opposite. This indicates that when the timespan for an evacuation is eight or sixteen hours, compared to an evacuation of one hour, more people decide to evacuate later instead of no evacuation. However, as indicated in the hypothesis, the effect is different when nuclear families are all together.

Figure 4 is a graphical representation of the influence of household status (joined or separated) on the utility for time. Time is represented as a dummy variable, thus the y-axis represents the difference in utility for the alternatives, compared with a 1-hour time span. For immediate evacuation, the values are negative, which indicates that the longer timespan (eight or 16 vs. one hour) results in a lower participation for immediate evacuation. As becomes clear in the graph, when people are together, this effect is less strong. One could state that, if people are together, the time span is less influential and people tend to evacuate immediately. For later evacuation, we see a similar effect for united households. However, when households are divided, and the time span for evacuation is 8 or 16 hours (compared to 1 hour) people have a higher utility for leaving later, than for not leaving at all. One can explain this using the definition of leaving later, which was stated as "you wait to see what happens, are able to pack some bags, wait for other people and leave later". It is reasonable that people choose this alternative when 8 or 16 hours are available. It seems that a one-hour time frame is too short to pack personal belongings or wait for household members. Therefore people tend to refuse evacuation.

Figure 4 Graphical representation, effect of joined / divided households on time

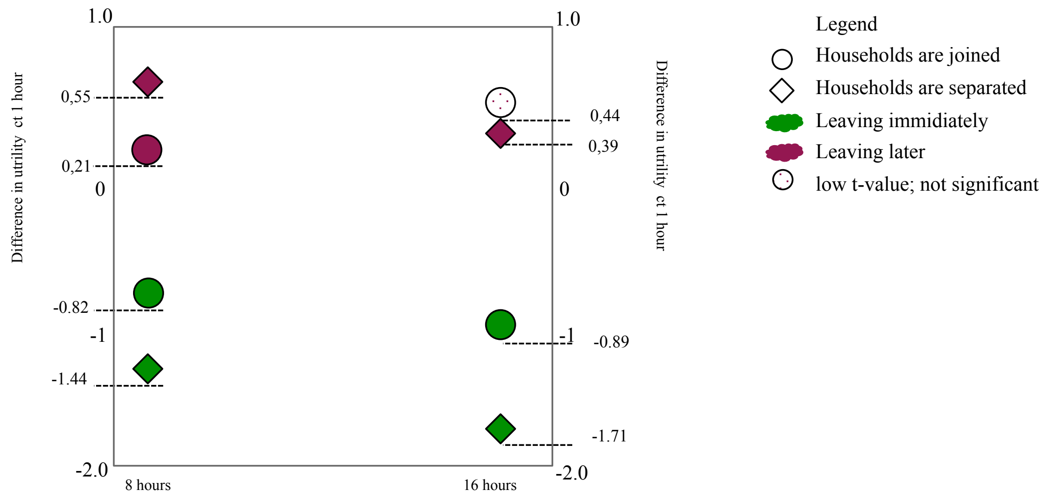


Table 6 Descriptive statistics explanatory variables

variable	mean	median	standard deviation
# children in the household	1.9	2	0.44
Age	49.13	49	14.69

Furthermore, as the outcomes of the factor analysis suggested, latent classes may improve the model results. In addition to the above model, a latent class model is estimated, based on the equations 4 until 7. The marginal differences between the basic MNL-model and the latent class model are shown in table 7. The latent class model lead to a significant improve in explained variance, the Rho^2 in this model was 0.391.

Table 7. Marginal differences latent class model vs. basic MNL Model

Parameter leave immediately	Marginal difference	Parameter leave later	Marginal difference
ASC_{imm}	1,91	ASC_{lat}	1,17
β^1_{chemie}	0,36	β^2_{chemie}	0,18
β^1_{atom}	0,21	β^2_{atom}	0,09
β^1_{fire}	0,05	β^2_{fire}	0,01
β^1_{age30}	-2,76	β^2_{age30}	-1,90
β^1_{age60}	-2,89	β^2_{age60}	-2,13
β^1_{time8}	-0,22	β^2_{time8}	-0,09
$\beta^1_{hhunit1}$	-0,30	$\beta^2_{hhunit1}$	-2,33
β^1_{time16}	-0,28	β^2_{time16}	-0,12
$\beta^1_{hhunit2}$	0,15	$\beta^2_{hhunit2}$	-1,81

Accounting for latent classes increases the strength of the cause and age-variables. Especially the age-parameter shows a large difference. Furthermore, an increase in the impact of the spatial segregation of households is observed. When all household members are together, the time span available for the evacuation is less important.

Other hypotheses suggested the information source and social status also as influential attributes. Different models were tested with information source, education level and income level as explanatory variables. These attributes did not impact the evacuation decision. The gender of people does also not affect the chance for evacuation, according to the model. The preference of car is confirmed in the descriptive statistics. The literature study and expert interviews also suggested an interaction between reason and information source. The model does not confirm this hypothesis. The remaining hypotheses of table 3, which were about isolated people and people with language problems cannot be checked with the current MNL Model since the survey questions were not suited for this.

6 Conclusion and further research

This paper presented a decision model based on a stated preference experiment, which aimed to verify supposed influences and quantify the behaviour of people during a large-scale evacuation. Data from 1008 households in the German and French speaking part of Switzerland were used to estimate a latent class MNL model. This type of model is able to retrieve richer patterns of heterogeneity by linking the class allocation to socio-demographic indicators. The outcomes of the decision model will be implemented in the agent-based model MATSim. In this way, it allows new simulation runs of evacuation events under more realistic behavioural assumptions.

The model supports the hypothesis of a heterogeneous population. The segmentation found consists of two latent classes. The first class "Care takers" corresponds to households with children and a driver license. Second class, which is called "Assistance needy" includes people who are more likely to use public transport during an evacuation and do not have children. For an implementation in MATSim, different functions should be assigned to the different classes of people. The spatial segregation of households during an evacuation, whether they are joined or divided, should be considered for only the family class. In addition, the age coefficient is important for the second class, but not for the first. Furthermore, the model underlines that people have a larger chance for participating in evacuation for nuclear and atomic disasters. The available time-span has an influence on the participation rate, but this depends on the spatial segregation of the families.

However, one must consider that this is only a first step in modelling the behaviour of people during a large-scale evacuation. Much work can be done to optimize the estimated parameters. For example, As the model was built, the effect of households being joint or together on different variables was not always robust. More advanced models; with for example more latent classes, need to be explored. Besides this, latent *variables* can be measured. Since the initial idea of a latent class model did not exist during the survey set up, questions about attitudes were not included in the dataset. Additional indicators like this will help building a more specific behavioural model. Nonetheless, including the latent classes for this model lead to an improve in model fit, which makes it definitely usable as first behaviour input for the MATSim simulation model.

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