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Modelling risky driving behaviour - the role of latent variables in overtaking decision on two-lane highways

Gila Albert[1]
Faculty of Technology Management, HIT – Holon Institute of Technology, Holon, Israel.

Shlomo Bekhor[2]
Faculty of Civil and Environmental Engineering, Technion - Israel Institute of Technology, Haifa, Israel.

This paper aims to demonstrate that advanced technique of modelling may provide insights and improve our understanding of driver behavior in risky decision-making situations. The paper introduces a Hybrid choice model in order to explain the overtaking decision on two-lane highways, which is well known as a risky decision in the safety literature. This model integrates a latent variable model and an overtaking choice model by combining their measurement and structural equations. Specifically, the paper investigates the role of four personality latent variables: *Thrill and Adventure Seeking*, *Boredom Susceptibility*, *Geographic Ability*, and *Driving Anger*. Respondents to a web-based survey ranked their likelihood to overtake on two-lane highways; two scenarios were captured via short videos: the first presenting a straight section of a road with good visibility, and the second approaching a curve with reduced visibility. Several indicators were collected via self-reported questionnaire. Results indicate that, two out of the four personality latent variables investigated, *Thrill and Adventure Seeking* and *Geographic Ability* provide significant explanation for overtaking decision. Both of them are positively correlated with higher risky overtaking behavior. The Hybrid model, by considering latent variables alongside observable variables and attributes of the decision, enhances the comprehension of overtaking behaviour, and therefore may be deployed for explaining other decisions related to risky driving behaviour.

Keywords: *driver behaviour, Hybrid model, latent variables, overtaking.*

1. Introduction

Risky driving behaviour is well recognized in the literature as a major concern in road safety. Research indicates that various types of this behaviour such as speeding, complicated maneuvers, aggressive driving style, all result in increasing the risk of involvement in a crash. Overtaking decision, especially on two-lane highways, is acknowledged among these risky behaviours (Polus et al., 2000; Gray and Regan, 2005; Bar-Gera and Shinar, 2005; Farah et al., 2009; Bella, 2011; Llorca et al., 2013; Llorca et al., 2015; Boora et a., 2016).

The ultimate overtaking behaviour is inherently a complicated decision-making process which involves human cognitive dimension and various characteristics of the transportation system such as traffic conditions and road alignment. Jenkins and Rillet (2005), Bella (2011) and Llorca et

[1] A: 52 Golomb St., Holon, 58102, Israel T/F: +972 3 502 6744 E: gilaa@hit.ac.il
[2] A: Technion City, Haifa, 32000, Israel T: +972 4 8292460, F: +972 4 8225716 E: sbekhor@technion.ac.il

al. (2015) studied the effect of the following gap on overtaking behaviour – the distance between the passing and the passed vehicles at beginning of the maneuver; Farah et al. (2009) highlighted the effect of traffic volume when performing a passing maneuver; Jenkins and Rillet (2004) and El-Bassiouni and Sayed (2010) dealt with the distance of passing - the distance travelled on left lane by passing vehicle in order to complete the passing; Jenkins and Rillet (2004), El-Bassiouni and Sayed (2010), Farah et al. (2009) and Leung and Starmer (2005), emphasized the time to collision - the remaining gap (in seconds) between passing and oncoming vehicles at the end of the passing maneuver; Vlahogianni (2013) also modelled the duration of the passing maneuver.

Pertaining to the impact of socio-economic characteristics on overtaking behaviour Llorca et al. (2013) found that age and gender of the overtaking driver play a role; for example, young male overtaking drivers have shown a more aggressive behaviour. Farah (2011) reported on significant differences in the overtaking behaviour of drivers depending on their age and gender. These differences are mainly in the frequency of overtaking maneuvers, overtaking time duration, following distances, critical overtaking gaps, and desired driving speeds. For example, young male drivers overtook in less time than old and female. However, there is a lack of evidence pertaining to the influence of human factors on overtaking (Llorca et al., 2013).

A broad array of disciplines (e.g., Psychology, Economics, Marketing, Transportation) has shown a general interest in enhancing behaviour models by considering the incorporation of latent personality factors affecting decision making. In road safety, it has been reported that underlying latent variables may play a role while designing countermeasures and intervention strategies for mitigating risky driving behaviour; e.g. considering *Locus of Control*[3] in structured learning (Huang and Ford, 2012), encouraging people to think about the meaning of life when designing safe driving campaigns (Taubman-Ben-Ari, 2012), and affecting family climate for road safety to improve young drivers reckless behaviour (Taubman–Ben-Ari et al., 2016).

In this regard, interesting is the notion of *Sensation Seeking*, which is commonly used in behavioural science. *Sensation Seeking* is defined "the need for varied, novel, and complex situations and experiences, and the willingness to take physical and social risks for the sake of such experiences" (Zuckerman, 1994). *Sensation Seeking* in its original framework includes four domains and is generally measured with the Sensation Seeking Scale (SSS). One of its domains - *Thrill and Adventure Seeking* (TAS) - which reflects sensation seeking in the area of sports and physical activities, was found in numerous studies to be positively related to reckless, aggressive, and risky driving behaviour (Zuckerman and Neeb, 1980; Dahlen et al., 2005; Dahlen and White, 2006; Jonah et al., 2001; Roberti, 2004; Schwebel et al., 2006; Wishart et al., 2017). Another domain of *Sensation Seeking* is *Boredom Susceptibility* (BS), which represents intolerance for repetition and routine of any kind. Albert et al. (2011) reported that individuals who scored higher on the BS were likely to switch their routes more frequently. Therefore, BS may play a role in overtaking behaviour as drivers with high BS might be more likely to overtake.

A relevant latent variable which was emerged as a viable predictor of unsafe driving behaviour is *Driving Anger* which is generally measured with the Driving Anger Scale (DAS) (Deffenbacher et al., 1994). *Driving Anger* is a propensity to become angry while driving, which leads to engagements in more traffic violations, aggressive and risky behaviour on the road (Deffenbacher et al., 2000; Jovanović et al., 2011; González-Iglesias et al., 2012; Stephens and Sullman, 2014; Zhang and Chan, 2016; Zhang et al., 2018).

[3] *Locus of Control* refers to the degree to which people perceive they have control over the outcomes of the situations they experience (as opposed to external forces beyond their control).

Additional latent variable that should be probed is *Geographic Ability* (GA), which is usually described as a component of a more general characteristic, known as spatial ability, and is defined as "a person's mental capability to learn, organize and recall spatial information" (Ramming, 2002). GA was found related to route choice behaviour as drivers with higher geographic abilities tended to switch their routes more often (Albert et al., 2011). Due to its nature of spatial perspective our hypothesis suggests that this variable may account for overtaking behaviour. More specifically, drivers with higher geographic abilities will have a tendency to overtake.

Overtaking behaviour can be modelled in few manners. In this regard one of the updated established methods in the field of route choice behaviour is the Hybrid choice model, which integrates many types of modelling methods to account for both latent and observed variables (Ben Akiva et al., 2002). Prato et al. (2012) developed a Hybrid choice model, which integrates latent variables in route choice models and consists of measurement and structural equations. Bekhor and Albert (2014) showed that considering latent variables alongside observed variables in this advanced technique of modelling in route choice behaviour provides insight into and enriches the comprehension of route choice behaviour.

This paper focuses on the impact of latent personality variables on overtaking behaviour on two-lane highways. The motivation for this is to fulfil the lack of evidences pertaining to the influence of personality latent variables on this risky decision. According to our hypothesis these variables, which play a role in risky driving and route choice behaviour, may provide insights and enhances our understanding of overtaking behaviour.

The contributions of the present paper are twofold: the first is the introduction and testing of latent personality variables such as TAS, BS, Anger, and GA, in an attempt to probe overtaking decisions. To the best of our knowledge, no other efforts have been made to relate BS and GA to driving behaviour. The second is the adaptation of the Hybrid choice model to explain these decisions. More specifically, the paper aims to demonstrate that, with latent concepts incorporated in advanced technique of modelling, our understanding of overtaking driving behaviour may be improved.

The rest of the paper is organized as follows: the methodology section describes the experiment and the proposed overtake choice model. The results section presents the sample, a statistical analysis of the overtake decisions, and the estimation of the overtaking choice model. The final part of the paper summarizes and discusses the main results.

2. Methodology

2.1 Experiment setup

The framework of the experiment was set up in order to capture the effect of the driver latent variables and socio economic characteristics, as well as scenario attributes on overtaking decision in two lane highway. Hence, a web-based survey has been conducted and included three parts. First, two shorts videos, approximately 8 seconds each, were presented. In the videos, a real world two-lane highway during free flow traffic conditions was present. The videos were filmed from a moving following vehicle during a sunny day, which keeps approximately two seconds head-way time from the followed vehicle ahead. Respondents were asked to indicate if they would overtake the vehicle ahead on the following scale: 1= very high, 2= high, 3= maybe, 4= low, 5= very low. The first video presented a straight section of a road with good visibility. The second video described a riskier situation compared to the one presented in the first video: it was taken in a curved spot of the highway under partly sunlight dazzle conditions, and the site view

was limited. Hence, the overtaking maneuver was notably less safe. Figures 1 and 2 present screenshots of the videos and illustrate the two situations the respondents faced.
With the aim to identify which latent variables may affect the overtaking behaviour, in the second part of the experiment we used the general frame of the Sensation Seeking Scale (SSS) form V (Zuckerman, 1994). This SSS is estimated on the basis of a questionnaire which includes 10 items for each domain, presented in a random order in the format of a "forced choice". However, the "forced choice" scale, which is occasionally criticized in the literature (see for example, Arnett, 1996), was replaced with a finer Likert-type format. That is, for each item, respondents were asked to indicate the extent to which they agree with the stated item on a scale of 1 to 5, where 1=strongly disagree and 5=strongly agree.

Two variables from this SSS were included:
• *Thrill and Adventure Seeking* (TAS) - desire for outdoor sports and physical activities involving unusual sensations and risks. It can be summarized as a positive answer to "I sometimes like to do things that are a little frightening".
• *Boredom Susceptibility* (BS) - represents intolerance for repetition and routine of any kind (e.g., work) and a restless reaction to unvarying situations. An example of a statement expressing sensation seeking in this domain: "The worst social sin is to be a bore".

Figure 1. Screenshot of the first overtake situation

Figure 2. Screenshot of the second overtake situation

Similarly, we included, based on the literature review, two other variables that according to our hypothesis may play a role in overtaking behavior: *Driving Anger* – a propensity to become angry while driving which leads to engagements in riskier behavior and *Geographic Ability* (GA) - a person's mental capability to use spatial information. Each of these two factors, in accordance to TAS and BS, was also reflected by 10 indicators with the same five scale Likert-type format of 1 to 5, where 1=strongly disagree and 5=strongly agree.

The indicators for Anger were based on Deffenbacher et al. (1994); for consistency and based on a pilot we used 10 items from the 14 items short-form of Driver Anger, as described in Dahlen and White (2006). The indicators for GA were based on Ramming (2002) and we used the 10 items presented in Albert et al. (2011).

Table 1 describes the 40 indicators that formed the four latent variables in the experiment. The 40 indicators were purposely scrambled in the questionnaire and some of the questions were asked in reverse mode in an attempt to maximize the awareness of the respondents.

The third part of the experiment included items regarding socio-economic characteristics such as age, gender, marital status and items pertaining to travel behavior patterns: availability, frequency of driving, and the annual mileage driven.

2.2 The overtaking choice model

This section presents the methodology for formulating and estimating models from the collected data. The Hybrid discrete choice model framework integrates a latent variable model and an overtaking choice model by combining their measurement and structural equations. Figure 3, adapted from Bekhor and Albert (2014), illustrates the overtaking choice model.

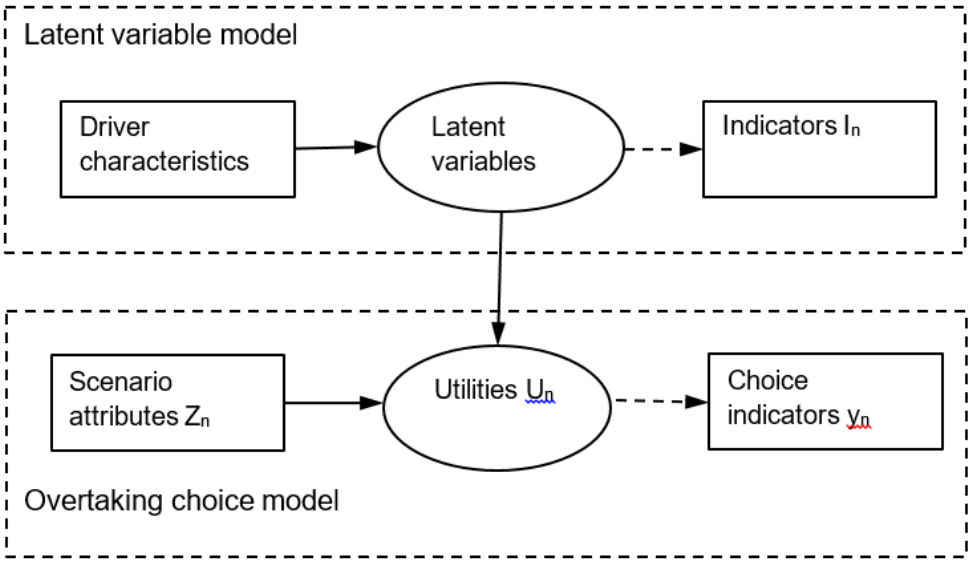

Figure 3. Overtaking choice model (adapted from Bekhor and Albert, 2014)

The Hybrid choice model enhances the comprehension of overtake behaviour by considering latent variables which represent unobserved constructs (e.g. domain of sensation seeking), alongside observable variables which represent individual characteristics (e.g. gender) and attributes of the alternatives, (e.g., the overtake scenario).

Table 1. Indicators of the latent variables

Latent variable	Indicator	Description
TAS Thrill and Adventure Seeking	I_3	Wish to be a mountain climber
	I_{11}	Tendency to do things that are a little frightening
	I_{16}	Tendency to take up the sport of water skiing
	I_{17}	Tendency to try surfboard riding
	I_{20}	Tendency to learn to fly an airplane
	I_{21}	Tendency to go scuba diving
	I_{23}	Tendency to try parachute jumping
	I_{28}	Tendency to dive off the high board
	I_{38}	Tendency to sail a long distance in a small but seaworthy sailing craft
	I_{40}	Enjoy the sensations of skiing very fast down a high mountain slope
BS Boredom Susceptibility	I_2	Can't stand watching a movie that I've seen before
	I_5	Get bored seeing the same old faces
	I_7	Predict almost everything a person will say he/she must be a bore
	I_8	Don't enjoy a movie where I can predict what will happen in advance
	I_{15}	Looking at someone's home movies, videos, or travel slides bores me tremendously
	I_{24}	Prefer friends who are excitingly unpredictable
	I_{27}	Very restless if I have to stay around home for any length of time
	I_{31}	The worst social sin is to be a bore
	I_{34}	Like people who are sharp even if they do sometimes insult others
	I_{39}	No patience with dull or boring people
GA Geographic Ability	I_1	Judging where North is in an unfamiliar city is extremely easy for me
	I_{12}	Knowledge of Identifying specific building from different point of reference is easy
	I_{13}	Clearly provide directions
	I_{25}	Point out toward the direction of my house from anywhere
	I_{29}	I prefer that someone else will navigate
	I_{30}	Getting confused while driving in the "wrong" side of the road
	I_{32}	Unclear where I am located on the map
	I_{33}	Often using navigator, even in familiar places
	I_{35}	Prefer to explore by myself with a map a new place
	I_{36}	Afraid to get lost in an unfamiliar place
Anger	I_4	Avoid shouting and comment to other drivers
	I_6	Like to "punish" other drivers (e.g. by glaring)
	I_9	Speed up when someone try to pass me
	I_{10}	Upset because some people don't know how to drive
	I_{14}	Frustrating traffic conditions are integral part of driving
	I_{18}	Had various conflicts with other drivers
	I_{19}	Tend to use to horn to in order to urge other drivers
	I_{22}	Upset when someone is slow in parking and holding up traffic
	I_{26}	Respond when someone makes an obscene gesture toward me
	I_{37}	Try to get close or change lane when stuck in a traffic jam

Using the notation from Figure 3, the structural equations of the choice model express the distribution of the utilities (Walker, 2001):

$$U_n = V(Z_n, X_n^*; \beta) + \varepsilon_n \quad \text{and} \quad \varepsilon_n \sim D(0, \Sigma_\varepsilon) \tag{1}$$

Where U_n is a vector of utilities of the alternatives for individual n, Z_n is a vector of attributes of the alternatives, ε_n is a vector of error terms following distribution D with covariance matrix Σ_ε, and β is a vector of parameters to be estimated. The latent variables X^*_n are expressed by the following structural equations:

$$X_n^* = g_1(S_n;\gamma) + \omega_n \quad \text{and} \quad \omega_n \sim D(0,\Sigma_\omega) \tag{2}$$

where X^*_n is a vector of latent variables, S_n is a vector of characteristics of individual n, ω_n is a vector of error terms following distribution D with covariance matrix Σ_ω, and γ is a matrix of parameters to be estimated. In this paper, it is assumed that g_1 is a linear function.

As indicated in the previous section, the measurement equations of the latent variable model associate the latent variables to the indicators according to the correspondence in Table 1. The functional relationship of the measurement equations is given by relating the indicators to the latent variables as follows:

$$I_n = g_2(X_n^*;\alpha) + \upsilon_n \quad \text{and} \quad \upsilon_n \sim D(0,\Sigma_\upsilon) \tag{3}$$

where I_n is a vector of indicators, υ_n is a vector of error terms following distribution D with covariance matrix $\Sigma\upsilon$, and α is a vector of parameters to be estimated. In this paper, it is assumed that g_2 is a linear function. As observed by Raveau et al. (2012) equations (2) and (3) correspond to the Multiple Indicator Multiple Cause (MIMIC) model. All the error terms are independent of each other.

The choice indicators y_{in} are expressed as follows:

$$y_{in} = \begin{cases} 1 & \text{if } U_{in} \geq U_{jn} \ \forall j \neq i \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

The Hybrid choice probability function involves three components as follows (Ben-Akiva et al., 2002):

$$P(y_n, I_n | Z_n, S_n, \beta, \alpha, \gamma, \Sigma_\varepsilon, \Sigma_\upsilon, \Sigma_\omega) = \int_{X_n^*} P(y_n | X_n^*, Z_n, \beta, \Sigma_\varepsilon) f_2(I_n | X_n^*, \alpha, \Sigma_\upsilon) f_1(X_n^* | S_n, \gamma, \Sigma_\omega) dX_n^* \tag{5}$$

Where $P(y_n | X_n^*, Z_n, \beta, \Sigma_\varepsilon)$ is the overtaking choice probability (in this paper, a binary logit model), f1 and f2 are respectively the densities of the latent variables and the indicators. In this paper it is assumed normal distribution of the error terms for the indicators and latent variables, and Gumbel distribution for the error terms of the utility functions.

Model estimation was performed in the AMOS software (Arbukle, 2001) using the maximum likelihood approach.

3. Results

3.1 The sample

The sample was recruited from different e-mailing lists: Israeli students at the Technion and at Holon institute of Technology, the mailing list of The Ran Naor Research Institute and followers of Or Yarok association for safer driving in Israel. The survey was constructed using the Qualtrics Research Suite platform, which also enabled monitoring and performing logical checks. Two questions were used for filtering out the participants: possession of driving license and experience on driving in interurban roads.

Out of 339 entries in the internet survey site, approximately half completed the survey, and several observations were removed after realizing that the data were not completed appropriately (e.g. when the whole survey was done in less than one minute). The resulting

sample used for the analysis contained 151 respondents, driving license holders, 64% males and 36% females. 10% were 17-20 years old, 10% were 21-24 years old, 20% were 25-30 years old, 20% were 31-40 years old, 21% were 41-50 years old, 9% were 50-60 years old, and 7% were above 61 years old. 66% of the respondents reported that they drive a passenger car every day and 20% indicated to do so almost every day. 15% reported that their annual mileage driven is 15,000-20,000 km, 40% reported on lower values, 18% on higher values, and 15% were not able to estimate the amount of their annual mileage. Note that the average annually mileage in Israel is about 17,000 km.

3.2 Associating overtaking decisions

Table 2 presents the distribution cross results of overtaking decisions in the two situations which were sequentially presented in the experiment.

As expected, the table shows a lower chance to overtake in the second situation (the more dangerous case). None of the respondents indicated that the chance they would overtake in the second situation is very high and only 8% respond that this chance is high. In comparison, 15% indicated that their chance to overtake in the first situation is very high and 28% respond that the chance is high. Interestingly, 14% who indicate that their chance to overtake in the first situation is high or very high respond that the chance they would do it in the second situation is very low. Note that the choice decision in the second overtake situation (the more dangerous case) is dependent on the decision in the first overtake situation, and there is clearly a correlation between them (0.312, significant at the 0.01 level).

Table 2. Overtaking choice decisions in the two situations

First overtake	Second overtake situation					
situation	Very high	High	Maybe	Low	Very low	Overall
Very high	0%	3%	5%	2%	5%	15%
High	0%	3%	9%	7%	9%	28%
Maybe	0%	2%	5%	22%	15%	44%
Low	0%	0%	1%	3%	6%	10%
Very low	0%	0%	0%	0%	3%	3%
Overall	0%	8%	21%	33%	38%	100%

The next step of the analysis was to perform factor analysis to identify which of the four latent factors should be included in the structural models. Table 3 presents the results obtained including all the four factors. The Keiser-Meyer-Olkin measure is 0.68, which is below the acceptable threshold of 0.75. As can be seen from comparing Table 1 and Table 3, the results for Anger and BS appear to be less fitting than the results for TAS and GA.

The best statistical results obtained including only two factors - TAS and GA - and Table 4 shows the rotated component matrix. The Keiser-Meyer-Olkin measure of sampling adequacy for these two factors is 0.79. Figure 4 presents the Scree plot for these factors and show a sharp decrease in the Eigenvalue after two factors. The extraction method applied was the principal component analysis, and the rotation method was the Varimax with Kaiser normalization. For ease of interpretation, absolute values lower than 0.3 were suppressed.

Furthermore, Table 5 presents the statistics of goodness to fit of three calibrated models (using the same set of other variables in all the models): Model 1(without latent variables), Model 2 (with two latent variables: TAS and GA), and Model 3 (with the four latent variables). There are several fit statistics used to assess structural equation models. Kline (2005) suggests that at a

minimum the following indices should be reported: (a) Chi-squared test: assess overall fit and the discrepancy between the sample and fitted covariance matrices. P-values closer to zero indicate a better fit. (b) Root Mean Square Error of Approximation (RMSEA): A parsimony-adjusted index. Values closer to 0 represent a good fit. RMSEA < 0.08 represents a good fit. (c) Comparative Fit Index (CFI): compares the fit of a target model to the fit of an independent, or null, model. CFI ≥ 0.90 represents a good fit. (d) SRMR (Standardized Root Mean Square Residual): The square-root of the difference between the residuals of the sample covariance matrix and the hypothesized model. SRMR < 0.08 represents a good fit. As can be seen in the results in Table 5, Model 2 provides the best statistical results, and therefore has been used for further analysis.

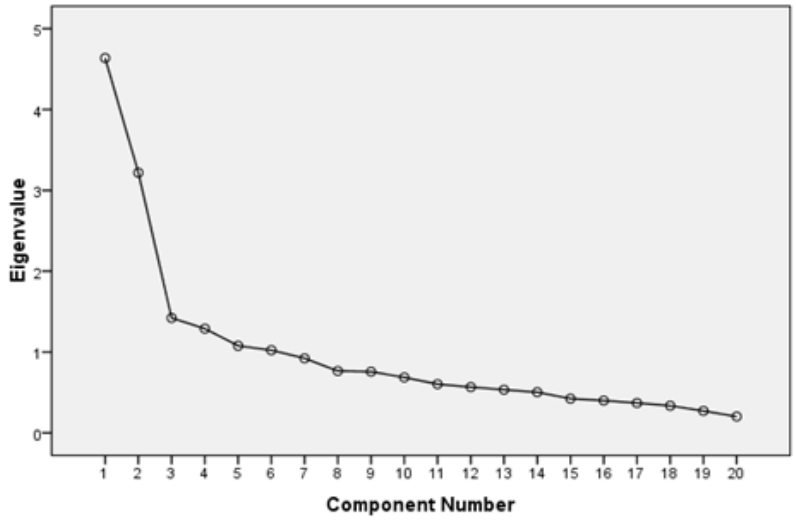

Figure 4. Scree plot (two components)

3.3 Model estimation results

Formulating and estimating the model describing the overtaking choice decision are based on a Hybrid choice model framework. This model integrates a latent variable model and a choice model by combining their measurement and structural equations, which were presented in the Methodology section**.**

Table 6 presents the estimation results of the structural equations of the latent variable model. Figure 5 illustrates the correlations between each variable in the model, and the double curved arrows represent covariance. The variables correspond to those defined in the Methodology section. Table 7 presents the variances of the error terms.

As can be seen pertaining to the overtaking decision and the impact of latent variables, clearly, choice 2 (the more dangerous case) is dependent on choice 1; this may be a consequence of the order in which scenarios were presented. Choice 1 which in turn is dependent on the two latent variables TAS and GA. That is, drivers who scored higher on *Thrill and Adventure Seeking* are more likely to overtake; drivers with higher *Geographic Ability* tend more to overtake.

There are significant correlations between individual characteristics and these latent variables. For example, males turn out to perceive their *Geographic Ability* to be higher; drivers with lessen annual average mileage driven tend to perceive less their *Geographic Ability*. In line with the literature (Zuckerman, 1994), TAS was found higher for males, and for young drivers.

Table 3. Factor analysis results (four components)

	Indicator	Component			
		1 (TAS)	2 (GA)	3 (Anger)	4 (BS)
I_1	Judging where North is in an unfamiliar city is extremely easy for me		.681		
I_2	Can't stand watching a movie that I've seen before				.499
I_3	Wish to be a mountain climber	.606			
I_4	Avoid shouting and comment to other drivers			.573	
I_5	Get bored seeing the same old faces			.352	
I_6	Like to "punish" other drivers (e.g. by glaring)				.333
I_7	Predict almost everything a person will do and say he or she must be a bore			.341	
I_8	Don't enjoy a movie or play where I can predict what will happen in advance				.402
I_9	Speed up when someone try to pass me				.531
I_{10}	Upset because some people don't know how to drive			.399	.432
I_{11}	Tendency to do things that are a little frightening	.590			
I_{12}	Identifying specific building from different point of reference is easy		.643		
I_{13}	Clearly provide directions		.634		
I_{14}	Frustrating traffic conditions are integral part of driving			.710	
I_{15}	Looking at someone's home movies, or videos bores me tremendously				.466
I_{16}	Tendency to take up the sport of water skiing	.796			
I_{17}	Tendency to try surfboard riding	.777			
I_{18}	Had various conflicts with other drivers				
I_{19}	Tend to use to horn to in order to urge other drivers			.469	
I_{20}	Tendency to learn to fly an airplane	.652			
I_{21}	Tendency to go scuba diving	.761			
I_{22}	Upset when someone is slow in parking and holding up traffic			.394	.312
I_{23}	Tendency to try parachute jumping	.658			
I_{24}	Prefer friends who are excitingly unpredictable				.417
I_{25}	Point out toward the direction of my house from anywhere		.610		-.332
I_{26}	Respond when someone makes an obscene gesture toward me			.717	
I_{27}	Very restless if I have to stay around home for any length of time			-.360	
I_{28}	Tendency to dive off the high board	.520			
I_{29}	I prefer that someone else will navigate		.521		
I_{30}	Getting confused while driving in the "wrong" side of the road		.305		
I_{31}	The worst social sin is to be a bore				
I_{32}	Unclear where I am located on the map		.674		
I_{33}	Often using navigator, even in familiar places				
I_{34}	Like people who are sharp and witty even if they do sometimes insult others			.383	
I_{35}	Prefer to explore by myself with a map a new place		.585		.307
I_{36}	Afraid to get lost in an unfamiliar place		.686		
I_{37}	Try to get close or change lane when stuck in a traffic jam			.388	
I_{38}	Tendency to sail a long distance in a small but seaworthy sailing craft	.539			
I_{39}	No patience with dull or boring people				
I_{40}	Enjoy the sensations of skiing very fast down a high mountain slope	.536			

Table 4. Factor analysis results (two components)

Indicator		Component	
		1 (TAS)	2 (GA)
I_1	Judging where North is in an unfamiliar city is extremely easy for me		.704
I_3	Wish to be a mountain climber	.595	
I_{11}	Tendency to do things that are a little frightening	.610	
I_{12}	Identifying specific building from different point of reference is easy		.651
I_{13}	Clearly provide directions		.635
I_{16}	Tendency to take up the sport of water skiing	.803	
I_{17}	Tendency to try surfboard riding	.796	
I_{20}	Tendency to learn to fly an airplane	.672	
I_{21}	Tendency to go scuba diving	.768	
I_{23}	Tendency to try parachute jumping	.647	
I_{25}	Point out toward the direction of my house from anywhere		.609
I_{28}	Tendency to dive off the high board	.514	
I_{29}	I prefer that someone else will navigate		.513
I_{30}	Getting confused while driving in the "wrong" side of the road		.316
I_{32}	Unclear where I am located on the map		.684
I_{33}	Often using navigator, even in familiar places		
I_{35}	Prefer to explore by myself with a map a new place		.593
I_{36}	Afraid to get lost in an unfamiliar place		.712
I_{38}	Tendency to sail a long distance in a small but seaworthy sailing craft	.531	
I_{40}	Enjoy the sensations of skiing very fast down a high mountain slope	.523	

Table 5. Statistics of goodness to fit

Statistic	Model 1 (no latent variables)	Model 2 (Two latent variables: TAS and GA)	Model 3 (Four latent variables)
Number of parameters	21	83	143
Chi-square	536.89	797.56	2156.29
RMSEA	0.270	0.080	0.074
CFI	0.037	0.713	0.545
SRMR	0.061	0.085	0.109

Table 6. Structural model estimation and measurement model results (with two latent variables)

	Estimate	S.E.	P
Thrill and Adventure Seeking (TAS) variables			
Dummy variable (age > 60)	-.363	.134	.007
Dummy variable (age < 30)	.251	.132	.058
Dummy variable (Male person)	.256	.102	.012
Dummy variable (has children)	-.258	.108	.022
Dummy variable (license years > 10)	.157	.081	.053
Geographical Abilities (GA) variables			
Dummy variable (Male person)	.422	.128	.000
Dummy variable (has children)	-.389	.106	.000
Dummy variable (Single person)	-.681	.152	.000
Dummy variable (license years > 10)	-.361	.145	.013
Dummy variable (license years < 1)	-.387	.184	.036
Dummy variable (drives every day)	.503	.163	.002
Dummy variable (annual km < 15,000)	-.543	.130	.000
"No pass in scenario 1" variables			
TAS (latent variable)	-.416	.151	.006
GA (latent variable)	-.121	.097	.102
TAS Indicators			
I_3 - Wish to be a mountain climber	1.000		
I_{11} - Tendency to do things that are a little frightening	1.062	.224	.000
I_{16} - Tendency to take up the sport of water skiing	1.982	.333	.000
I_{17} - Tendency to try surfboard riding	2.045	.344	.000
I_{20} - Tendency to learn to fly an airplane	1.649	.308	.000
I_{21} - Tendency to go scuba diving	1.862	.323	.000
I_{23} - Tendency to try parachute jumping	1.518	.304	.000
I_{28} - Tendency to dive off the high board	.859	.206	.000
I_{38} - Tendency to sail a long distance in a seaworthy sailing craft	1.090	.238	.000
I_{40} - Enjoy the sensations of skiing very fast down a mountain slope	.904	.222	.000
GA Indicators			
I_1 - Judging where North is in an unfamiliar city is easy for me	1.000		
I_{12}- Identifying specific building from different reference is easy	.637	.102	.000
I_{13} - Clearly provide directions	.586	.102	.000
I_{25} - Point out toward the direction of my house from anywhere	.674	.119	.000
I_{29} - I prefer that someone else will navigate	.520	.118	.000
I_{30} - Getting confused while driving in the "wrong" side of the road	.409	.122	.000
I_{32} - Unclear where I am located on the map	.868	.139	.000
I_{35} - Prefer to explore by myself with a map a new place	.738	.136	.000
I_{36} - Afraid to get lost in an unfamiliar place	.810	.124	.000
"No pass in scenario 2" variables			
"No pass in scenario 1"	.308	.077	.000

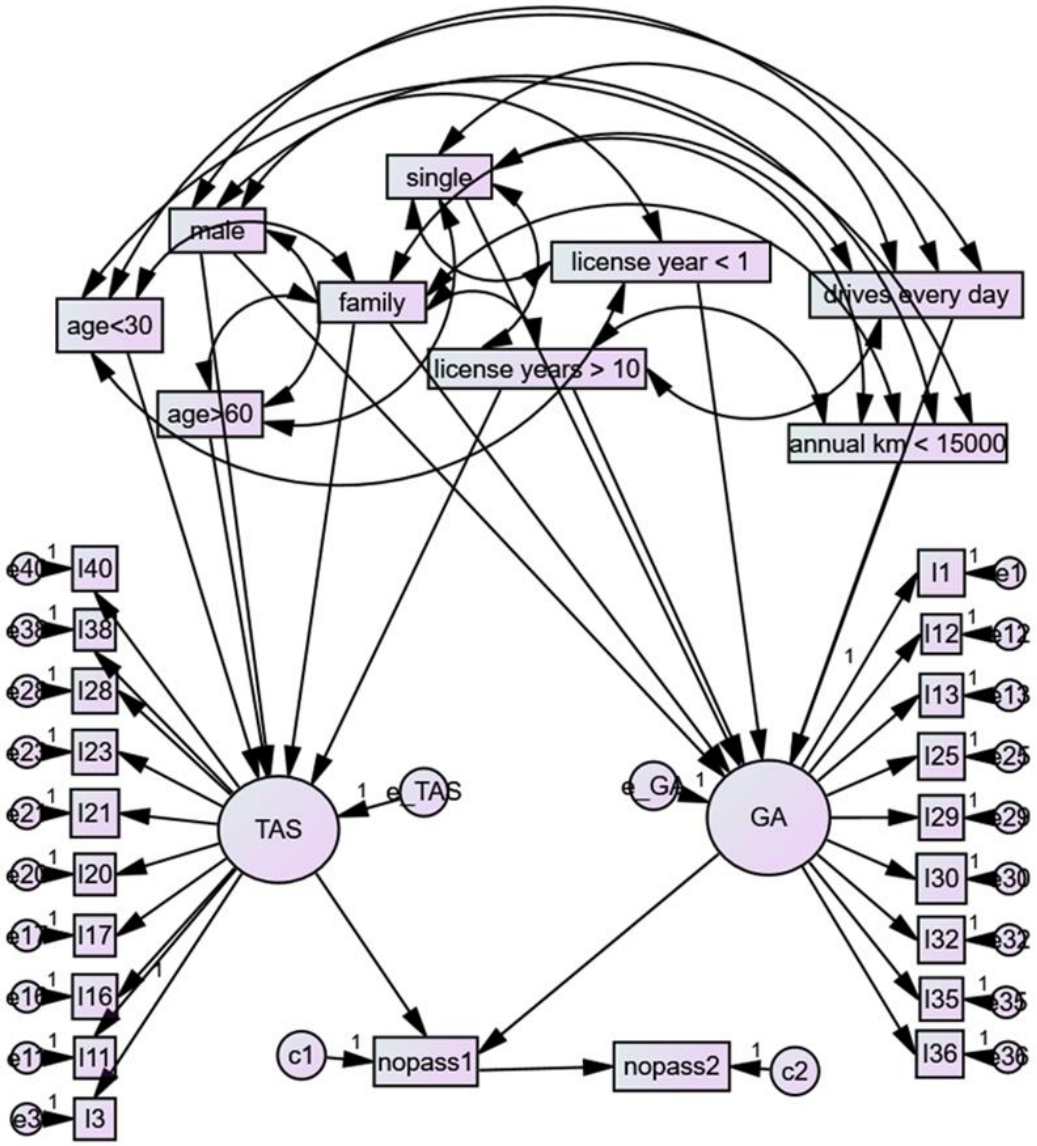

Figure 5. Correlations among the variables

4. Discussion and Conclusions

This paper provides insight into overtaking decision, which is well recognized in the safety literature as is risky driving behaviour. We demonstrate that with latent concepts incorporated in advanced technique of modelling our understanding of the risky driving behaviour of overtaking on two-lane highways is improved. Hence, the contributions of the paper are twofold: the first is the introduction and testing of personality latent variables such as *Thrill and Adventure Seeking*, *Boredom Susceptibility, Driving Anger*, and *Geographic Ability*, to shed light on overtaking decision. Please note that all these latent variables represent the manner in which they perceived by the respondents rather than objective measures. The second is the adaptation of the Hybrid choice model, which integrates a latent variable model and an overtaking choice model by combining their measurement and structural equations, in order to explain the overtaking decisions on two-lane highways.

Table 7. Variance of the error terms

	Estimate	S.E.	P
e_TAS – variance of error term of TAS	.254	.085	.003
e_GA – variance of error term of GA	.567	.135	.000
c1 – alternative specific constant "no pass in scenario 1"	.857	.100	.000
c2 – alternative specific constant "no pass in scenario 2"	.819	.095	.000
Error terms of TAS Indicators			
e3	1.132	.135	.000
e11	1.022	.123	.000
e16	.588	.092	.000
e17	.663	.102	.000
e20	1.274	.160	.000
e21	.836	.115	.000
e23	1.623	.198	.000
e28	1.125	.133	.000
e38	1.251	.150	.000
e40	1.335	.158	.000
Error terms of GA Indicators			
e1	.875	.126	.000
e12	.548	.072	.000
e13	.628	.080	.000
e25	.859	.109	.000
e29	1.026	.124	.000
e30	1.222	.144	.000
e32	1.022	.135	.000
e33	.796	.092	.000
e35	1.159	.145	.000
e36	.740	.101	.000

The results confirm our hypothesis that latent variables may provide insights and enhances our understanding of overtaking behaviour. More specifically, one domain of *Sensation Seeking -Thrill and Adventure Seeking* (TAS), and the concept of *Geographic Ability* (GA) are significant in overtaking decision. TAS, which is well known in the safety literature as positively related to reckless and aggressive driving behaviour, was found in this study to be a key factor explaining risky overtaking decision; Drivers who are more thrill and adventure seeking are more likely to take risky overtaking decisions. In line with the literature (Zuckerman, 1994), TAS was found higher for males, and for young drivers. GA, to the best of our knowledge, is a novel concept in driving behaviour. According to our findings GA turns out to be a major factor affecting overtaking decisions; drivers who scored high on *Geographic Ability* tend to overtake in riskier situations.

Furthermore, the results show that socio economic characteristics such as age, gender, family status, and average annual mileage driven, may provide insights and serve as causal variables for these important latent variables. This may enrich our understanding of results such these presented in Farah (2011) who reported on significant differences in the overtaking behaviour of drivers depending on their age and gender. In this regard, it should be noted that while considering socio economic characteristics, gender plays the foremost role in the overtaking decision, as is shown in Table 8.

Pertaining to the role of *Driving Anger* and *Boredom Susceptibility* in overtaking behaviour, the analysis revealed weak relationship between the latent variable and the measurement indicators; hence, their impact on overtaking behaviour is questionable. While *Boredom Susceptibility* has been rarely

probed in the context of driving behaviour, *Driving Anger* has been evaluated in numerous studies.

However, it seems that our result pertaining to the role of *Driving Anger* is not in line with the common literature which indicates that risky driving is positively related to *Driving Anger* (see for example results from a meta-analysis reported by Zhang and Chan, 2016). Though these studies referred to many types of risky driving behaviour and not in particular on overtaking decisions, the impact of *Driving Anger* on overtaking behaviour should be further explored and evaluated.

Table 8. Passing probabilities

Passing probability	Scenario 1	Scenario 2
overall sample	60.5%	24.8%
male	77.4%	37.6%
male and young (age < 30)	78.0%	37.9%
male, young and frequent driver	79.0%	38.1%

Furthermore, although the literature seems to be ambiguous pertaining to role of latent variables in affecting choice behaviour (see for example, Chorus and Kroesen, 2014; Vij and Walker, 2016), this paper may suggest various practical implication. Policy implications may consider these variables in framing training program, planning of drivers' assistance systems and designing of road alignment and traffic signals. For example, in Israel a training driving program is common for drivers with traffic offenses. Driving training program may impact latent variables that affect driving behaviour; e.g., it has been already been shown that structured learning affects the latent variable *Locus of Control* and this change causes an improvement in safe driving behaviour (Huang and Ford, 2012). Hence, in these training courses a focus should be put on mitigating latent factors that trigger drivers to perform risky driving decisions such as overtaking.

While this study seems promising, its limitations should be acknowledged. Although based on solid statistical analysis, similar to exploratory studies, the sample size, which consists of 151 respondents, may consider to be relatively small and not representative of the drivers' population. In addition, the experiment setup reflects only two scenarios of overtaking, and a further analysis should benefit from investigating more situations. This should be further probed and evaluated, and may include also additional unobserved constructs.

To conclude, this paper extends the common characteristics used in driving behaviour analysis and sheds light on the importance of latent, personal variables. That is, latent variables emerged as a viable predictor of unsafe/safe driving behaviour. These concepts, incorporated in new technique of choice modelling, may improve our understanding of driving behaviour. Furthermore, this paper suggests the use of the Hybrid choice model, which enhances the comprehension of overtaking behaviour, in order to explain additional decisions related to risky driving behaviour, for example, speeding and texting while driving.

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