https://doi.org/10.25100/iyc.v18i2.2150

CIVIL ENGINEERING

Safety perception in transportation choices: progress and research lines

INGENIERÍA CIVIL

Percepción de seguridad en elecciones de transporte: avances y líneas de investigación

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(Recibido: Abril 14 de 2015 - Aceptado: Diciembre 18 de 2015)

Abstract

The contribution of human factors in traffic accidents has been widely acknowledged in road safety research globally. Although there is sufficient evidence linking the individual behavior with traffic accidents, perceptions are not always included in model specifications to study transportation choices. In the context of transportation choices, this review article makes a significant contribution to understand and model safety perception, identifying issues that have not been addressed sufficiently in the literature, such as measuring indicators, inclusion of objective factors and the link between other latent variables and safety perception. Based on this review it will be possible to formulate novel methodological and econometric approaches to address the inclusion of safety perception into choice models and build a methodological framework for modelling safety perceptions in transportation choices.

Keywords: *Choice modelling, hybrid modelling, safety perception, transportation safety research.*

Resumen

Investigaciones en el ámbito mundial con respecto a la seguridad vial han encontrado que los factores humanos contribuyen de manera importante en los accidentes de tránsito. Aunque es ampliamente aceptado que existe un vínculo entre los factores humanos y los accidentes de tránsito, las percepciones de los individuos no siempre han sido incluidas en la especificación de modelos de elección de transporte. En el contexto de elecciones de transporte, el presente artículo de revisión hace una significativa contribución en la comprensión y modelación de la percepción de seguridad, identificando aspectos que no han sido tratados lo suficiente en la literatura, tales como: instrumentos de medición, inclusión de factores objetivos y el efecto de otras variables latentes en la percepción de seguridad. A partir de esta revisión será posible formular aproximaciones metodológicas y econométricas novedosas para abordar la inclusión de la percepción de seguridad en modelos de elección y construir un marco metodológico para modelar las percepciones de seguridad en elecciones de transporte.

Palabras clave: *Investigación en seguridad del transporte, modelación híbrida, modelos de elección, percepción de seguridad.*

1. Rationale

Recent evaluations regarding the effects of road accidents show that traffic crashes are responsible for the loss of over a million human lives a year, which is a major public health issue (World Health Organization, 2013). The numbers of road accidents in Colombia are also alarming because traffic accidents have become the second leading cause of violent death and the leading cause of death for young people under 30 years of age (Office of the Colombia's General Comptroller, 2012). While road accident records are predominant in the other modes of transport such as rail, water and air for example, accidents also occur and therefore affect users' perceptions of safety. During 2013 five people were killed in Colombia in water vehicles, two of them as passengers; while three deaths occurred on helicopter, including that of a passenger (Vargas, 2013).

The statistics of 2012 are notable for the differentiated way accidents occurred in the country, considering the 22.132 injured drivers, 61.6% of them were motorcyclists and, in relation to passengers, considering the 11,710 injured, 44.5% of them were also on a motorcycle (Moreno, 2012). These figures highlight the high risk associated with motorcycle accident for both the driver and passengers, suggesting that safety analysis in the national context should consider this mode of transport. The important role of motorcycles in Colombian road accidents is a problem that had already been expressed at the regional level (Pan American Health Organization, 2009). The report on the status of road safety in the region of the Americas established that in the past decade motorcycle-related deaths grew dramatically in Latin America: from 3,209 recorded in 1998, to 10,505 in 2010, reaching an increase of 227%. One of the statistics that caught the attention of this study was the fact that Colombia was ranked as the country with the highest mortality rate of motorcyclists in Latin America, with 3.6 deaths per 100,000 inhabitants, followed by Brazil 2.9, Paraguay 2.5 and Suriname with 2.2.

In general, it can be said that human error is responsible for the majority of accidents, at a rate which lies in a range between 60% and 80% (Shappell & Wiegmann, 2013). The contribution of human factors in traffic accidents has been widely recognized worldwide (Huguenin, 2005), finding enough evidence linking the behavior of people in traffic accidents (Nordfjærn et al., 2011, Eiksund, 2009). For this reason, some studies to develop strategies to reduce accidents, have strongly recommended the implementation of campaigns that affect the behavior of individuals (Akaateba et al., 2015), which implies the choice of a modeling framework that enable correct assessment of personal behavior which can be influenced significantly through perceptions of safety.

With respect to the modeling framework used, the initial efforts to incorporate latent variables in the models of discrete choice used attitude indicators directly in the utility functions, regardless of errors (Koppelman & Hauser, 1978). Approaches were also used based on the factor analysis of indicators (Morikawa, 1989) and tested with the use of latent attributes without indicators (Elrod & Keane, 1995). However, the specification of indicators directly in the utility function, regardless of the presence of measurement errors, may lead to inconsistent estimates and inadequate treatment caused by the correlation between the indicators and the error of the utility function that can lead to endogeneity bias.

Finally, although safety perceptions have been studied in other contexts, it is necessary to do the same in the Colombian context as compared with developed countries; the evidence indicates that drivers and pedestrians exhibit behaviors that are different (Tulu et al., 2015). In addition, progress can be achieved in understanding the behavior of individuals with regard to accidents would help the country reduce their accident rates, especially when concern exists for defining and implementing policy guidelines that promote and facilitate the institutional and inter-sectorial coordination of actions in road safety (Ministry of Transport, 2014). In particular, with regard to

measures on human behavior, the national plan has provided a set of general actions that could be improved if changes in attitudes of individuals are modeled (Jakobsson et al., 2011; Johansson et al., 2006).

2. Theoretical framework for modeling the perception of safety in the choice context

The theoretical framework for modeling behavior in choice contexts proposed by Ben-Akiva et al. (1999) can be understood as a process of decision-making that follows a sequence of mental operations, from an initial state of individual knowledge (experience and information of individuals) to a final state or response. This process is influenced by memory, motivation, perceptions, attitudes, tastes, beliefs, and preferences.

Walker (2001) clearly shows the complexity underlying the process of choice considering the interrelationship between memory, motivation, attitudes, tastes, perceptions and preferences. However, it is seen as relevant whether or not to consider such complexity as from the perspective of modeling it is recommended to use parsimonious models. Beyond this reflection, it is clear that the complexity of behavior can be adapted to the models for several reasons to: correct biases, improve forecasting, test theories, and study certain behavior or relationships that may provide additional useful information regarding the choice process, among others. It is also clear that, from the modeling perspective, it is necessary to consider the relationships that quantify these psychological constructs to explain how they influence the responses (choices).

The theoretical framework developed gives rise to a methodology that integrates the choice model with a latent variable model, incorporating indicators that explicitly measure the latent variables of interest. Normally these indicators are based on the answers given by individuals to a set of statements or questions about attitudes, perceptions, motivation and memory, which In short, the integrated model is composed of two parts: a discrete choice model and a latent variable model, with one or more structural equations and one or more measurement equations.

The introduction of perceptions and latent factors in the discrete choice models has been treated under two main approaches: latent variable models and latent class models. The latent variables approach deals with the explicit modeling of psychological unobserved characteristics such as attitudes and perceptions (Walker, 2001). In turn, the latent class approach assumes that the population can be probabilistically segmented into groups with different behaviors. Considering these two approaches, keeping in mind the idea of modeling perceptions of safety, this work ranks in the first category, that is the latent variables approach.

The framework is defined a little more to be placed in the context of the transport choice, a field which, given its complexity, has been the subject of experimentation and analysis of human behavior (McFadden, 2007). In general, transport is affected by human behavior, manifested not only by users but also involving service providers, business leaders, planners, policy makers and even voters who can determine certain transport policies through their choices.

It is clear that while there are complex factors that affect transportation choices such as lifestyle, attitudes and perceptions (McFadden, 1986), in a traditional way the models of travel demand have considered quantitative variables to explain the mode choice (Ben-Akiva & Lerman, 1985). There are important advances in the study of perceptions in the transport context, but there are still many gaps to be closed. Precisely, identifying gaps indicates that it is important to address in greater depth three topics: the most appropriate indicators to study perceptions; the use of hybrid models for predictive purposes, by incorporating objective factors which allow the evaluation of policies related to safety, and the effect of other latent variables in the perceptions.

3. State of the art

It is appropriate to differentiate between attitudes and perceptions. In general, the attitudes of individuals may be the reflection of needs, values, tastes and capacities (Daly et al., 2012), which are formed over time and are affected by experience and external factors (Walker & Ben Akiva 2002). Perceptions, however, measure the cognitive ability of the individual to assess the attributes of the different alternatives. In the context of transportation choices, perceptions are important as they determine how an individual distinguishes the levels of attributes considered (Bolduc et al., 2008).

The important role of attitudes and perceptions in explaining the behavior of transport choice has been recognized for years (see for example, Koppelman & Pas, 1980). However, the incorporation of latent factors in discrete choice models is relatively recent. In the last fifteen years, research work has broadened the traditional approach to make modeling attitudes and perceptions more explicit, combining measurable variables with unobservable factors in discrete choice models (Ben-Akiva et al., 2002).

Within the analysis of transportation choices based on hybrid models, the state of the art indicates that there are many latent variables that have been taken into consideration. Possibly the most general latent variables have been: happiness, studied by Duarte et al. (2010) in the context of a network of universities; satisfaction, reported in the work of Tam (2010) in the context of travel to Hong Kong International Airport, and justice, studied by Di Ciommo et al., (2013) in the context of inter-city road pricing.

Among latent variables common to almost all transport modes can be found: accessibility (Yáñez et al., 2010), comfort (Walker, 2001; Vredin Johansson et al., 2006; Yang et al., 2009; Yáñez et al., 2010; Paulssen et al., 2014; Commander et al., 2014; Habib et al., 2014; Márquez et al., 2014), reliability (Yáñez et al., 2010), convenience (Walker, 2001; Vredin Johansson et al., 2006; Yang et al., 2009; Paulssen et al., 2014; Fernández-Heredia et al., 2014), connectivity (Puello & Geurs, 2015), flexibility (Vredin Johansson et al., 2006; Yang et al., 2009; Paulssen et al., 2014) and property (Paulssen et al., 2014).

Also specific latent variables have been studied with regard to certain modes of transport, where a particular interest in the analysis of non-motorized transport modes is shown. Some of these latent variables can be cited as follows: appreciation of the new car features (Bolduc et al., 2008), perceived quality of Bicycle infrastructure (Puello & Geurs, 2015), willingness to walk and ride (Kamargianni & Polydoropoulou, 2014), willingness to walk (Kamargianni et al., 2014), bicycle ownership (Habib et al., 2014) and the pro-bicycle latent variable (Fernández-Heredia et al., 2014; Maldonado-Hinarejos et al., 2014).

Environmental characteristics have also been developing latent variables, for example: environmental awareness (Bolduc et al., 2008), context (Maldonado-Hinarejos et al., 2014.), environmental preferences (Vredin Johansson et al., 2006), resistance to change (Link, 2015) and external constraints (Fernández-Heredia et al., 2014). In some cases proposals have been mixed latent variables, which can be difficult to interpret, such as: convenience/comfort (Vredin Johansson et al., 2006; Paulssen et al., 2014), property/safety (Vredin Johansson et al. 2006), and comfort/safety (Yáñez et al., 2010). Some of them were the result of surveys not specifically designed to study the effect of latent variables in the choices. Of course, the perception of safety has also been the subject of study.

3.1. Safety perception

Safety perception (or perceived risk) can be defined as the expectation of an undesirable outcome such as a traffic accident (Hamed & Al Rousan, 1998). Clearly, the assessment of risk perception is subjective because it can vary from person to person according to their background (experience and information) and how they deal with risks (Adams, 1988).

Safety perceptions are complex because they differ from one city to another and change with the environment, the characteristics of individuals and the selected mode of travel, among other factors. An example of this is the work of Chataway et al. (2014) who showed that, compared with cyclists in Copenhagen, cyclists in Brisbane perceive certain infrastructures as less secure and feel more fear of traffic. Even perceptions of others about safety can be important. For example, parental concern about traffic safety is especially important for children traveling as pedestrians or cyclists (Johansson, 2006; Ewing et al., 2004). Also, infrastructure can indirectly influence the decision of the parents through the perception of neighborhood safety and traffic, and also about transportation options available at home, as seen in Nevelsteen et al. (2012).

In general, Mannering & Bhat (2014), in the same line Bolduc et al. (2005) and McFadden (2013), consider that the safety analysis can be improved by including latent variables. This is corroborated in some works that initially did not consider the perception of safety but ultimately recommended the need to include this variable to improve the performance of the models and the analyses derived from them. For example, Tam et al. (2010) did not consider the safety perception in the specification of the model but noted that the tolerance of the margin of safety should be included in the integrated model to provide a better understanding of the passenger's model needs.

There are several works that consider latent variables related to safety, but did not prove these variables statistically significant in all cases. For example, Vredin Johansson et al. (2006), in the context of mode choice between Stockholm and Uppsala, found that safety preferences were insignificant possibly due to safety differences between the modes being considered too small to be discernible by individuals. They further stated that mixing public safety indicators with traffic safety could not have contributed to the significance of the variable.

Also, Yang et al. (2009), in a choice context between public transport and cycling, justified the fact that the safety perception had not been significant due to the level of risk of the baseline being so small that the planned changes were not perceived by respondents. However, as explained, it does not mean that safety considerations are not important in the choice of mode. In the same vein, Yáñez et al., (2010) when seeing that safety was not statistically significant decided specify the mixed comfort/safety latent variable, which behaved properly in the model.

3.2. Indicators of safety perception

Latent variables represent characteristics of individuals (Walker, 2001; Ashok et al., 2002) that are incorporated into a measurement model relating the latent variables with the indicators observed in a system of structural equations (see for example Morikawa et al., 2002; Hess & Stathopoulos, 2013). Indicators are introduced to characterize latent and unobserved variables and, econometrically, allow their identification, providing, in addition, greater efficiency in estimating the full model (Kim et al., 2014). Thus, indicators of latent variables are proposed in the surveys as questions or statements about attitudes, perceptions and memory.

Statistically, indicators have the particularity of being endogenous to the choice process and therefore are not used by the model in the predictive mode (Walker, 2001; Rungie et al., 2012). Perhaps, for that reason, sufficient attention has not been paid to the design of indicators in the contexts of transport choice. In fact, it is common to construct indicators of latent variables based on open questions or satisfaction surveys, which sometimes accompany stated preference surveys, without further consideration of the appropriateness or not of such questions. An example of this is the work of Yáñez et al., (2010) which is based on a survey that was not designed to obtain indicators of latent variables, but it served to estimate a hybrid model with three latent variables: accessibility, reliability and comfort/safety, the latter difficult to interpret. Another work that has built indicators from complementary questions to the stated preference surveys, without considering a previous design,

can be seen in Marquez et al., (2015). These studies have shown that it is possible to construct ex-post indicators, although as recommended by Yáñez et al., (2010) it is necessary to ex-ante identify the appropriate factors to determine the perception indicators.

The concern of how the measurement methods of indicators affect the analysis of the choice process was manifested by Ben-Akiva et al. (1999) in the context of the integrated model choice and latent variables, highlighting the importance of carrying out preliminary works such as focus group meetings, always taking into consideration the choice context, further suggesting that the measurement methods could well be a future research line. It must not forget that the estimation of the models depends on the indicators used as process causal variables (Walker, 2001); therefore, the selection of indicators should not be a trivial task.

Not all studies report the indicators used to measure perceptions of safety. For example, the work of Yang et al., (2009) noted that 13 questions were formulated as indicators, but these were not reported. However, some studies have stated the construction of indicators based on questions on the use of safety equipment (Vredin Johansson et al., 2006; Márquez et al., 2015), on the understanding that not wearing a safety device, as a helmet or seat-belt, it is an indicator of the perception of the individual regarding the safety mode of transport taken into consideration. Some indicators have also been built based on the individuals' stated behavior, for example, reducing speed or not in a situation that would be considered risky (Márquez et al., 2015), or based on the rating given regarding the condition of the equipment in which the transport service is provided (Márquez et al., 2014). In other cases, respondents have been asked to rate various policies (Daziano, 2012) or simply it has been investigated directly as it applies to the perception of safety (Yáñez et al., 2010) using pre-established rating scales.

Studies such as Tsirimpa et al. (2010), Habib et al. (2014), Márquez et al. (2014) and Maldonado-Hinarejos et al. (2014) have used sets of increasingly numerous indicators: 6 in the first case, 10 in the second and third cases, and 19 in the last ones, to measure the perception of safety and other latent variables. In general, indicators are formulated as statements in terms of:

"For me, using a car to go to work is ..." (Domarchi et al., 2008).
"I hate ...", "I like ...", "I prefer ...", "Something that bores me is ..." (Tsirimpa et al., 2010).
"Need to ..." (Habib et al, 2014.).
"Level of caution while ..." (Marquez et al, 2014.).
"Using bike is ...", "Using bicycle makes you ...", "Using bike is good for ..." (Maldonado-Hinajeros et al., 2014).

It could be seen that the systems of measurement indicators almost always include one of three types: rating scales, hierarchy and discrete choice. Typically, indicators are measured on rating scales although other systems have also been used for special cases (Lenk & Bacon, 2012). In the context of transportation choices, in general, it has been common to use Likert scales (Ory & Mokhtarian, 2005), almost always in odd numbers, in a wide range of presentations:

4 points, from *completely agree* to *completely disagree* (Di Ciommo et al., 2013).
5 points from *very bad to very good* (Walker, 2001).
5 points, from *completely agree* to *completely disagree* (Ory & Mokhtarian, 2005).
5 points from *very important* to *not important* (Paulssen et al., 2014).
5 points from *very satisfied* to *very dissatisfied* (Tam, 2010).
6 points from *not important* to *important* (Fernández-Heredia et al., 2014).
7 points, from *strong support to strong opposition*, or from *it is not a problem* until *it is a major problem*, or from *not important* to *very important* (Bolduc et al., 2008).
7 points, from *completely agree* to *completely disagree* (Kamargianni & Polydoropoulou, 2014; Kamargianni et al., 2014).
10 points, from *unhappy* to *very happy* (Duarte et al., 2010).

Specifically, the indicators used to measure the perception of safety have changed as follows:

5 points, from *not important* to *very important* (Daziano, 2012).
5 points, from *bad* to *excellent* (Márquez et al, 2014.).
10 points, from *completely agree to completely disagree,* or from *not important to extremely important* (Tsirimpa et al., 2010).

It can show that there is no standard to measure perceptions, although some outstanding patterns can be identified, for example, it is more common to use 5-point scales. It can also be seen that three types of indicators have typically been used: quality (bad ... excellent, very bad ... very good); in accordance with (completely agree ... completely disagree, very satisfied ... not satisfied); and importance (not important ... very important). It is necessary to take into account that when studying the consequences of the type of indicator chosen, Raya (2009) found that although initial assessments showed no significant differences, the effects on the variables can be very important because each indicator has specific characteristics, concluding that the use of an unsuitable indicator can be misleading.

Another important issue regarding the indicators is associated with standardization. In this regard, McFadden et al., (2005), in the context of a health survey using Likert scales from 5 to 7 points from bad to excellent, found that while 62% of Danish men choose excellent, only 14% of French men do, even though the latter ones have a greater life expectancy of two years. McFadden et al. (2005) are clear that when making interpersonal comparisons or inter-temporal comparisons, and in the case of an individual, it requires some kind of "escalation" which in any case should also be considered in the context of transport choices.

3.3. Objective factors

While socioeconomic variables and attributes of transportation alternatives have been key elements in most of the models used by transportation planners and support decision-making (Shiftan et al., 2008), the complex interaction of factors presented in the choice process has led to the formulation of the integrated model of choice and latent variables (Walker & Ben-Akiva, 2002; Ben-Akiva et al., 2002). This modeling approach which has developed significantly over the past decade (see for example, Abou-Zeid & Ben-Akiva, 2011; Prato et al., 2012; Kamargianni & Polydoropoulou, 2014. Glerum et al., 2014, & Paulssen et al., 2014) has not been developed enough in terms of prognosis and evaluation of policies (Yáñez et al., 2010). In fact, although hybrid models are theoretically and statistically superior to models based on the traditional approach (Walker, 2001), its added value compared to conventional models choice is quite limited for now (Chorus & Kroesen, 2014), especially in the analysis of policies affecting the transport system.

According to the tenets of Manheim (1979), changes in the transport system have impacts on travel patterns. However, in the context of hybrid choice models such impacts are not typically modeled as generally specifying structural equations usually considered economic characteristics of individuals, but not objective factors. In general, there is enough literature regarding forecast based on latent variable models that consider only socioeconomic variables (see for example Vredin Johansson et al., 2005; Bolduc et al., 2008), which normally specify attributes of the transportation system directly in the utility functions. However, not much progress has been made with respect to the problem of studying those cases where a policy changed perceptions; this is an issue that has not received adequate attention so far. Therefore, Yáñez et al. (2010) recommend testing the ability to include objective factors in latent variable models, for which it is suggested not using observed data but designing a stated preference survey that captures the acceptance of certain policies or interventions.

To explore the methods used in the analysis of transport policies, Di Ciommo et al. (2013), in the context of road pricing policies, found that surveys can be applied directly to road users, based

on assumptions about individual behavior (Jakobsson et al., 2000; Schuitema et al., 2007; Eriksson et al., 2008). They also consider the possibility of advancing empirical studies from a psychological analysis based on consistency tests (De Groot & Steg, 2006; Link, 2007). Or ex-post studies performed to investigate changes of individual behavior in response to policies (Ungemah & Swicher, 2006, Schade & Baum, 2007; Winslott-Hiselius et al., 2009). Clearly, the second method is aimed at assessing the acceptability of the measure either before or after application through stated preference surveys or revealed.

More recently, in the context of bike trips, Habib et al. (2014) recognized that the latent variables can be explained by different socioeconomic attributes, land use variables, variables related to infrastructure and even other latent variables. They found that it is important consider the perceptions of people in developing programs to promote cycling and to formulate strategies to maximize the effectiveness of such programs. Specifically, they concluded that greater provision of infrastructure for bike lanes in neighborhoods can increase the perception of safety, resulting in a greater likelihood that residents choose this transportation alternative. In the same vein, Maldonado-Hinarejos et al. (2014) recognize that hybrid choice models have significant potential to consistently predict the impact that is produced on the user's behavior like the adoption of certain "soft" policies destined precisely to change the attitudes of people. Also, it is used to compare the impact of "hard" policies, such as providing parking facilities; with respect to "soft" policies, such as programs promoting the use of bicycles.

3.4. Influence of other latent variables on the safety perception

It has been shown that the perception of information influences the behavior of individuals. For example, Tsirimpa et al. (2012) found that while individuals tend to maintain their normal pattern of travel, specific information related to the occurrence of an incident or closing a road, affects their travel behavior, particularly regarding the departure time and selected route. They also consider that an interesting basis to expand their analysis can be found in the work of Tversky & Kahneman (1981, 1992), Kahneman and Tversky (2000), Rabin & Thaler (2001) and Schwartz (2004).

McFadden (1997) had suggested that the main cognitive abnormalities in the framework of utility theory came from the way individuals store, retrieve and process information. In this sense, it is well known that the utility of choice of an individual is based on socioeconomic characteristics and psychological factors (Ben-Akiva et al., 2002), the latter ones being affected by the decisions and behaviors that are exhibited in the social environment of the individual and, also by the way individuals process this information (Kamargianni et al., 2014).

Another factor that influences the perception of safety has not been studied sufficiently and is related to traffic threats that may concern e.g. cyclists, who can be hit by cars or even may feel threatened by pedestrians invading lanes for bicycles. Specific situations such as serious traffic problems are perceived by individuals as a threat that could affect the perception of safety and consequently transportation choices.

4. Conclusions

The review of the state of the art has identified three gaps. First, although it is possible to estimate hybrid models based on questions (of any kind) as indicators, research is needed to determine the most appropriate indicators to study the perceptions of safety in transport choices. It is relevant to assess the influence that indicators and the chosen scale have in assessing the safety perception.

Secondly, there is still a gap in the use of hybrid models for predictive purposes for the evaluation of policies related to safety. What is common has been to specify socioeconomic variables, with the limitation that such specification would only assess situations which produce changes in the

In this context, it would be desirable to construct a methodological framework for the econometric modeling of the influence that safety perceptions have on the behavior of transport users regarding measuring instruments, including objective factors and the effect of the information. To this end, it is considered that in addition the development of studies in specific contexts of choice, it will be possible to build and validate this methodological framework. In any case, it will be necessary to at least develop the following activities: study of the behavior assumptions underlying the choices; development of econometric modeling framework involving perceptions and the influence that it has on the characteristics of individuals and objective factors; design of appropriate tools to assess the influence of the perception of safety; calibration of choice models, latent variables and categories or latent classes, and drawing conclusions from the modeling.

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