Paving the road from transport models to "new mobilities" models

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Abstract

For half a century, tremendous efforts have been invested in developing transport models as a decision aid for policy makers in designing effective policy interventions and deciding among costly public projects for the benefit of the population. Transport and activity-based models are often criticized for neglecting the "new mobilities" turn (Urry 2007, Cresswell 2006), namely multiple mobility aspects and rationales, including social, cultural, material, aesthetic and affective, in analyzing travel behavior. This paper aims at taking a tentative first step in bridging the gap between the traditional transport modeling approach and "new mobilities" research by suggesting a model framework that considers non-instrumental transport rationales, personal latent traits and intra-household decision dynamics.

1. Introduction

Traditional transport models represent the market shares of travel-related choices on the basis of random utility theory. These models are concerned with physical observable aspects of travel that can be weighted according to their expected utility. Namely, travel alternatives (e.g., routes, modes, destinations) are viewed as "utility bundles" that can be evaluated on the basis of their physical attributes (e.g. time, distance, price) and their linkage to individual socio-economic characteristics. Following 50 years of development, these models are widely applied, are easily estimated and are capable of representing a variety of linear and non-linear utility functions, similarity patterns across alternatives, population heterogeneity, heteroscedasticity and repeated choices over time (for extensive review see Train, 2009). However, these 50 years have also demonstrated that there is a considerable and almost systematic inaccuracy between forecasted and observed traffic flows (e.g., Bain, 2003; Bain and Plantagie, 2004; Bain

and Polakovic, 2005; Flyvbjerg, 2005; Flyvbjerg et al., 2006; Næss, 2011; Welte and Odeck, 2011; Næss and Strand, 2012), mainly related to the complexity of the system being represented and the estimation of modelled traffic flows as a point estimate rather than a central estimate and an overall range of uncertainty margins articulated in terms of output values and likelihood of occurrence (Boyce, 1999). Moreover, despite their advantages, current transport and activity-based models are often criticized for neglecting the "new mobilities" turn (Urry 2007, Cresswell 2006), namely multiple mobility aspects and rationales, including social, cultural, material, aesthetic and affective, in analyzing travel behavior. These aspects are hypothesized to have a strong influence on daily mobility and if integrated into future transport models might in turn lead to enhanced accuracy in long-term demand forecasts. Hence, the integration of the "soft issues" into transport and activity-based models might potentially improve transport planning to accede to the emerging aspects raised by the "new mobilities" turn. In the words of Jensen:

> 'Perhaps time has come to include the 'non-instrumental' and even at times 'irrational mobile subject' into the frame. Not as a substitute but as a corrective to the imaginary rational mobile subject that always seeks to minimize friction of distance and optimize an economic budget in a rational perception of time, distance and resources. So next to a language of 'Value of Time', 'Friction of distance' and 'Least Net Effort' we may need a vocabulary that opens up to how people feel, and what they think and hope as they move along the vast networks of contemporary societies. The 'meaning of movement' is what concern this sort of vocabulary as it aims to add to our basic understanding of mobilities. The 'non-instrumental mobile subjects' may not be great in numbers if we for example are looking at everyday commuters, but they are the ideal types that opens up the black box of travel behavior that are not able to be reduced to fastest mode or quickest route' (Jensen, forthcoming)

To deal with this new development and heightened academic interest for non-instrumental aspects within the fields of transport and mobilities research, there is no doubt this call for a new joint research agenda. However, it should be noted that there might be several 'paths' to constructively collaborate between traditional transport research and new mobilities research in developing and providing better decision support. A key question is seen from a mobilities perspective is 'what the potential and role of the new mobilities research is and how it can contribute?' The ambition of this paper is to explore one of these paths asking 'can non-instrumental aspects of mobility be integrated into an activity based transport model framework?' The project 'analysis of activity-based travel chains and sustainable mobility' (ACTUM), is trying to make a move in this research agenda by applying resources for both quantitative and qualitative data collection and investigative studies. Furthermore, the ACTUM project creates an opportunity for researchers from both transport and mobilities studies to share resources and competencies (for more information see the remarks at the end of the paper). This paper is the first outcome; it seeks to contribute with a tentative proposal of a conceptual and mathematical framework for embedding qualitative knowledge about transport rationales and social and psychological individual traits into activity-based transport models.

The fact is that non-instrumental aspects (besides the influence of cognitive and behavioral psychology) have to a large extent been ignored in transport modeling is evident by the lack of literature. One reasonable explanation for this might be that many of these complex social aspects of mobility do not easily conform and fit into strict nature of transport modeling as quantifiable entities. To integrate any non-instrumental aspect into an activity-based transport model framework is a difficult task. And in this regard,

the ACTUM project faces two fundamental challenges. Firstly, the ACTUM project explores how to integrate non-instrumental variables and latent traits alongside instrumental aspects traditionally found in transport model frameworks. And secondly, the ACTUM project is based on a shift in focus from the individual to the household unit of multiple individuals.

To engage with these challenges, this paper sets off by exploring the notion of transport rationales and personal latent traits as the basic motives for travel from the perspective of the individual. The current framework proposes to model transport rationales by means of integrated latent variable discrete choice models that are able to translate these perceived latent dimensions into measurable components. Then, the paper continues and enriches the representation of individual travelers by acknowledging that each traveler forms part of a family or household unit and shares kinship, desires and obligations with other household members. Therefore, the second step of this approach wishes to appreciate the household unit by representing family decision-making dynamic, social interactions, kinship and obligations in transport-related and activity choices. The embedding of household interactions can be conducted through a multi-linear household utility function, defined as the sum of weighted members' utilities and intra-household interaction. The multi-linear utility function allows representing various types of family interactions in four household types and structures. The remaining content of the paper unfolds the concept of transport rationales through empirical examples and the potential options for operationalization, followed by exploring the personal latent traits and their embedding into a transport model framework. The next section discusses the challenges relating to switching from a single agent based environment into a multi-agent household, followed by a discussion of the mathematical modeling of such household interactions. Finally, the paper ends with concluding remarks about the opportunities and challenges related to the implementation of the proposed framework.

2. The proposed conceptual and mathematical framework

As mentioned in the introduction we propose an approach where the complexity is increased step by step. Therefore in the first step, we unfold the concept of transport rationales through examples and tentatively suggested variables for operationalization as well as present the notion of personal latent traits and propose how to embed these non-instrumental aspects into a transport model framework. The non-instrumental aspects are characterized as single-agent frameworks taking point of departure in the individual agent. In the second step, we consider travel alternatives in relation to the multi-agent household unit. The approach is visualized in figure 1.
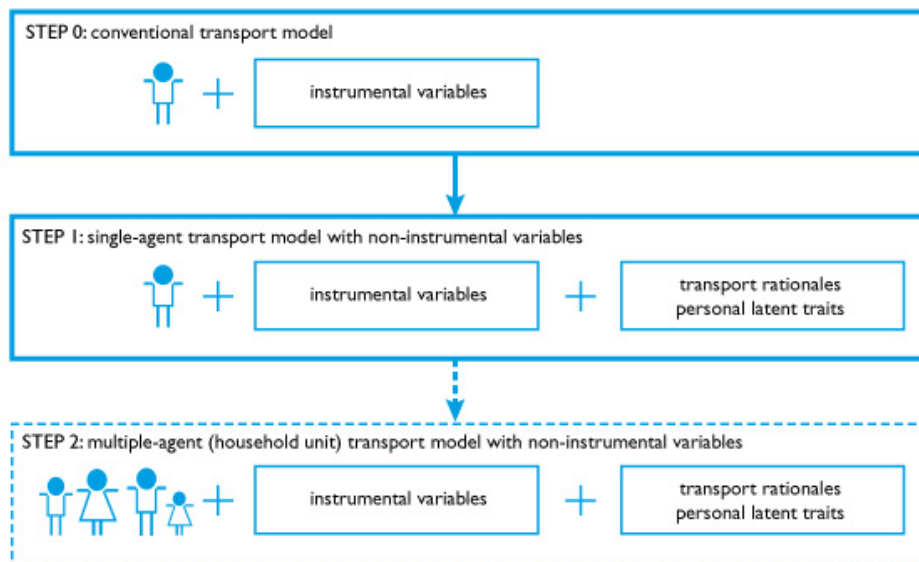
Figure 1 – Proposed approach

Each of these steps is associated with an increase in complexity which needs to be absorbed into the model framework. Although, proposing a conceptual framework for step 1 in itself immediately raises lots of questions and potential issues, we have tried to go further in step 2 by exploring some of the theoretical aspects put forward by mobilities research, as well as presenting some of the findings from ACTUM empirical material. Therefore, this is a 'peep into the engine room', and the conceptual framework presented here should be understood as tentative and work-in-progress.

2.1 Step 1: Transport rationales and their representation in transport models

2.1.1 Transport rationales

The framework considers multiple transport rationales (Næss & Jensen 2005) as the basic motives for travel. Contrary to the traditional stance of transport geography primarily based on rational choice theory to account for agent´s travel alternatives (e.g. routes, modes, destinations), the rationales elucidate qualitative dimensions of transport alternatives that only can be explored through individual subjective perceptions. By investigating social and ´non-instrumental´ factors of experience and emotion, there is a potential to address deviating behavior that might otherwise be labeled as variance. Based on mainly qualitative, but also quantitative data, Næss & Jensen (ibid.) propose the concept of transport rationales as an analytical tool. The transport rationales are distilled from the basic preferences and distinctions expresses by agents in rationalizing their behavior and transport choices. Therefore, they are *ideal type* constructs (Weber 1978) that are not likely to occur in their purest form, but rather as multiple rationales interwoven and overlapping. Furthermore, an important dimension is a basic understanding that transport is a form of consumption which the agent interprets and infuses with meanings. As any other type of consumption, this adds to the agent´s self-understanding and identity formation (Thomsen 2001). Finally, Næss & Jensen (ibid.) state that the agent employ a prioritization amongst the transport rationales, and even though this hierarchy is relatively stable in similar situations, it might drastically change according to changing purposes (i.e. going grocery shopping can be based on entirely different transport rationales than visiting grandparents during the weekend). Næss & Jensen propose six transport rationales, five of which are considered here: *aesthetic*, *safety*, *comfort*, *affect* and finally *instrumental*. The last transport rationale of "routine" is not considered in this initial framework as it to some degree overlaps the other five

rationales, and furthermore, is rather hard to validate and quantify. In the following we will address each of the remaining transport rationales through the use of examples from the empirical interview material from the ACTUM project. However, due to the limited space, this presentation will be far from exhaustive and only be able to address a very limited scope of the full extent of these rationales. The specific choice of framing for each of these rationales is to be understood as tentative ideas for operationalization. Thus, this also points to the need for further and extensive development of this 'translation' from transport rationales into measurable aspects as the presented examples in this section will merely be a small taste.

The *aesthetic transport rationale* represents the sensory experience of seeing, hearing and smelling as a factor in choosing among travel alternatives. In the empirical material this is mainly expressed in route choice where aesthetically attractive environments, views and sceneries are articulated as decisive factor. Especially the Lakes, in the center of Copenhagen, occur repeatedly in the empirical material. A mother explains her choice of route:

> *"This is Godthåbsvej and Rolighedsvej and Rosenlunds Allé leading to the Lakes. I always bike this way. At this side of the Lakes there is only bike and walk paths, which means that you can ride completely in peace, because there are only other bikes […] almost half of the trip is then without noise and exhaust from the cars – it´s absolutely wonderful."* (ACTUM data:FamB)

To operationalize this particular example of the aesthetic transport rationale, attention should be put upon the observable elements that can afford these sensory experiences. A viable quantifiable classification system for this could be *green* (trees, plants, lawns, parks etc.), *blue* (lakes, fountains, streams, canals etc.) and *gray* (buildings, plazas, streets, sidewalks etc.) elements along potential routes. Within urban design studies extensive research has been done investigating the relationship between spatial organization and perception in motion (Gehl 2010, Lynch 1984, Stefansdottir forthcoming).

The *safety transport rationale* covers the experienced sense of security and safety in transport alternatives. In the empirical material this particular rationale is most dominant, but not constricted to, the more 'vulnerable' modes of biking and walking. The presence of children is a strong incentive to choose less 'vulnerable' modes and safer routes if biking or walking. The safety rationale distinguishes itself in two ways, firstly as fear of crime and strangers, and secondly, as the heightened risk of bodily damage and accidents poses by other road users. A mother is asked about relevance of safety bringing the kids to kindergarten and school:

> *"Yes... I usually have him [the younger child] sitting behind me, and her [the older child] alone on a bike, and if something should happen, I cannot jump off my own bike. Therefore, I´m quite hysterical in picking the safer streets."* (ACTUM data:FamC)

To operationalize the safety transport rationale in this example, a safety assessment of the potential routes is required. This assessment could be comprised of perceived safety concerns along a certain route, as conducted for example in the "safe routes to schools" project in Odense (Jensen 2008), and the perceived level of safety the mode affords (i.e. cars perceived as more safe than bikes etc.), or by several key measurable variables, such as the amount of traffic (i.e. cars per hour), the type of traffic (i.e. rating auto traffic worse than bikes and mopeds), statistics of accidents, the physical layout of the street (i.e. presence of sidewalks, cycling lanes, width of road, lighting, signage etc.), and the physical ability (children and elderly are perceived as less safe in traffic due to their physical ability).

The *comfort transport rationale* represents the agent wish for minimizing physical exertion and inconveniences, while increasing indolence and relaxation during travel. In the empirical material the comfort rationale is often tied closely to the instrumental transport rationale. The type of mode combined with uncertain weather conditions and seasonal weather rhythms influence the use of more comfortable transport alternatives. A father is asked about modal choice to work:

> *"[...] it is sometimes very nice to have the car - if you have to go to down town or back again, then it´s a bit easier. [...] It is also a bit more practical; I wear a suit and stuff like that. I won't bike too far. And it is one of the reasons that I don´t bike to Hellerup [work location]. I only do it, if I can see that the weather will last. Sometimes I have tried to be caught half way home in a major rain shower."* (ACTUM data:H03)

Operationalization of the comfort transport rationale could be done through the variables of travel distance (i.e. longer distance increases the likeliness of more comfortable modes), typography of route (i.e. hills, turns, bumps, crossings etc.) and weather conditions (i.e. weather forecasts and characteristic seasonal weather). These variables could be weighed in relation to modal choices (i.e. in the empirical material rain, snow, wind can affect modal choice towards more enclosed modes such as car, bus, train, while sun and warmth might make walking, biking more attractive). Alternatively, it could be done by an attitudinal survey for measuring the perceived comfort dimensions (Eboli & Mazzulla 2011)

The *affective transport rationale* covers several aspects of emotions and feelings associated with travel. In the empirical material there are (at least) two categories in the transport rationale. The first is the embodied kinesthetic experience of moving and this affects travel alternatives of modal choice typically towards bicycle, car and motorbike. The second category expressed in the empirical material is the feelings evoked by and experiences of place, and the notion of atmosphere and ambience. This category especially seems to be able to influence travel alternatives of route and destination choice. A daughter is asked to describe her route to high school:

> *"Daughter: […] I prefer to bike here [her preferred route] because there are better bike paths. I actually think it's a little scary there [an alternative route].*
>
> *Mother: Because I actually think the other is faster, but Falkoner Allé and that way, it´s much nicer, there´s much more life. And you don´t get hit by falling tiles [jokes]*
>
> *Daughter: I go past the Lakes and then I have two options. There´s one with heavy traffic, it's really just a road. And then here [the second option], where I drive past my old school.*
>
> *Father: And city life with all the small shops, it is much cozier on Godthåbsvej…*
>
> *Daughter: Yes it is much nicer drive."*
> (ACTUM data:FamA)

The example used here clearly belongs to the second category of the affective transport rational. It could be operationalized in a similar fashion, as the aesthetic transport rationale, via measurable variables of elements (i.e. shops, walkable surfaces, bike paths, historic buildings etc.) and conditions (i.e. presence of other people, slow moving traffic etc.) associated with attractive atmospheres and ambiences. Moreover, the organization of these elements needs to be considered as different constellations of urban structures

(i.e. dense, open, enclosed, etc.) that affords different experiences and sense of atmospheres. These parameters could then be integrated into a limited number of identifiable typologies.

The *instrumental transport rationale* covers the economic and rational thinking where maximum utility is sought (in terms of time, distance and monetary cost). Indirectly this also covers the individual's usage skills of a particular transport alternative, as i.e. knowing the schedule of trains and busses or knowing how to get through heavy traffic might reduce the overall cost. A father explains his commuting route choice to be divided between two aspects of the instrumental rationale:

> *"I have two routes I use. It depends on the traffic, how I think it is. There is one route which is the fastest, but there can be heavy traffic, and therefore slower. And then there is a route which is longer, but there can be a much better flow of traffic."* (ACTUM data:H04)

As mentioned earlier, the transport rationales do seldom appear in a pure form, but rather as multiple transport rationales present at the same time in the evaluation of travel alternatives. In the empirical material the instrumental rationale can be considered a fundamental condition that transcends most travel alternatives, underlining that the purpose of much travel in daily life is simply to get from A to B. This, on the other hand, does not leave out the other transport rationales, but it rather points to a more complex decision process often involving several transport rationales. The instrumental transport rationale do allow for reduction in the maximum potential utilization, if the entire cost/benefit of the chosen travel alternative is perceived as satisfactory and acceptable in relation to the agent´s needs and wishes (i.e. the high school girl choose a slightly longer route to experience the nice city atmosphere or the mother choosing safer, but not necessarily faster, routes to accommodate for the children´s needs). As the examples above point to, the purpose, the involved agent(s) and the situation influences how the multiple transport rationales in a travel alternative are ordered. Nevertheless, an operationalization of this hierarchy could be done by sorting the transport rationales in a weighed order (from most influential to least influential): 1) the instrumental rationale, 2) the safety rationale, 3) the comfort rationale and 4) the aesthetical/affective rationale.

To engage with the model framework measurable variable have been suggested for the each of the examples of transport rationales. These have been summed up in table 1 below:

Transport rationale	Measureable variable
Aesthetical	Green (trees, plants, lawns, parks etc.), blue (lakes, fountains, streams, canals etc.) and gray (buildings, plazas, streets, sidewalks etc.) elements along potential routes.
Safety	Amount of traffic (i.e. cars per hour), the type of traffic (i.e. rating auto traffic worse than bikes and mopeds), the physical layout of the street (i.e. presence of sidewalks, cycling lanes, width of road, lighting, signage etc.), the perceived level of safety the mode affords (i.e. cars perceived as more safe than bikes etc.) and the physical ability (children and elderly are perceived as less safe in traffic due to their physical ability)
Comfort	Travel distance (i.e. longer distance increases the likeliness of more comfortable modes), physical layout of route (i.e. hills, turns, bumps, crossings etc.) and weather conditions (i.e. weather forecasts and characteristic seasonal weather – in the empirical material rain, snow, wind and sun can affect modal choice towards more enclosed modes such as car, bus, train)
Affective	Elements (i.e. shops, walkable surfaces, bike paths, historic buildings etc.) and conditions (i.e. presence of other people, slow moving traffic etc.) associated with attractive atmospheres and ambiences. Moreover, the organization of these elements needs to be considered as different constellations of urban structures (i.e. dense, open, enclosed, etc.) affords different experiences and sense of atmospheres. These parameters could be integrated into a limited number of identifiable typologies.
Instrumental	Time, distance and monetary cost. Skills and competencies of usage of transport systems and transport modes.

Table1 – Overview of transport rationales and proposed variables

2.1.2 Integrating the transport rationales and personality traits in choice models

Traditional transport models consider travellers as rational human beings able to maximize the utility from the travel alternatives. Models based on random utility maximization (RUM) are generally made operational as follows (see, e.g., Walker, 2001; Train, 2009):

$$U_{in} = V\left(X_{in};\beta\right) + \varepsilon_{in} \tag{1}$$

$$y_{in} = \begin{cases} 1 & if\ U_{in} = \max_{j}\left(U_{jn}\right) \\ 0 & otherwise \end{cases} \tag{2}$$

The structural equation (1) defines the utility U_{in} of alternative i for individual n as a function of observable characteristics X_{in} of alternative i as perceived by individual n, a vector of parameters β and random disturbance terms ϵ_{in}. The measurement equation (2) defines the choice y_{in} as corresponding to the alternative with the maximum utility within the vector of utilities U_{jn}.

Traditionally, utility functions are linear in parameters, observable characteristics X_{in} are measurable attributes of the alternatives, and random disturbance terms are distributed according to normal or extreme value distributions. Research in transport models continues to devote a large deal of attention to the distribution of the random disturbance terms, with model formulations depending on the selection of these distributions. However, in the last decade a broad array of disciplines (e.g., psychology, economics, marketing, transportation engineering) has shown a general interest in enhancing discrete choice models by considering the incorporation of psychological factors affecting decision making (Ben-Akiva et al., 2002) within the explanatory variables, rather than improving the random disturbance terms.

Although a gap still exists between economic modelers, who develop practical models of decision making, and behavioral scientists, who concentrate on the comprehension of agent behavior (Kahneman, 2002), a consensus has been reached about the necessity to bridge this gap with the incorporation of latent constructs in economic models of decision making. Recent examples include the investigation of comfort and reliability in public transport services (Habit et al., 2011), the selection of vehicles on the basis of their perceived safety (Daziano, 2012), the perception of security in railways (Daly et al., 2012), the influence of spatial abilities on the choice of route (Prato et al., 2012), and the effect of spatial abilities on the selection of thresholds within semi-compensatory choice models (Kaplan & Prato, 2012).

Among latent constructs, transport rationales and psychological traits would enrich the ability of models to explain current behavior and predict future behavior. The first step in the definition of latent variable models including transport rationales would consist in the design of attitudinal surveys alongside the collection of travel diaries. While the latter allows collecting traditional information on travel choices (e.g., departure time, destination, mode), the former enables gathering information on the rationales of these choices. Items based on Likert scales could be designed to shed light on transport rationales (Bailey 1994:256). Items could investigate the aesthetical rationale by asking travelers about the relevance to their travel choices of crossing green areas and avoiding built areas. Items could explore the routine rationale by checking whether travelers tend to repeat actions both related and unrelated to transport. Items could analyze the safety rationale by questioning travelers about their attitude toward avoiding congested roads and preferring specific physical street layout. Items could inspect the comfort rationale by enquiring travelers about the relevance of travel distance, weather conditions and dress requirements to their travel choices. Items could scrutinize the affective rationale by asking travelers about their attitudes toward certain elements of the environment in which they travel. Last, items could examine the instrumental rationale by assessing the importance for travelers of time, distance and monetary cost of their travel choices. Alongside transport rationales, the attitudinal survey could explore personality traits such as sensation seeking, risk aversion, extroversion, which could affect travel choices as travel time and cost do.

Once the items have been collected alongside the travel diaries, the second step consists in the formulation of the model as an extension of the traditional model presented in equations (1) and (2). Consider the problem of modeling the choice between travel alternatives (e.g., departure time, destination, mode, route). An integrated latent variable and choice model is able to consider transport rationales and personality traits as measurable components. The transport rationales and personality traits are described by measurement equations relating them to the designed attitudinal items expressing their perception by the individuals, and structural equations associating them with observable characteristics of the alternatives. The choice is described by a RUM-based discrete choice model where the utility functions of the travel alternatives contain both observable and measurable characteristics alongside the latent dimensions.

The structural equations of the latent variable model express the distribution of the transport rationales and the personality traits (see, e.g., Walker, 2001):

$$X_n^* = g_1\left(S_n; \gamma\right) + \omega_n \quad \text{and} \quad \omega_n \approx D\left(0, \Sigma_\omega\right) \tag{3}$$

where X_n^* is the vector of transport rationales and personality traits, S_n is a vector of characteristics of the individual n, ω_n is a vector of random disturbance terms that are distributed according to a distribution D with covariance matrix Σ_ω, and γ is a matrix of parameters to be estimated.

The structural equations of the choice model express the distribution of the utilities of the travel alternatives (see, e.g., Walker 2001):

$$U_n = V\left(Z_n, X_n^*; \beta\right) + \varepsilon_n \quad \text{and} \quad \varepsilon_n \approx D\left(0, \Sigma_\varepsilon\right) \tag{4}$$

where U_n is a vector of utilities of the travel alternatives, Z_n is a vector of attributes of the travel alternatives, ε_n is a vector of random disturbance terms that are distributed according to a distribution D with covariance matrix Σ_ε, and β is a vector of parameters to be estimated.

The measurement equations of the latent variable model express the distribution of the indicators obtained by answering the items related to the transport rationales and the psychological traits (see, e.g., Walker 2001):

$$I_n = g_2\left(X_n^*; \alpha\right) + \upsilon_n \quad \text{and} \quad \upsilon_n \approx D\left(0, \Sigma_\upsilon\right) \tag{5}$$

where I_n is a vector of Likert-type indicators, υ_n is a vector of random disturbance terms that are distributed according to a distribution D with covariance matrix Σ_υ, and α is a vector of parameters to be estimated.

The measurement equations of the choice model express the choice as a function of the utilities of the travel alternatives (see, e.g., Walker 2001):

$$y_{in} = \begin{cases} 1 & \text{if } U_{in} \geq U_{jn} \ \forall j \neq i \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

where y_{in} is the indicator of choosing travel alternative i over travel alternative j, and U_{jn} are the utilities of travel alternatives j.

Maximum simulated likelihood allows estimating the integrated latent variable and choice model. In the case that the transport rationales and the psychological traits were not present, the choice probability $P(y_n \mid Z_n, \beta, \Sigma_\varepsilon)$ of selecting the observed travel alternative would be sufficient to write the likelihood function. As the transport rationales and the psychological traits are present, the choice probability should be expressed as $P(y_n \mid X_n^*, Z_n, \beta, \Sigma_\omega, \Sigma_\varepsilon)$. However, the transport rationales and the psychological traits are not actually observed, but the indicators from the Likert items are. Hence, the choice probability would be obtained by integrating over the distribution of the latent variables:

$$P\left(y_n \big| Z_n, S_n, \beta, \gamma, \Sigma_\varepsilon, \Sigma_\omega\right) = \int_{X_n^*} P\left(y_n \big| X_n^*, Z_n, \beta, \Sigma_\varepsilon\right) f_1\left(X_n^* \big| S_n, \gamma, \Sigma_\omega\right) dX_n^* \tag{7}$$

where $f_1(X_n^* \mid S_n, \gamma, \Sigma_\omega)$ is the density function of the transport rationales and the psychological traits. Since the indicators are observed, the joint probability of observing choice and latent variable indicators is written as:

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

(8)

where $f_2(I_n \mid X^*_n, \alpha, \Sigma_\upsilon)$ is the density function of the indicators. The integral is multi-dimensional, with the number of dimensions equal to the number of transport rationales and psychological traits. The choice probability may be replaced by an empirical mean, and the maximization of the likelihood function may be performed simultaneously by simulating the integration of the choice model over the distribution of the fitted latent variables:

$$\max_{\alpha,\beta,\gamma} \sum_{n=1}^{N} \ln \tilde{P}\left(y_n, I_n \mid Z_n, S_n, \beta, \alpha, \gamma, \Sigma_\varepsilon, \Sigma_\upsilon, \Sigma_\omega\right) \tag{9}$$

It should be noted that the formulation of the model does not impose any specific distribution D of the random disturbance terms, and hence any selection of model form for both latent variable and choice may be accommodated within the framework. Moreover, the formulation of the model may be extended to capture different preferences from different individuals according to their probability of belonging to population segments on the basis of their personality traits and socio-economic characteristics. These segments may exhibit different choice behavior in terms of choice sets, decision protocols, tastes, or model structure (Walker, 2001), and although they cannot be identified deterministically, it is presumed that class membership probabilities can be estimated.

Given the probability $P(y_{in}, I_n \mid Z_{in}, S_n, \beta, \alpha, \gamma, \Sigma_\varepsilon, \Sigma_\upsilon, \Sigma_\omega)$ for individual n of selecting travel alternative i, this basic form of the latent class model is:

$$P\left(y_{in}, I_n \mid Z_{in}, S_n, \beta, \alpha, \gamma, \Sigma_\varepsilon, \Sigma_\upsilon, \Sigma_\omega\right) = \sum_{s=1}^{S} P\left(y_{in}, I_n \mid Z_{in}, S_n, \beta, \alpha, \gamma, \Sigma_\varepsilon, \Sigma_\upsilon, \Sigma_\omega; s\right) P\left(s \mid S_n\right) \tag{10}$$

where the choice probability $P(y_{in}, I_n \mid Z_{in}, S_n, \beta, \alpha, \gamma, \Sigma_\varepsilon, \Sigma_\upsilon, \Sigma_\omega; s)$ is class-specific, and the probability $P(s \mid S_n)$ expresses the probability of belonging to class s given the characteristics S_n of individual n. The probability $P(s \mid S_n)$ may be expressed by a discrete choice model. The estimation of the model implies that the conditional choice probabilities are first summed over all the latent classes s, and then integrated over the transport rationales and psychological traits. The resulting function is the probability of travel choice behavior as a function of observable explanatory variables (i.e., traveler characteristics S_n, alternative characteristics Z_n, indicators I_n) that allows for a rich specification including transport rationales and psychological traits alongside traditional variables entering the utility function of travel alternatives.

2.2 Step 2: Family dynamics and their representation in transport models

2.2.1 Family decision-making dynamics, kinship and obligations

The household unit can be described a cluster of individuals that interact socially and negotiate to satisfy needs, desires and obligations of all cluster members because of a strong sense of kinship. In particular, both individual and joint activities and travel patterns are related to the role of the individual as a family member, and defined by intra-household interactions (of negotiation, organizing and planning) in the attempt to satisfy the welfare needs and wishes of all household members while also enhancing the unity of the family. This turn from individual to household level does not only appreciate the complexity of household level decisions and strategies, but also acknowledges that individual´s travel alternatives are in fact relational to a wider context and situation and also highly dependent and influenced by other household member´s actions and decisions (Elliott & Urry 2010; Larsen et al. 2006).

Empirical qualitative studies of everyday mobility of households indicate that to a large extent travel alternatives of household members are more or less stabilized in fixed travel patterns and

routines (Godskesen 2002). Everyday life is for many households comprised of timetabled and reoccurring activities and events (i.e. work, school, daycare, leisure activities, shopping etc.). Through time and repetition, this has naturalized travel alternatives that, first of all, fits within the objective and subjective conditions of the household, and secondly, has proven themselves suitable of handling the projects of the household in an acceptable and satisfying manner. Routines are therefore stable sets of particular travel alternatives that are performed on a regular and continual basis, thus creating a natural order. Giddens (1984) state that routines are placed in the *practical consciousness* and are a way of coping with uncertainty in daily life, creating *ontological security*, while also saves the agent of the burden of constantly considering alternatives.

The routinized actions and stabile transport choices can be seen as *mobile scripts* that are developed over time, guided by the household´s notion of the good life. Lassen & Jensen (2004) uses the concept of *mobility coping strategies* to engage with routines and scripts and investigate how these are related to the overall organization and co-ordination of the household. These coping strategies of the household dictates how projects are handled and what welfare needs and wishes are prioritized. This prioritized order, and thereby also the transport rationales, is directly tied to how the household makes sense of their life and themselves. Thus, mobility coping strategies are sensitive to changing household- and contextual conditions, and must therefore be considered as a process in continual development and negotiation, rather than fixed and stable organizations. The everyday mobility of the household, or travel alternatives situated in routines, can be understood as multiple mobility coping strategies intertwining and layered. Some are aligned and compatible, while others are contested, colliding and destructive. An example could be parents who wish to pursue a career strategy while raising small children. While most households experience several conflicting mobility coping strategies, for the purpose of this paper, the focus will mainly be on the household´s dominant mobility coping strategy. Although different households deal with unique objective and subjective conditions, it is possible to identify various ideal types of overarching mobility coping strategies (Lassen & Jensen 2004).

We will now turn to the empirical material and propose a tentative approach for operationalization of the household decision-making dynamics through the use of the mobility coping strategies. If the dominant mobility coping strategies of the household are expressions of the negotiated prioritization of the household member´s needs and wishes, they are worth investigating as windows to understanding the household decision-making dynamics in travel alternatives. We propose that one way to operationalize and integrate the household decision-making dynamics into a transport model framework, is to construct a number of ideal type households typologies based on mobility coping strategies. As the empirical material from work package 2 of the ACTUM project is focused mainly on households with children, other types and configurations of households lies outside the immediate scope of this paper. Needless to say, a general household typology would need to include a greater diversity in socio-demographic variables (i.e. age, gender, income, household size etc.).

The households in the empirical material are employing diverse mobility coping strategies in handling and organizing their daily life, travel and activities. One aspect of daily life, and where these varying mobility coping strategies become visible, is in the way the households negotiate, plan and perform common 'family' activities, how and if they spend time together, and to what degree the sociality of the household is prioritized as opposed to a more individualized lifestyle. Although much of the daily activities (i.e. school, work, day-care, fitness, sports, shopping, etc.) are typically performed apart, most families in the empirical material spend time together, especially during meals (usually breakfast and dinner) which for most households is a common point of reference. In addition, according to the survey results from ACTUM (Thorhauge et al. 2012), many partially joint tours are conducted in the morning and evening peak hours as

the parents share equal responsibility for bringing children to day care facilities, schools and leisure activities. Due to the sheer amount of mandatory activities, work and social obligations in their daily life, some of the households have to prioritize the meals to achieve family togetherness on a regular basis. Household members socializing may present itself in many forms including shared meals, keeping schedules free on Fridays after work and school, to do nothing, 'cozy-weekend', Sunday drives and other types of weekend leisure activities, spending holidays together, shopping together, joining same sport activity and travelling together in commute or the escort of children. On the other hand, there are households who conduct separate activities and lead much more individual lives. There is a great variance in how the households approach this and to what degree togetherness is needed to fulfill the unity of the household and the meaning of family, but joint travel seems to play a major role in fulfilling this goal. Partly, this is influenced by internal and external conditions (i.e. presence and age of children, working hours, commuting distance etc.), but it is also affected and motivated by the norms, values and attitudes of the household members. Therefore, all households agree upon a particular organization of daily life, travel and activities in relation to sociality and individuality of the household, what could be denoted as a specific type of coping strategy. To engage with this we propose the concept of *household elasticity*. A household with low elasticity has a high degree and need for socializing and common activities, while a household with high elasticity has a high degree and need for individualizing and separate activities, at the extreme this could be a marriage of convenience or simply two persons sharing a household.

In the empirical material, one of the main factors in determining the household elasticity seems to be the presence and age of children. The households in the empirical material all have children, but in varying ages and numbers. Especially age is directly tied to the elasticity and togetherness of the households. Naturally, young children and babies need a high level of physical co-presence, nurture and care. Thus, households with younger children often have low elasticity. As the children age and mature, they become more independent and autonomous and have fewer needs they cannot satisfy by themselves. Surprisingly, this does not lead to an unambiguous raise in household elasticity in the empirical material. Many keep a relatively low elasticity for a long period of the children's childhood, building strong relationships and nursing the unity of the household. Finally, in households with older children, fully capable of handling their own mobility and daily activities, there is tendency in the empirical material towards higher levels of household elasticity, but there is still significant variation. It would be easy to assume a direct and linear relation between number/age of children and elasticity. However, firstly the data material used in this study is not broad enough (let alone representative) to substantiate such a claim, this need further investigation. Secondly, within the empirical material there are variations as a few households with young children could be categorized as having an individualized organization and vice versa. Thirdly, there are also households who lead a lifestyle that could be characterized as both high and low elasticity, i.e. changing to rhythms in work.

From these aspects, the mobility coping strategies of household elasticity and the age of children, we propose to construct four household typologies. The proposition is that each of these four household typologies has different organizations of their daily lives. From the empirical material it is possible to distill certain dispositions and preferences in aspects such as transport modes, routes, activities, social networks, needs etc. that are distinctive for each of the ideal type household. The four household typologies are (see figure 2): a) "household with traditional lifestyle", b) "household with individualized lifestyle", c) "household with focus on family life", d) "household with focus on work life".
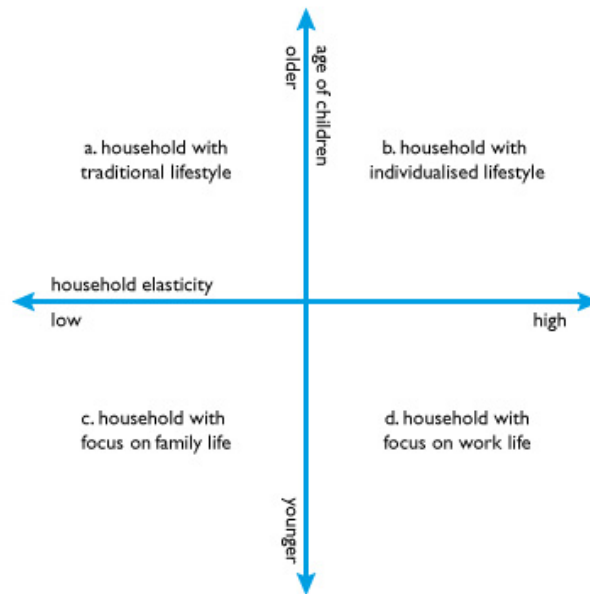
Figure 2 – Household typologies

In terms of integration into a transport model framework these household typologies are interesting, if it can operationalize household preferences in travel alternatives. More work is needed for such a qualitative model to be developed. However, if we sort the empirical material into the four typologies, we can see that it does affect the weighed order of the transport rationales, i.e. the safety transport rationale will be downgraded to the least important rationale in household type a and b, while it may indeed be the most important in household type c.

2.2.2 Integrating family decision-making dynamics in choice models

The described formulation of the model considers the individual as the decision maker. This is in line with the traditional approach in transportation research, which has been dominated by discrete choice models representing individual decision-making mechanisms. However, it is known that individual choice behavior is often influenced by the behavior and the judgment of other people, and in some cases choice behavior is the one of a group of people rather than the one of an individual.

An analysis of households in the Greater Copenhagen area shows that travel behavior is performed jointly at least partially for several tours (Thorhauge et al. 2012). When analyzing the tours, most are either performed alone or partially with others during morning peak hours, most are split between fully joint and solo tours during midday, more than half of the tours are fully joint and less than a third of the tours are conducted alone during the afternoon peak hours, and more than half of the tours are conducted alone during the evening. The tour patterns of households in the Greater Copenhagen area confirm that individual decision-making is influenced by the behavior of the other household member, and hence interactions between household members should be considered within the proposed model framework.

Household decision-making is different from individual decision-making not only because it involves several individuals, but also because these individuals might have different preferences. Decision rules could be applicable for both individual and household decision-making, but the mere existence of other individuals might result in adaptation of decision rules and hence different decision outcomes (Zhang et al., 2009). The adaptation could be either consensual or accommodative (Davis, 1976): consensual decision-making implies that the household continues to search for travel alternatives until one satisfies the minimum level of expectations of all members; accommodative decision-making implies that the

household selects a travel alternative that does not satisfy all its members. In the latter case, household members do not maximize their own utility through the recursion to various strategies (e.g., bargaining, compromising), but the household minimizes social and economic costs by trying to make an optimal choice after passing through a commonly satisfying interaction process (Kirchler, 1995). In this sense, RUM-based models may be applied to household decisions by appropriately defining the utility function.

In principle, the utility could be specified and the choice probability could be computed for each travel alternative and for each household member, and then individual choice probabilities could be aggregated into household choice probabilities through proportionality rules, weighted probability rules, minimum endorsement and preference perturbation rules. Although popular in family-buying, organizational-buying behavior models developed in marketing (e.g., Wilson et al., 1989), travel behavior analysis does not adopt such modeling approach.

In practice, the utility could be specified and the choice probability could be calculated for each travel alternative for the household rather than for the household members, where the household utility reflects the preferences of all the members involved in the joint decision. As each household member has their own preference and adopts various strategies to interact with other members, the utility function should reflect this process (Zhang et al., 2009):

$$U_{gj} = f\left(u_{g1j}, ..., u_{gnj}, ..., u_{gNj}\right) \tag{11}$$

where g is the household, n are the N household members and j are the J travel alternatives. A multi-linear household utility may be defined as the sum of the weighted utilities of household members and intra-household interactions (Zhang et al., 2009):

$$U_{gj} = \sum_{n=1}^{N} w_{gnj}u_{gnj} + \lambda\sum_{n=1}^{N}\sum_{n'>n}\left(w_{gnj}w_{gn'j}u_{gnj}u_{gn'j}\right) \tag{12}$$

$$w_{gnj} \geq 0 \quad and \quad \sum_{n} w_{gnj} = 1 \tag{13}$$

where w_{gnj} is the weight parameter representing the influence of household member n in the joint decision, and λ is a parameter representing household interaction that reflects the concern of each household member to achieve equality of utilities. It should be noted that the intra-household interaction is defined in a multiplicative form of the utilities of household members, and that the extension to higher-order interactions of the binary interaction is possible. Moreover, it should be noted that the number of household members involved in the decisions is given a priori, but it may vary across households.

Equation (12) embeds several types of utility function used to represent several decision strategies that may be relevant to the four household types identified in the current study, namely "household with traditional lifestyle", "household with individualized lifestyle", "household with focus on family life", "household with focus on work life". A household with a traditional lifestyle can be associated with an autocracy-type decision maker, in the sense that one member (usually the bread-winner) makes the decision on behalf of the household. Households with individualized lifestyle may not engage in any negotiations, so the utility of the household is simply the additive utility of all household members, since they mostly engage in independent activities and travel. In households that focus on family life some household members possibly will sacrifice their own wishes and desires in order to engage in activities with other household members, in particular in households involving children. These households may take the

altruistic behavior of each household member into account and the utility of each member will be defined as the average utility of other members. Last, households that focus on work-life balance may take either an autocratic approach in the case of one earner households, so that the working spouse can achieve a work-life balance, or a compromise approach, in which the utility function assumes equal weight for each member, in the case of two earner households.

In equation (12), the additive-type utility function is represented with $\lambda=0$ that excludes the existence of household interaction. The compromise-type utility function is characterized by equal weights w_{gnj} across household members. The capitulation-type function is symbolized by the weight (or utility) of a member being defined as the average weight (or utility) of other members, and hence takes altruistic behavior of each member into account. The autocracy-type is denoted by the weight of a member being equal to one, and hence takes patriarchal behavior into account. Accordingly, the specified utility function can accommodate several strategies for the interaction between household members and can enter any discrete choice model formulation. It should be noted that a latent class approach could allow for heterogeneity across households in terms of their decision-making strategies, in the moment that classes s apply different strategies (i.e., additive, compromise, capitulation, autocracy, mixed) and the probability of each strategy to be implemented is a function of the characteristics of the household.

3. Concluding remarks

The paper proposes a framework for bridging the gap between the 'mobilities turn' and transport modeling by looking at the possibility to relate transport rationales, psychological traits and household interaction to models representing choices between travel alternatives. As this approach to bridging the gap between mobilities research and transport modeling is tentative and experimental we believe it is important to allow for reflection on the conceptual framework's opportunities and challenges for further development and potential implementation.

The strengths of the approach have been discussed at length throughout the paper. Transport models continuously move toward the representation of heterogeneity across travelers and households, and hence it appears only natural to embed within models transport rationale and psychological traits underlying their choices. As a transport model is only as good as its predictions are accurate, it seems obvious that neglecting aspects clearly entering the choice processes of individuals and households has drawbacks in terms of the potential of models to correctly represent current behavior and predict future behavior. Thus the proposed approach opens a unique opportunity to enhance both the behavioral-realism and forecasting ability of future transport models.

One of the main challenges is related to data needs. The best way for gathering information regarding the transport rationales and latent traits is by means of in-depth interviews and qualitative analysis. However, in-depth interviews are relatively lengthy (about 90 minutes) and expensive and hence can be conducted only at a small scale. In contrast, transport models rely on large scale surveys and hence the surveys are typically short (only 13 minutes by phone interview) and consist only of the most important or relevant information, so they are not comprehensive by nature. In addition transport rationales are subjective and personal, while transport models typically rely on objective measures that can be evaluated in the same manner for the entire population. Finally, transport rationales are based on verbal accounts, they are rationalizations of past actions and choices while transport models are aimed at forecasting future choices. To operationalize these aspects for integration into the transport model framework, it is necessary to identify suitable variables. The variables obviously need to be quantified to a certain extent in order to 'enter models'. Two basic methods spring to mind. The first is simply to look at 'objective' dimensions such as trip length and duration. Also in this 'descriptive' category are identification of mode of transport and

choice of route (which in a given context can be quantified as relative to other options). Secondly, the method that needs to be applied consists of attitudinal surveys that are aimed at obtaining reliable estimates of the distribution of the rationales and the psychological traits across the population. Specifically, in attitudinal surveys the respondents to evaluate certain dimensions of the qualitative variables on a quantifiable scale (e.g. Likert Scale where respondents rank statements related to the phenomenon in question from 1-5 or 1-7). All of the qualitative types of data presented within this paper will in principle be able to be matched with some sort of quantitative variable. Notably, while travel diaries reach large samples of travelers and hence are extensively used in activity-based modeling, attitudinal surveys are scarcely used and generally reach small samples that cause the distribution of the rationales and traits to remain vastly unexplored. Having said so, the design of attitudinal surveys that can capture the six rationales must be discussed with much care and reflection to how this is done and there are arguably variables for which such quantifying attempts will not make sense. In addition, since the inclusion of an attitudinal survey within the current survey framework may induce unnecessary respondent's burden, methods of reducing this burden by using data from technological aids such as GPS (work is currently conducted on this dimension within another WP in the ACTUM project) seems as a logical and necessary step toward the collection of large amount of data through large-scale penetration devices. In particular, the model framework necessitates data fusion between small-scale in-depth interviews, large-scale attitudinal surveys, travel habit surveys and GPS data for the same household units.

The obvious upside of using of the transport rationales framework for categorizing transport behavior is the capability to include various non-instrumental aspects to the model framework. However, there are several issues worth noticing. As mentioned the household elasticity and each of the transport rationales needs to be further developed and there are dimensions that might be hard to quantify. Following this work, there is a more fundamental concern related to quantifying qualitative 'soft' aspects. For instance, it is speculative if the transport rationales categories are precise enough, especially the affective- or aesthetic rationale are deeply individualized and subjective and at aggregate level they might loose their precision. What are the consequences of conforming qualitative data to the strict framework of transport modeling? Also, the severe reduction in complexity to conform to integration into transport models is an issue that needs to be reflected further upon. However, it is important to keep in mind the ambition of this paper is not to develop a sensitive framework for investigating and understanding mobility in sociological terms, but rather to reduce complexity, enable and facilitate the inclusion of strategically selected aspects in detail into transport modeling to enhance precision. Nonetheless, as this paper sat out to explore a path for integration of mobilities research and transport modeling, the issue and critique of data-, time- and resource usage as transport models grow larger and more complex needs to be addressed.

Much uncertainty prevails in respect to creating true dialogue between quantitative transport models and qualitative mobilities research. However, with this paper we are beginning to 'pave the road' from transport models to models of new mobilities.

Acknowledgements and remarks

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