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# Incorporating User Behaviour Into System Dynamics Modelling: A Case Study of Private vs. Public Transport in Latvia

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***Abstract* – In this paper, a newly developed dynamic simulation model for transport user behaviour analysis is presented. The study aims to evaluate the impact of various factors on human behavioural intentions, identify the inconvenience costs of public transport, and identify the necessary improvements to shift the demand for population mobility from private cars to public transport. The assessment of such aspects as travel time and travel cost is presented. Modelling assumptions are based on a specially designed public survey allowing to improve the reliability of the developed system dynamics model. Modelling results highlight the multiplicative effect of factors influencing mode shift.**

***Keywords* – Human behaviour; modelling; public transport; system dynamics**

## 1. INTRODUCTION

According to the Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (Renewable Energy Directive, RED II), EU Member States are obliged to reach at least 14 % renewable energy share in final transport energy consumption by 2030 but then allows member states to bring this target down if they have a lower limit on food-based biofuels [1]. The majority of countries face difficulties in achieving the target. In 2019 (latest data available) only 5 countries had reached the target of at least 10 % renewable energy share by 2020 set by the Renewable Energy Directive, namely Sweden (30.3 %), Norway (23.5 %), Finland (17.4 %), Netherlands (11.4 %), and Iceland (10.9 %) [2].

It is up to the Member States to decide how to achieve the goals set by RED II: they are developing alternative fuels, increasing vehicle efficiency and taking other measures to reduce energy consumption in the transport sector. Previous research outlines also the potential of the transition from private to public transport in decarbonizing the transport sector [3], [4]. By switching peoples' transport modes towards public transport which is run on alternative fuels, great results might be achieved in terms of greenhouse gas emission savings [5], [6].

However, the reality shows opposite development trends. The average per capita car ownership increases, meanwhile popularity of public transport decreases. Factors such as personal comfort, saving time and money play a role in favour of the car [7], [8], while the major drawbacks of public transportation are: longer travel time, crowding, low travel comfort, etc. [8], [9], [10].

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Several authors compile surveys of the population to better understand the current situation regarding the attitude of the population towards public transport, as well as to determine what improvements are needed. For example, Juan de Oña *et al.* surveyed 525 respondents who use public transport and 500 respondents who choose private transport to identify factors influencing the quality-of-service perceptions, satisfaction, and attitudes toward public transport [11]. The largest differences in the scores for the public transport of both groups were related to attitude towards lifestyle, travel time, and costs. Another finding was that to promote public transport, efforts should focus on developing policies to change the attitudes of private vehicle users towards public transport services, as well as their perceptions of proximity, speed and intermodality [11]. Other studies, that evaluated decision influencing factors concluded that the main efforts in policy planning should be put towards the improvement of a well-coordinated transportation environment as well as other service quality attributes [12], [13]. Regarding travel costs Owen Bull *et al*. study in Santiago, Chile showed an overall increase in travel by 12 % and an increase in the total number of trips by 23 % after the invention of fare-free public transport [14] while some studies showed that economic factors, such as fuel prices or public transport fares, are not very effective in terms of influencing people who intend to use public transport [15], [16]. The main research results indicate that the main focus should be put on service quality improvement as well as on psychological and behavioural interventions such as changing the attitudes to public transport and cars and breaking commuters' habits [17], [18].

To evaluate the transition potential from private cars to public transport in Latvia, a mathematical simulation model was developed using the system dynamics modelling approach. The model represents major human decision influencing factors related to the transition from private cars to public transport. Data assumptions regarding human behaviour aspects needed for the model were obtained with the help of a specially designed public survey. The major scientific novelty of the research is the attempt to integrate the social dimension of the transport system (results of the survey) with a mathematical modelling task. As transport users' behaviour is very important in this context, such an approach allows for increasing the reliability of the developed system dynamics model, as the assumptions used are based on the results of real survey data. The novelty of this work is the development of a methodology for modelling human behaviour and policy that would promote the switch from private car use towards public transport as well as the achievement of renewable energy sources (RES) goals in the transport sector in Latvia. In this paper, the first results are presented covering two of the five selected factors influencing mode shift - travel cost and travel time. This type of research in the Latvian context has not been performed before. The results obtained can be used in policy planning.

## 2. METHODOLOGY

An overall description of the research methodology is given in Fig. 1. It consisted of three successive phases. During the preparation phase, a scientific literature study about factors affecting transport mode choice was performed. Outcomes of the desk research were later presented in several group brainstorming events with colleagues and university students to collect first impressions and opinions about the topic. Based on the outcomes of the discussions, the first conceptual system dynamics model was developed and a survey questionnaire was designed.

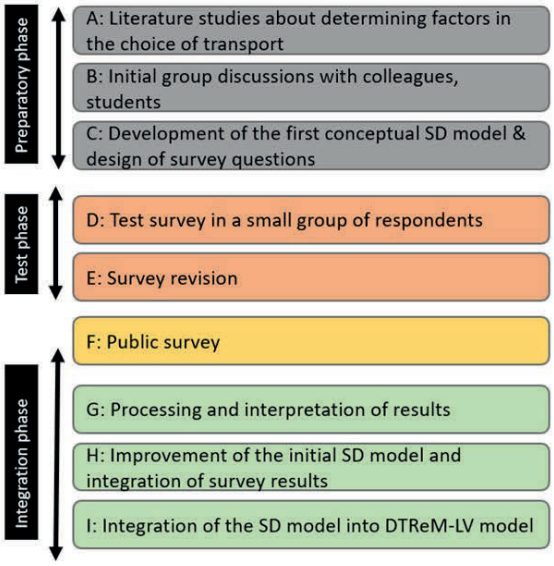



Fig. 1. Research methodology.

The second – test phase – was divided into two parts. At first, a test survey in a small group of five respondents was made. Their feedback showed that the first version of the survey was too long, as well they indicated a few survey questions that could be misunderstood and should be paraphrased. Changes were made accordingly to the feedback and the final version of the survey was shared via social media for two weeks for April–May, 2021.

The last phase of the research (still ongoing) involves processing and interpretation of the survey results, improvement of the initial conceptual system dynamics model and integration of survey results into the model. After the finalization of the private vs. public transport sub-module, it will be integrated into the whole transport system model for Latvia DTReM-LV (Dynamic Transport emission Model for Latvia) [19]. This study builds upon the previous work and aims to supplement the existing model to represent the inconvenience costs that are associated with public transport use.

## 3. Results and Discussion

### *3.1. Integration of survey results into the system dynamics model*

To reduce carbon emissions in the transport sector, it is necessary to stimulate a change in human behaviour. Shifting human flows from private to public transport is influenced not only by the costs of the transport but also by the cost of inconveniences, such as travel time, travel comfort, congestion etc. [8], [20].

To explore the attitude of private car users towards public transport in Latvia, a preference survey was carried out which included 350 respondents. Results from the public survey performed in this research show that similarly to previous studies costs of the transport mode are considered as important however many factors are rated higher, such as travel time and comfort, ease of use, infrastructure availability and the possibility to carry passengers and

luggage (Fig. 2). These results go along with a previously performed study in Poland about the main reasons for choosing a private car for daily commuting [20].

For the integration in the system dynamics model, factors influencing travel mode choice from the survey were grouped creating five major groups: (i) time, (ii) cost, (iii) infrastructure availability, (iv) comfort and (v) prestige (Fig. 3).

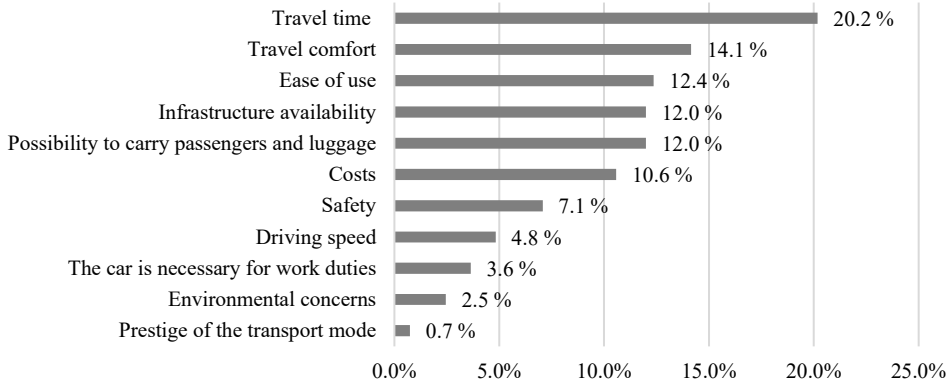



Fig. 2. Answers to the question 'Which of these factors do you find most important? (3–5 answers)'.

In the following sections step by step methodology and results are presented for two of the five factors, time and cost, namely. The effect of the time and travel cost on mode shift from private cars to public transport is modelled in a system dynamics model based on responses collected from the survey.

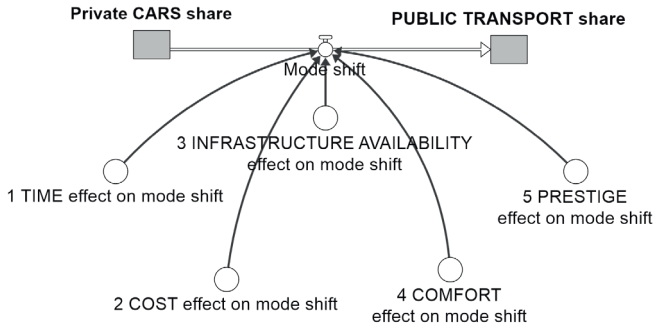



Fig. 3. Factors influencing mode shift included in the system dynamics model.

### *3.1.1. Travel time*

As seen in Fig. 2 the highest-rated factor influencing the choice of transport mode is travel time. To determine the average travel time to be included in modelling assumptions, respondents were asked to indicate the average travel time from the moment of leaving home to reaching their destination (door-to-door) and to describe how this time would change if public transport was used instead of the private car. The average travel time was taken separately for respondents living in cities and for those living in regions and was compared with the time estimate provided by the respondents, which would be necessary to perform the same route by public transport. After comparing travel time for both transport modes results

show that on average trips by public transport take 133 % more time than by private car (median is 100 %) and only 10 out of 281 comparable responses (when respondents knew what is the travel time for both transport modes) or 3.6 % thinks that the trip by public transport could be faster than the trip by private car and 7.1 % believes that it would take the same time. Results for travel time compared by residence (urban or regional) are given in Table 1.

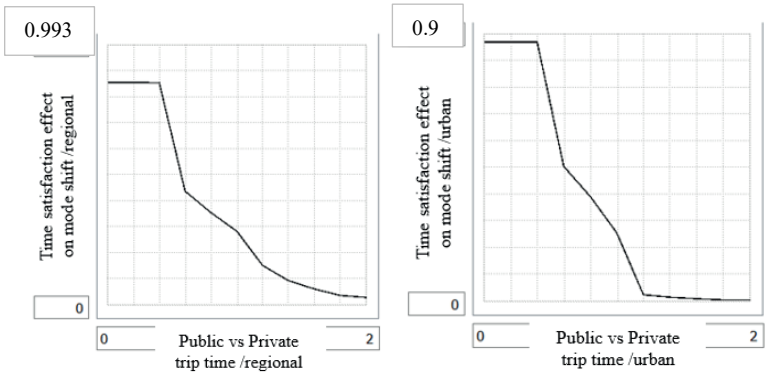
TABLE 1. TRAVEL TIME COMPARISON FOR THE URBAN AND REGIONAL AREA

| | **Urban area** | **Regional area** |
|---|---|---|
| Average time spent travelling by car (door-to-door) | 41.3 min | 57.7 min |
| The average time that would be spent if the same distance was driven by public transport | 78.5 min | 82.6 min |
| Share of people who did not know the average time that would be spent if the same distance was driven by public transport | 15.8 % | 45.7 % |
| Average travel time difference (public vs private car) of respondents who could provide numerical answers about travel time | +132.2 % | +138.0 % |

To include scenario analysis in the model allowing to project changes in transport mode, respondents were asked what travel time by public transport (compared to a private car) could motivate them to mode shift. The following options were offered:

- if it takes significantly less time than driving a private car;
- if it takes less time than driving a private car;
- if it takes about as much time as driving a private car;
- the journey time by public transport can be longer than by the car if I can do something useful during this time, and;
- I use the car for work which is not possible with public transport.

Based on obtained results, the key functions for the variable '1 Time effect on mode shift' (Fig. 3) were developed. In Fig. 4, the graph functions of the time satisfaction effect on mode shift are presented based on survey results. The x-axis shows the part of the population that is satisfied with the travel time, while the y-axis shows the travel time (up to 2 h). E.g. when the public vs. private travel time is equal (x-axis value is 1), the time satisfaction effect on mode shift is around 25–28 % (y-axis), i.e. around 28 % of the population is considered as willing to do the mode shift in case of regional travellers (Fig. 4(a)) and around 25 % – in case of urban travellers (Fig. 4(b)).




(a) (b)

Fig. 4. Time satisfaction effect on mode shift (a - regional, b - urban).

To understand the impact of the policies which could reduce the total public transport travel time, the following question was asked – 'Let's imagine that as a result of various improvements, the journey by public transport takes significantly less time than by private car. How many of the 10 car journeys would you be willing to replace by public transport?'. The results for this question are presented in Table 2 regarding the place of residence of respondents.

TABLE 2. NUMBER OF TRIPS REPLACED WITH PUBLIC TRANSPORT IF TRAVEL TIME BY PUBLIC TRANSPORT SIGNIFICANTLY DECREASES

| Number of trips replaced with public transport | All answers | Urban residence | Regional residence |
|---|---|---|---|
| Share of respondents | 100 % | 86.86 % | 13.14 % |
| Mean | 4.84 | 4.87 | 4.61 |
| Median | 5.00 | 5.00 | 5.00 |
| Std. deviation | 3.00 | 3.03 | 2.84 |

Most people chose to replace 5 trips if the travel time by public transport decreased significantly. The total time effect on mode shift is then calculated using formula 1:

$$E_{\text{time}} = T_{\text{r time}} \cdot S_{\text{r time}} \cdot R_{\text{r time}} + T_{\text{u time}} \cdot S_{\text{u time}} \cdot R_{\text{u time}}, \quad (1)$$

where

$E_{\text{time}}$ Time effect on mode shift;
$T_{\text{r time}}$ Share of trips for income group out of all trips in regions of total trips;
$S_{\text{r time}}$ Share of users who would switch to public transport in regions;
$R_{\text{r time}}$ Share of car trips replaced in regions;
$T_{\text{u time}}$ Share of trips in the urban area of total trips;
$S_{\text{u time}}$ Share of users who would switch to public transport in the urban area;
$R_{\text{u time}}$ Share of car trips replaced in the urban area.

### *3.1.2. Travel costs*

The second factor influencing the mode shift from private cars to public transport presented in this paper is the cost. Cost is one of the factors that can be determined easier as it is not based on the inner feelings of the population. To determine the cost effect on the travel mode choice respondents were divided into three groups based on monthly income:

- up to 750 EUR per household member;
- 750–1500 EUR per household member, and;
- above 1500 EUR per household member.

Similarly to average travel time, respondents were asked about monthly average household expenditures on a vehicle, as well as how much should the monthly cost of using a private car increase to give up a private vehicle. Results show that the majority of the respondents (49.4 %) spend 50–150 EUR per month on a private car. The indication of the average monthly expenditure that would make respondents switch from the usage of a private car in daily commuting to public transport showed that 43.4 % will not abandon using a private car no matter the expenditures. The results showed that people who have a monthly income of up to 750 EUR per person in the household on average are setting the maximally allowed price for the car by 128.9 % and people who earn 751–1500 EUR per month on a person in the household are willing to pay by 207.8 % more. Interestingly but people who earn more than 1500 EUR per month per person in the household are willing to pay less than those who earn 751–1500 EUR per month (144.3 % increase).

To understand the mode shift potential due to the cost factor, respondents were asked about their travel mode choices in case the private car costs reach an unbearable amount. The results show that 11.4 % will continue to use a private car without changes, 45.4 % would reduce the number of car trips, and 2.6 % would drive with fellow passengers. Only 4 % would be ready to switch to public transport and 25.7 % would be ready to use it in combination with walking and cycling. The results also show that people with kids are slightly more open to walking and taking public transport and less towards travelling by bicycle. They are also more willing to combine walking, cycling and public transport. They are not willing to pay more than people without kids because fewer people chose to not change anything as well as they are less open to the idea to drive a private car with fellow passengers. Based on survey outcomes, the key functions for the variable '2 Cost effect on mode shift' (Fig. 3) were developed. In Fig. 5, the graph functions of the cost satisfaction effect on mode shift in each income group are presented based on survey results. The x-axis shows the part of the population that is satisfied with the cost of travel, while the y-axis shows the travel cost per one trip (up to 15.67 times more than the current expenses).

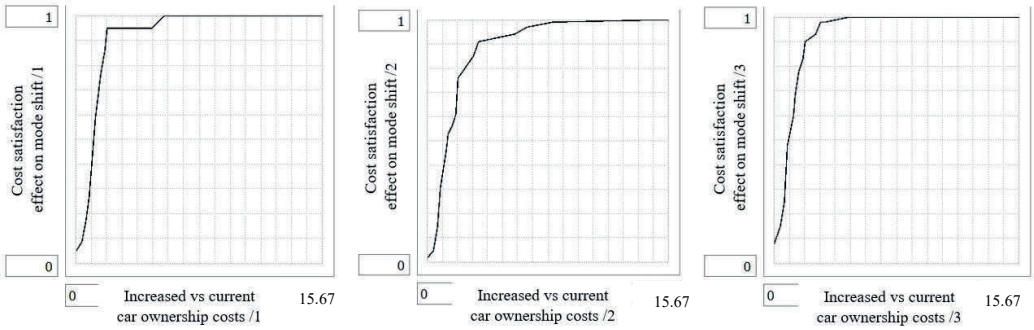



Fig. 5. The cost satisfaction effect on mode shift for different income groups: (a) income up to 750 EUR on a household member; (b) 750–1500 EUR on a household member; (c) more than 1500 EUR on a household member.

The share of people who would switch to public transport was calculated using formula (2):

$$S_{\text{cost},i} = SE_{\text{cost},i} \cdot M_{\text{cost},i}\,, \tag{2}$$

where

$S_{\text{cost},i}$ The share of people who would switch to public transport;
$SE_{\text{cost},i}$ Cost satisfaction effect on mode shift;
$M_{\text{cost},i}$ Maximal population accepting public transport alternative;
$i$ Income group.

The total cost effect on mode shift is calculated according to formula 3:

$$E_{\text{cost}} = T_{\text{cost},i1} \cdot S_{\text{cost},i1} \cdot R_{\text{cost},i1} + T_{\text{cost},i2} \cdot S_{\text{cost},i2} \cdot R_{\text{cost},i2} + T_{\text{cost},i3} \cdot S_{\text{cost},i2} \cdot R_{\text{cost},i3}\,, \tag{3}$$

where

$E_{\text{cost}}$ Cost effect on mode shift;
$T_{\text{cost},i}$ Share of trips for income group out of all trips of each income group;
$S_{\text{cost},i}$ Share of users who would switch to public transport of each income group;
$\text{R}_{\text{cost},i}$ Share of car trips replaced by each income group;
$i1$ Income group up to 750 EUR per household member;
$i2$ Income group 750–1500 EUR per household member;

*i*3 Income group above 1500 EUR per household member.

It was assumed that the share of the urban trips was 68 % while the share for the regional trips is 32 % according to the statistics. The share of the car trips that should be potentially replaced was taken from the survey results.

### *3.1.3. Mode shift model with time and cost factors*

To get the total impact of travel cost and travel time effect on mode shift both previously described sub-models were put together. Representation of the developed system dynamics model in *Stella Architect* software is shown in Fig. 6.

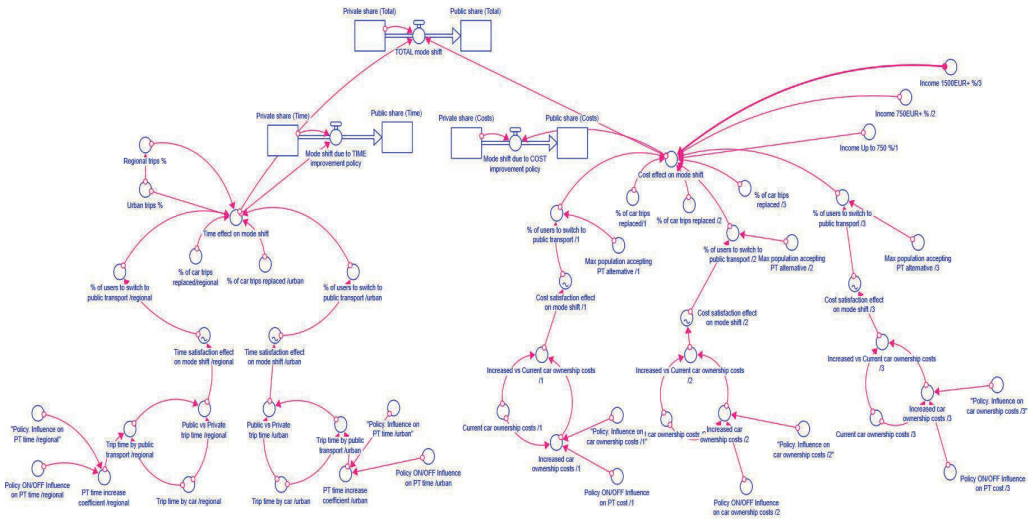



Fig. 5. Total effect on mode shift in the system dynamics modelling software Stella Architect.

The total mode shift is calculated using the formula 4:

$$\text{Total mode shift, \%} = \text{Private}_{\text{share}} \cdot E_{\text{time}} \cdot E_{\text{cost}}\,, \tag{4}$$

where

Total mode shift — Rate of share change of people who uses public transport;
$\text{Private}_{\text{share}}$ — Share of people who uses private cars;
$E_{\text{time}}$ — Time effect on mode shift;
$E_{\text{cost}}$ — Cost effect on mode shift.

Lastly, public transport share is calculated by using formula 5:

$$\text{Public transport}_{y} = \text{Public transport}_{(y-1)} + \text{Total mode shift}\,, \tag{5}$$

where

Public transport — Public transport users at a year $y$;
$\text{Public transport}_{(y-1)}$ — Public transport users in the previous year (in 2020 = 0.18);
Total mode shift — Rate of share change of people who uses public transport;
$y$ — Year.

### *3.2. Sensitivity analysis*

The modelling results are presented in three previously described modes: (i) travel time effect on mode shift, (ii) travel cost effect on mode shift and (iii) combination of travel time effect and travel cost effect.

#### *3.2.1. Baseline scenario*

The baseline scenario describes the situation when no additional policies are being added to the current situation. In the baseline scenario, it is assumed that the share of people who are using the private car in 2020 is 82 % while the share of people who are using public transport equals 18 %. The results about travel cost impact show that if the only concern which is stopping people from public transport use would be travel costs, an increase in the public transport sector by 57.3 % reaching 75.3 % share of public transport users would happen by 2030. This is due to the lower costs that public transport is offering in comparison with the increased car costs. This trend shows, that if the only important factor was car costs more people would switch to public transport. Results show that if the only parameter that would be taken in the count was travel time (which is different in urban and rural areas accordingly to the survey data), 24.1 % of people (an increase of 6.1 %) would use public transport. This shows that if the only factor influencing transport mode choice was travel cost then the public transport share would be much higher in comparison with the situation when only travel time is important. This highlights that when talking about human behaviour it is important to consider different parameters influencing it at once. After the multiplication of both previously mentioned factors, the switch to public transport use increases only by 0.6 % reaching 18.6 % public transport mode share. This shows the importance of considering as many influencing parameters as possible to get more precise results, as the total impact can drastically change after adding new multiplicators.

#### *3.2.2. Policy testing*

To see what the changes would be if the travel time and travel cost decreased, policy testing has been presented.

Several scenarios were developed, to see each aspect's influence if it was the only important aspect for travel mode choice and to see each aspect's influence on public transport share if it is combined with the second aspect. Three scenarios are presented:

- Travel time matters scenario (travel time is the only important aspect);
- Travel costs matter scenario (travel cost is the only important aspect);
- Both matter scenario (the combination of travel time and travel cost impact).

The impact of the travel time changes was assessed. The impact of the place of residence was taken into account, as road conditions inside and outside the cities are different and would require different policy instruments to reduce public transport time. Results show that if the travel time was the only aspect that would be important then getting travel time for public transport to be the same as private transport travel time would lead to an increase of public transport share for up to 76.8 % while 98.1 % of public transport share could be achieved by decreasing public transport's travel time by half in comparison to private cars. However, as it was described previously, despite travel time there are many other aspects influencing transport mode choice. In this scenario, the same tendency is visible however the values of the mode shift are much smaller. Results show that if the travel time is considered together with travel costs then getting travel time for public transport to be the same as private transport travel time would lead to an increase of public transport share for up to only 27.1 %

while 40.1 % of public transport share could be achieved by decreasing public transport's travel time by half in comparison to private cars.

Similarly, an assessment of the travel costs is presented. In this scenario, a great mode shift is achieved by increasing travel expenditures for private cars. Thus 81.5 % share of public transport could be reached just by increasing average monthly car costs by 50 EUR, while 90.0 % public transport share mark is passed when costs increase by 150 EUR. In the 'Both matter scenario' the maximal share of public transport that could be achieved is smaller by 74.6 % and reaches only 19.2 % if the monthly car costs increase by 500 EUR. 18.7 % share of public transport is achieved when an additional 50 EUR are added to the average monthly car costs while 19.0 % are achieved by increasing costs by 150 EUR. For a better understanding of travel time and travel cost impact on the total mode shift 'Both matter' scenario was divided into smaller parts. The combinations considered are shown in Fig.6.

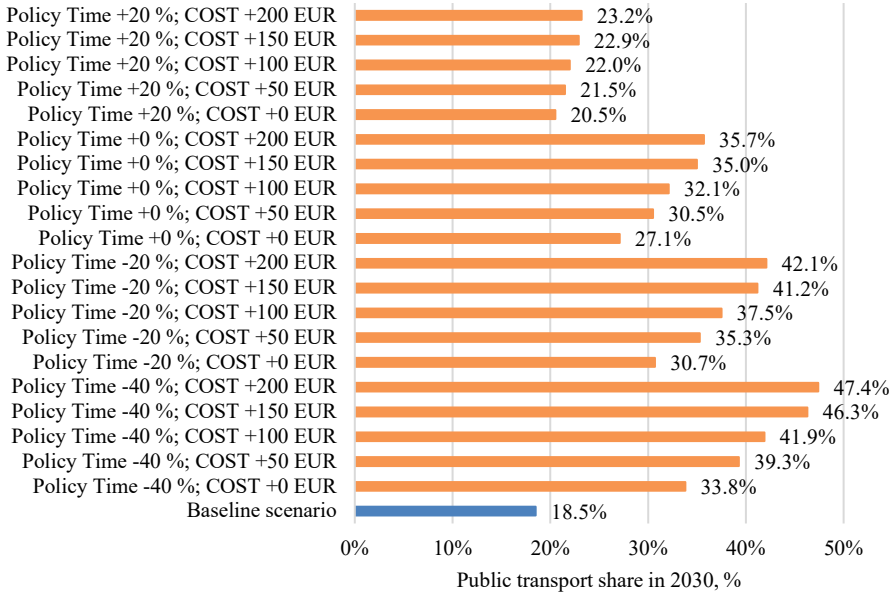



Fig. 6. The total effect on public transport share in 2030 (Both matters scenario).

The results show what rates of improvement give the biggest impact on public transport share increase. The best results were achieved by combining the biggest values of both policies (40 % travel time reduction and increase in travel costs by 200 EUR per month). This shows that for better results improvements have to be made in several sectors.

Results also show that there are several ways how to get similar public transport share:

- 'Time-40 %: COST+100 EUR' (41.9 %) and 'Time-20 %, COST+200 EUR' (42.1 %);
- 'Time-20 %: COST+50 EUR' (35.3 %) and 'Time+0 %, COST+150 EUR' (+35.0 %);
- 'Time+0 %: COST+50 EUR' (30.5 %) and 'Time-20 %, COST+0 EUR' (30.7 %).

This indicates the need for further cost and benefit assessment that has to be applied to determine which measures would be the most efficient and most cost-effective.

The travel time required for public transport can be reduced by redesigning existing public transport networks, introducing more bus lanes, as well as expanding micro-mobility opportunities, thus solving the first-mile and last-mile problems. It is also possible to use

other policies that would extend the journey time by private transport. Measures to make private transport more expensive could be tax increases, the proceeds of which could be used to purchase more environmentally friendly public transport, build infrastructure and improve the urban environment. An assessment of the impact of policy instruments needs to be established.

## 4. CONCLUSIONS

This paper aims to evaluate the impact of various factors on human behavioural intentions, identify the inconvenience cost of public transport, and identify the necessary improvements to shift the demand for population mobility to public transport.

To explore the attitude of private car users towards public transport in Latvia, a preference survey was carried out which included 350 respondents. The survey's results were in line with previous studies and showed that such aspects as travel time, travel comfort, ease of use, availability and the possibility to carry other passengers and luggage were rated higher as the most important aspects of transport mode choice than travel costs. Within the framework of the study, 2 out of 5 factors influencing transport mode choice, which were defined by the survey as important for transport users, were considered for the further integration of the survey results into the system dynamic model. The integration of other factors into the system dynamics model will be continued within the framework of the 4muLATe project until the end of 2021. Independent sub-models have been developed for the considered behavioural factors.

Results of the modelling showed that when considering only one factor (travel time or travel costs) a great achievement can be reached in terms of public share increase, however as soon as these factors are multiplied their impact on the switch to public transport drastically decreases. This shows the importance of considering several decision-influencing factors at once. Policy analysis indicated that the same results in terms of public transport share increase can be achieved by the combination of different policies, which indicates the need for further cost and benefit assessment that has to be applied to determine which measures would be the most efficient and most cost-effective. An assessment of the impact of policy instruments needs to be established to determine how to get such travel time reduction or private car cost increase most cost-effectively. It is recommended to use Statgraph or similar software to present an even more detailed analysis of the variables such as household size, number of kids, education level, etc. For more precise results more answers for the same survey are needed. At present, the analysis does not take into account possible changes over time, how the importance of the defined factors could change (for example, as wealth increases, the importance of costs decreases even more, but something else increases). Thanks to the open structure of the developed model, these shortcomings can be improved in the future, as well as it this methodology could be used for further planning of the development of the transport sector not only in Latvia but in other countries too if used parameters are adjusted to the local context.

## ACKNOWLEDGEMENT

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