GROWTH MODEL4: THE NEW DUTCH NATIONAL PASSENGER TRANSPORT MODEL

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Significance

The Netherlands has a long history of strategic passenger transport modelling. Over the last decades the National and regional models (Landelijk Model Systeem, LMS, and Netherlands Regional Model, NRM) have continuously been improved based on user experience, data availability, methodological developments and policy demands from the clients. During 2019 and 2020 the Growth Model of the LMS and NRM has been re-estimated (GM4) to update and enhance the model specification. The first application of the new GM4 model will be for the policy study 'Integral Mobility Analysis' –IMA- for the Ministry of Infrastructure and Water. The IMA started November 2020 and was published June 2021[i]. Aim of the study is to provide insight in the long-term challenges in the transport system as input for the formation of the new political coalition after the national elections in March 2021. Furthermore, LMS and NRM are widely used for general policy studies (such as road pricing), and for impact analysis for all the strategic road and/or rail investments in the Netherlands. In addition, the model is also used for other modes of public transport or regional studies assessing the accessibility impacts of regional developments.

1. INTRODUCTION

This paper will give an integral overview of the scope of work for the development of the GM4 model. The paper will present the topics that were researched, the choices that were made for the final model specification and the performance of the resulting model. For some aspects of the model re-estimation more detailed conference contributions and journal papers are anticipated. The re-estimation of the Growth model is a joint project between Rijkswaterstaat, responsible for the trunk road system in the Netherlands, and ProRail, responsible for the National Rail system, and was executed by Significance.

Based upon previous model development experiences an evaluation framework has been set-up at the beginning of the project to assess the resulting models on many aspects throughout the whole project. The evaluation framework builds upon existing knowledge from previous national and international research work on cost and time elasticities and recent data from the National Transport Survey in the Netherlands.

The assessment of the models includes the model fit, check on 'acceptable' bandwidths for cost- and time elasticities and VTT (based upon literature including previous model outcomes) and reference values for key transportation figures from the National Travel survey like mode shares (tours and km) and trip length distributions by mode, both at National level as well as for the 4 largest cities in the Netherlands.

Based upon the assessment of the models a proposal for the final specification has been formulated and discussed with a team of external academic experts. The final model was implemented and tested in practice and the assessment of this model will be described in the paper.

2. PROJECT SETUP AND EVALUATION FRAMEWORK

The estimations have been set up in three phases. In the first phase, the specification phase, several potential model improvements have been tested in parallel. These model improvements can be divided into three groups: 1) advanced estimation techniques, 2) improved public transport modelling and 3) adaptations related to other improvements in GM4. At the end of the specification phase the results of the tests were discussed with the project team of the client, consisting of experts from the client organisations and other governmental research institutes, and with a panel of external academic experts. Agreement was reached about which potential improvements were to be implemented in the model.

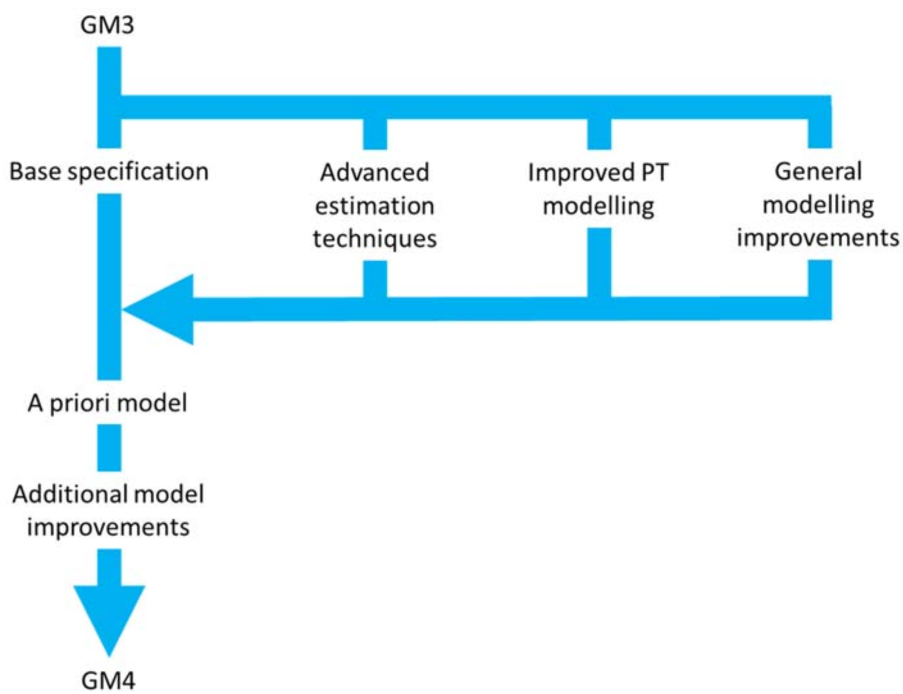


Figure 1: Estimation approach

In the second phase, the production phase, the selected model improvements from the parallel tests were combined into a single model specification. This model specification was implemented in software as a first version of GM4 model that was used to generate the so-called a priori matrices which were needed for the parallel project in which the Car-driver matrix was calibrated. The LOS from the calibrated base matrix was fed back into the GM4 estimation procedure for estimating the final model specification. Hence one feedback loop between estimation of the GM4 and estimation of the base matrices has been realized.

The evaluation of the specification phase, with external experts, resulted in a number of remaining issues that required additional specification testing in an additional third phase. These issues were the treatment of travel cost reimbursement for commuting tours, the inclusion of non-fuel variable car costs in addition to fuel costs in the model and use of qualitative aspects about the labour market (working force and jobs by level of education). The final model specification of GM4 was enhanced with the outcome of this additional test phase.

In total the following aspects were tested:

1. Re-estimation of the base specification from the previous model (GM3) using recent survey data available for the estimation of GM4
2. Advanced estimation techniques
    a) Destination sampling
    b) Cost coefficients per income class
    c) Cost coefficients per mode
    d) Flexible nesting structures / Cross-nested models
    e) RP-SP combined estimations
3. Improved PT and Bike modelling
4. Improved car ownership (distribution) model using new data on parking permits
5. Car cost specification and reimbursement policies for commuting
6. Improvements in modelling education level as explanatory variable at production side (population by education level) and attraction side (education level of jobs)

Throughout the whole project a wider evaluation framework was used to assess the resulting models on many aspects. The evaluation framework was defined before commissioning the project. The assessment of the models includes the model fit, check on ‘acceptable’ bandwidths for cost- and time elasticities (for tours an KM) and VTT based upon literature, and reference values for key transportation figures like mode shares (tours and km) and trip length distributions by mode, both at National level as well as for the 4 largest cities in the Netherlands. For Train also targets were defined on how the ranking of largest stations and largest relations between regions were reproduced compared to the observed station relation matrix.

In the estimation phase the newly estimated models were applied on the estimation data in so-called apply runs. The outcomes of the apply runs were checked on the reference values. After selection of the final model estimation and implementation in stand-alone software the model was tested extensively. The base year patterns and time and cost elasticities of the final model were evaluated against the evaluation framework. Furthermore, test runs were applied to check whether the model provided plausible forecast results. The results of the test runs, to produce forecasts and to calculate the impacts of policy measures, were discussed with experts to get their input on the plausibility of the results and if differences with the previous model version could be contributed to model improvements.

The scope of the project was limited to re-estimation of the choice models. Model inputs like zoning, Socio-economic data, networks and base matrices (for Car Driver, Train, Bus and Tram-Metro) were developed in parallel projects. However, where relevant, data and information were exchanged between the projects. Like LOS data from the networks and Socio-Economic data that are needed for the estimation.

2.1. Available data for model estimation

The following data sources were used for estimation:

1. *National Travel Survey* 'Onderzoek Verplaatsingen in Nederland', OViN 2015-2017.
   This is the main estimation source. After cleaning the data a total of 77,832 observed respondents on working days are available that conducted a total of 90,292 home based tours. For these respondents detailed information on the respondents and their household members are available (home location, age, sex, work status, income, education, licence holding, car ownership, Student Public Travel Card ownership) and all details of the travel diary.
2. *Klimaat 2014* A survey specifically on Train users conducted by the Dutch Railways (NS). From a total of 47,792 respondents after cleaning 5,684 respondents with full information, and 19,620 respondents with partial information remain. This data was mainly used for the estimation of the station-choice model.
3. *2019 SP Time-of-Day study* The study yielded in 1094 usable interview. This data was used for the specification of the Time of Day models for Car driver and Train.
4. *The Schiphol Survey 2017 and 2018* The Schiphol survey is a survey among air travellers leaving the Netherlands via Schiphol airport, held by the airport authority. This data is used for the estimation of the Airacces models. A total of 33,263 access travellers and 27,914 egress travellers are available for model estimation
5. *LOS data for the transport modes*. From the parallel project LOS data for Car driver, Car Passenger, Rail, Bus, Tram-Metro, Bike and Walking were provided. For Car this was congested travel time, distance and –costs for morning peak, evening peak, shoulders of the peak periods and off peak. For Rail, Bus and Tram-Metro the LOS was provided for morning peak, evening peak and off peak. Bike and Walk LOS were based on free flow LOS. For Rail fare reductions per time period and per purpose for Workers, Students and Other occupations were determined. For Bus and Tram-Metro fare reductions per person type (students with, week-/weekend PT-card, children <12, youth 12-18, Elderly 55-75 and 75+ and Other) and purpose were determined.

2.2. Reference values from data sources and literature

The results of the estimated models were compared to a set of key figures that are found in literature or calculated from datasets. The details of these key figures are specified in the memo ‘Toetsingscriteria bij modelschatting en streefwaarden kwaliteit a-priori matrices’ (RWS-WVL, 2019). The key figures to test are as listed in **Table** (note: MDToD = Mode-Destination Time-of-Day models)

Table 1: Reference criteria

	Criterion	*Source*	*Modules*
1	Number of tours, by mode, travel purpose and region	OViN 2015-2017	Tour frequency / combination [ii]
2	Person kilometres travelled, by mode, travel purpose and region	OViN 2015-2017	Combination
3	Mean tour length, by mode, travel purpose and region	OViN 2015-2017	MDToD
4	Modal split in number of tours, by mode, travel purpose and region	OViN 2015-2017	MDToD
5	Modal split in kilometres travelled, by mode, travel purpose and region	OViN 2015-2017	MDToD
6	Tour length distribution, by mode and travel purpose	OViN 2015-2017	MDToD
7	Railway traveller flows (number of passengers) between regions	Rail matrix	Combination
8	Station ranking of (dis)embarking passengers	Rail matrix	Combination
9	Elasticities and cross elasticities, by mode and travel purpose	Literature survey	MDToD[iii]
10	Values of time, by mode and travel purpose	Literature survey	MDToD

The reference values that were derived from the OViN, Klimaat and the rail matrix will not be given here. The reference values for elasticities and VOT that were used in the previous re-estimation project (GM3) were updated using new literature review and discussions within the project group. The selected reference values are:

Table 2: Recommended bandwidth for direct elasticities

	Tour elasticity	**Km elasticity**
	Recommended band width	**Recommended band width**
Train costs	-0.2 to -1.1	-0.6 to -1.2
Train in-vehicle time	-0.2 to -0.8	-0.3 to -0.9
BTM costs	-0.3 to -0.9	-0.4 to -1.0
of which: bus	-0.4 to -1.0	-0.5 to -1.1
of which: tram and metro	-0.2 to -0.8	-0.3 to -0.9
BTM in-vehicle time	-0.4 to -0.9	-0.5 to -1.3

of which: bus	-0.3 to -0.8	-0.4 to -1.2
of which: tram and metro	-0.5 to -1.0	-0.6 to -1.4
Car driver fuel costs	0.0 to -0.3	-0.2 to -0.5
Car driver time	-0.15 to -0.5	-0.2 to -0.9

Table 3: Recommended bandwidth for value of (in vehicle) time

Value of time (2010 € per hour)		Recommended band width (2018 € per hour)
Train	Commute	10 to 14
	Business	23 to 41
	Other	7 to 10
BTM	Commute	7 to 11
	Business	20 to 31
	Other	6 to 8
Car driver	Commute	9 to 14
	Business	21 to 41
	Other	7 to 12

3. SPECIFICATION PHASE AND SELECTED MODEL SPECIFICATION

Section 2 lists the aspects that were investigated during the specification phase of the project. These tests were executed in parallel giving the opportunity to test relatively many aspects for model improvements. The results of the estimations of the specification phase were discussed in a workshop with two external experts. In this workshop the choices for the preferred model specification were identified.

In line with the aim of this paper to provide an integral overview of the re- estimation project this section will qualitatively present the topics that were tested in the specification phase.

Section 3.2 to 3.9 describe tests that were done for the specification of the Mode-Destination-Time-of-Day (MDToD) model that represent the core of the GM4.
The subsequent sections 3.9 and 3.10 describe the tests for the other modules of GM4.

Re-estimation of the GM3 specification

The project started with re-estimation the GM3 specification on the new data (OViN 2015-2017), using the GM3 zonal data and LOS data. Though coefficients did vary, and sometimes changed sign, the general conclusion was that the GM3 specification proved to be robust. The nesting structure was confirmed and the most important (time and cost related) variables showed a stable behaviour and did not change very much. Also model fit and apply run results were satisfactory.

Destination sampling

In order to be able to test as many specifications as possible, in the preparation phase an analysis was done to determine an optimal balance between destination sampling, run-time, and accuracy of the estimated coefficients against a reference estimation without destination sampling.
The selected settings for the destination sampling resulted in an estimation time of approximately 10 hours for Commute, while the estimation time without sampling could be one week. Applying the destination sampling made it possible to test a wide set of different model specification with sufficient accuracy for the test phase. The coefficients of the final model specification were eventually estimated without destination sampling.

3.1 Urbanization Levels

An important attribute in strategic transport models is the level of urbanization. Until GM3 the definition in 5 levels of urbanization of the National Bureau for Statistics was used. This definition does not differentiate very much between the real large urban areas in the largest cities and less urbanized areas. Therefore, a new definition was developed for the level of urbanization consisting of 6 levels. This definition is better capable of capturing the centres of the largest cities in the Netherlands as an own category.

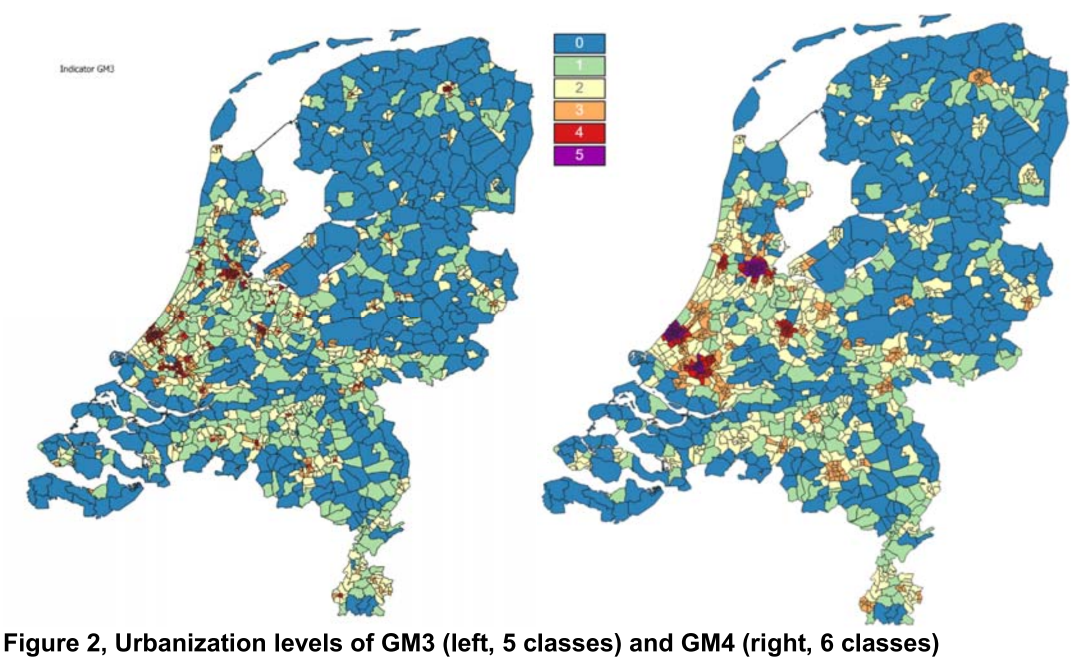


Figure 2, Urbanization levels of GM3 (left, 5 classes) and GM4 (right, 6 classes)

3.2 Cost Coefficients Per Income Class

In general from a theoretical perspective, it is expected that higher income classes are less cost sensitive than lower income classes. However, the form and magnitude of this relationship is not known for specific purposes and local conditions.

In the previous GM3 model, for most purposes, a corrected cost coefficient *CostCoef* is calculated from the estimated cost coefficient *MixCost* by applying two elasticities: a fixed cross-sectional income elasticity for the cost coefficient and a longitudinal elasticity of general welfare increase (*GWI*) in combination with the travel cost reimbursement (*Funding*):

Equation 1, correction of the cost coefficient in GM3:

$$CostCoef = \frac{MixCost}{\left(\frac{Income_{Base\ year}}{Avg\left(Income_{Base\ year}\right)}\right)^{0.2} * \left(GWI + \frac{Funding_{Scenario}}{Income_{Base\ year}}\right)^{0.5}}$$

In GM3 both elasticities were exogenous input and not estimated. The cross-sectional income elasticity was set to -0.2 by using personal income, and the longitudinal elasticity –in line with the CBA handbook- was set to -0,5.

In the estimations for GM4 it was tested if the fixed cross sectional income elasticity can be replaced by estimating cost coefficients per income class. The tests resulted in the following conclusions:

1. For Commute and Other: using cost coefficients per income class works well, with personal income in 8 and 3 classes respectively.
2. For Business: a fixed income elasticity for the cost coefficient is most logical because of the small number of observations. Using an elasticity of -0.35 (best model fit) was recommended.
3. For Education: cost coefficients per income class do not give logical results, but a segmentation of the cost coefficient for two age classes (< 18 years old and 18+ years old) gives substantially and significantly different cost coefficients and was recommended.
4. For Shopping the difference between the cost coefficients is very small and a difference is not expected. A model without income elasticity (as for GM3) was recommended.

3.3 Cost Coefficients Per Mode

The cost coefficients in the GM are not mode-specific, unlike the travel time coefficients. Although this is supported by theoretical considerations, in the literature there are examples where cost coefficients are differentiated by travel mode based on empirical arguments. External reviewers of the GM3 model have indicated that this could potentially have a positive effect on the plausibility of the cost elasticities and/or the travel time valuations (but also a negative effect). Therefore, in the specification phase models are tested with different cost coefficients for car and public transport.

From the tests the following conclusions were drawn.

1. Although the models show a very significant increase in loglikelihood, the tests reveal some problems with separate cost coefficients per mode:

   a. The difference between the cost coefficients for car and public transport can be quite large, which is difficult to explain.
   b. The cost elasticities for car driver, which were already at the upper end of the acceptable range, will become even larger.
   c. Some cost coefficients for public transport become positive, which is unacceptable.
2. The difference between the cost coefficients per transport mode is much larger than can be explained from differences in actual cost sensitivity.
3. The positive cost coefficients for public transport are unacceptable and indicate an issue with the accuracy of measuring public transport costs for individual travellers.
4. If there are differences in the accuracy of the cost calculations across modes, then this would advocate a common cost coefficient across modes.
5. There is the theoretical point that using different cost coefficients per mode would be inconsistent with economic theory assuming a constant marginal utility of income over the various modes.

3.4 Flexible Nesting Structures

The GM3 model uses a nested logit structure. However, in the estimation of GM3, it appeared difficult to achieve a good distance distribution for train travel. Particularly, short distance travel by train tended to be overestimated relative to long distance travel if not corrected by specific distance constants. A major reason for this was thought to lie in the model structure and specifically in the nesting of alternatives. If there are good alternatives for travelling to the same destination, as is usually the case for short distance travel, one would expect lower use of the train for this destination. But the current nesting structure does not take account of this as all purposes have a M>D structure.

A second aspect concerns forecasts for investments in a particular transport corridor. If, for example, travel time for one travel mode is improved in a corridor then most effect on the other travel modes is expected in the same corridor. With the current model structure of the GM, different mode choice options in the same corridor have the same relationship to each other as these have to mode choice options in other directions. Therefore, the effect of this travel time change on the competing modes will be the same in all directions, all else being equal.

In the GM4 project it was tested if it is possible to implement a more flexible nesting structure, which means that a choice alternative can be partly in the M>D nest as well as in the D>M nest. This was done by estimating cross-nested logit models by approximation using error components. This approach was tested for commute, shopping and other.

The analyses show that it is theoretically and technically possible to estimate cross-nested logit models by following the proposed approximation method. The method is not very practical, as the estimation run times are still very long: several weeks to

months, depending among other things on the number of simulation draws required and the quality of the starting values.
The resulting error components models for the three travel purposes tested are predominantly mode above destination, i.e. with destination choice being more elastic than mode choice. This is in line with the nesting structure generally used in the GM. Also in the final GM4 model specification is mode above destination.

For GM4 it was concluded not to use cross-nested logit models yet. The most important reason for this choice is the very long estimation run times that are to be avoided in a time-critical project like the GM4 estimation. It is also uncertain how the cross-nested structure interacts with other changes to the model, such as optimisations on the train trip length distribution. Finally, a solution needs to be found for time-of-day choice and station access and egress mode choice, as an integrated estimation with these choices is not feasible with cross-nested logit.

3.5 RP-SP combined estimations

The objective of this test was to jointly estimate the demand models of GM4 (RP data from OViN) with the SP data collected for the Time of Day (TOD) survey of 2019 in order to obtain better specification in the substitution pattern between alternatives. RP data itself can have some drawbacks such as the often high correlation between attributes (e.g. time and cost) or lack of variation in an attribute (e.g. road transport costs by time of day).

The results of the analysis done were:

1. The general results suggest that, even when the proportion of SP data in the overall dataset is relatively small, it can change the nesting and parameter estimates. This effect could be inflated because the estimations did not take into account the panel structure of the SP data
2. the Value of Travel Time changes. With a lower impact of the cost and a higher influence of time, the VTT increases. Especially for commuting and business, models that use the SP TOD data give rather high VTTs, clearly above the values that are used in cost-benefit analysis in The Netherlands.
3. The fixed and free nest models give elasticities which in several cases match better with the elasticity ranges set for this project.

Based on the mixed results of the analyses and theoretical concerns about combining RP and SP data, it was decided not to proceed with these combined RP-SP estimations. Instead, the approach of GM3 is continued, which is fixing the Mode-ToD nesting in the RP model estimations to the nest coefficient values from the SP model. The Mode-ToD nest coefficients in this approach are updated to the values from the new 2019 ToD SP.

3.6 Improved Public Transport And Bike Modelling

In the Netherlands the sales and use of e-bike is growing fast. With about 50% of the new sales being an e-bike. The use of e-bike is different in the sense that the mean distance per trip is significantly higher, and –for example- e-bike is becoming more and more popular for commute trips. In order to capture this bike was split into separate modes e-bike and normal bike. Given the available data in the National travel Survey it appeared to be possible to estimate separate models for both e-bike and normal bike.

The re-estimation of GM version 3 focussed on improving the modelling of train. Although good results were obtained, in the GM4 project further improvements for modelling Train and regional public transport were investigated. For the train mode it was tested how the trip length distribution, station choice and attractiveness of urban areas could be improved. For other PT modes, experiences with the previous GM3 showed that local and regional public transport modes (bus, tram and metro, BTM) are too diverse to be modelled as a single mode.

A detailed paper will be presented at the ETC 2021 on the modelling of Public transport in GM4. For further information about the PT improvements in GM4 see the reference to that paper in the bibliography. The tests on PT improvements concluded that it is possible to model public transport in three separate PT modes: Train, Tram-Metro and Bus. Also introducing a separate Public Transport nest in GM4 below the Mode nest indicating a higher correlation and cross-elasticities between the PT modes.

For the train several improvements were realized including on the rules for selecting for which relations the train is an option, optimizing the use of LOS data and station size variables and estimation of separate coefficients for sprinter in-vehicle time and intercity in-vehicle time (reflecting differences in comfort), service interval penalty and transfer penalty in the station-pair choice model.

These improvements in combination with using education as explanatory variable (as will be described in section 3.8), in the modelling of train resulted in a much better representation of the trip length distribution in GM4 eliminating the need for distance dummies for train in the model.

3.7 Car Cost Specification And Reimbursement Policies For Commute

In GM3 car costs per kilometre are based on fuel costs only for all purposes but Business where extra costs are added. Internationally other models vary in their approach towards variable car to be included and several models include also additional costs per kilometre like maintenance costs. Unfortunately, fundamental research on variable costs as perceived by consumers is missing as far as we know. Economic theory would suggest distinguishing between fixed and variable costs and to include all variable costs as marginal costs.

The variable costs to be included or not influence the overall costs and costs elasticities. In general, international literature on cost sensitivity is based on 'car-fuel cost' sensitivity. In the GM 4 project our reference values for elasticities are also based on 'car-fuel cost' elasticities. In this project it was tested if model fit and car-fuel cost elasticity improved when adding variable maintenance costs to the costs per kilometre. For nearly all purposes this was the case. Only for business it was concluded that the original specification –that already used higher costs per kilometre- was preferred.

In equation 1 it is shown that GM4 specification includes the travel cost reimbursement that is provided. Higher travel cost reimbursement results in a lower cost sensitivity.

In GM3 the travel cost reimbursement is specified as an income component and therefore it influenced the cost sensitivity via an income elasticity. As there are many options for travel reimbursements in the Netherlands this might be only the most suitable solution for some of the different arrangements for travel cost reimbursement. Some of the travel reimbursement arrangements existing in practice seem to have a more direct impact on the perceived travel cost (like reimbursement of actual costs made via cost statement).

Another aspect is the level of the travel cost reimbursement. In GM3 all commuting and business travellers who pay to travel are assumed to receive the maximum tax-free reimbursement: 19 €ct/km for car travel and the complete fare for public transport. In reality, however, not everyone receives a travel cost reimbursement and, for those who do, the travel cost reimbursement is not always the maximum tax-free value and for example maximum distance rules apply.

Using data of the Dutch National Mobility Panel (MPN) an analysis was done to determine how people receive travel cost reimbursements for commute trips. The best approximation leads to the conclusion that around 50% of the people receive their reimbursement as a fixed part of their income, 25% directly via the kilometres travelled and 25% receive no reimbursement at all. This specification, along with three alternative specifications were tested.

All tested specifications showed model fit improvement in relation to the (GM3) reference specification. The specification without assuming travel cost reimbursement showed the best results in improvement of the model fit. However, this specification would result in a model with no sensitivity to policies aimed at the travel cost reimbursement. After discussion in the project group and with external experts it was decided to implement the specification with cost reimbursement implemented in line with how it is observed in the MPN. This gives an improvement in model fit compared to the existing model and still facilitates to analyse cost reimbursement policies. As main reason why the estimation results of the more 'realistic' alternatives were not better we expected the lack of data in the NTS on the actual reimbursement by record to be a main issue.

3.8 Education As Explanatory Variable

For commute and business tours the destination choice largely depends on the availability of jobs. Therefore, the number of jobs is included as a size variable in the current MD-ToD model specification. However, in a preliminary study it has been shown that this is not sufficient to correctly model certain spatial patterns. A notable example is the underestimation of long-distance commute trips to locations with specialist jobs for highly educated people (Amsterdam, Utrecht, Eindhoven, etc.). By considering employment only quantitatively, these tours are distributed over all zones with jobs.

The annual EBB (Enquete Beroeps Bevolking) survey in the Netherlands (Netherlands Statistics) includes information on the employment level of jobs which can be classified by high, medium and low. This data has been processed by PBL to produce information on job education levels by the following dimensions:

- By education level – high, medium and low;
- By economic sector – industry, services, government and other;
- Spatial units – 30 largest cities and 40 Corop regions (excluding the cities).

In total five years of EBB survey data have been used to respect privacy regulations and to ensure a number of observations that is sufficient to produce region specific figures. The classification by education level of the jobs matches with the education classification in the LMS model as used for the workforce.

In addition to that also spatial information on the education level high-medium-low of the population is available from Statistic Netherlands. This information makes it possible to control for the level of education in the population and provides an observed basis to add education level as a scenario variable in model application.

Especially for the modelling of Rail adding information on education levels of jobs, and introducing interaction variables between personal education level and education level of jobs at the destination improved model fit. Also the train trip length distribution and train flows to the G4 cities are better represented now.
The improved model fit implies an improvement in the destination choice modelling and a more realistic segmentation of the population will be traveling to these locations. The model is therefore likely to better deal with future changes in education level and the related impact on, for example, bicycle and train usage.

3.9 Car Ownership Model

Car ownership is an important variable in the model since it determines the modelling of car availability. For car ownership the GM receives targets for the total number of cars in the Netherlands, and targets for the number of households with one, two or more than two cars in the household.
The car ownership model in GM4 distributes these targets over the zones in the model. In addition to the estimation of the coefficients for the explanatory variables in the car ownership model, the model is calibrated to the base year spatial distribution of car ownership. Until GM version 3, in forecast year applications car ownership in dense

urban areas is growing stronger than expected. Therefore, next to updating the estimation data, additional information on parking permits the largest 30 municipalities was used in the car ownership models. Adding this information as an explanatory variable in the models improved model fit. Also estimation separate income coefficients for urban and rural areas improved model fit. Tests of the implemented model proved that in GM4 applications the growth of car ownership over the urbanization levels is more plausible than in GM3.

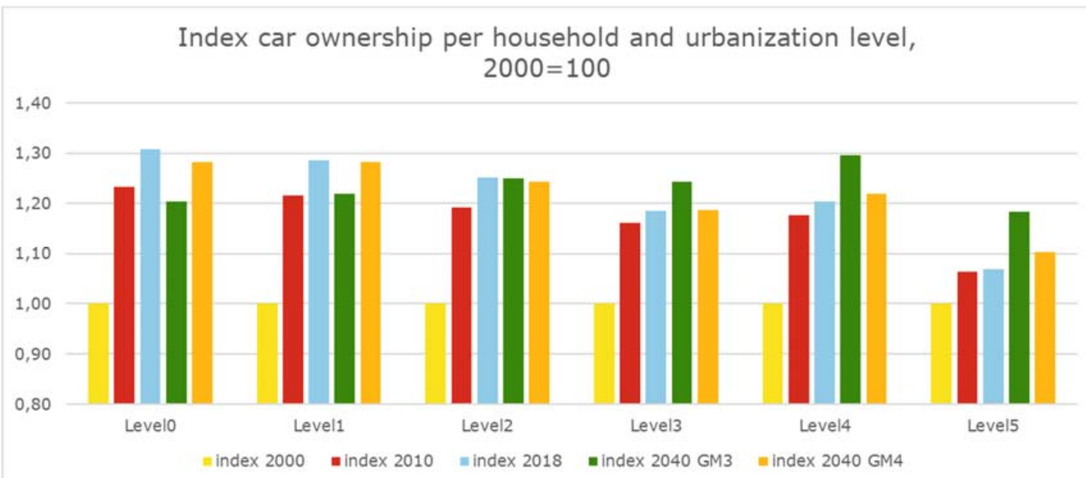


Figure 3, Modelled development of #cars per household in GM3 and Gm4

3.10 Remaining Modules And Selected Model Specification

Apart from the main modules described in the previous paragraphs all other GM4 modules were re-estimated using new estimation data. In some cases, minor specification tests were done. These modules are:

1. Models for cross border traffic
2. Models for higher order destinations to model more complex tours / additional tour legs
3. Airport access and egress models
4. Tour frequency models

4. MODEL RESULTS

From the tests presented in the previous section the final model specification was defined and estimated.

The main improvements in the model specification of GM4 can be summarized as follows:

1. Improvements in the modelling of public transport by
    a. Splitting BTM in B and TM
    b. Introduction of a separate Public Transport nest
    c. Improved use of availability rules for train
    d. Introducing new station size variables

   e. Using information on sprinter in-vehicle time, intercity in-vehicle time, service interval penalty and transfer penalty in station-pair choice
   f. Use of information on education levels for both population and jobs
2. Improvements in the car-ownership model
3. Use of education level of the population as scenario variable that is controlled for
4. Better cost specification for variable car-kilometer costs
5. Improved definition for travel cost reimbursement

This section presents the sensitivities of GM4 and key characteristics on representation of modal split and trip length distribution of the implemented model.
In section 5 the main conclusions

Table 5: GM4 tour elasticities compared to GM3 and literature band width

Tours									
Scenario	**Mode**	**Education**	**Commute**	**Business**	**Shopping**	**Other**	**Total**	**GM3**	**Band width**
Car fuel cost	Car driver	-0.06	-0.10	-0.02	-0.19	-0.13	-0.12	-0.18	-0.10 - -0.40
Car time	Car driver	-0.37	-0.22	-0.03	-0.13	-0.07	-0.15	-0.17	-0.15 - -0.50
	Car passenger	-0.51	-0.41	-0.09	-0.26	-0.15	-0.23		
Train cost	Train	-0.21	-0.36	-0.28	-1.00	-0.65	-0.36	-0.32	-0.20 - -1.10
Train time	Train	-0.55	-0.66	-0.24	-0.40	-0.35	-0.56	-0.40	-0.20 - -0.80
BTM cost	Tram/metro	-0.15	-0.29	-0.22	-0.61	-0.36	-0.29	-0.27	-0.20 - -0.80
	Bus	-0.19	-0.33	-0.20	-0.62	-0.41	-0.32		-0.40 - -1.00
BTM time	Tram/metro	-0.45	-0.30	-0.46	-0.28	-0.16	-0.31	-0.31	-0.50 - -1.00
	Bus	-0.53	-0.47	-0.17	-0.31	-0.24	-0.41		-0.30 - -0.80

Table 6: GM4 km elasticities compared to GM3 and literature band width

Kilometres									
Scenario	**Mode**	**Education**	**Commute**	**Business**	**Shopping**	**Other**	**Total**	**GM3**	**Band width**
Car fuel cost	Car driver	-0.20	-0.27	-0.13	-0.53	-0.70	-0.36	-0.49	-0.15 - -0.50
Car time	Car driver	-1.40	-1.05	-0.39	-0.71	-0.83	-0.89	-0.92	-0.20 - -0.90
	Car passenger	-1.10	-1.08	-0.35	-0.81	-0.80	-0.86		
Train cost	Train	-0.22	-0.46	-0.38	-0.95	-0.89	-0.45	-0.47	-0.40 - -1.20
Train time	Train	-1.15	-1.19	-0.51	-0.76	-0.84	-1.07	-0.80	0.30 - -0.90
BTM cost	Tram/metro	-0.19	-0.33	-0.26	-0.74	-0.46	-0.33	-0.32	-0.30 - -0.90
	Bus	-0.23	-0.37	-0.24	-0.75	-0.49	-0.35		-0.50 - -1.10
BTM time	Tram/metro	-0.98	-0.69	-0.91	-0.63	-0.50	-0.74	-0.89	-0.60 - -1.40
	Bus	-1.04	-1.00	-0.66	-0.69	-0.76	-0.95		-0.40 - -1.20

The modal split of GM4 compared to the national travel survey gives the following results:

Table 7: Modal split in tours from GM4 compared to OViN

Tours	*Train*	*Car driver*	*Car passenger*	*Tram/ metro*	*Bus*	*E-bike*	*Cycle*	*Walk*
GM4 2018	3.7%	40.9%	7.3%	1.9%	2.4%	3.6%	28.3%	11.9%
OViN 2015-2017	3.9%	42.2%	7.3%	1.9%	2.3%	3.6%	27.1%	11.6%

Table 8: Modal split in kilometres from GM4 compared to OViN

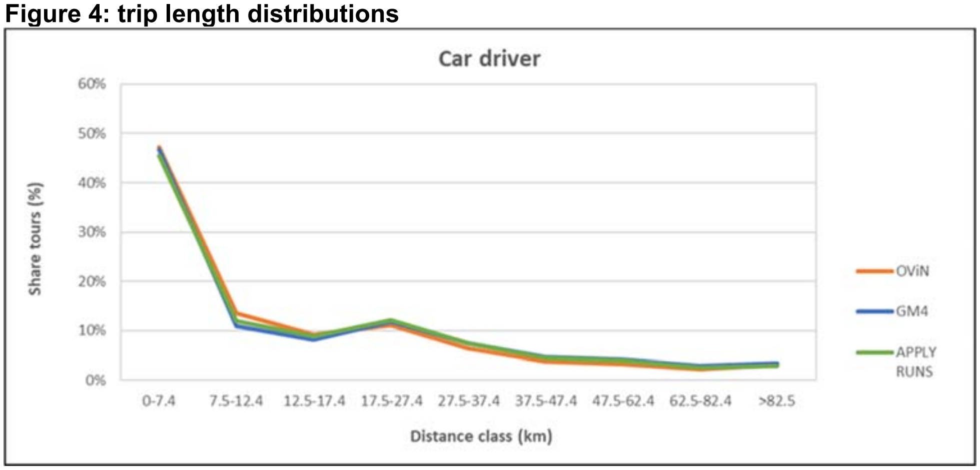
KM	Train	Car driver	Car passenger	Tram/ metro	Bus	E-bike	Cycle	Walk
GM4 2018	13.2%	62.4%	9.2%	1.8%	2.5%	1.2%	8.2%	1.3%
OViN 2015-2017	14.8%	62.9%	9.5%	1.6%	2.3%	1.1%	6.8%	1.1%

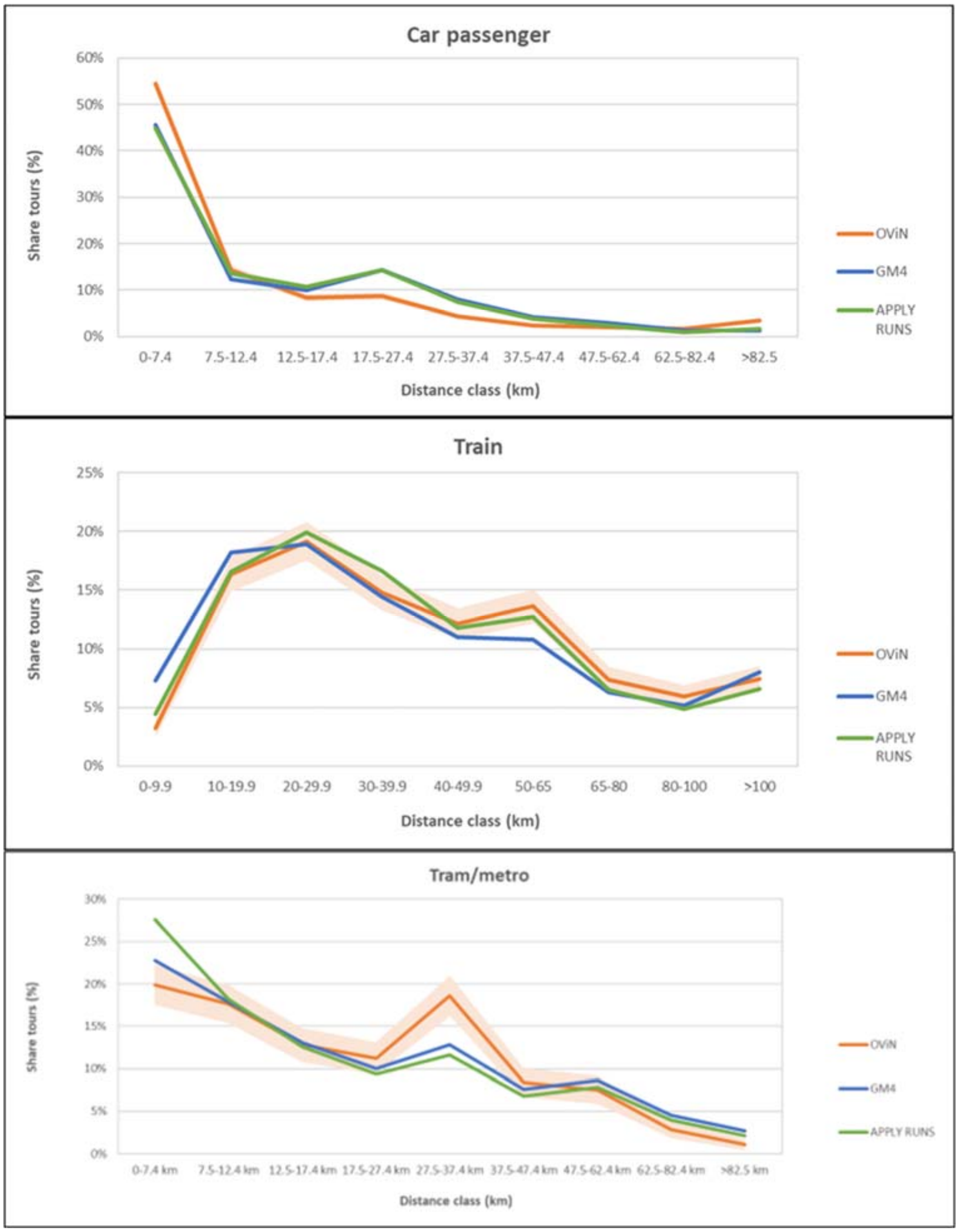
The mean trip length and trip length distributions of the implemented model of GM4 are given below:

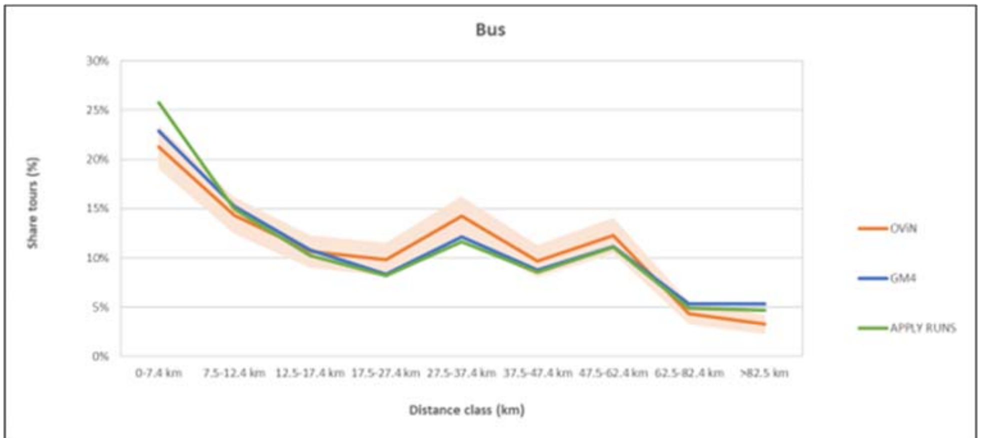
Table 7: Mean tour leg length (half tour length as proxy for trip length) from GM4 compared to OViN

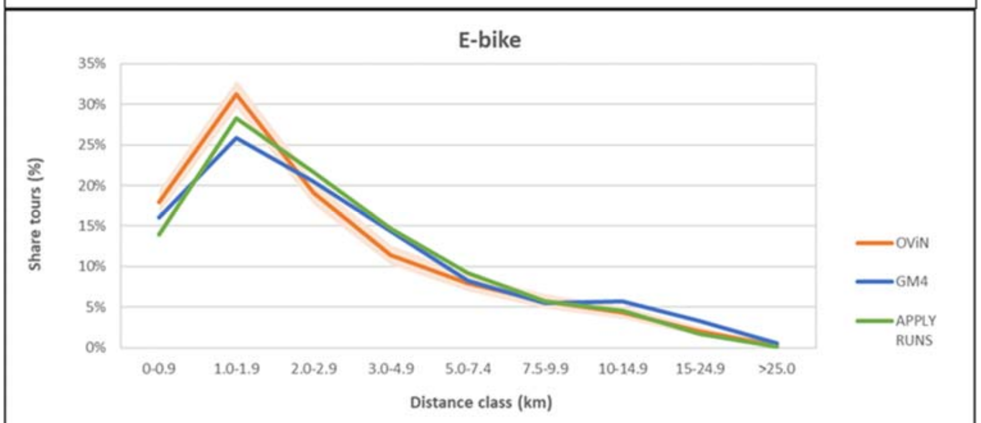
KM	Train	Car driver	Car passenger	Tram/ metro	Bus	E-bike	Bicycle	Walk
GM4 model	43.88	18.04	14.84	10.60	12.80	3.48	3.05	1.25
Apply runs	43.79	17.59	15.24	9.28	13.33	3.58	3.39	1.25
OViN	47.03	17.29	15.14	9.86	12.13	3.47	2.91	1.24
Difference GM4 vs. OViN	-7%	4%	-2%	8%	6%	0%	5%	1%

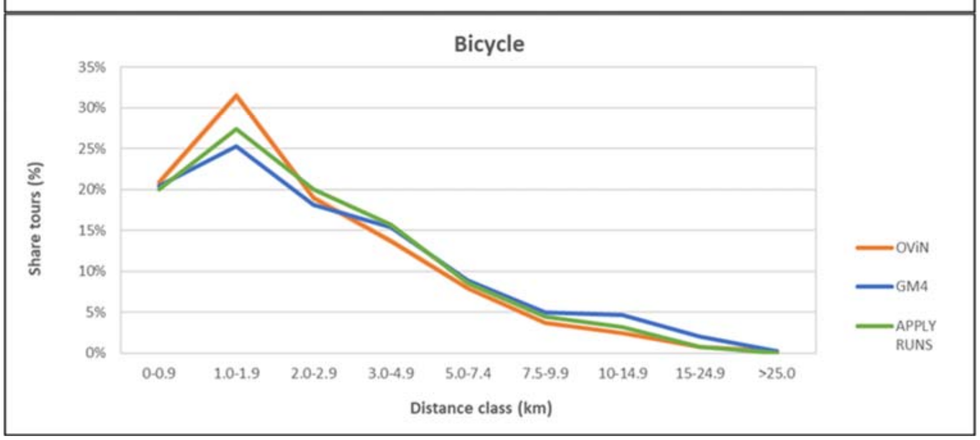
Figure 4: trip length distributions

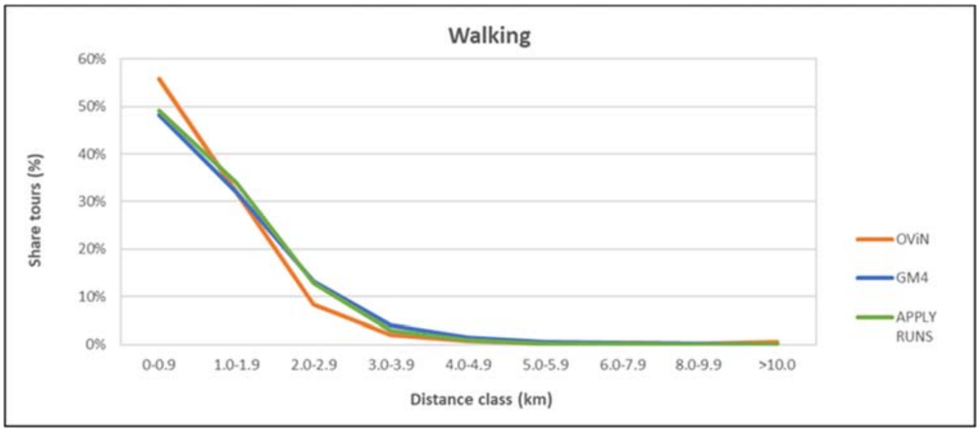



Car passenger
Share tours (%)
60%
50%
40%
30%
20%
10%
0%
0-7.4
7.5-12.4
12.5-17.4
17.5-27.4
27.5-37.4
37.5-47.4
47.5-62.4
62.5-82.4
>82.5
Distance class (km)
OViN
GM4
APPLY RUNS
Train
Share tours (%)
25%
20%
15%
10%
5%
0%
0-9.9
10-19.9
20-29.9
30-39.9
40-49.9
50-65
65-80
80-100
>100
Distance class (km)
OViN
GM4
APPLY RUNS
Tram/metro
Share tours (%)
30%
25%
20%
15%
10%
5%
0%
0-7.4 km
7.5-12.4 km
12.5-17.4 km
17.5-27.4 km
27.5-37.4 km
37.5-47.4 km
47.5-62.4 km
62.5-82.4 km
>82.5 km
Distance class (km)
OViN
GM4
APPLY RUNS


Bus
30%
25%
20%
15%
10%
5%
0%
Share tours (%)
0-7.4 km
7.5-12.4 km
12.5-17.4 km
17.5-27.4 km
27.5-37.4 km
37.5-47.4 km
47.5-62.4 km
62.5-82.4 km
>82.5 km
Distance class (km)
OViN
GM4
APPLY RUNS


E-bike
35%
30%
25%
20%
15%
10%
5%
0%
Share tours (%)
0-0.9
1.0-1.9
2.0-2.9
3.0-4.9
5.0-7.4
7.5-9.9
10-14.9
15-24.9
>25.0
Distance class (km)
OViN
GM4
APPLY RUNS


Bicycle
35%
30%
25%
20%
15%
10%
5%
0%
Share tours (%)
0-0.9
1.0-1.9
2.0-2.9
3.0-4.9
5.0-7.4
7.5-9.9
10-14.9
15-24.9
>25.0
Distance class (km)
OViN
GM4
APPLY RUNS



5. CONCLUSIONS

5.1 model specification phase

Aspect tested	Findings	Inclusion in model	Future ambition
Destination sampling	Enabled large scale specification phase	Not applied in the model	Use this again
Cost coefficients per income class	Improve model fit and responsiveness	Included	Use this again
Cost coefficients per rmode	Empirical findings not satisfactory and theoretical questionable	Not included	None
Flexible nesting	Interesting insights and option but too time consuming and complex for now	Not included	Interesting option but needs estimation software than can both estimated CNL and deal with size of GM estimation
RP-SP combined	Interesting insights but need to deal better with panel aspect of data and aspect of combining these data sources	Not included	Interesting option but more fundamental research is needed on combining these sources.
Improved PT estimation separating Bus and Tram/metro	Satisfactory results and important improvement also including PT nest under mode nest	Included	Use experiences with GM4 to improve and refine for next version. More attention for hub facilities and role of PT as egress transport for car.
Improved bicycle modelling	Modelling electric bikes separately was successful and makes the model more sensitive to developments in type of bikes	Included	Will only become more important and experiences with GM4 can be used to specify further improvements.
Car costs specification	Results of including other variable costs as well are satisfactory	Included	Open options to explore impacts of differences in

			other variable costs between fuel and electric cars as well. Need for more fundamental understanding of appreciated costs by consumer.
Reimbursement policies	Gives model additional policy option but empirical results are unsatisfactory	Included	Plan to add additional information on travel cost reimbursement to NTS. This gives better data to improve estimation of this aspect in the future.
Education level for employees and jobs	This gives substantial improvement in model fit and is highly relevant for scenario studies as there is a strong trend in increasing levels of higher educated people.	Included	Improve data on education level by job – currently estimated on survey data. Option to estimate sub-purposes for commuting by education level. More fundamental understanding of relationship between developments in income and education level
Car ownership	Adding information on parking permits and separate income coefficients for urban and rural areas improves the modelling of the spatial distribution of car ownership	Included	

5.2 model performance

The ultimate conclusions on the performance of the GM 4 model can only be drawn after several years of practical applications in scenario and policy studies. The conclusions presented here are therefore temporarily based upon the extensive model test phase of the GM4 project and first application in the IMA study for the Ministry.

Comparing the model with the reference values resulted in the following conclusions:

- The cost and time elasticities for the various modes of transport are satisfactory and mostly within the band widths from the literature. In general, the elasticities in the Netherlands are at the higher end of the band width from the international literature. This might be related to the dense spatial structure of the Netherlands and high service level for alternative modes (relatively many reasonable alternatives). Another aspect might be the number of choices included in the modelling (mode, destination, ToD);
- The trip length distribution for the modes and match with survey data is satisfactory representing a substantial improvement for the TLD for the train in comparison with the GM3 model. Another improvement is a better representation of the specific trip length distribution and flow to and from the four main cities in NL, the so-called G4 area;

- Comparison of model results with other external data sources, like developed base matrices for car and public transport (based of PT card data), shows larger differences for example in OD flows for car or PT or the number of passengers at specific stations. It is a future challenge to better understand the differences between these data sources and the NTS data and to explore options to further combine the strengths of des-aggregated and aggregated data sources.

The application of the National Model system with GM4 for policy study IMA proved to be very satisfactory. The results were plausible and especially, with the introduction of also Bus and Tram-Metro base matrices in combination with the improved Public Transport modelling, for public transport much more information was available from the new model. Also, the explorative options of GM4 (not described in this paper) for self-driving car and modelling of new concepts like MaaS and car-sharing services provided valuable insights in the sensitivity analysis of the IMA.

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Notes

[i] Publication of the IMA: Kamerbrief bij Integrale Mobiliteitsanalyse 2021 | Kamerstuk | Rijksoverheid.nl

[ii] The number of tours follows from the tour frequency and the mode follows from the mode/destination choice. For the estimations it is only relevant to evaluate the results of the tour frequency models for the number of tours per travel purpose per region (thus without making distinction by mode).

[iii] Changes in tour frequency can have some effect in these elasticities, but generally this impact is found to be small and the MD-ToD module is found to give a good approximation of the GM elasticities.