

2014•2015
SCHOOL FOR TRANSPORTATION SCIENCES
Master of Transportation Sciences

Master's thesis
MORBAMS: Setting up a regional MatSim model

Supervisor :
Prof.dr.ir Tom BELLEMANS

Frederik Bockemühl
*Thesis presented in fulfillment of the requirements for the degree of Master of
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PREFACE

This report was written as a master thesis to conclude the Traffic Sciences programme. It is the continuation of a project started in 2013 by Stefan Flügel at the Transportøkonomisk institutt in Oslo. In 2014 I got involved during an internship. Working with the code already set-up by Julia Kern from the TU Berlin a base model was created. Some small case study was performed as well, which will be discussed briefly as well. During this time I got to know MATSim as a program and my enthusiasm grew as the opportunities became apparent. This has led me to devote my thesis to the same subject.

It has been a study with a lot of ups and downs. And, as is the nature of programming, a lot of unforeseen problems as well. Nonetheless it has been a very instructive project which I would do again if given the choice.

I still believe in the potential of MATSim as an open-source traffic model, but during my experiences I did realize it is not yet a finished product. Hopefully the program will continue to grow and one day will become easier to use even without a programming background.

Of course this thesis is not my work alone. I would like to thank Prof. Dr. Kai Nagel (TU Berlin), Dr. Marcel Rieser (Senozon) and Dr. Andreas Horni (ETH Zürich) especially. Without their help this report would probably still be stuck at some programming error.

Big thanks to Dr. Stefan Flügel as well for allowing me to continue work on his project and helping me along the way during the internship and the master thesis.

And finally Prof.dr.ir Tom Bellemans and Prof. dr. ir. Bruno Kochan for their feedback and understanding even when the report did not seem to be moving forward.

Frederik Bockemühl

August 2015

SUMMARY

This report handles the process and results of implementing facilities for activities into the agent-based MATSim model.

First the land-use models are discussed to establish a baseline. The link between land-use and transportation is explained by using the land-use transport feedback cycle. Next the subsystems of urban change according to Hensher and Button (2004) are being used to show the difficulties in modelling land-use together with transportation. Especially the timeframes play an important role here.

In the next part the advantages and disadvantages of trip-based modelling and activity-based modelling are discussed. These show us that while trip-based modelling is ahead of activity-based modelling, the last one is more capable of predicting the effects of policies. Combined with the current political change towards traffic management these types of models become more important.

In a recent study (Efthymiou et al., 2013) an attempt was made to use MATSim as a plug-in for UrbanSim. This is a first step towards combining both the land-use models and the transportation models. However, this study focussed more on land-use while transportation was more a side effect.

After this literature review some of the workings of MATSim are explained. This is to provide an insight of the program which will be used in the study. Next the the model of Trondheim, which is used to analyze the program, is explained. Finally the testing set-up is described. Four scenarios have been created adding workplace facilities to the reference model.

Looking at the results the facilities file works like it should within MATSim. It allows the agents within the model to switch their destination location to a free facility somewhere else. This changing improved the agents' scores by reducing the travel times. This means more time is available for actual activities which increases the score.

Unfortunately it is still needed to work with a pre-filled agenda for the agents as no new activities can be added between iterations at the moment. This means it is still required to have some data to start with.

Right now building a model in MATSim is a very time consuming effort. Between the programming knowledge, knowledge of MATSim's coding and the calculation times building a model might not be worth the time and price for smaller projects. Further development can be very promising however, as a full model allows a fast prediction of the effects.

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1. INTRODUCTION

With an ever increasing knowledge about various economic, social and environmental structures comes an increase of the understanding of the size and complexity of the urban environment. Together with this comes an increasing demand for models being able to handle those newly developed insights. One of the strategies to achieve this goal is to create models which integrate both land-use and transportation models, also known as Land-use/Transport Interaction Models (LUTI). This combines two different visions and approaches: the more activity-based urban complexity which comes from land-use and the more mathematical simulation techniques from the transport models. Both of these can help the other to better understand the situation and the interaction between land-use and transportation. This better understanding is needed in order to make the right policy planning decisions (Waddell, 2002). Further technical enhancements can be achieved by the use of the Geographical Information Systems (GIS), while this is more useful for visualizing outcomes and comparing different alternatives (e.g. Shaw and Xin, 2003).

This increased attention and need for better modelling techniques for a better forecasting of the effects of land and transport policies on the economy, environment and transportation, has led to the creation of various new models and frameworks around the world.

In the development of these new models many technical difficulties arise. From gathering the required data to better computational performances to handle the requirements of demanding simulations. Nonetheless the improvements within the field of developing LUTI models are significant. Various models have been (successfully) applied to cases in Europe, America and Asia. The cases range from cities to regions and even an entire country, Switzerland. However most of these models were made for research into this types of models and not (solely) for the purpose of evaluating policies. A reason for this is simply because the development of these combined models is a resource and time intensive task and thus a risk which governments and private parties alike, are hesitant to make.

Despite all the work in the last decade still a lot of uncertainties about activity-based models, and LUTI models in particular remain. Especially their efficiency and forecasting capabilities have not been tested as extensively as the trip-based four-step model (FSM) over the last 50 years. Hunt et al. (2005) made an extensive review of known LUTI models, and point out the pros and cons of each, and Curtis (2011) reviewed the inefficiencies of the current integrated land-use and transport models in measuring the accessibility of public transport.

The MATSim model (Multi-Agent Transport Simulation) being used in this report is under development for quite some years now. Using elements from early

microsimulation of travel demand (Poeck and Zumkeller, 1976; Zumkeller, 1989; Axhausen and Herz, 1989), ideas around the combination of travel demand and traffic flow simulation developed in the process of the TRANSIMS project (TRANSIMS, 2006; Nagel, Beckman and Barrett, 1998) and fast traffic flow simulations (Nagel and Schreckenberg, 1992; Gawron, 1998) the first framework for the program was created at the ETH Zürich in 1998. By now the project is being developed as a joint effort between the TU Berlin, ETH Zürich and Senozon. While many of the original concepts have been replaced or expanded with more recent research, the basic theory about the co-evolutionary algorithm which relaxes after a set of iterations is still retained. This means that after performing the initial travel demand the results are used to update the schedules of the agents. Changes in activity sequences, their timing, locations, modes and routes are all possible. This process will repeat itself until there is no more room for unilateral improvement.

The goal of this report is to study the effects and need for land-use data within a transportation model, MATSim.

Land-use data will be implemented within the MATSim environment and can then be used in the replanning module in order to influence the behavioral choices to be more realistic. Further the results will be analyzed in an effort to determine the value of the input data, survey and land-use.

2. RESEARCH QUESTIONS

2.1. Main research question

What are the effects of adding land-use data to an activity-based model in MATSim?

2.2. Other research questions

Regarding the activity-based approach:

- 1) What is the activity-based approach?
- 2) What is the trip-based approach?
- 3) What are the main differences between the activity-based approach and the trip-based approach?
- 4) Why should the activity-based approach be used?

Regarding land-use and modelling:

- 1) How does land-use (modelling) influence transportation?
- 2) Which aspects of land-use modelling overlap with transportation modelling?

Regarding MATSim:

- 1) How does MATSim compare against other models?
- 2) How does the iterative process of MATSim work?

Regarding input data analysis:

- 1) How does the land-use map compare to the activity map from the extrapolated survey?
- 2) Do the relative frequencies of activity types correspond with the frequencies in the survey?
- 3) Which changes in the simulation can be expected when using the land-use data?

Regarding analysis of the results:

- 1) Do the added land-use data cause visible changes in the traffic simulation?
- 2) Do the added land-use data cause visible changes in the location choice for activities?
- 3) Is the total simulation more realistic with the added land-use data?

Regarding sensitivity analysis:

- 1) Is the simulation realistic when only land-use data is used?
- 2) How close to the reality would a simulation without survey data be?

- 3) Are there differences in the results between the simulation with only land-use data and the simulation with only survey data?
 - a) What are these differences?
 - b) What are the cause and the consequences of these differences?

- 4) Are there differences in the results between the simulation with only land-use data and the simulation with survey data and land-use data?
 - a) What are these differences?
 - b) What are the cause and the consequences of these differences?

2.3. Methodology

In order to answer these questions a literature review will be performed first. This should cover the background of the various modelling types and their attributes.

First the land-use models will be discussed giving more insight in the link between transport and land-use modelling. After that the history of activity-based modelling and trip-based modelling will be covered as well as the positive sides and limitations.

Next the way MATSim works will be briefly explained and compared to other models.

In the second part the land-use data will be implemented in the existing model for Trondheim. These data will be analyzed and compared to the current activity map before. Afterwards to goal is to analyze the differences between the various possibilities of modelling with(-out) land-use data. This should show the sensitivity of the model to a more detailed activity map.

3. LAND-USE AND MODELLING

According to Hensher and Button (2004) spatial development, or land use, determines the need for spatial interaction, or transport, but that transport, by the accessibility it provides, also determines spatial development.

3.1. The land-use transport feedback

Hansen (1959) demonstrated for Washington, DC that locations with good accessibility had a higher chance of being developed, and at a higher density, than remote locations ("How accessibility shapes land use"). The recognition that trip and location decisions co-determine each other quickly spread among planners. As a result transport and land use planning needed to be co-ordinated and the 'land-use transport feedback cycle' became well-known.

While there are a number of variations, depending on the specific topic or goal of each paper, the most sets of relationships implied by this term can be briefly summarised as follows (see Figure 1):

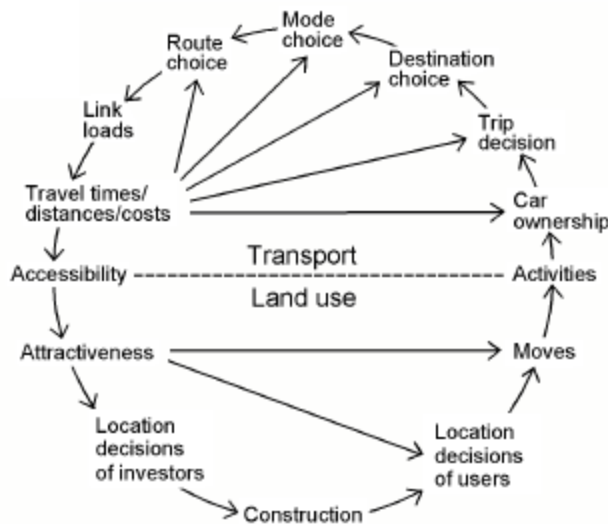


FIGURE 1 The land-use transport feedback cycle (Hensher and Button, 2004)

While this seems very logic to anyone in the field of transportation and land-use it is difficult to empirically isolate impacts of land use on transport and vice versa because of the multitude of concurrent changes of other factors. This causes problems when trying to calculate the possible impacts of integrated land-use and transport policies. In general 3 prediction methods are used to make such predictions:

- 1) Stated preference: This way people are asked to fill out a survey on how their behaviour and locations choice would be affected if certain factors like transportation costs would change.
- 2) Revealed preference: In this method people are observed while they make decisions under different conditions. These can be simulated or in real life. Conclusions are drawn from the observed decision behaviour on how they would be likely to behave if these factors would change.

- 3) Mathematical models: This way human behaviour is modelled as close as possible by mathematical models. Any changes in this model are then assumed to follow a human-like decision making process. Often the parameters within a mathematical model are based on a stated or revealed preference experiment.

All three methods have their advantages and disadvantages. Surveys can reveal also subjective factors of location and mobility decisions, however, their respondents can only state what choice they are likely to make, while in reality this might not be the case. Especially habits and 'socially acceptable' answers are big contributors to discrepancies between stated and revealed preference (Hermans, 2011).

Empirical studies based on observation of behaviour produce detailed and reliable results. However these are only possible for existing situations or situations which can be simulated. Therefore the assessment of new, untested policies is hard and especially long term effects like location choice for housing are hard to simulate. In addition it is usually not possible to associate the observed changes of behaviour unequivocally with specific causes, because in reality several factors change at the same time.

Lastly mathematical models are usually based on empirical surveys or observations of human behaviour as well. As a result the outcome of mathematical models is, strictly speaking, no more universally valid than the empirical studies they were based on. Thus the model can only be used in situations where the parameter estimates are similar to those of the original region. However it is possible to predict human behaviour in mathematical models within certain limits to new, unknown situations. Also, within these models it is possible to alter one specific factor and analyze the results while keeping all others fixed.

3.2. Subsystems of urban change

As for today there is still a split between land-use models and transportation models. While this divide is not ideal it is certainly understandable depending on the research goal. Land-use models are more focussed on how land-use will change in the future and the changes in the spread of functions within the city. Transportation models focus more on the resulting traffic obviously. While these are certainly influenced by each other the timeframes differ. Changes in travel behaviour change much more quickly than changes in the physical structure of the city. There are strategic transport models which try to predict transportation patterns 40-50 years in the future, however these aren't used very often.

Hensher and Button (2004) describe 9 subsystems of urban change. One of them, the urban environment, is too complex to model. It ranges from transport noise which can change on a very short timescale to soil and water contamination and even climate effects which can only be measured over various

decades if not more. The other 8 can be used for the evaluation of operational urban models. They are ordered by the speed by which they change, from slow to fast processes (Hensher and Button, 2004):

- Very slow change: networks, land use. Urban transport, communications and utility networks are the most permanent elements of the physical structure of cities. Large infrastructure projects require a decade or more, and once in place, are rarely abandoned. The land use distribution is equally stable; it changes only incrementally.

- Slow changes: workplaces, housing. Buildings have a life-span of up to one hundred years and take several years from planning to completion. Workplaces (non-residential buildings) such as factories, warehouses, shopping centres or offices, theatres or universities exist much longer than the firms or institutions that occupy them, just as housing exists longer than the households that live in it.

- Fast change: employment, population. Firms are established or closed down, expanded or relocated; this creates new jobs or makes workers redundant and so affects employment. Households are created, grow or decline and eventually are dissolved, and in each stage in their life cycle adjust their location and motorization to their changing needs; this determines the distribution of population and car ownership.

- Immediate change: goods transport, travel. The location of human activities in space gives rise to a demand for spatial interaction in the form of goods transport and travel. These interactions are the most flexible phenomena of spatial urban development; they can adjust in minutes or hours to changes in congestion or fluctuations in demand, though in reality adjustment may be retarded by habits, obligations or subscriptions.

3.3. Overview of land-use models

Around 50 years ago the Model of Metropolis (Lowry, 1964) was one of the first attempts at implementing the land-use transport feedback cycle described above. Later on this inspired others (e.g. Goldner, 1971; and Mackett, 1983) to create more and more complex modelling approaches. Boyce et al. (1981) developed combined equilibrium models of residential location, mode and route choice. From here a wide range of models emerged. Some specifically for one region, others in an attempt to create a framework for further development.

Hensher and Button (2004) provided an overview of 20 important models at that time and how they managed to model the several subsystems of urban change as a showcase of the amount and complexity of the available models.

Models	Speed of change							
	Very slow		Slow		Fast		Immediate	
	Networks	Land use	Work-places	Housing	Employment	Population	Goods transport	Travel
BOYCE	+				+	+		+
CUFM	(+)	+	+	+	+	+		(+)
DELTA	(+)	+	+	+	+	+		(+)
ILUTE	+	+	+	+	+	+	+	+
IMREL	+	+	+	+	+	+		+
IRPUD	+	+	+	+	+	+		+
ITLUP	+	+			+	+		+
KIM	+				+	+	+	+
LILT	+	+	+	+	+	+		+
MEPLAN	+	+	+	+	+	+	+	+
METROSIM	+	+	+	+	+	+		+
MUSSA	(+)			+	+	+		(+)
PECAS	+	+	+	+	+	+	+	+
POLIS	(+)	+			+	+		(+)
RURBAN	(+)	+			+	+		(+)
STASA	+	+	+	+	+	+	+	+
TLUMP	+	+	+	+	+	+	+	+
TRANUS	+	+	+	+	+	+	+	+
TRESIS	+	+	+	+	+	+		+
URBANSIM	(+)	+	+	+	+	+		(+)

(+) provided by linked transport model

FIGURE 2 Overview of 20 land-use models and their characteristics (Hensher and Button, 2004)

4. ACTIVITY BASED MODELLING

What is the activity-based approach (ABA) and how is it different from the more standard trip-based model?

There are many types of transportation models available. From the basic 4-step model to various computer assisted nationwide models. All of them have their own advantages and disadvantages.

Jones et al. (1983) first described the activity-based approach as an alternative to the trip-based four-step travel demand and assignment model over thirty years ago. Starting from the work on choice (Chapin, 1974; Domencich and McFadden; 1975) and constraints (Hägerstrand, 1970; Lenntorp, 1978) in travel demand another decade ago. The next decades a whole range of issues have been researched under the header of activity-based models (Goodwin, Kitamura and Meurs, 1990; Axhausen, 2006). With the arrival of more computing capacity and digital data analytics work is starting to focus on replacing the four-stage model with advanced, but robust application-ready models. While it can be argued that the current available model systems are not ready to completely replace the trip-based commercial software, which now have over 50 years of development, rapid advances in the last years are slowly closing this gap.

4.1. History

The conventional trip-based approach, commonly referred to as the four-step model (FSM), grew as a way to evaluate traffic decisions during the economic boom after the world wars. Most of these decisions however were based on the idea of always continuing growth in which the supply usually followed the demand without really steering it. For this idea the economic based models were sufficient to calculate the relative performance of alternatives. As it helped prove the costs and gain from capital-intensive investments in transportation. Later on changes in the environment like traffic safety, congestion and energy efficiency came to life and traffic policies had to be reconsidered. It was during this period that the ABA started to become an alternative approach (Jones et al., 1990).

From here a whole range of theories, studies and approaches emerged in an effort to help predict and evaluate projects while the policies were changing. These advances shared "a common philosophical perspective, whereby the conventional approach to the study of travel behavior ... is replaced by a richer, more holistic, framework in which travel is analyzed as daily or multi-day patterns of behavior, related to and derived from differences in lifestyles and activity participation among the population" (Jones et al., 1990). This philosophical perspective resulted in the ABA. The reasoning behind the ABA is that the traffic demand is a result of human activity behavior. This means that

any travel decisions are only the second step in the process where activity behavior is the first step. This way the ABA starts on an area where the classic FSM is unable to make predictions, namely to calculate the effects for policies aiming to manage transportation instead of a constant expansion of transportation infrastructure.

4.2. The trip-based approach

In the conventional trip-based approach, with the FSM as the best example, the travel demand and network characteristics work as determining factors for the performance. These will tend towards an equilibrium. Further there are connections to location for both the input and feedback.

The FSM is a great tool for evaluating large scale infrastructure projects as well big changes in major capacity improvement through policies. This aim was exactly geared to forecast future demand and performance of regional networks. However when applied to policies involving management and control of the existing network, especially for restrictive policies, this approach falls short.

Working of the FSM

However the model has been altered, enhanced and modified over the last decades it still holds on to the basic principles which started in the late 50s. These principles start out with trips as a unit to analyze while immediately aggregating them into production and attraction sums. This step is called the trip generation and will create the travel demand. The demand side is estimated on a frequency by trip purpose basis. On the other hand are the trip ends or destination zones assumed to be a function of households and other available zonal characteristics. During the second step this demand is spread over the network based on estimated attractions for the various zones as well as a pre-determined travel impedance which can include anything from time, distance to a generalized cost. The result is an origin-destination matrix (OD-matrix) for the demand.

The third step is the mode choice. Here the OD-matrix from step two will be factored with the modal split ratios recorded or estimated for the region.

Finally in the last step the various OD-matrices will be set on the mode specific networks and, if applicable, the route choice will happen. If needed the OD-matrices will be split in various timeframes either before the third step or step four.

In most specific applications there is also some feedback possible to previous steps to achieve an equilibrium after a few iterations.

Limitations

For the trip based approach the trip generation is the first step and is usually used as a means to scale any problems. For instance 'What would happen if...?'

Since there is a lack of feedback to this level, the overall demand is essentially a fixed number or at least independent of the transportation network.

During the process the exact origin and destination is lost due to the aggregation into production and attraction ends. Parameters like the modal split will have to be estimated via independent models, so any direct feedback is nearly impossible.

The fundamental base of travel demand is that travel is a demand derived from the demand for activity participation. However, especially due to the ignorance of the spatial and temporal inter-connectivity of household behaviour is making it hard to adapt to some of the modern needs in travel prediction. This is also the primary reason why induced travel demand is impossible to predict with most FSM's. More recent models do incorporate some feedback between demand- and supply-iterations. This information can then be used to predict changes in the mode choice and induced travel demand in an endogenous, mathematical way.

The weaknesses and limitations of trip-based models have been discussed by many. McNally and Rindt (2008) briefly summarized these limitations of the trip based approach as:

- 1) Ignorance of travel as a demand derived from activity participation decisions;
- 2) A focus on individual trips, ignoring the spatial and temporal interrelationship between all trips and activities comprising an individual's activity pattern;
- 3) Misrepresentation of overall behavior as an outcome of a true choice process, rather than as defined by a range of complex constraints which delimit (or even define) choice;
- 4) Inadequate specification of the interrelationships between travel and activity participation and scheduling, including activity linkages and interpersonal constraints;
- 5) Misspecification of individual choice sets, resulting from the inability to establish distinct choice alternatives available to the decision maker in a constrained environment; and
- 6) The construction of models based strictly on the concept of utility maximization, neglecting substantial evidence relative to alternate decision strategies involving household dynamics, information levels, choice complexity, discontinuous specifications, and habit formation.

These theoretical deficiencies appeared as most prominent in the inability of conventional models to adequately perform in complex policy applications, despite their acceptable performance in certain well-defined situations. In summary, trip-based methods do not reflect (a) the linkages between trips and activities, (b) the temporal constraints and dependencies of activity scheduling, nor (c) the underlying activity behavior that generates the trips. Therefore, there is little policy-sensitivity.

4.3. The Activity-based approach

The first link between activity choice and travel behaviour and inquiries into this behaviour are about as old as the trip-based approach (Mitchell and Rapkin, 1954). However during this time period the policy makers were more focused on a simple, yet robust economic solution for traffic decisions. This is quite understandable given the amount of traffic at the time as well as the constant growth of the post-war economy. Unfortunately this led to the model in which the link between activities and travel is limited to the trip generation.

Over the next decades intensive research into the activity-based approach was rather scarce while the trip-based approach was being perfected. In the 70s Hägerstrand (1970), Chapin (1974), and Fried et al. (1977) each worked on their own approach to the problem. Hägerstrand used a time-geographic approach to link a set of constraints with activity participation in time-space. Chapin's research was going into the patterns created by behaviour in time and space, while Fried et al. explored a more sociological approach about why people participate in activities. Jones et al. (1983) combined these various studies and linked them together in an effort to define and empirically test the activity-based approach. Within their studies an attempt at modelling complex travel behaviour was completed.

Travelling can be seen as an attribute of activities, just like duration. As such attributes like mode use and travel time can be seen as, more detailed, but attributes of activities nonetheless. While at the same time these attributes are seen in the trip-based approach as attributes of travel and used as the focus of descriptive and predictive models while ignoring most other activity attributes. This way the trip-based approach can be seen as a special case within the activity based approach. While trip-based approaches are satisfied with models that generate trips, activity-based approaches focus on what generated the activity which created the trip in turn.

Theory behind the activity based approach

The activity-based approach began with the studies of everyday human behaviour, although with a more specific focus towards travelling (Fried et al., 1977). Even early indications of the incompatibility of the trip-based approach and the new policy direction towards management did not immediately result in a boost of research. Instead, work-around solutions to enhance the FSM received most of the focus. This is where the equilibrium assignment and disaggregate models became more widespread. However, these very disaggregate models are nowadays often key components within activity-based models.

The fundamental theory behind the activity approach is that trips as such cannot be analyzed on an individual trip basis. Instead these trips are formed by a set of travel decisions which form a collection of activities or agenda to participate in

various activities. As a result, the choice for each individual trip can only be understood within the context of the entire agenda. This agenda comprising all of the activities and trips of a person together with all the restraints in the travel environment form patterns which can be described as complex travel behaviour. Further these patterns can be bundled to represent the activity programs of each household. Within these any interactions between the household members and decision processes for sharing the various transportation methods available can be understood. In the end, it is the individual who will complete their agenda, which is bound by the many constraints, and this results in the revealed travel behaviour.

Characteristics of the activity-based approach

The characteristics of what the activity-based approach exactly is, hasn't always been very clear. Mostly this is due to the fact that, unlike the trip-based approach and the FSM, there is no exemplifying model. Instead there is a plethora of theoretical, methodological, and empirical approaches over the course of years. Remaining the question if there is a strong enough common background to speak about an "approach". At the same time this sheer amount of concepts illustrates the common target of understanding the complex phenomena that is travel behavior.

McNally and Rindt (2008) described several interrelated themes which characterize ABAs, and methods and models generally reflect one or more of these themes.

- 1) Travel is derived from the demand for activity participation;
- 2) Sequences or patterns of behavior, and not individual trips, are the relevant unit of analysis;
- 3) Household and other social structures influence travel and activity behavior;
- 4) Spatial, temporal, transportation, and interpersonal interdependencies constrain both activity and travel behavior; and
- 5) Activity-based approaches reflect the scheduling of activities in time and space.

Within the ABA the basic unit of analysis is the travel-activity pattern (or household pattern), unlike the trip in the trip-based approach. This pattern represents the revealed behaviour, thus travels and activities over a specified period of time, usually a day. While this travel-activity pattern is formed through the scheduling and planning of the households individual members. The individual patterns are then formed by the individuals within the range of constraints like the environment and transportation, but also within the household pattern. The activity programs are some sort of agenda with the plan to participate in various activities. After scheduling these become the individual travel-activity pattern.

Note that some activity-based models use tours, which are essentially trip chains, as the basic unit of analysis.

Complexity of human behaviour

Abstracting the reality into models is understandable since human behaviour, in general, and travel behaviour in particular is very complex. However, part of abstracting this behaviour is of course the question to what degree we need to keep the complexity in order to fulfill the goals of the model, namely the forecast travel behaviour and policy effects. While there is no clear answer to this question it may be clear that the FSM does no longer suffice to predict all the necessary changes and thus some more complexity is required.

As a brief mathematical example to illustrate the complexity of the problem:

Imagine a single-person scheduling his day. Only three non-home activities will have to be performed and going back to home between all activities. Consider three possible transport modes and six possible route choices for each trip. This already adds up to over a hundred possible potential combinations. Perhaps this amount can be reduced by rationalizing the possible transport modes and route choices, but when combined with larger households, interactions between agents and replanning during the day, the amount of possibilities is beyond count.

Clearly the complexity of human behaviour does not facilitate easy mathematical modelling and leads to inconsistencies in empirical studies.

In order to tackle this issue Fried et al. (1977) developed a comprehensive adaptation theory for activity and travel behavior. Focusing on the concept of a person-environment or P-E which describes the perception of an individual on how well it can perform its activities within the constraints of the physical and social environment. This was done by developing sets of routines which satisfy the individual's need for the medium and long term. From this the activity program or agenda for each individual can be analyzed. Fried et al. describe this positioning "as a set of role complexes filled by the individual and representing different societal role classes associated with different activity types." If and when the environment of the individual changes this leads to a reconsideration if the routines still sufficiently satisfy the needs. If not, the imbalance with the P-E will motivate the individual to adapt. This might be small adaptation like a route change or changing the departure for an activity. The development of routines can be viewed as a heuristic problem solving procedure. Continued rescheduling will be rendered obsolete once a satisfying pattern is found, since this can be reused. However frequent minor tweaking within the routines might occur often. For this one has to bear in mind the effort these tiny changes compared to the perceived benefits. If too many small adaptations are needed within a routine an individual might be forced to make bigger changes. For example, an individual can change work or residential location to avoid a lengthening commute.

MATSim is using a similar approach in its replanning module (see chapter 7).

Required data

For research, and especially transportation research, the validation of theory and models is necessary and valuable. On the other hand this usually requires a lot of data. Many times constraints of time and money impede the ability to gather enough data. While, at the same time, it is important to keep in mind which data are needed. This is especially true for younger research areas and new models.

Over the past decade travel surveys have been changed from trip-based formats to more activity-based surveys. Obviously this caused an increase in detail available to researchers. However the range of the information collected stayed (mostly) the same. Especially data about the specific temporal, spatial and interpersonal constraints within each household is often forgotten. Probably this is part due to the need to collect data for the more trip-based models, but perhaps also due to the lack of knowledge which data are most relevant. While at the same time one has to keep in mind if all the gathered data are actually useful. With the continuous growth of technology with monitoring of travel and activity via internet-based and remote sensing technologies, such as global positioning systems (GPS), more data will be available, but the issue of what data is needed still must be resolved.

5. CASE STUDY: BRUSSELS

In 2013 a study has been set-up by Efthymiou et al. to analyze a way to combine UrbanSim and MATSim. It presents a case study for the city of Brussels (Belgium).

The use of UrbanSim allows the model to predict future changes in the land-use while using MATSim to simulate the traffic situation. By doing so one can create a set of stages, based on the used time frame, to predict both the land use and traffic over time.

For Brussels a base scenario has been created for the years 2001 to 2020. Intervals for the simulation have been set to 1 year for UrbanSim and every 9 years for MATSim (2001, 2010 and 2019). Also a random selection for 10% of the agents using the car for work related trips have been selected. Both of these are done in order to keep the time needed for the calculations to a minimum.

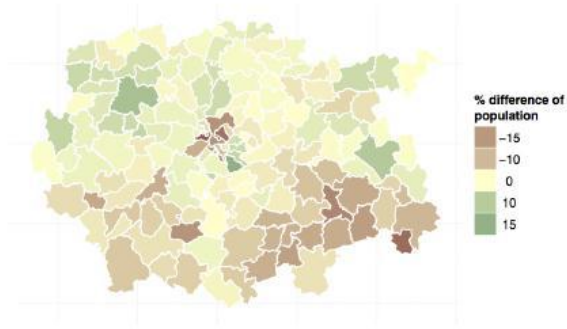
After the simulation the results are compared to real-world data in order to evaluate the model. On figure 3 the results of the model are shown. On figure 3(a), 4(a) and (b) the efficiency of the prediction in population is demonstrated. It shows that the model, with a considerable accuracy, is able to predict these numbers very well. However the populations of the central communes of Brussels (Schaerbeek, Sint-Jans-Molenbeek and Saint-Josse-ten-Noode) as well as the south-eastern communes are being underestimated. For the city center this can be explained by the under-prediction of the house prices 3(d), which leads – according to the household location choice model– less households to be located in that particular region (Efthymiou et al., 2013).

Despite being able to predict the spatial distribution of location of new households rather well, the real estate prices for communes where a significant increase was observed tend to be underestimated (see figure 3(c) and (d)). This might be explained by the usage of an ordinary least square hedonic model for the real estate prices. This causes them to be dependent on attributes of the location but independent of market conditions.

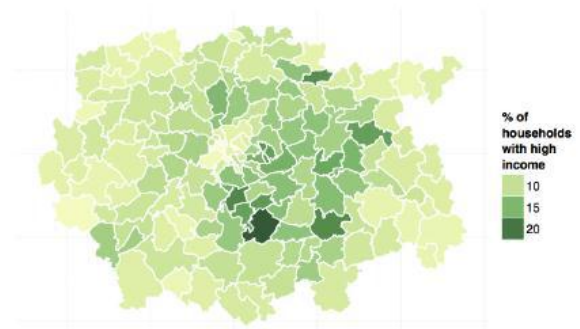
However the identification of these errors has been indicated to be a matter of future research. Also potential ways to improve this model aren't discussed in great detail, but a more realistic market clearing mechanism (Hurtubia and Bierlaire, 2012) and the use of spatial autoregression models for the real estate price (Efthymiou et al., 2012) have been suggested.

Unfortunately the traffic situation from the model hasn't been compared to the real values. MATSim did produce a figure 3(f) which shows the car accessibility per zone.

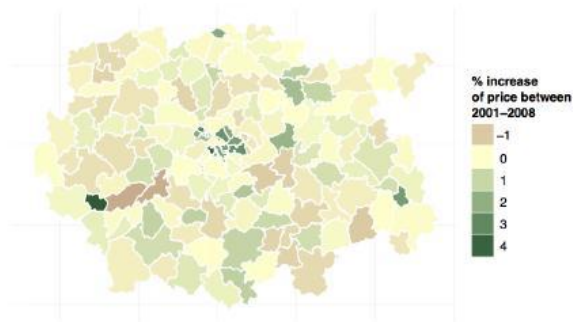
(a) Difference of Observed and Simulated Population in year 2008



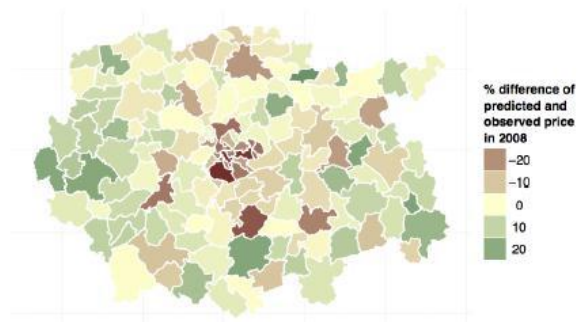
(b) Percentage of Households with High Income in 2008



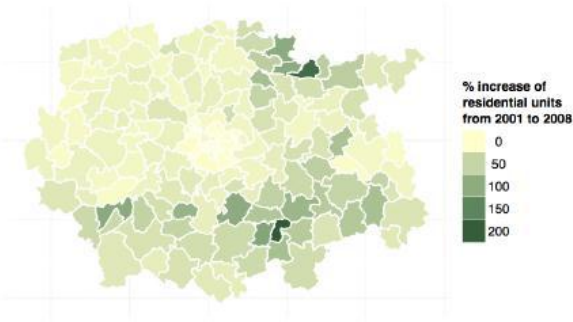
(c) Increase of Price Between 2001 and 2008



(d) Difference of Predicted and Observed Price in 2008



(e) Increase of residential units 2008



(f) Car accessibility in 2008

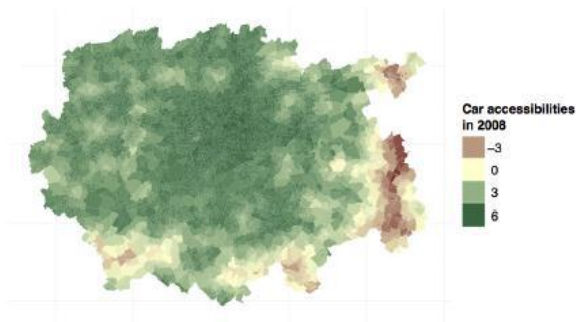
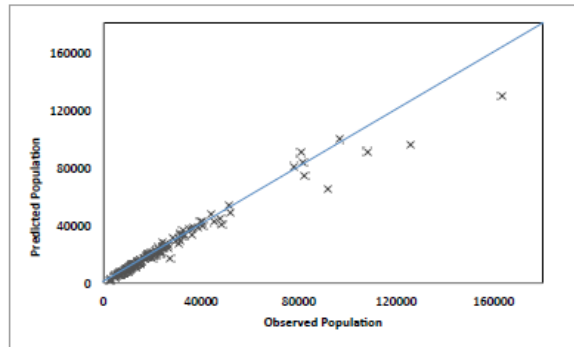
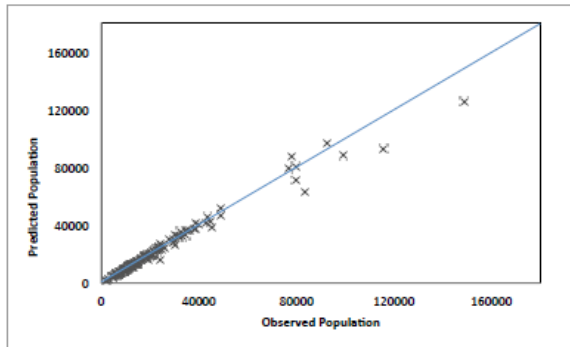
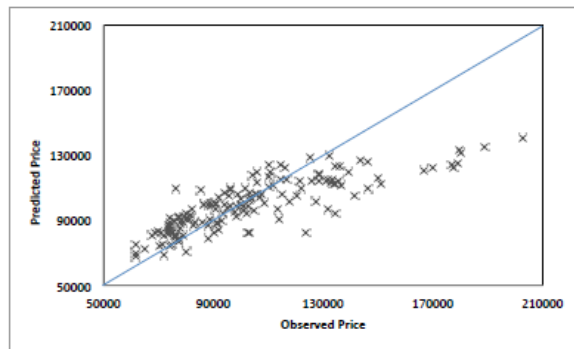
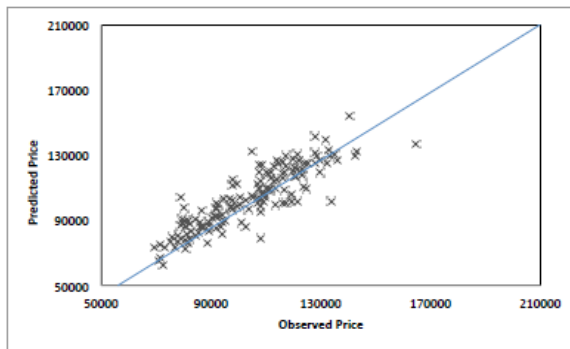


FIGURE 3 Validation plots of reference scenario results (Efthymiou et al., 2013)

(a) Comparison of observed and predicted population in year 2008 (b) Comparison of observed and predicted population in year 2011



(c) Comparison of observed and predicted prices of houses in year 2002 (d) Comparison of observed and predicted prices of houses in year 2005



(e) Comparison of observed and predicted prices of houses in year 2008 (f) Comparison of observed and predicted prices of apartments in year 2008

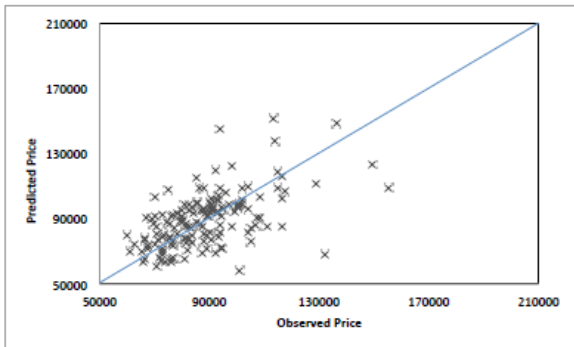
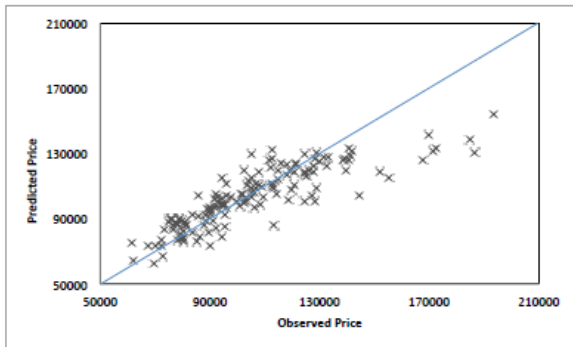


FIGURE 4 Validation diagrams of reference scenario results (Efthymiou et al., 2013)

6. SUMMARY

There are various types of models being used to predict the traffic state of the future. While all of them have their advantages and disadvantages, some overall groups can be formed.

Land-use models have been used to predict housing prices and model functions within a city. A wide variety of models have been constructed all with their own specialties. This is somewhat necessary in order to be able to capture the right timeframe, since some city-wide changes can be achieved within months while others will take years or even decades to complete.

Traffic models have always been somewhat separate from the land-use models. And even within traffic models 2 types can be defined:

The trip-based models, with the four-step model as its prime example, are currently one of the best developed models out there. However, it uses the trip as a base unit, thus negating a lot of the social behaviour and interactions which leads to the trip generation.

The activity-based modelling is trying to resolve that issue by using daily agendas or trip-chains. These require bigger computational performances as well as rationalization within the choice behaviour as not everyone uses the same reasoning when making a decision.

Lately realization of the interconnectivity between land-use and traffic has become a major issue. This brings the need for models which can handle the link between the two. Some studies have been made to implement MATSim into UrbanSim, but the conclusions are still based on the land-use side instead of making the link between them.

7. MATSIM

MATSim is an open source program for activity-based traffic modelling. As it focusses more on agents it is also commonly referred to as an agent-based model. It's been developed at the Technical University of Berlin (TUB), the ETH Zürich and a startup founded by two PhD students, Senozon. The program aims to be a high quality and affordable modelling package for public and private parties alike (Raney and Nagel, 2006).

The program uses a modular approach to allow a great deal of possibilities. MATSim offers all basic elements for an activity based model and a default set of parameters. However they can all be changed depending on the necessities of the project. Users can also write their own Java modules which can be added to an online database. From this database it is also possible to install various modules written by the MATSim community.

MATSim is based on an iterative process. It starts from an initial condition and continues to calculate new situations while the generated agents adapt. While this is running other conditions, e.g. toll prices and road capacities are kept the same.

7.1. Comparison between MATSim and the FSM

A difference between MATSim and more traditional models, like the FSM, is the route choice (see figure 5). Both model types start out with "higher level behavior". These are all the steps before actually planning a trip. For instance, the choice for travelling and the destination choice. This behaviour is not modelled within the program it is rather imported as a baseline.

Together with this both calculate mode choice and the departure time. Usually these are based on a survey or on a previous iteration.

For the next step there is a difference. Agent-based models like MATSim now calculate the route choice as part of the previous two choice groups. As a result the route choice is not part of an assignment module. A suggested effect here is a more clear separation between the choice factors or "human factors" and the more mathematical network assignment.

Finally both models produce a network assignment which can then be visualized as a flow.

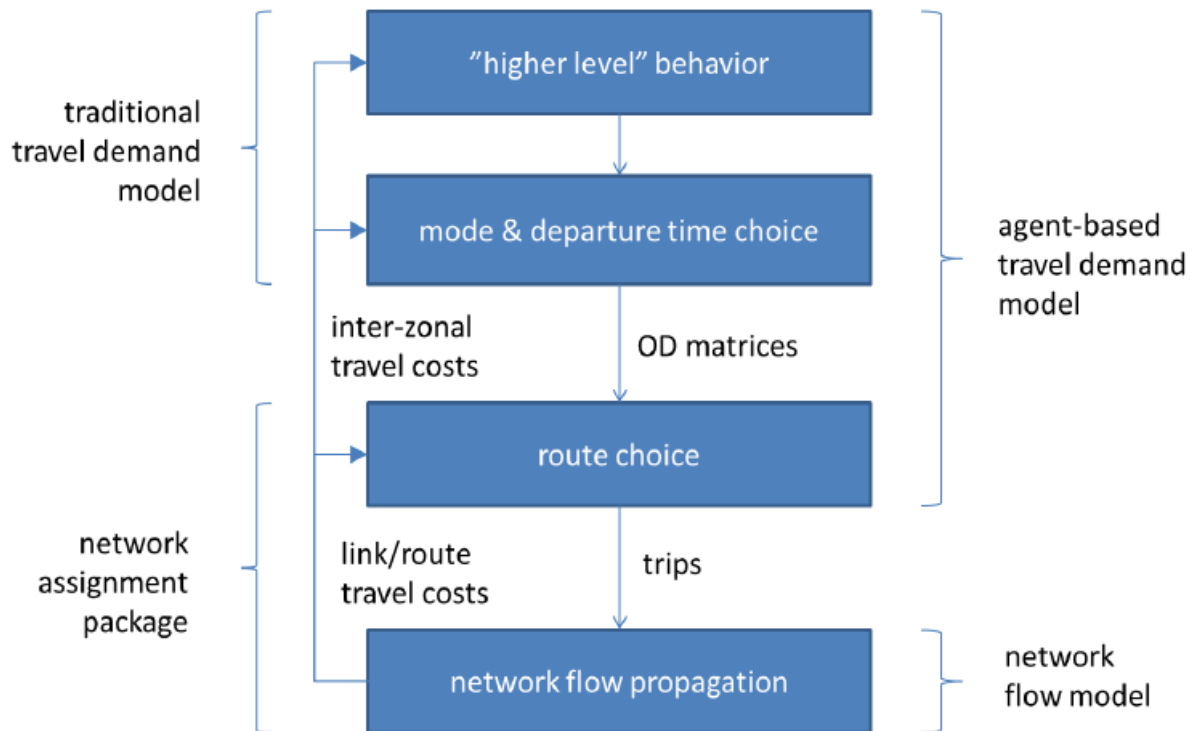


FIGURE 5 Step comparison between the traditional travel demand model and an agent-based travel demand model (Berglund et al., 2014)

As a result of the division in MATSim to make the route choice part of all the other choice dimensions, a typical MATSim run can be defined by the following elements:

- Boundary/initial conditions (land use, transport network, demographics, etc.)
- List of choice dimensions that are/can be adapted

A possible problem here is that most choice dimensions will have to run twice. Once for the initial condition and once after the adaptations have been chosen. This is why a more modular has been built into the program, so the modules can be called upon when needed.

7.2. MATSim components

When looking at MATSim specifically 3 major components can be separated, as seen in figure 6 below.

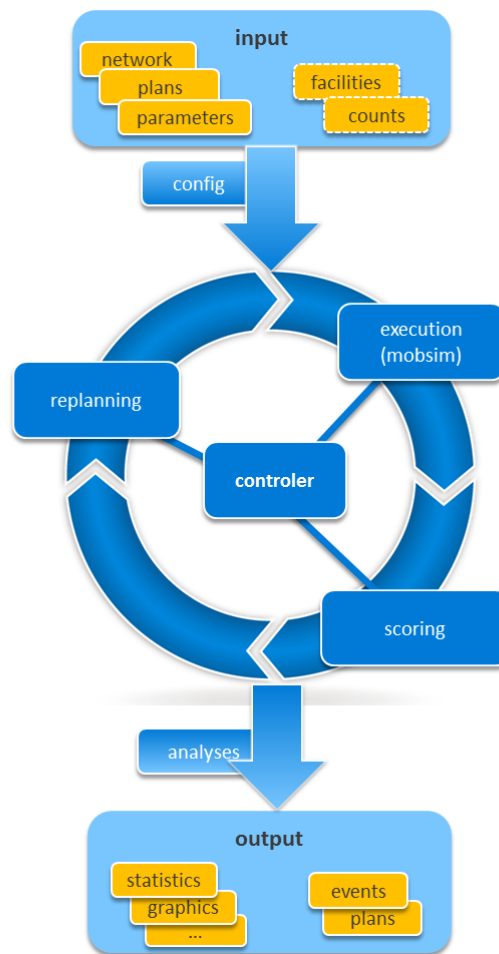


FIGURE 6 Buildup of the MATSim process

First the input. This are all data imported from various sources as well as the parameters.

The network is added here which includes the node and link coordinates as well as specific conditions like capacity, free speed, etc.

The plan file is another required dataset. Here an initial plan is described. These are often based on a survey, but other sources are possible as well. Next the parameters are set. Default numbers are coded in, but all of them can be changed when required.

Also parts of the input are the facility and count data. Count data don't actually influence the simulation but will be added to the result, so they can be easily compared afterwards.

The facility data however will influence the replanning module. If allowed, they will be used to choose other destinations and choice of departure time as opening times are part of this dataset as well.

Altogether this forms the input data which are called upon and read by the configuration file to start the actual calculations.

The second part of the process in MATSim is the iterative process. Here the plans are executed and tested on the network. This will usually cause a very congested result. All individual plans will receive a score based on how well they performed. For instance, if they caused the agent to be late everywhere they will receive a low score. After this the replanning is performed. In the parameters a set portion of the agents will be selected at random. These will be allowed to change certain characteristics of their plan. Once completed the process starts over with the execution on the network.

After all the iterations, usually at least 100, a more or less stable traffic system will be reached.

With these data an output can be generated. Tables, statistics, graphs can be drawn and analyzed based on the needs of the research. Some can be acquired through MATSim itself, for others specific software can be used.

7.3. Scoring

After each iteration the plans for each agent are scored by a predefined scoring function. Standard in MATSim this is the Charypar and Nagel scoring function. Basically this function describes the (dis-)utility or individual costs of a plan.

Everything an agent does in MATSim is rewarded or punished by "utils". This value includes monetary values, but also other factors can be integrated like a favorable view on biking. These utils for each activity will have to be changed based on the region although default values or of course present.

As an example travelling by bus will usually result in negative utils, but performing an activity will give back positive utils. In the end this will result in a certain balance whether or not it is worth it for an agent to travel for performing an activity.

Most of these utils received for a certain activity will have a decaying effect. This makes it less attractive to perform a single activity for an entire day. The speed of decay will obviously differ between the activities.

For example: The first hour at work may yield 10 utils per hour. However a 10th hour of work on the same day will only yield 5 utils to encourage agents to perform more realistic behaviour. Of course the utils for work will drop later compared to the utils for performing sports. While it isn't uncommon for people to work 5 hours a day, most people won't sport 5 hours a day.

The sum of all utils will result in the score for the plan. In the end the goal is to end up with only good plans.

During the course of various iterations the system will "relax" in a more or less stable state which can't improve much anymore. At this point an optimum has been found.

The way this is reached is through a "co-evolutionary algorithm". This means that each agent will simultaneously try to get as many good plans as possible.

For this to happen each plan will have to be evaluated after use. This is done by the scoring function. Each agent can have a predefined set of plans, whenever that number is reached and a new plan has to be generated, the plan with the lowest score will be discarded.

Only a specified amount of random agents can alter their plans in a specific way. This is to avoid a bouncing effect where everyone is constantly switching between two possible routes. Each agent allowed to change their plans can do this within a specific "search space". This means that some agents will be allowed to change their mode choice, while others can only change their departure times and yet another group can change their route choice. This will limit the options per agent and per iteration, but in the long run the possibilities will remain the same.

After a certain set of iterations some modules are shut down. These modules are the ones that allow "innovation" or the generation of new plans. However after a while the gains from this innovation is so limited a relaxed state will be reached easier by just allowing to choose from their already good plans. The probabilities are automatically recalculated according to their specific weights.

8. MORBAMS

This thesis will be a part of the project called "MODellering av Regional Biltraffik med Aktivitets-orientert Mikro-Simulering" or MORBAMS. This translates freely to "Modelling of regional road traffic by activity-based microsimulation". The project is performed by the "Economics and Modelling" department from the TØI. It is being financed by the TØI as well with the buildup of expertise at the TØI and to obtain a first model as the main objectives. In a later phase it's supposed to convince the Norwegian Road Administration and Research Council about the possibilities of activity-based micro-simulations and to receive a commission for a bigger project.

Activity based models are not yet a common practice in Norway. Most predictions for strategic transport planning are made through trip based models which are developed by economists and rely on maximizing economic utility. However these models fail to account for some other factors like a daily time schedule. Also, these models are not as capable to predict the specific effects of certain changes in the traffic system like congestion or cut-through traffic. Activity-based micro-simulations on the other hand will have a harder time calculating long-term economic benefits.

In May 2014 a reference scenario was reached. This model was used to run a first small case study involving a toll ring around the city of Trondheim.

8.1. The population

The population data for the project were gathered from a survey performed in the region of Trondheim. For Belgium the survey can be compared to the OVG (Onderzoek Verplaatsingsgedrag Vlaanderen). A selection was made for trips with at least one beginning or ending in the simulated region.

The data was provided in a dbf-form and with too much information for the model. The conversion was done using a "population converter". This is a part of java-code to extract the required information from the database and convert it to the necessary xml format.

In the later phases a random 10% of the agents was removed to represent the number of travelers better.

8.2. The network

The network data were extracted from the GIS-information provided by the Norwegian Road Administration. For the simulation a region from Trondheim and the neighboring municipalities was selected as well as the municipality with the airport.

Only the car network has been generated. Other modes of transport like public transport, walking and biking are being teleported. The speed of teleporting can

be set manually, which has been done several times to match the counted data as much as possible.

In the end the following parameters have been used:

- Walk speed: 4 km/h
- Bike speed: 17 km/h
- Public transport speed: 7,2 km/h

Within the network one ferry connection is present as well. This ferry transports cars from a nearby island to the main land. In the simulation this connection is shown as a link with a free speed of 15 km/h.

The free speed on the roads is the same as it is in real life while the road capacity is set to a flat 1800 vehicles per hour per lane.

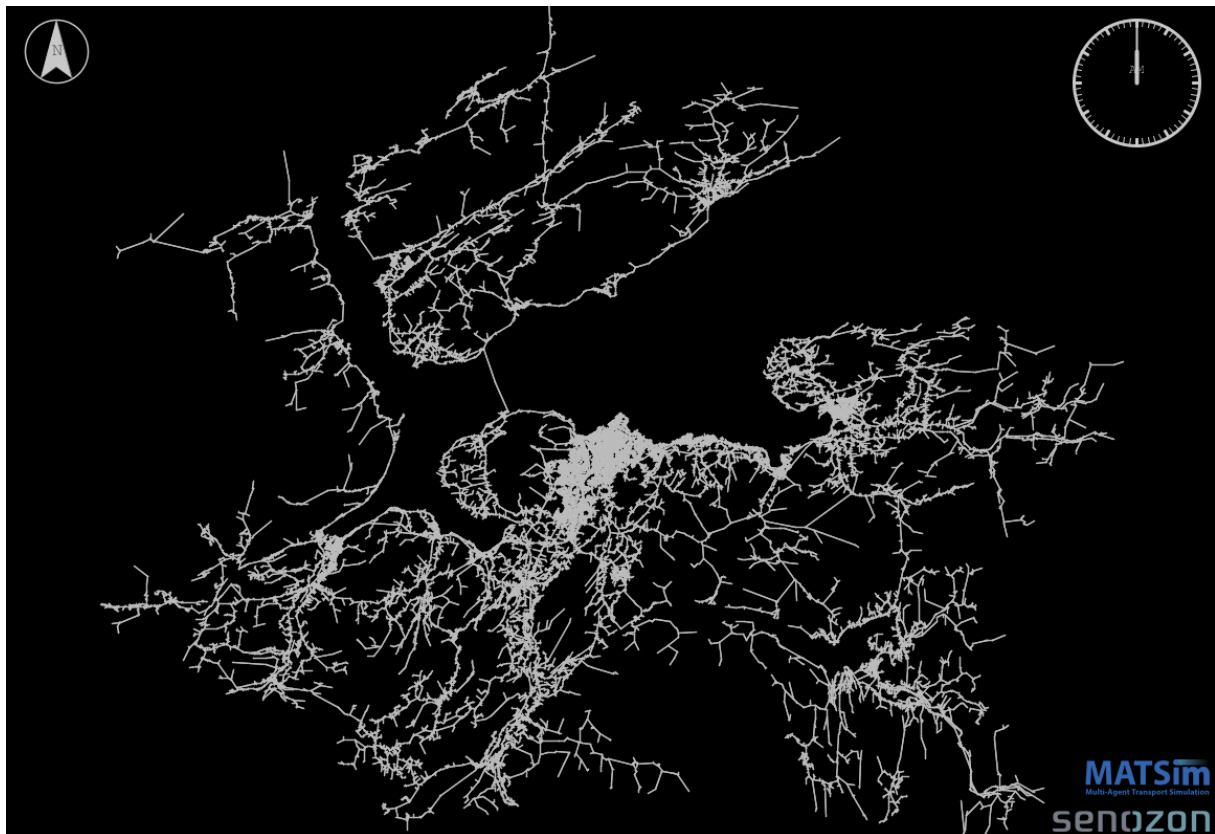


FIGURE 7 The final network used for the case study with Trondheim in the center the airport in the east

8.3. The reference scenario

After some calibration and testing a reference scenario was established. The evolution of the scores over the course of the iterations is visualized by MATSim in a graph as seen in figure 8.

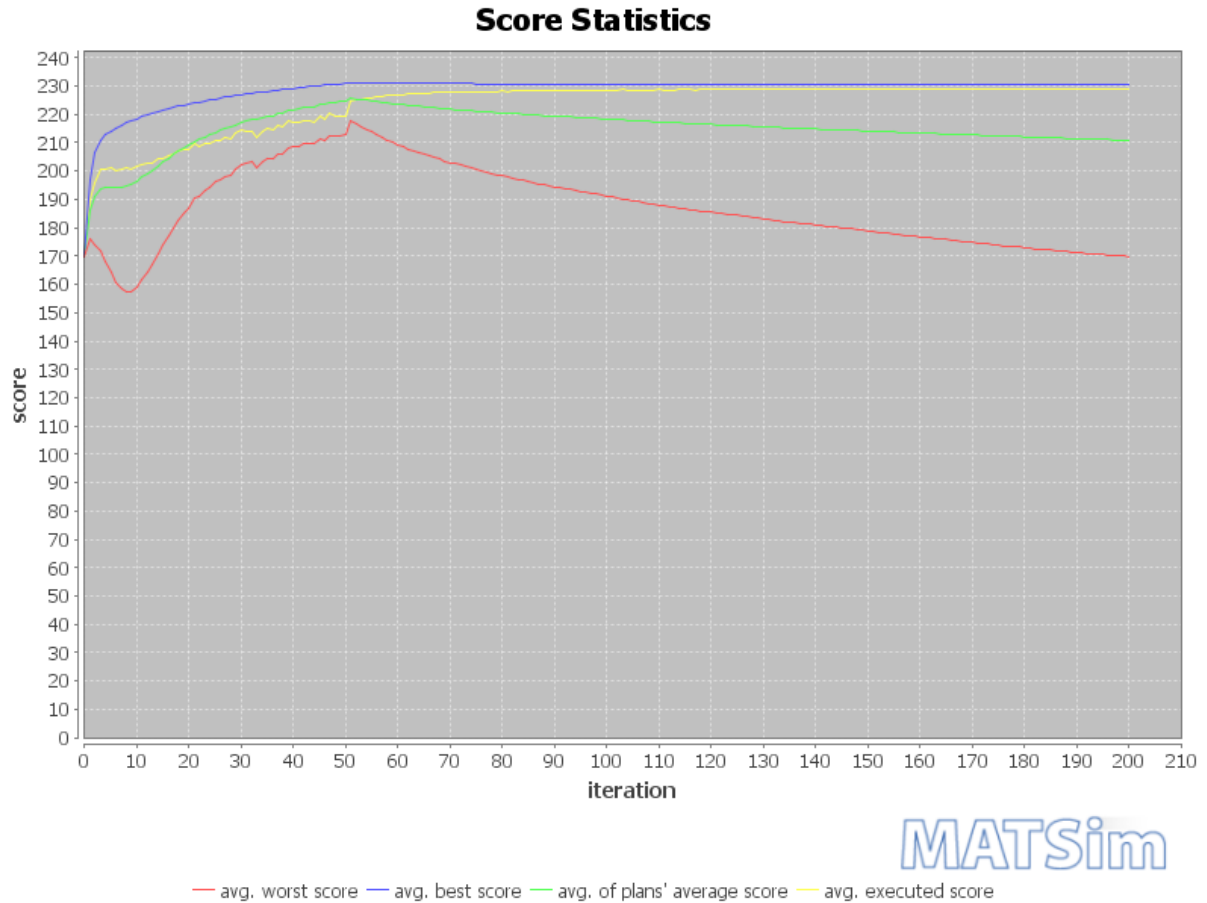


FIGURE 8 Evolution of the plan scores over 200 iterations for the reference scenario

8.4. Modal split

The modal split for the reference scenario is approaching the situation from the survey nearly perfect. The public transport share is somewhat overestimated, however it can be expected this is slightly underestimated in the survey. The data are some years old and the amount of passengers in Trondheim has been steadily increasing over the last years, possibly due to the new public transport network.

Meanwhile walking and biking is being underestimated slightly. Possibly this is due to skewed transport times as these modes are not modeled on the network.

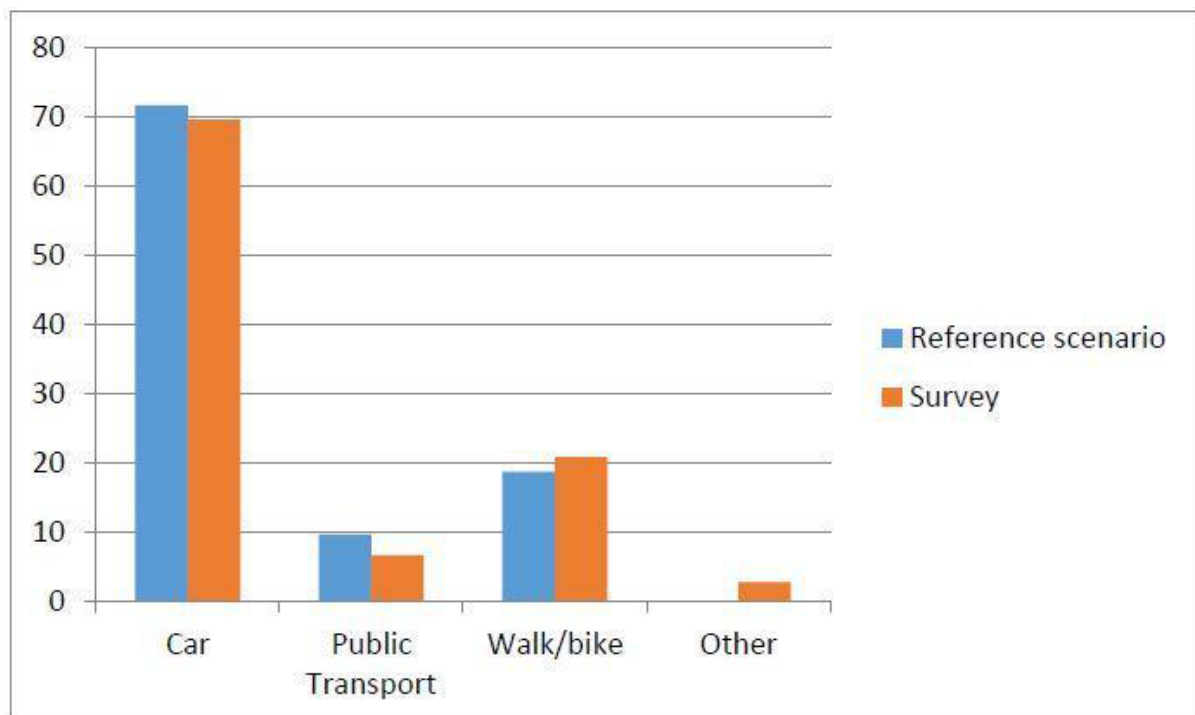


FIGURE 9 The modal split between the reference scenario and the survey data in %

8.5. Counting stations

Count data for several locations around Trondheim have been provided by the Road Administration. These counting stations have been converted to an xml-file usable by MATSim and VIA. During the simulation runs they were used to test and optimize the simulation.

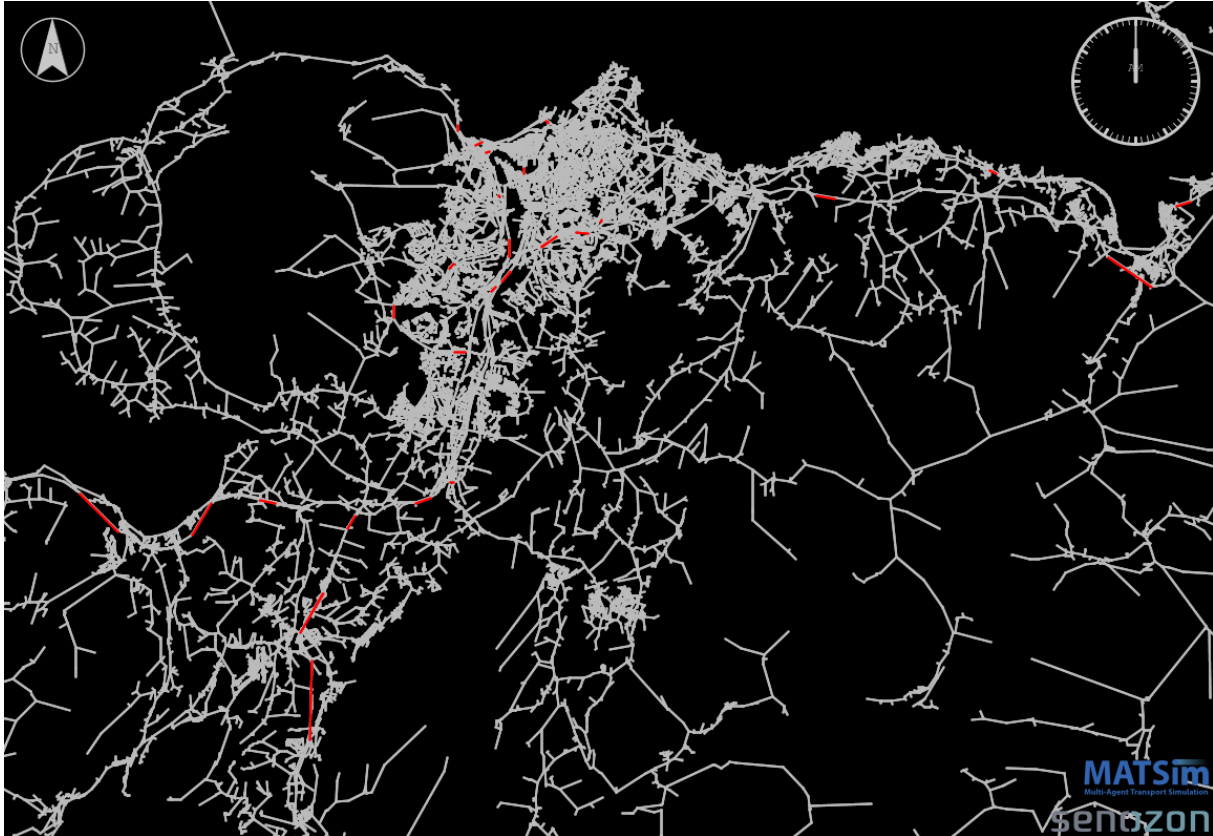


FIGURE 10 The locations of the counting stations in and around Trondheim (in red)

Many of the counting stations are from tunnels leading towards or within the city itself. A few are strategically placed on the highway which passes the city. Due to most of them being tunnels it is to be expected most traffic to and from the city will have to pass one at some point. As a result these stations should capture any commuting traffic very well.

Daily Traffic Volumes

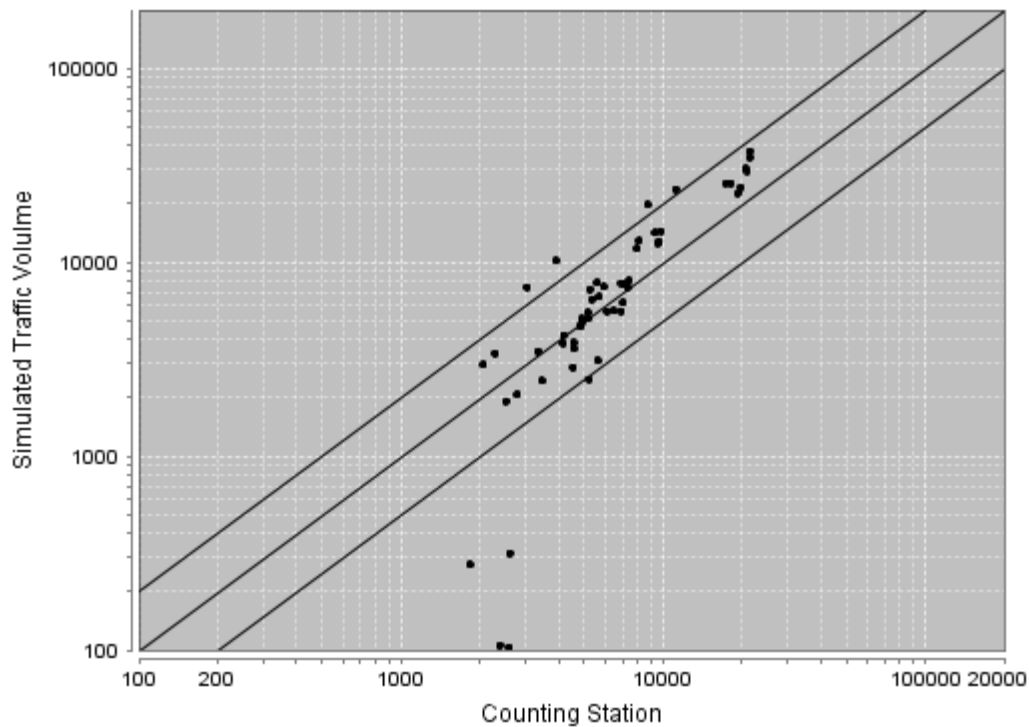


FIGURE 11 Comparison of traffic volumes between the simulated traffic and the real counts

The simulation is slightly overestimating the traffic passing the counting stations. However most of the volumes remain within an acceptable range. Four counting stations are really underestimating traffic. This can be explained because these stations are located near the edges of the simulated region. It is to be expected that this influences the amount of cars passing at these point. Moreover the traffic at these locations is very low (<2000 vehicles / day).

Altogether it is assumed that the simulation approaches the reality sufficiently for the case study to show realistic results.

8.6. Toll scenario

To test the model a toll scenario was set-up to see how the travel behaviour changes. To do this a new toll ring was created around the very city center of Trondheim.

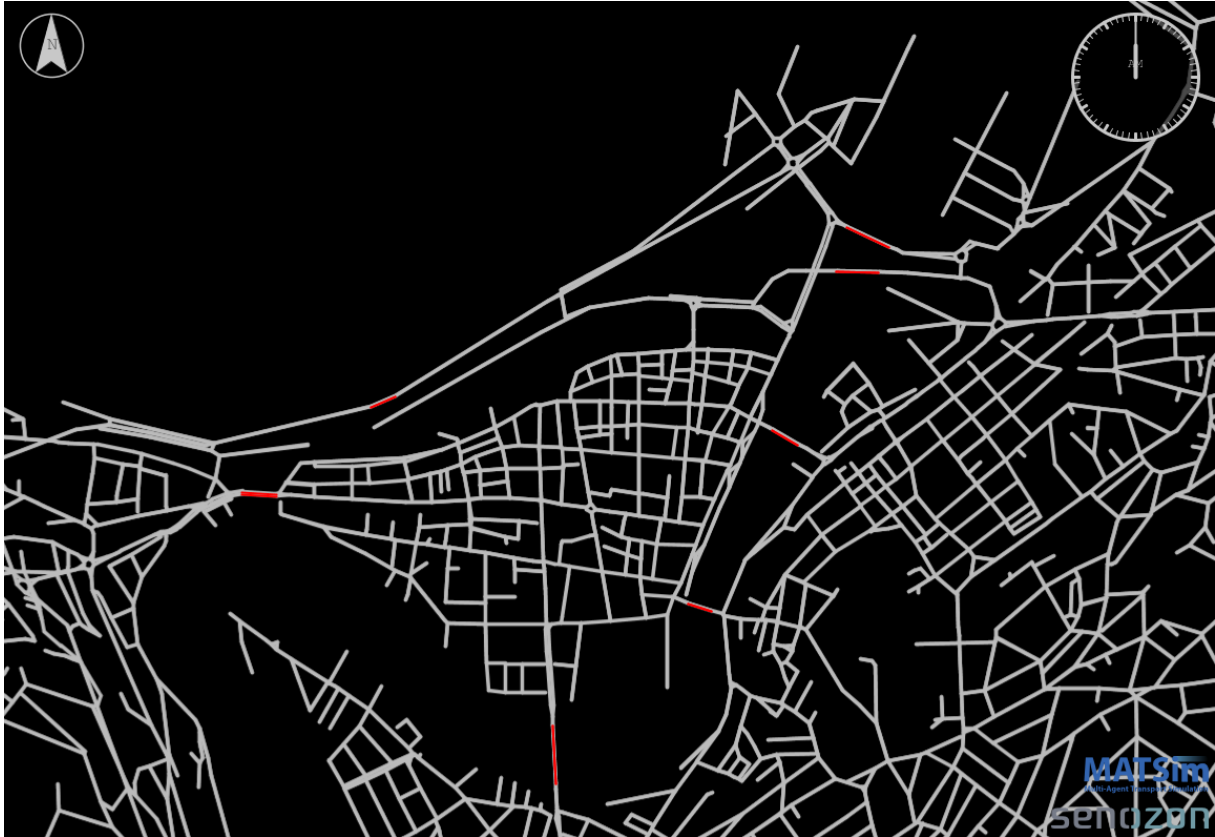


FIGURE 12 In red the locations of the new toll ring around Trondheim city center

Various pricing schemes were used in order to test the effects on the model.

First a toll costing 20 kroners during the peak hours and 10 kroners off-peak has been used. This is the most common pricing scheme around Trondheim with about half of the toll stations using this.

The second run assumes a flat toll of 15 kroners not depending on the time of the day. This is currently not used around Trondheim, but other values like 8 and 30 kroners are present, so a median value was used.

Finally the third run doesn't have a toll off-peak, but a high 50 kroners during peak-hours. This type of pricing scheme is currently not in use in the region around Trondheim.

Results

The modal split in the cases doesn't differ that much from the reference scenario. There is a small decrease in car use for all scenario's which mostly results in a slightly higher share for public transport.

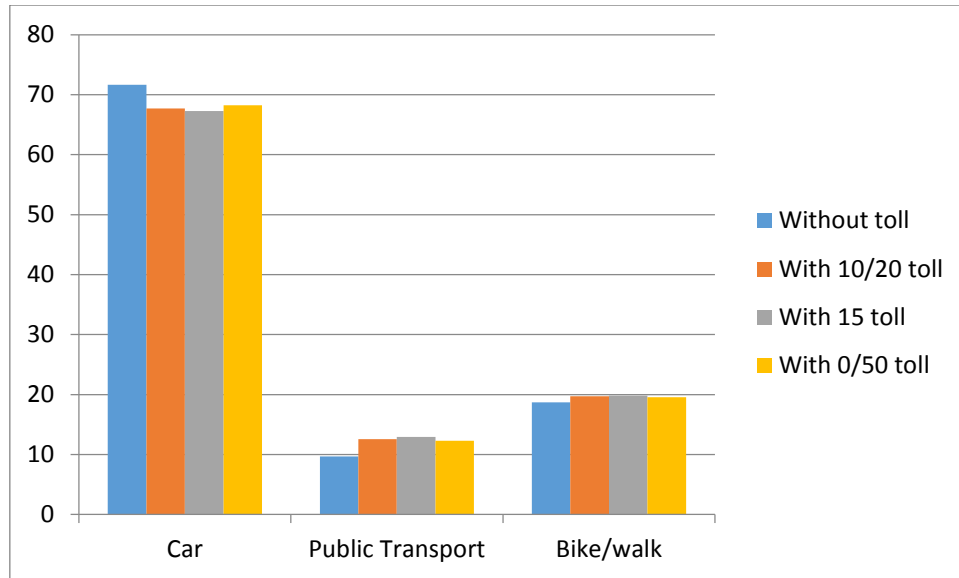


FIGURE 13 Modal split for the various toll scenarios

When looking in detail the flat 15 kroners toll has the biggest decrease in car use and the largest increase for public transport. The 0/50 kroners toll has the least decrease in car use. The differences are so small however, they should not be considered significant.

The traffic entering and leaving the city does change between the various runs. Without toll the number of cars entering or leaving, summed up over all links, the city center is clearly higher. With the tolls this amount is decreased. Because of the minimal change in shares, it can be assumed more people took an alternative route to their destination outside of the city center.

Between the various runs it can be seen that the curve (figure 14) is "flattened out" during the day when peak hours are charged more. For the 0/50-curve the amount of cars during the peak hours is even lower than some off-peak times. The same trend, although with smaller differences can be seen on the 10/20-curve compared to the 15-curve. This shows that the pricing scheme has a clear impact on the decision making of agents.

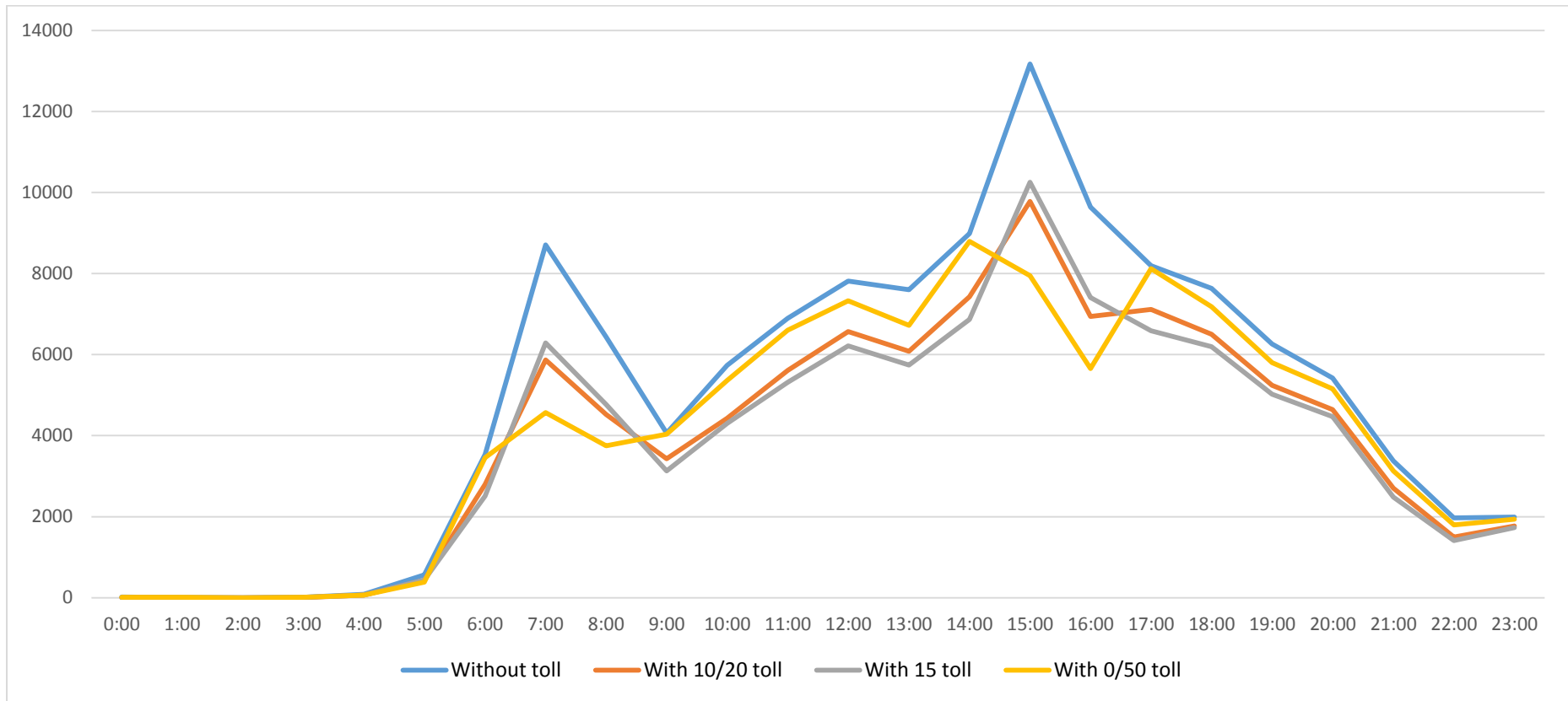


FIGURE 14 The amount of cars entering or leaving the city center of Trondheim in the toll scenarios

9. FACILITIES

In this next chapter the facilities will be discussed. An explanation will be given about the build-up and function within MATSim as well as how this has been used in the case study.

9.1. The facilities file

The facilities are a function within MATSim which influences the activities in various ways. The facilities file consists of a list of locations, described by a x- and y-coordinates, their capacity and their opening times. For work locations, this list can often be derived from governmental databases.

X- and y-locations are the most important. They can come from already existing databases or retraced from a survey. These locations are compared by MATSim with the network file. The closest link will be coupled with the facility and used as the "entrance".

The capacity is the amount of agents which can be present at the same time at the facility. For working facilities this translates to the amount of workplaces while for shopping locations they can be linked to the floor size.

Although opening times are often standardized, another option is to leave the times blank in which case the default values will be used. The same happens when no facilities file is added.

9.2. Use of the file

In theory the file on its own does little to nothing. The information within the file however can be accessed by the configuration file which is the heart of the simulation. In this file the coding can use the data within the facilities file in many ways. Eventually the goal is to allow agents to build their own agenda based on the facilities alone. At this moment however, this is not yet possible. It is possible, as will be shown in the case study, to allow agents to switch their destination to a facility with open capacity. They cannot add or remove activities in their plans. The first and last activity of the agenda, usually the home activity, has to remain the same.

```

<person id="1.2999525E7-1" employed="yes">
  <plan selected="yes">
    <act type="home" x="272977.0334571426" y="7042386.729273574" end_time="07:35:47" />
    <leg mode="car">
    </leg>
    <act type="other" x="274075.0854435207" y="7039024.6913022045" end_time="11:12:40" />
    <leg mode="car">
    </leg>
    <act type="work" x="272961.1911592363" y="7042253.665541278" end_time="18:38:05" />
    <leg mode="car">
    </leg>
    <act type="home" x="272977.0334571426" y="7042386.729273574" />
  </plan>
</person>

```

FIGURE 15 Example of an agent plan with changeable parts in grey

In the above figure the greyed attributes can be changed by MATSim between the iterations in the following ways:

- End_time: The time an activity will end can be altered. This way an agent can try to avoid traffic congestion.
- Leg mode: The leg mode determines the mode choice for travelling from this activity to the next and can be changed.
- X and Y location: For a work activity agents can switch to a new free location. This would be possible for other activities as well, but no free locations were added to allow this.

As a reminder MATSim cannot:

- Add or remove legs within a plan.
- Change the activity type of a trip (act type).
- Change the location of "home" and "other" activity types since no free locations will be available.

The most common is to use the file to add the opening times to the facilities. This will influence the simulation as agents will be limited in their planning to these opening times.

In this case study the opening times have been kept to their default values. This means nothing will change between the reference scenario and the case study simulations. To achieve this, the opening times in the facilities file have been left blank.

The x and y location data was supposed to come from a database. However, unfortunately these data were listed in a different format for the coordinates. This could not be fixed in time; as a result the locations were taken from the same survey as the original planning data.

The capacity is usually linked to the number workplaces, the floor space in case of leisure or shopping activities and type of house for the home locations. In the case study, due to the problems with the coordinates the capacity could not be linked to specific locations either. As a workaround all locations from the agents'

plans received a one person capacity. This means that without anything added or changed to the facilities file all agents will be able to perform their plan, but no location changes are possible since all locations are already taken.

9.3. Data within the facility file

As mentioned the used facilities file is based on the survey and the agents' plans. As a result a simulation without any changes to the facilities file will give the same result as without it. While this is not very realistic it allows to see the effects of only a single change at a time.

For this case study new locations will be added and agents can switch their current work location to one of the new ones as long as the capacity has not been reached. In turn, the places they leave can then be taken by others. To make things easier to interpret, the results have been broken down in a few regions. This way changes can be viewed on an aggregate level and it allows for an easier comparison. The chosen regions can be seen on figure 16.

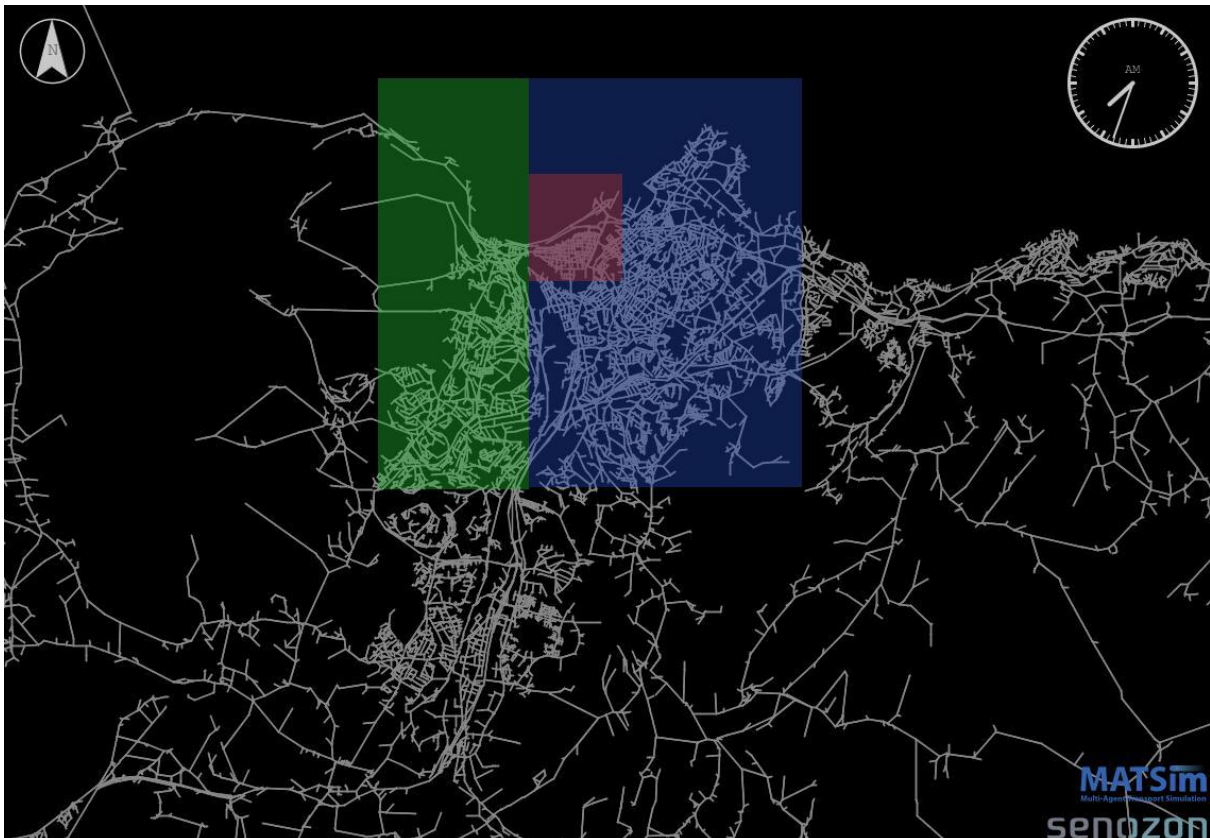


FIGURE 16 Map of Trondheim divided in 4 regions

The following regions are visible on the map:

- 1) The central city (red). This is about the region which was surrounded by a toll ring during the toll case study.
- 2) The right bank (blue). This is the region of the city on the right river bank, except for the central city. This is the region with the biggest amount of activities within.

- 3) The left bank (green). The region of the city on the left river bank.
- 4) The outskirts and region (no color). This covers the whole area outside of the city of Trondheim. Within are the outskirts of the city, an industrial zone in the south, some countryside as well as the airport of Trondheim. While covering the biggest area it does not have the most activities within. It also stretches beyond the borders of the map.

To start the facilities from the agents' plans have been counted per region to give an overview. On figure 17 this distribution is visible.

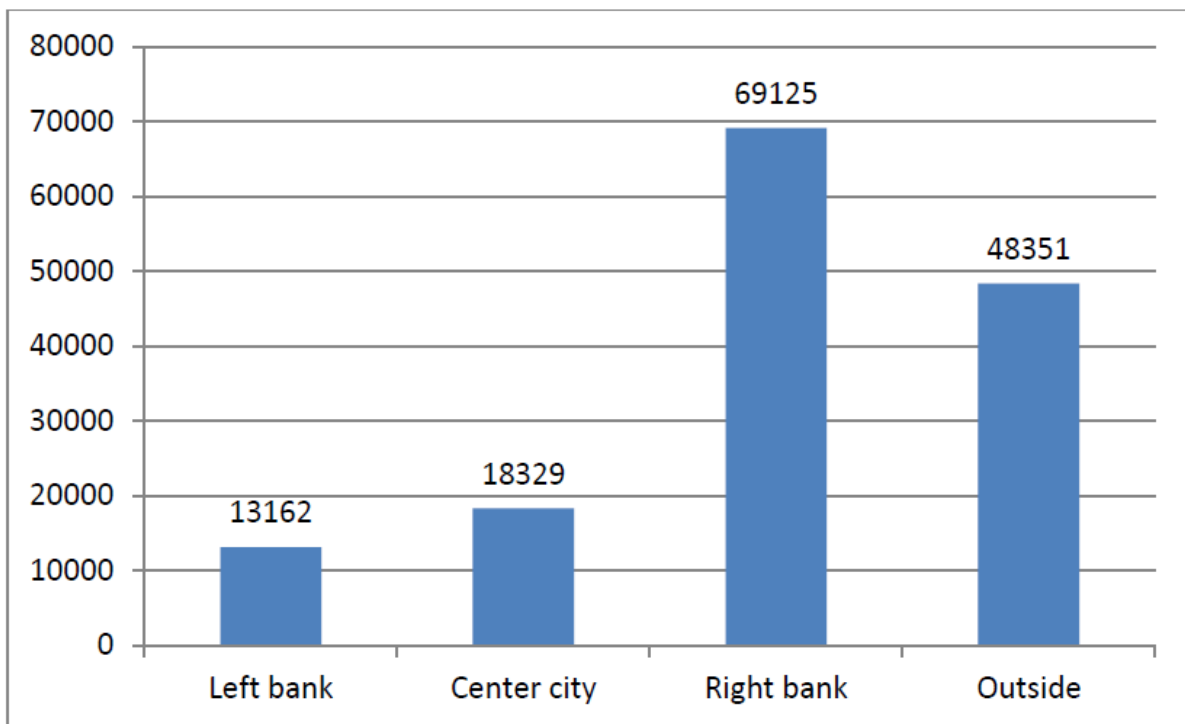


FIGURE 17 The number of work related trips to a region

As discussed before the right bank area contains the most work activities as it occupies the biggest part of the city. Nearly half of the 148.967 workplaces are located within this region. The outside region is the biggest in terms of area, but does not have as much to offer. The center city and left bank are smaller parts, but the center city has a lot of places despite its size.

10. CASE STUDY: FACILITIES

To test the facility options within MATSim a case study has been performed. This study adds a new work facility within the city of Trondheim. The effects on the plans of the agents can then be analyzed in order to evaluate the resulting changes.

In order to isolate the results only a new work location was added. This location contains 10.000 new work spaces. This is about 8% of the original available work places. All other locations remain the same, although as people move to the new work locations their original places become available for others. This can cause shifts towards or away from certain regions.

For home and other activities no location changes will be possible, so they will remain the same.

10.1. Reference scenario

For the reference scenario the same base data as for the case study described in 8. MORBAMS has been used. No extra toll scenario was used for the reference. This means the survey data will be used to build the initial plans for the agents. No location changes are possible during the simulation. Departure times and modal changes are possible however. As discussed before (9.3. Data within the facility file) the city will be divided into four regions. These regions will allow comparisons on an aggregate level of data.

Together with the regions the modal split is taken into account as well. Public transport, bicycle and walking is being teleported using a fixed time setting based on the straight distance to the destination. This means they will only be a better choice if the car has to do a lot of detours or when there's a lot of congestion.

10.2. Results for the reference scenario

Beneath the work trips for the reference scenario are described. The trips are divided by the region and the modal split.

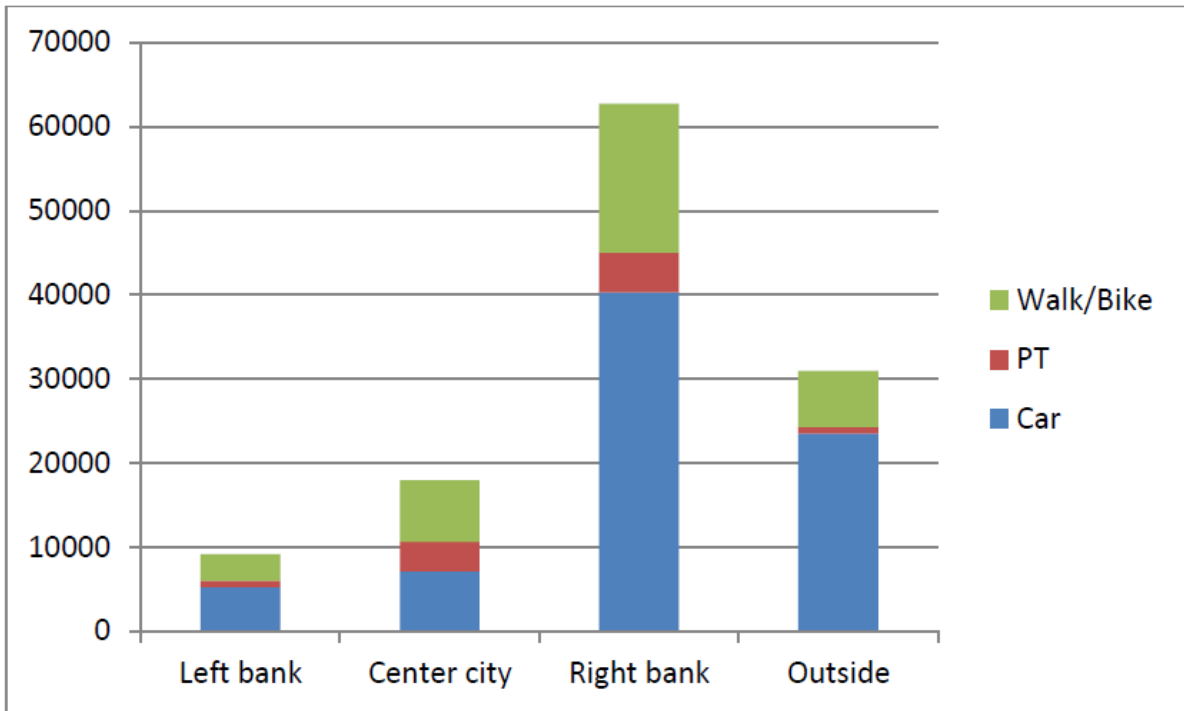


FIGURE 18 The number of work related trip to a region per mode for the reference scenario

Looking at the graph above the expected division can be seen. The right bank, which encompasses most of the city has most of the activities. Meanwhile the center city attracts a lot of trips for its size.

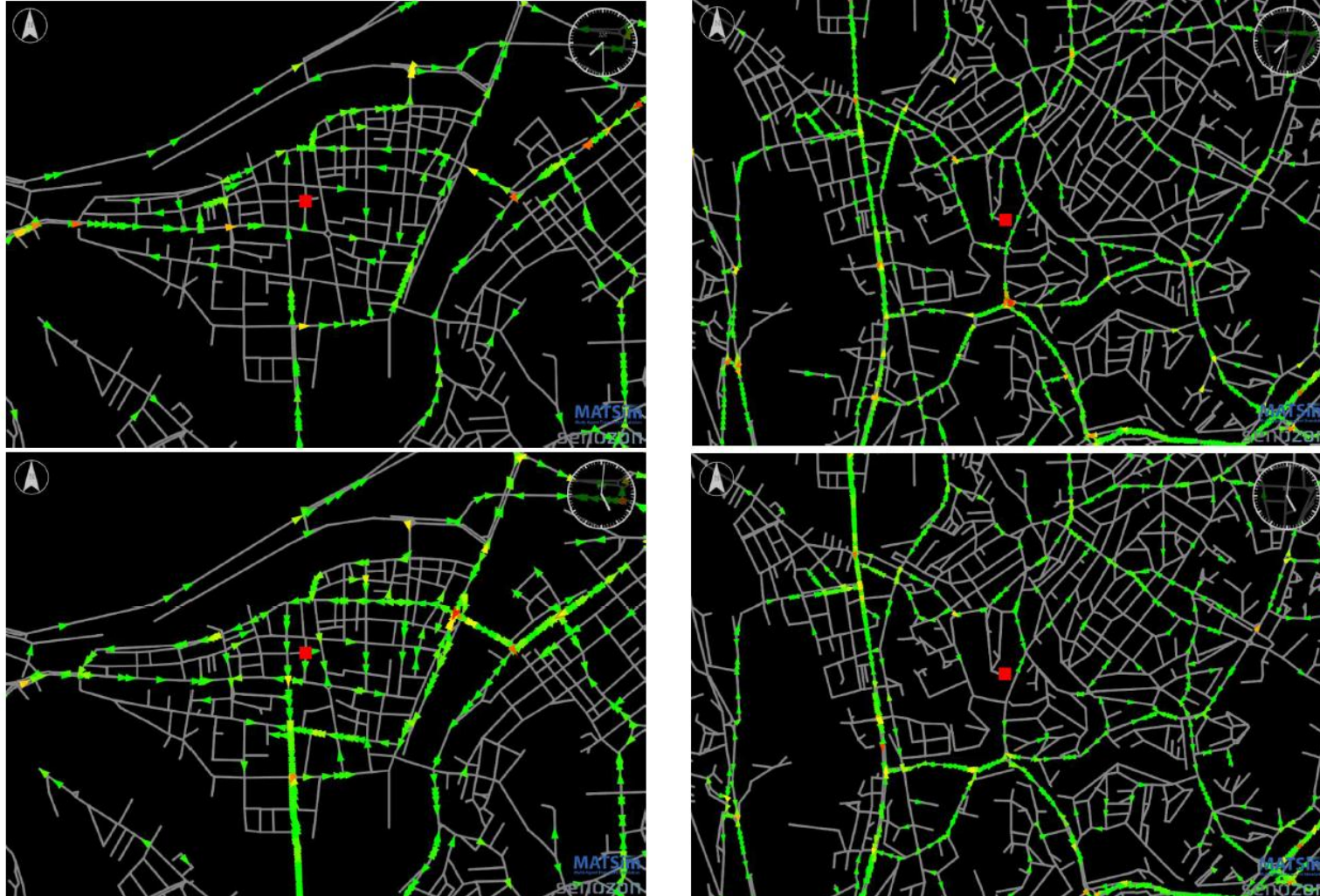


FIGURE 19 The traffic situation in the reference scenario during rush hour around the new working locations

Top left: Center city 7:30am // Top right: Right bank 7:30am

Bottom left: Center city 5pm // Bottom right: Right bank 5pm

On the above maps the traffic situations at rush hour around the locations where new work locations will be added in the case study. Both locations are away from the main streets, so any effects will be really visible on the smaller streets around.

10.3. Central new work location

In this first scenario a new work location with 10.000 places will be created within the city center as can be seen on the map below.



FIGURE 20 Map of Trondheim with the new working location in the city center

This location is within the toll ring from the previously described toll ring scenario. As a result two runs will be done. One without the toll scenario and one with a toll scenario. In this toll scenario a toll costing 20 kroners during the peak hours and 10 kroners off-peak has been used. As this is the most common pricing scheme around Trondheim.

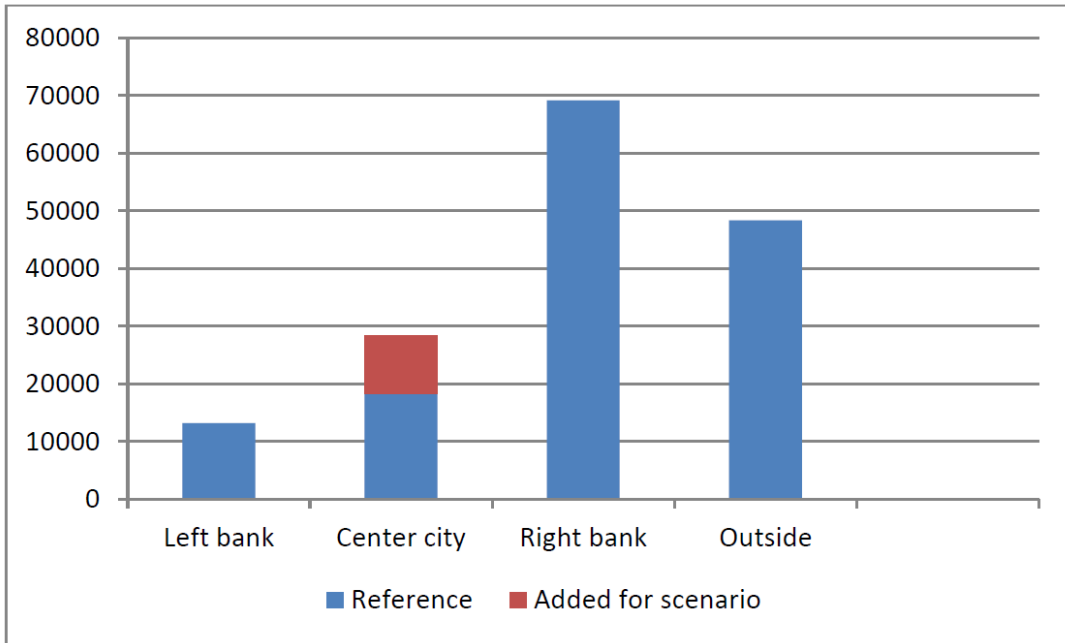


FIGURE 21 The number of working locations per region and the addition

10.4. Without toll scenario

First the scenario is run in a similar fashion as the reference scenario. The only difference is the possibility for the agents to switch their work destination to a new location. In the beginning only the 10,000 new workplaces in the city center are available as alternatives, but as people change their destination their original workplaces become available for others. Per iteration 5% of the agents is given the chance to change their destination choice. The resulting plans after 200 iterations, divided by region and mode choice can be seen below.

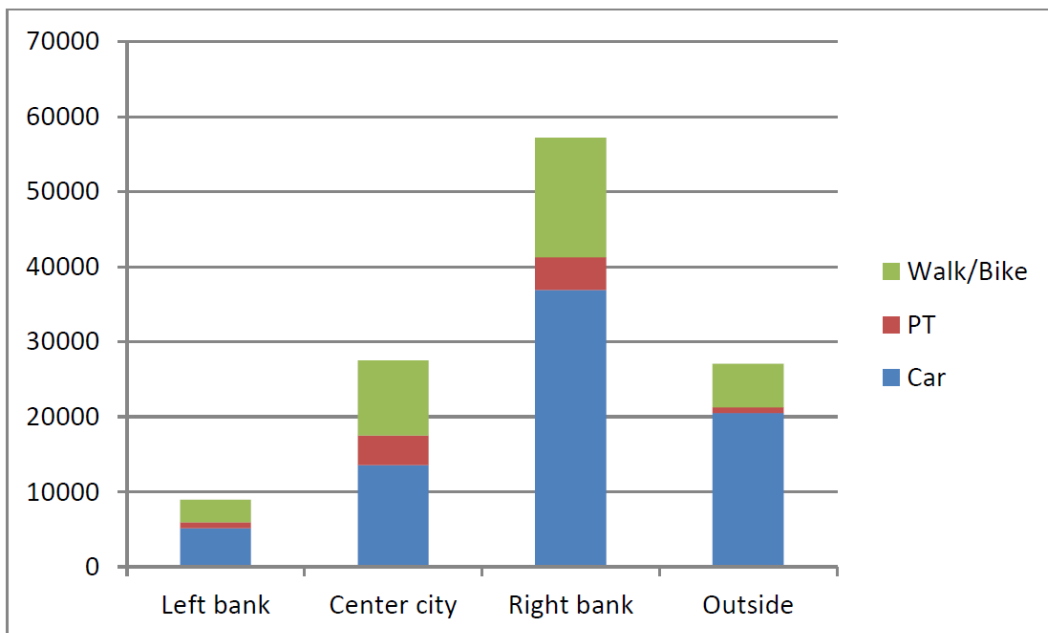


FIGURE 22 The number of work related trip to a region per mode for the center city without toll scenario

A roughly similar view compared to the reference scenario, though, as expected, a lot more activities in the city center. It seems most of these came from the right bank. This is unsurprising as this is the closest region.

Central city without toll				Reference				
Car	PT	Walk/Bike	Total	Total	Car	PT	Walk/Bike	
5145	778	3014	8937	9144	5248	778	3118	Left bank
13559	3972	9999	27530	17962	7108	3564	7290	Center city
36905	4371	15911	57187	62672	40251	4726	17695	Right bank
20497	769	5807	27073	30949	23499	822	6628	Outside

FIGURE 23 Comparison of the number of trips per region and per mode between the center city without toll and reference scenario

In the above table the differences are more visible. In the city center there are 9568 more work related activities. This means the 10.000 new places are nearly maxed out. At least half of these came from the right bank. Since the right bank is the closest to the city center and the area with the most activities it is to be expected many of the new trips came from here.

Also the new trips cause a shift in the modal split. The car share in the reference scenario in the center city was about 40%. However in the new trip the car share is about 67%. As a result the new modal split in the center city region is nearly 50%. This causes some visible changes in the congestion.

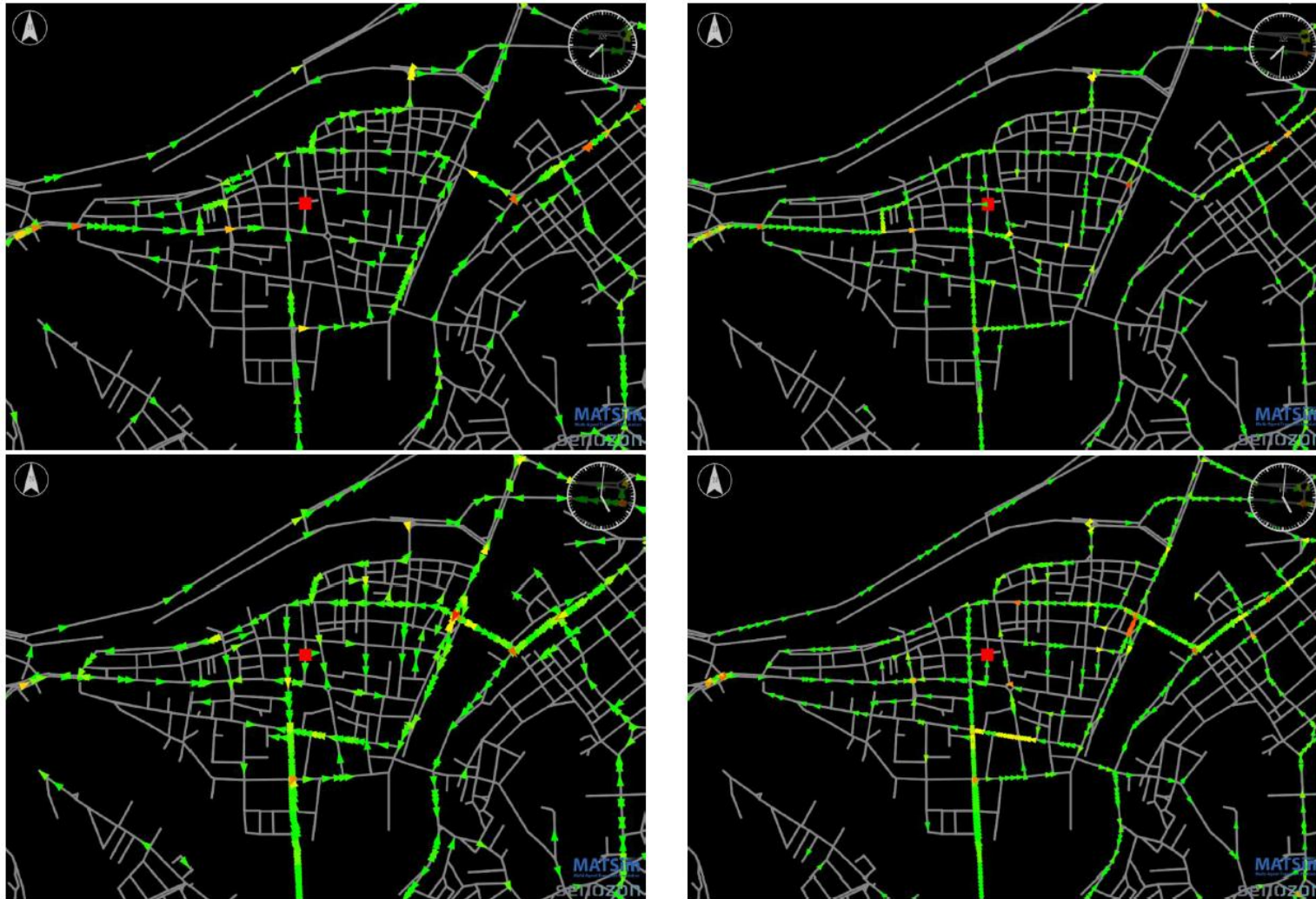


FIGURE 24 The traffic situation during rush hour around the new center city working location
Top left: Center city 7:30am reference scenario // Top right: Center city 7:30am center city without toll scenario
Bottom left: Center city 5pm reference scenario // Bottom right: Center city 5pm center city without toll scenario

As can be seen above there is somewhat more traffic around the new location. In the morning traffic the west and south main roads seem to have a lot more traffic. This difference is less visible at 5pm, although there is more traffic during the evening rush as can be seen by the numbers below.

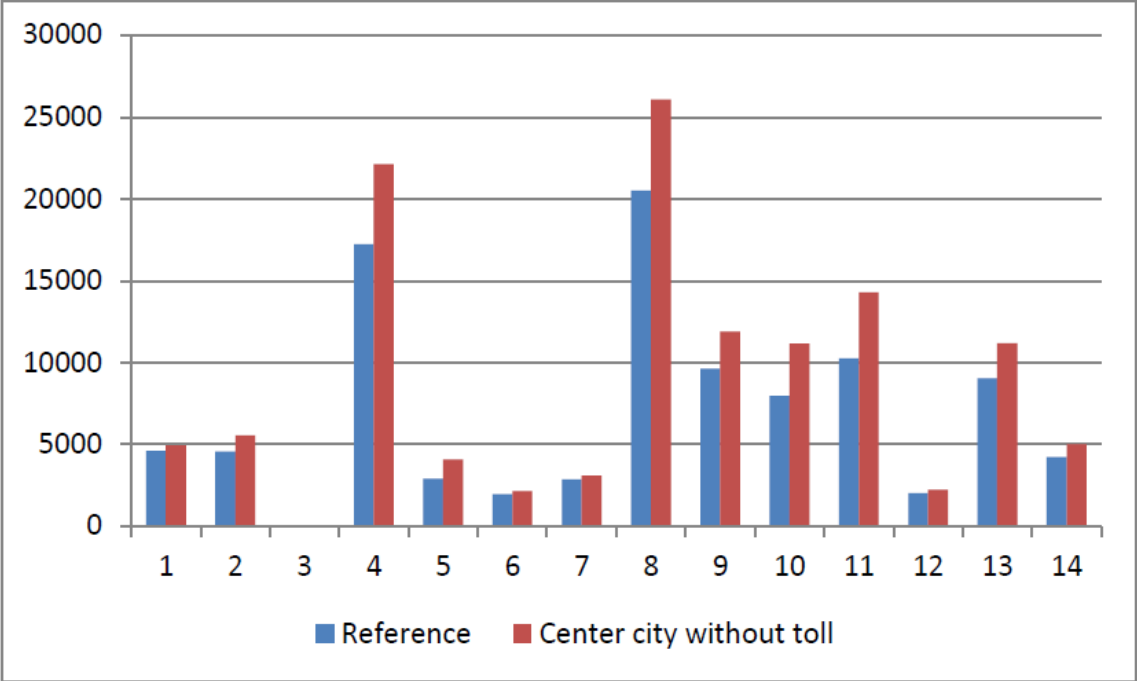


FIGURE 25 Comparison of traffic intensities on roads leading to the center city

On figure 25 a clear increase can be seen when compared to the reference scenario. On all links leading to the city center this is visible. This is line with the previous findings of 10.000 additional work activities within this center city. The new work locations appear to be very attractive.

In the next step we will add the toll scenario again. All the links checked in the graph above will receive a toll as described below.

10.5. With toll scenario

Next the same scenario is run. All settings are the same, expect the toll scenario has been added again. This is a toll ring around the center city. The scenario used here uses 20 kroners during the peak hours and 10 kroners off-peak as toll. The result will probably be that the city center will be less attractive and thus have less trips going towards it.

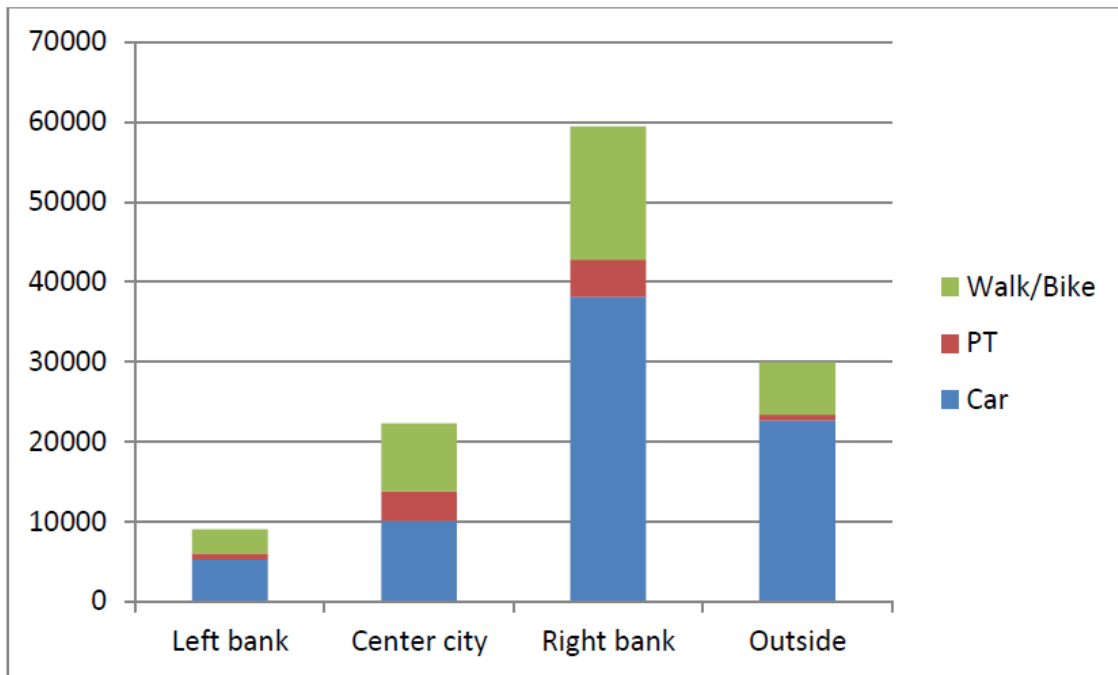


FIGURE 26 The number of work related trip to a region per mode for the center city with toll scenario

The overall view is the same as the reference scenario. However there is an increase of work trips towards the city center. Most of these have changed from the right bank. A more specific look can be gained from the table below.

Central city with toll				Reference				
Car	PT	Walk/Bike	Total	Total	Car	PT	Walk/Bike	
5248	778	3014	9040	9144	5248	778	3118	Left bank
10086	3719	8492	22297	17962	7108	3564	7290	Center city
38120	4624	16701	59445	62672	40251	4726	17695	Right bank
22652	769	6524	29945	30949	23499	822	6628	Outside

FIGURE 27 Comparison of the number of trips per region and per mode between the center city with toll and reference scenario

In the above table shows a clear increase of 4335 work trips to the center city. This is not even half of the 10,000 new workplaces. This is obviously still a good increase of nearly 25% compared to the reference scenario. However compared to the previous run without the toll included, the increase is less than half.

The modal split of the added trips is still very much oriented towards the car. It is even higher in this run with a little over 68%. However, since the amount of trips is less the new modal split for the car is 45% in the center city region.

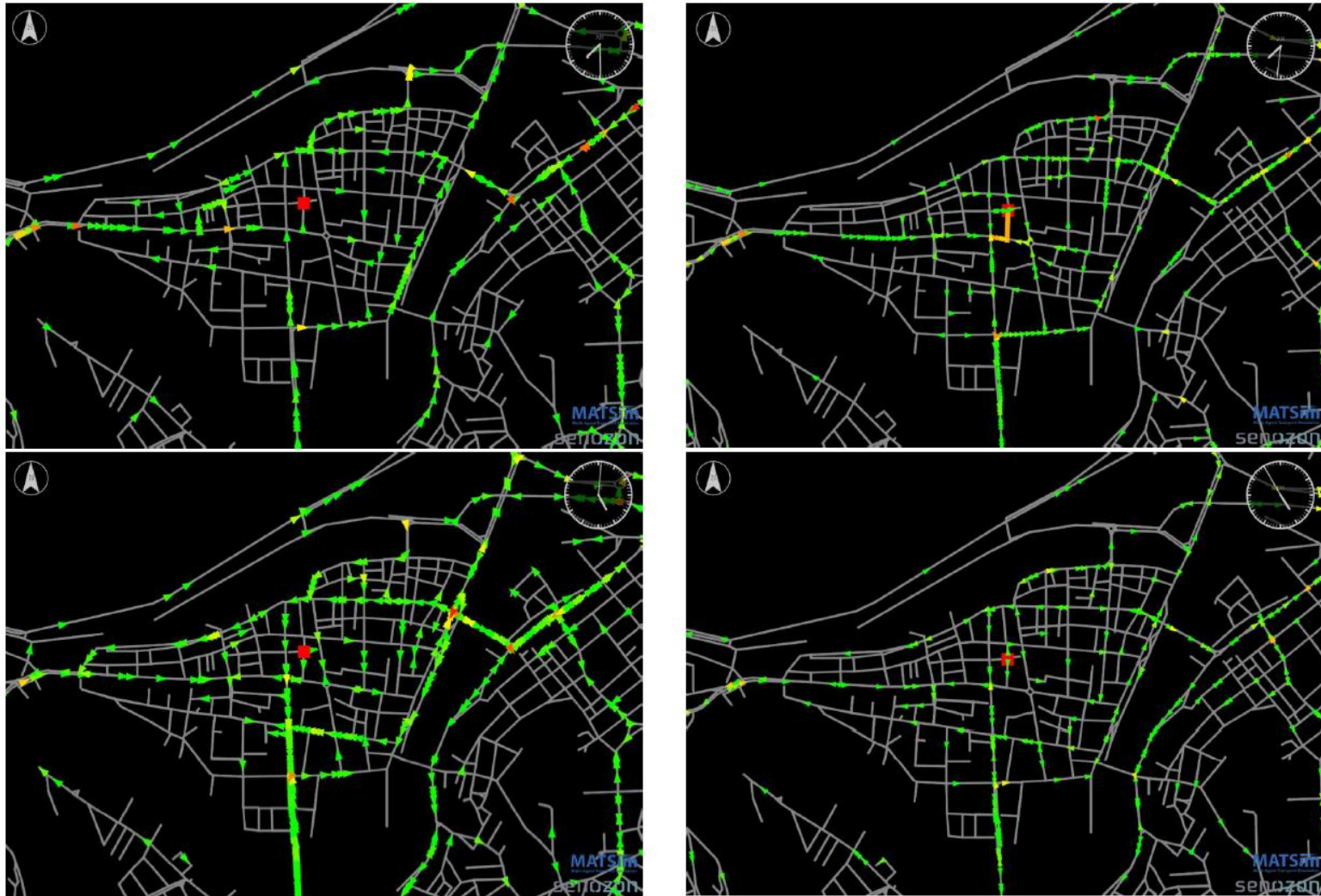


FIGURE 28 The traffic situation during rush hour around the new center city working location
Top left: Center city 7:30am reference scenario // Top right: Center city 7:30am center city with toll scenario
Bottom left: Center city 5pm reference scenario // Bottom right: Center city 5pm center city with toll scenario

Once again slightly more traffic is visible around the new location. However, compared to the previous this is less pronounced. Obviously this is to be expected due to the lower increase of traffic in the center city in this run.

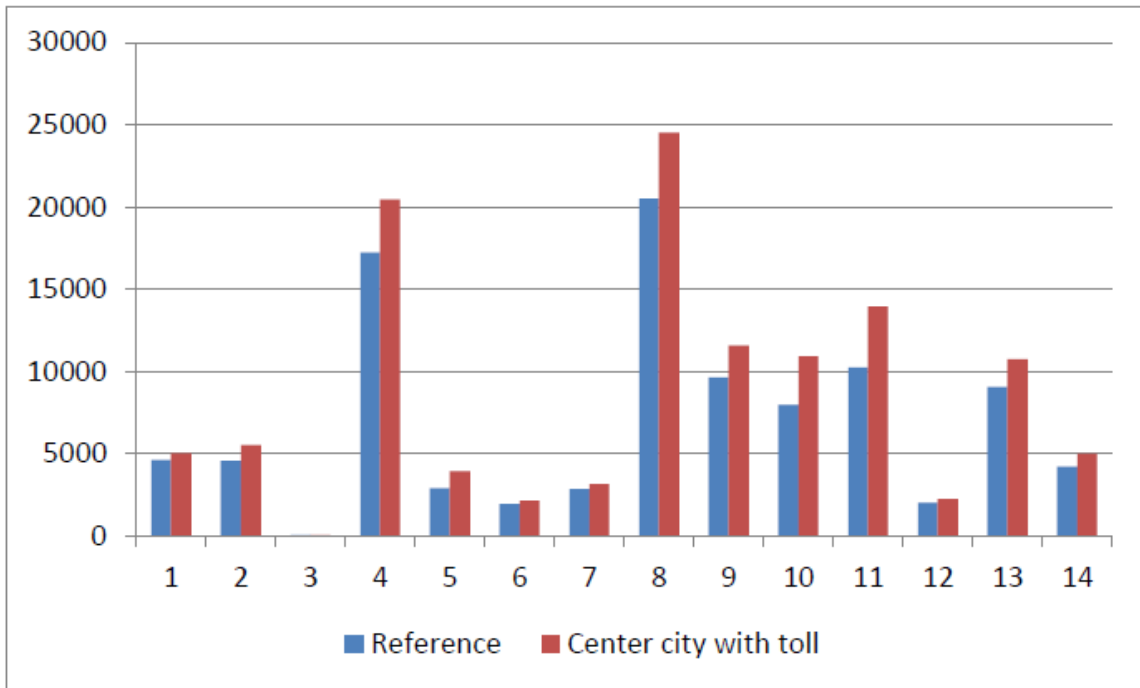


FIGURE 29 Comparison of traffic intensities on roads leading to the center city

Although not really visible on the map, there appears to be a clear increase when comparing the number of cars passing the new toll links of this scenario with the reference scenario. Although there is a toll on all of the links, the added work locations do still attracts a lot more cars. Due to the modal split of the new agents being shifted more towards the car this is even more present.

10.6. Non-central new work location

The second scenario a new work location with 10.000 places will be created on the right bank of the river. This location is in the middle of the city in general as can be seen on the map below.



FIGURE 30 Map of Trondheim with the new working location in the right bank region

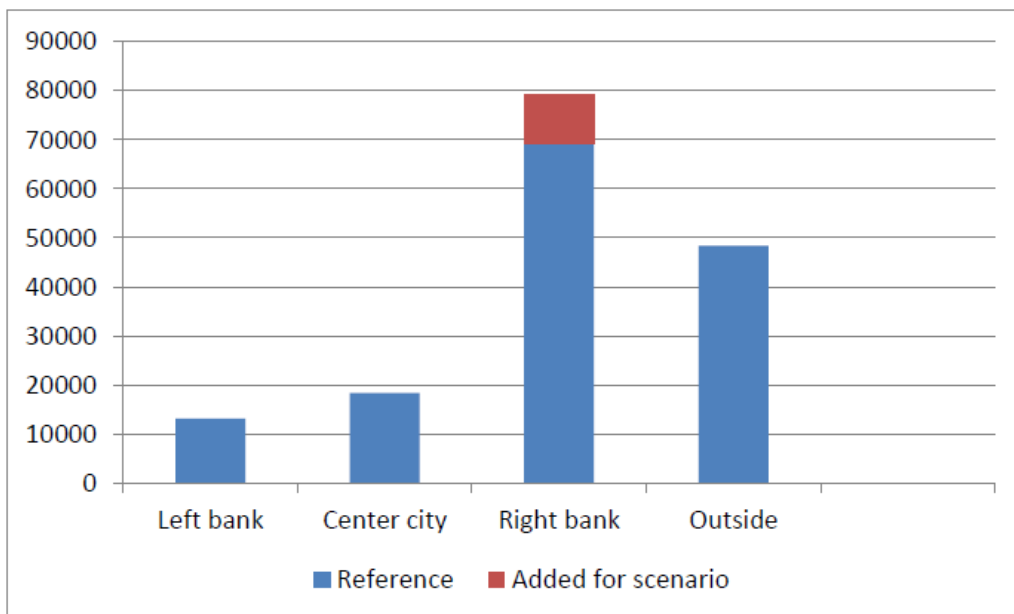


FIGURE 31 The number of working locations per region and the addition

This location is outside of the toll ring from the previously described toll ring scenario. As before two runs will be done. One without the toll scenario and one with the toll scenario. It is to be expected that this time the scenario with the toll ring will have a bigger attraction to the new location. This is because the working places within the city center will be less attractive because of the toll.

10.7. Without toll scenario

As before the scenario is run similarly to the reference scenario. Obviously the difference is again that agents can switch their work destination to a new location. This time 10.000 new workplaces are available in the beginning on the right bank side. Later on, as before, as people change their destination their original workplaces become available for others. Per iteration 5% of the agents is given the chance to change their destination choice. The resulting plans after 200 iterations, divided by region and mode choice can be seen below.

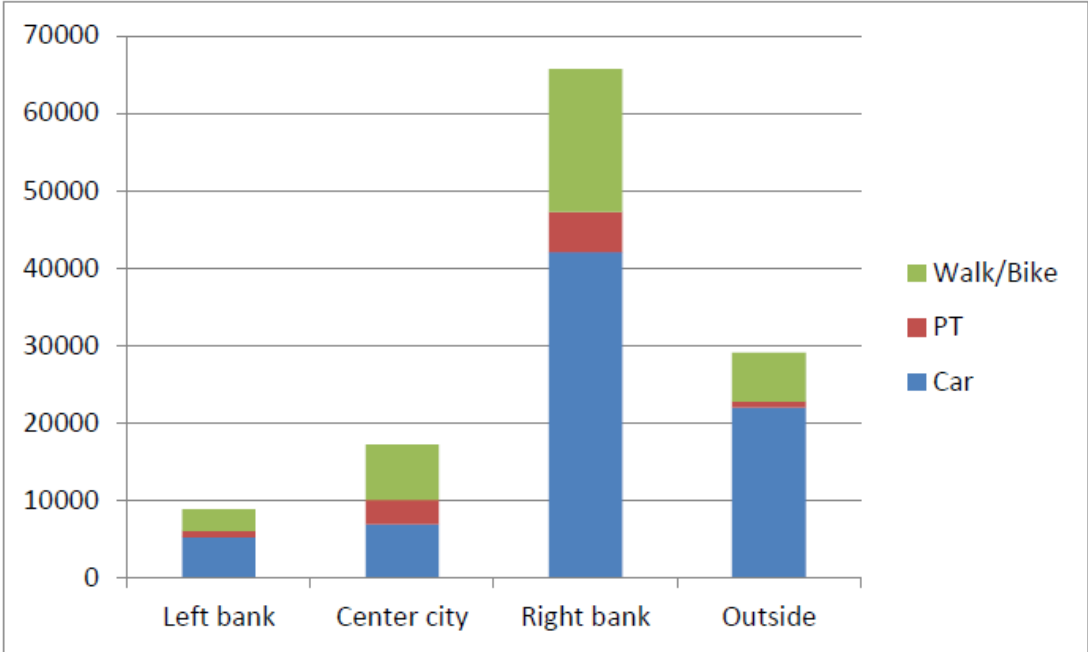


FIGURE 32 The number of work related trip to a region per mode for the right bank without toll scenario

As in the previous simulations the overall distribution of trips is the same as the reference scenario. There is however a visible increase of work activities on the right bank. Unlike the previous runs there is no clear indication visible as to which regions lost a lot of attraction.

Right bank without toll				Reference				
Car	PT	Walk/Bike	Total	Total	Car	PT	Walk/Bike	
5196	778	2862	8836	9144	5248	778	3118	Left bank
6897	3169	7084	17150	17962	7108	3564	7290	Center city
42068	5173	18417	65658	62672	40251	4726	17695	Right bank
21945	770	6368	29083	30949	23499	822	6628	Outside

FIGURE 33 Comparison of the number of trips per region and per mode between the right bank without toll and reference scenario

A similar view can be seen in the above table. While there is a decent increase of 2986 trips towards the right bank, the decreases are somewhat spread between the other regions. Surprisingly the outside region decreases the most and not the center city which has a lot of congestion.

As for the modal split the differences are less explicit. The original modal split in the right bank region was already 64% for the car. The new trips have a 60% car share, but because of the small amount they do not change the modal split by much. Comparatively the PT share of the changing trips is much higher. This will be discussed further later in this report.

As can be seen below, in this scenario the area around the new location on the right bank has clearly more traffic than the reference scenario. Especially during the morning rush hour the streets in the north leading towards the location have a higher number of cars.

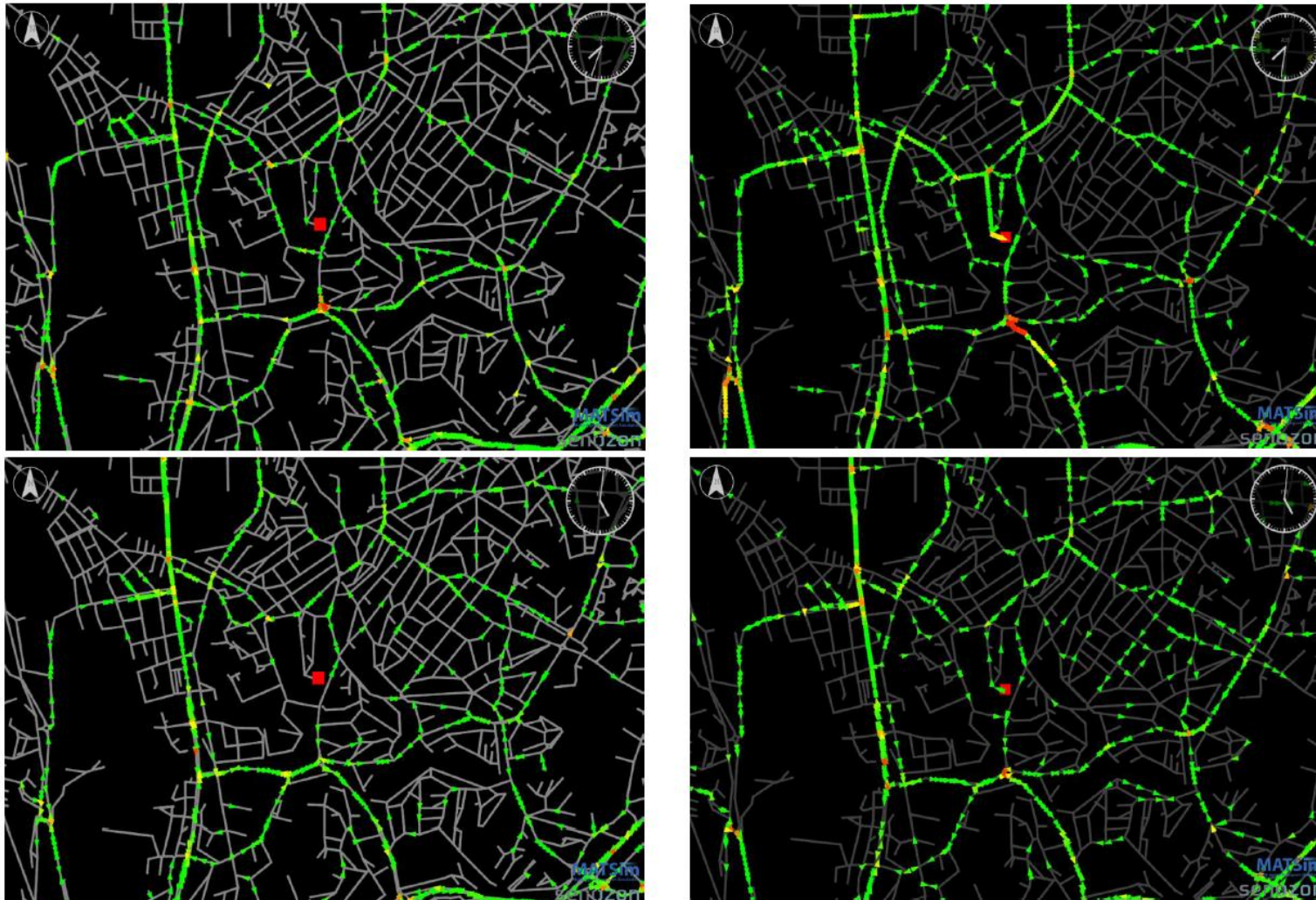


FIGURE 34 The traffic situation during rush hour around the new right bank working location
Top left: Right bank 7:30am reference scenario // Top right: Right bank 7:30am right bank without toll scenario
Bottom left: Right bank 5pm reference scenario // Bottom right: Right bank 5pm right bank without toll scenario

10.8. With toll scenario

Finally the last scenario is run. This simulation is the same as the previous one, except for the toll scenario to be added again. The same toll, ..., has been used again.

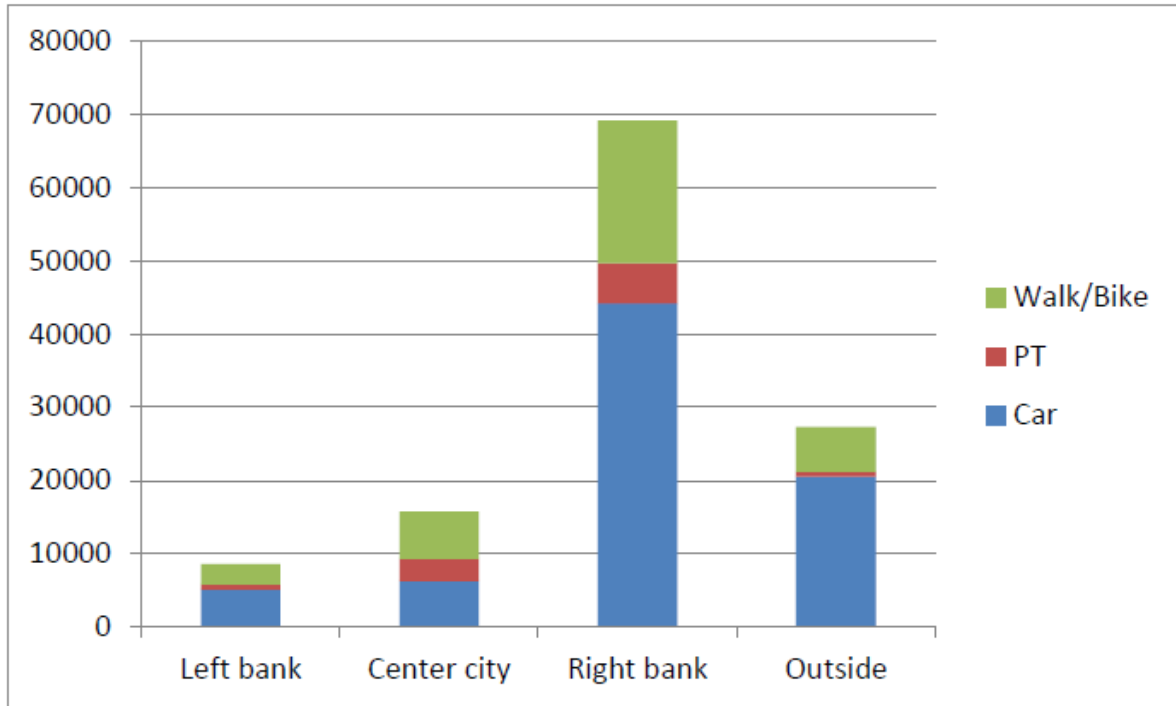


FIGURE 35 The number of work related trip to a region per mode for the right bank with toll scenario

As all the previous runs, the overall view is the same as the reference scenario. Of course there is an increase of work trips towards the right bank. Now there is a more visible difference in the outside and center city, while this wasn't as explicit in the previous simulation.

Right bank with toll				Reference				
Car	PT	Walk/Bike	Total	Total	Car	PT	Walk/Bike	
5146	677	2760	8583	9144	5248	778	3118	Left bank
6272	3012	6487	15771	17962	7108	3564	7290	Center city
44139	5537	19432	69108	62672	40251	4726	17695	Right bank
20549	664	6052	27265	30949	23499	822	6628	Outside

FIGURE 36 Comparison of the number of trips per region and per mode between the right bank with toll and the reference scenario

The results are clearer in numbers. There is an increase of 6436 work trips towards the right bank. This is remarkable increase compared to the previous simulation. Partially this can be explained due to the toll ring and agents not going to the city center anymore. On the other hand there is also a decrease visible for the outside region and the left bank, which is more surprising. A possible explanation is a shift from agents. This means agents changing from the

city center to the new location in the right bank region. Next agents who go to the left bank or outside region might have changed to the city center again.

For the modal split a very similar situation with the previous run is visible. The modal split for the car is already quite high with 64%. The new trips have a modal split of about 60%. However this time due to the bigger number of new trips there is a slightly bigger difference visible, not enough to be significant though.

On the figures below the traffic situation around the new location clearly shows the increased traffic. Since the location is in an environment with only low capacity roads a traffic jam has formed during the morning rush hour. All bigger routes leading to the new location also notice increased use as agents look for the fastest way.

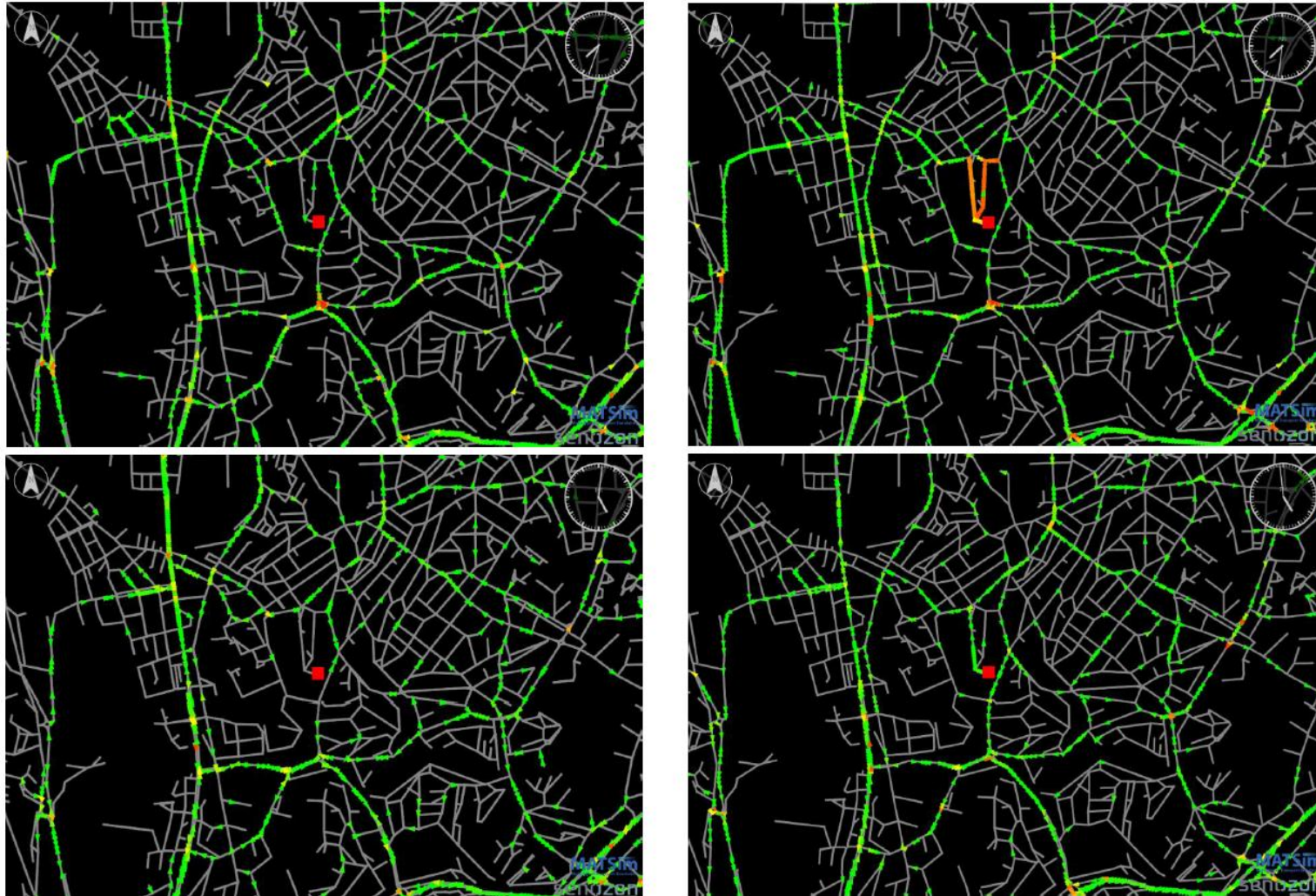


FIGURE 37 The traffic situation during rush hour around the new right bank working location
Top left: Right bank 7:30am reference scenario // Top right: Right bank 7:30am right bank with toll scenario
Bottom left: Right bank 5pm reference scenario // Bottom right: Right bank 5pm right bank with toll scenario

10.9. Overall comparison

Overall it is visible the replanning module works like it should. The agents are switching their plans towards the new available location. While in none of the simulations all 10.000 possible places were filled, there is most likely some switching to previously occupied location as well.

The goal of switching for the agents is of course to maximize their score. Changing their destination helps in this regard. A reduced travel time allows for more time to be spent doing an activity and thus get a higher score. This is visible in the average travel time for the entire simulation.

Scenario	Avg travel time
Reference	15:40
Center city without toll	12:28
Center city with toll	12:24
Right bank without toll	12:23
Right bank with toll	12:39

FIGURE 38 Comparison of the average travel times per scenario

The reference scenario has a clear higher average travel time compared to any of the scenarios. The scenario with the new working location in the right bank region without the added toll around the city center has the lowest average travel time. This is quite logic as the right bank location is the most central and can thus be reached by more agents. It is still slightly better than the same scenario with toll as in the toll scenario congestion leading towards the new location was visible. Too many agents wanted to switch reducing the total average travel time as a result.

Adding the toll has the reverse effect on the scenarios with the new work location in the city center region. Here the added toll ring around the city center causes agents to spread out more to other places outside of the city center. Due to this spread less congestion is created going to one specific place, the new work location.

Central city without toll	Central city with toll	Right bank without toll	Right bank with toll	Reference	
8937	9040	8836	8583	9144	Left bank
27530	22297	17150	15771	17962	Center city
57187	59445	65658	69108	62672	Right bank
27073	29945	29083	27265	30949	Outside

FIGURE 39 Comparison of the work related trips to a region per scenario

In the above table a comparison is made between the amount of work related trips for the various scenarios and regions. The trends are quite obvious. The left bank and outside region always seem to lose some agents as they change to the new work location. Also surprising is the fact that in the right bank with toll scenario more agents move away from the left bank and outside regions although the toll most likely does not influence their trips. It is likely they switch to one of the new free locations in the center city over the course of the iterations.

In the end, the tests show the module works well. Unfortunately it is still needed to work with a pre-filled agenda for the agents as no new activities can be added between iterations at the moment. This means it is still required to have some data to start with.

With a good dataset this addition might be capable of calculating more realistic traffic pattern compared to extrapolated survey data.

11. CONCLUSION

11.1. Activity-based modelling

Overall, as technology evolves, activity-based models have a good chance of developing beyond the capabilities of trip-based models in the future with the same calculating. This is required as trip-based models ignore a lot of social behavioral factors. The downside of activity-based models is the fact that they are still less developed and their computational needs. Both are getting improved rapidly the last decades.

11.2. Land-use and traffic modelling

Land-use and traffic have always been linked together. Unfortunately this link is not as easy to achieve in planning and modelling. The very probable reason for this is the difference in timescales. Where traffic is usually more fluid and fast changing, land-use is more rigid and major changes only happen over the course of years or even longer.

An in-between solution would be possible with MATSim. When creating a scenario a land-use model can be used to determine the most likely regions where changes in land-use will take place. This information can then be added to MATSim using the facilities to calculate the traffic pattern for one day.

11.3. Analysis of results

The facilities file works like it should within MATSim. It allows the agents within the model to switch their destination location to a free facility somewhere else. This changing improved the agents' scores by reducing the travel times. This means more time is available for actual activities which increases the score.

In the simulation a clear decrease in the average travel time is visible when compared to the reference scenario. Between the various scenarios smaller, logical differences can be observed.

Unfortunately it is still needed to work with a pre-filled agenda for the agents as no new activities can be added between iterations at the moment. This means it is still required to have some data to start with.

12. DISCUSSION

Unfortunately not all research questions could be answered within this report. Due to some technical difficulties with the coordinates in the land-use database only dummy data were used. While this does not invalidate any findings, it did prevent any comparisons with real-world counting data; both the counts data from the tunnels in the region as well as the statistical data about location of working places. This might have given useful information as the goal of any traffic simulation is to predict the real world as close as possible.

Also the MATSim as a program is still not a complete package like some commercial programs. This creates both the opportunity to program any possible scenario and analysis wanted and some holes which makes some analysis can't be done. In theory anything can be calculated, but only when enough knowledge of programming and MATSim is present.

For instance at the moment it is not possible to have agents add or remove legs to their agenda. As a result, an agent without a pre-filled agenda will not be able to do any other activities during the simulation.

Right now building a model in MATSim is a very time consuming effort. Between the programming knowledge, knowledge of MATSim's coding and the calculation times building a model might not be worth the time and price for smaller projects. Further development can be very promising however, as a full model allows a fast prediction of the effects.

Further research can be oriented to filling some of the gaps in MATSim's possibilities and creating a more user-friendly environment. This can allow, for instance, smaller municipalities to make use of the program for their own projects.

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Datum: **21/08/2015**