Supporting policy analysis in the Dutch rail sector using System Dynamics

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With a sizeable expected growth of demand for rail transport in the Netherlands in the coming decades, and limited resources for expansion of the rail network, intensified utilization of the infrastructure is to be expected. To adequately manage this growth, appropriate tools for policy analysis are needed. The possibilities and pitfalls of using System Dynamics for policy analysis in the Dutch rail system have been explored by performing a modelling study into the interrelations of modal split, mobility and operations using System Dynamics. Additional scrutiny is placed on the method, because of the unstructuredness of many problems in the rail sector, and decision-making in a network type environment. Results show that the reliability of infrastructure is a major component in the extent of delays. Furthermore, the effect of unreliability in a train trip and the characteristics of a car trip are important for the choice between train and car. Although classical policy analysis has proven to be possible, modelling the operational part of the system has proven challenging due to the spatial and discrete characteristics of parts of the system. Recommendations are given to improve the model and model use to better suit the unstructuredness of the problems.

Keywords: Rail System, Netherlands, Policy Analysis, System Dynamics

1. Introduction

The Netherlands has one of the heaviest utilized railway networks in the EU (CBS, 2009). In 2006, trains travelled over 135 million kilometres on the network. This traffic is mainly generated by passenger trains, which account for 80% of all reserved train paths. Combined passenger and freight train paths total around 2.5 million each year (ProRail, 2011). All this is done on a network which in 2004, was only 2,796 km long, and which consisted of 6,517 km of track. The Dutch railway system is very complex, due to its heavy utilization and network design (ECMT, 2005), organizational and institutional arrangements (Tijdelijke Commissie Onderhoud en Innovatie Spoor, 2012), and number of stakeholders (ProRail, 2011).

In the Netherlands a lot of train movements take place on a relatively small network. Additionally the structure of the rail network in the Netherlands adds to the overall complexity. The network can best be described as having a polynuclear structure, with several cores. This creates a criss-cross of traffic between and inside agglomerations (Nijman, 2012a, 2012b). To complicate matters more, both local and intercity trains operate on the same network. They must share the same infrastructure, complicating operations further. First of all, local problems can spread through the network because of local and intercity trains influencing each other. Secondly local trains have a lower average speed than intercity trains. Speed differences on a railway track severely influence the capacity of the track.

The coming decade a further growth of traffic is expected, and the rail infrastructure manager of the Netherlands, ProRail, has set itself the goal to increase the capacity of the network by 50% in 2020 (ProRail, 2012). With only limited financial resources and an already complex network the goal is to achieve this increase in capacity by more efficient planning and scheduling of railway traffic (MinIenM, 2011). Measures to increase capacity through heavier utilization of the network can harm the robustness of the network. Both may be achieved, but at a very high cost. The real challenge therefore is striking a new balance between capacity, costs and robustness.

Policy Analysis and the resulting decision making process takes place in an environment which can be described as a network. The rail sector in the Netherlands has a separation of infrastructure manager and train operators. These organizations are independent of the Ministry of Transport, although the ministry has the tools and obligation to steer the sector.

The Dutch railway system is complex in many ways: whether you look at the technical infrastructure, organizational layout, operational planning, (number of) actors (i.e. stakeholders) involved, goals to be reached or decisions to be made; all of these are complex in themselves. Due to the high interdependence of all these parts the overall picture is even more complicated, and in this environment sound decisions have to be made.

Further muddying the waters is the fact that when looking at the policy problems facing the railway system, these problems can only be described as unstructured. Unstructured problems are defined as problems where there is no consensus on values and neither a consensus on knowledge (Hisschemöller, 1993; Hisschemöller & Hoppe, 1995). Although the main actors are all invested in delivering the best train services possible, the definition of this value ‘best’ may vary. Any policy will be a trade-off between these values, and all of these values will be weighted differently by the actors.

For analysing and designing policies in this complex system the System Dynamics (SD) methodology can be used. It supports not only the design of policies themselves (Forrester, 1961), but can also help understand the complexity of a system. Additionally it can also be used in a multi actor environment to communicate about findings and for collaborative analysis and design. Enhancing learning about complex dynamics systems is one of SDs major purposes (Sterman, 2001). This can be done by qualitative analysis of models, but also by using simulation to show users the effects of their decisions. Feedback is not only used in the models themselves, but is central to the methodology.

2. Approach

The goal of this research is to explore the possibilities of System Dynamics to better understand the complexity of the Dutch railway system, by modelling the relationships in and between sub-systems. This understanding will have to be used and communicated in a complex multi-actor setting when designing policies.

The use of SD modelling in the rail sector has mostly been limited to the modelling of vehicles and vehicle interactions. In the last three decades four studies have been performed into the dynamic effects of the overall railway system. These focussed on: the effect of maintenance on performance (Gottschalk, 1983); strategic management with a focus on competitiveness with regard to maintenance and investment strategies (Schmidt, 1989); a strategic planning model (Homer, Keane, Lukiantseva, & Bell, 1999); and a study of the performance of the Indonesian railways (Lubis, Pamungkas, & Tasrif, 2005).

In light of the limited literature on SD for analysis of the rail system, an SD simulation study was undertaken to experience first-hand the pros and cons of using SD for analysis of the rail system. This was done by modelling the relations between traveller choice of transport modes and the effect this has on the operations on the network. The SD approach to this problem facilitated a structured approach to system analysis, identification of the feedback structure of the modelled system, evaluation of uncertainty and identification of directions for further policy analysis.

The model itself, the results of qualitative and quantitative analysis, the modelling process and the results of validation and verification have been used to evaluate the usability of SD for policy analysis in this specific case. Recommendations will be given on how the SD methodology can be used for policy analysis in the Dutch rail sector.

The article is structured in sections as follows. Section 3 describes the conceptual model of the railway system and the most important concepts that have been included. In section 4 the implementation of the model is discussed as well as verification and validation. Section 5 discusses the results of simulation and further quantitative analyses. Section 6 discusses the validity of the model in the context of policy analysis in a network environment. In section 7 conclusions will be drawn and recommendations for use of SD in the Dutch rail sector will be given.

3. System Conceptualization

In the model that describes the relations between the choice of travel mode and the operations on the rail network, three distinct subsystems can be found: one that describes the modal split, one that describes demand for mobility and one that describes operations. These subsystems influence each other as depicted in Figure 1. Each of them will be described briefly. After that a distinction between trip types will be made. Finally the overall feedback structure will be presented.

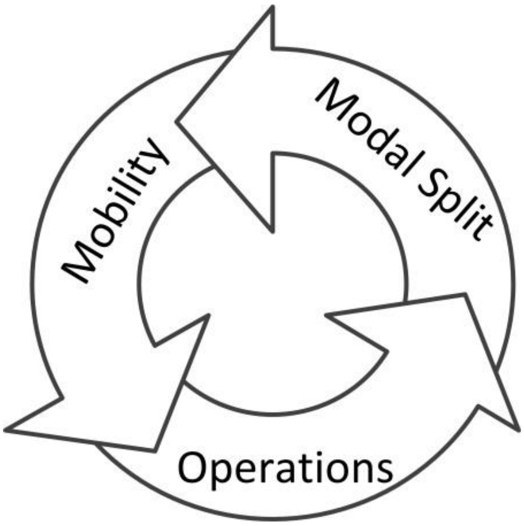

Figure 1: General depiction of interrelations between the three subsystems.

Modal split
Given the distance of trips performed by train in the Netherlands, the car is often the only viable alternative. In the model the modal split therefore represents the ratio between train and car usage for a certain trip type.

When a traveller wants to take a trip, the modes which are available can be seen as products that satisfy this need to a certain degree. The characteristics of a product provides benefits and satisfies needs to varying degrees (Kotler & Armstrong, 2001). Rating of the train service in the Netherlands has revealed ten unique dimensions on which passengers rate a trip (Brons & Rietveld, 2009). The three most prominent characteristics on which trips are rated are: the price-quality ratio, travel comfort and travel time reliability.

The characteristics are operationalized by: determining the monetary costs of a trip; the valuation of travel time; and the costs of unreliability. The monetary costs are determined for a whole trip, including parking costs or costs for access and egress to stations, if applicable. The valuation of travel time is modelled using the disutility travellers experience during a trip, which relates the time spent traveling and the comfort of different part of the trip (Vaessens, Van Hagen, & Exel, 2008; Wardman, 2004). This concepts is graphically depicted in Figure 2. The costs of unreliability in a trip are modelled by determining the rescheduling costs, which are the costs of early and late arrival due to unreliability, and takes into account the tendency of travellers to leave early in order to prevent arriving late at their destination (Brons, 2005). The higher the unreliability, the higher the rescheduling costs will be.

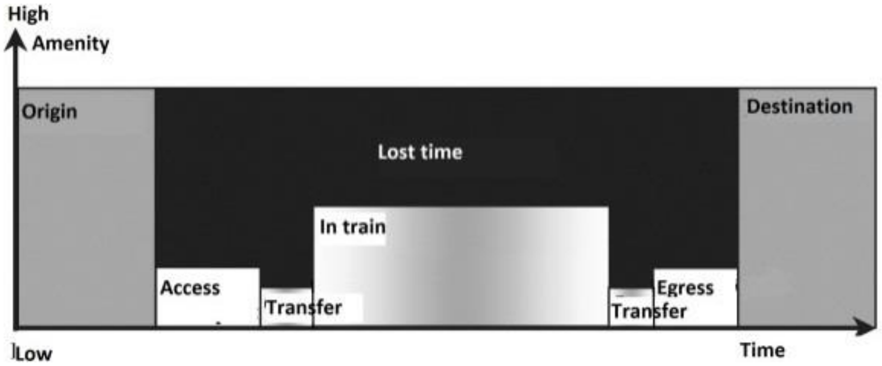

Figure 2: The disutility of time as experienced by a railway passenger. Adapted from: (Peek & van Hagen, 2004)

Mobility

Of the total amount of kilometres travelled in the Netherlands, only a small amount is done by train. Based on the feasibility of making a trip by train three groups can be distinguished: the train is unfeasible (car captives); the train is an option; the train is the only possibility (train captives) (Van Hagen, 2011). Of the trips in which the train is an option, about 9.5% is actually done by train. The distribution of mobility by feasibility is shown in Figure 3.

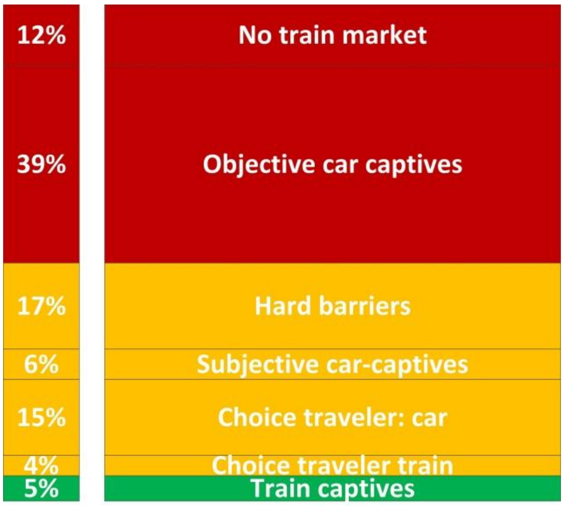

Figure 3: Distribution of mobility in km per year. The trips can either not be done by train (red), possibly be done by train (yellow) or only be done by train (green). Adapted from: (Van Hagen, 2011)

Operations

The demand for transport by rail leads to a capacity requirement which must be fulfilled by train services on the rail network. Additional equipment will lead to an increase of incidents related to equipment. Incidents related to infrastructure are influenced by the quality of the infrastructure. Besides equipment or infrastructure 'other' type of incidents are distinguished, that are often caused by passengers, personnel or third parties. The time needed to recover from an incident and the frequency of the train service determine how many trains are affected by an incident.

Besides these delays that are directly caused by incidents, disruptions will also lead to a spread of delays further through the network, caused by interactions between equipment, personnel or

infrastructure. The amount of secondary delays will increase when the utilization (complexity) of the network increases.

Distinction of Trip Types
The rail network and road network in the Netherlands both have a dual function. They are used to transport people within agglomerations, as well as between agglomerations. For the rail network this means that different types of services have to be offered: local and intercity.

Different trips will have different characteristics. For a long train trip a transfer is, for instance, more likely than for a short trip. The effects of access and egress costs and time will relatively be higher for a short trip than for a long trip by train. The same is true for the parking costs of a car. Furthermore a trip can be made with different purposes such as leisure or business.

In the model a distinction is made between trips performed during peak-hours and between short and long distance trips. This results in four trip types as displayed in Figure 4, each with their own set of characteristics, such as value of time.

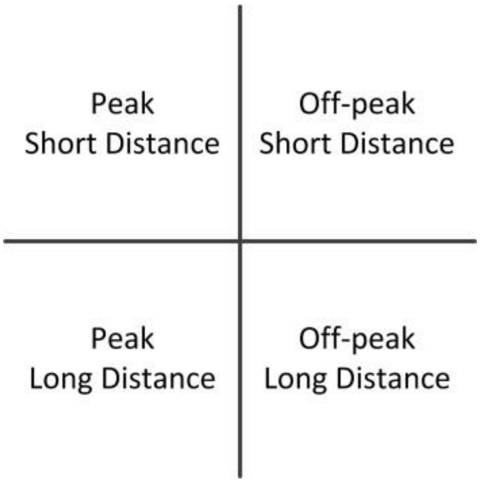

Figure 4: The four types of trips in the model.

Feedback Structure
Analysis of the feedback structure leads to the identification of seven unique feedback loops, as shown in **Fout! Verwijzingsbron niet gevonden.**. Each of the seven feedback loops will be discussed briefly. Feedback loop:

1. Describes the relation between demand for train transport and frequency. A higher demand can lead to an intensified train service. This leads to a higher frequency of trains, limiting the time lost when a connection is missed. In turn this reduces uncertainty about the arrival time, increasing the quality of the service, leading to a higher demand.

2. A higher train frequency will also lead to less waiting for a train to arrive. This will reduce the waiting time at a station between transfers. This will reduce the travel time of the trip by train, leading to an increased quality, leading to a higher demand.
3. Is almost the same as the previous feedback loop. An increased frequency will also reduce the waiting time when arriving at the first station of a trip. This time can have a different time value than time spent waiting in between trains.
4. A higher train frequency will also lead to higher utilisation of the infrastructure. This means that incidents with other trains will have a higher indirect effect, leading to larger delays and waiting time. This will reduce the quality of the service and lead to a lower demand.
5. Another result of a higher frequency, and thus more trains on the network is that the number of trains affected by an incident increases. When part of the network is out of operation for an amount of time a high frequency will mean more trains are impacted by this. This will increase delays and, thus reduce the quality of the service.
6. An increase in required capacity will lead to an increase of equipment in use. As a results of this also the number of equipment related incidents will increase. This will then lead to an increase of total incidents which will lead to an increase of delays and reduced quality of the service.
7. Finally and increase of incidents will also increase the number if trains indirectly affected, further increasing delays and reducing service.

The main conclusion that can be drawn from this causal model is that an increase of capacity through a higher frequency of train services will lead to a decrease of travel time and uncertainty about arrival, but will also complicate operations leading to an increase of delays and thus of travel time.

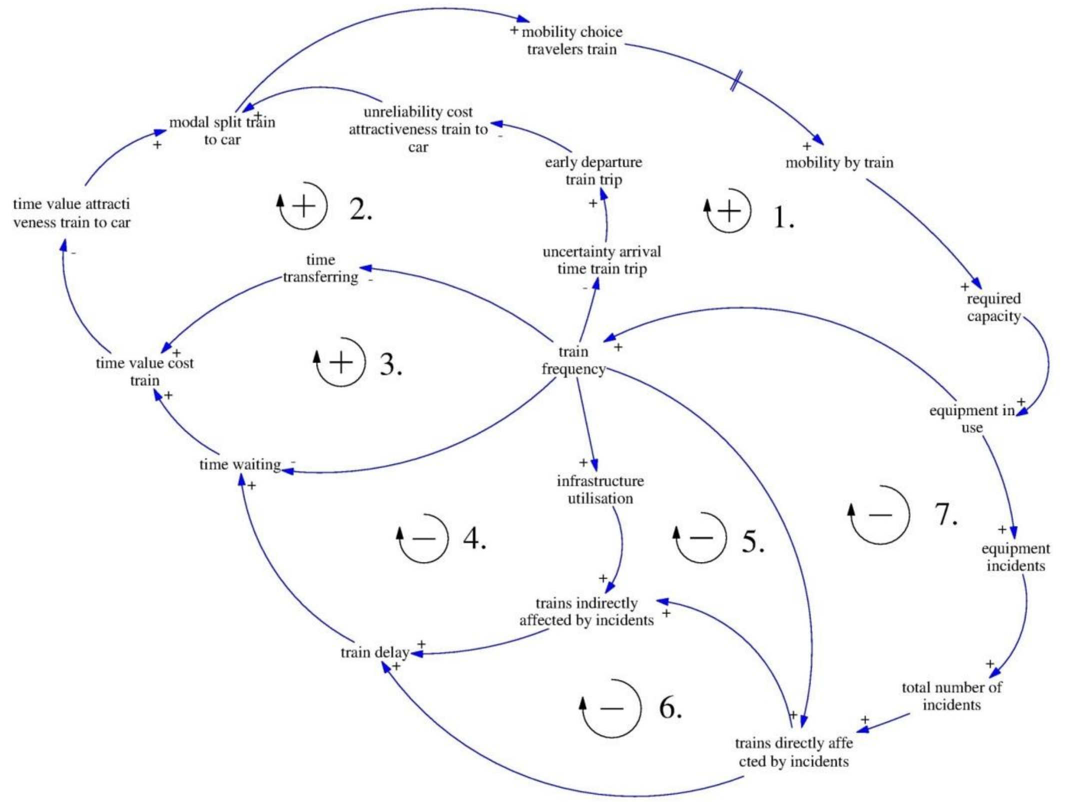

Figure 5: Feedback structure of the conceptual model.

4. Model Specification

The model was implemented in Vensim Professional 6.0. Besides the basic functionality required for the implementation and simulation of SD models, it supports the use of subscripts, which means part of the model can be reused if similar concepts (such as different types of passengers) have to be implemented. A full overview of the model equations and values of constants can be found in Appendix A.

Data on the valuation of travel time and reliability was mainly found in scientific articles. Extensive research on this subject has been performed in the United Kingdom (Wardman, 2001, 2004) and the Netherlands (Tseng, Verhoef, & Rietveld, 2012). Values for variables regarding operations were often found and derived from reports by Dutch Rail (NS) and the network manager (ProRail) that contained information on the network and operations.

Most of the data on mobility was derived from 'Onderzoek Verplaatsingen in Nederland 2011', performed by Statistics Netherlands (CBS, 2011). This dataset provides information on the daily mobility of the Dutch population and contains responses of 37,754 persons. The total dataset contains 127,410 cases which relate to parts of a trip. For these cases 150 variables are defined, which relate to characteristics about household, trip purpose, mode of transportation, departure, arrival, etc. For the purpose of this research this dataset was reduced to trips of interest: namely where car or train were the main mode of transportation. These trips were then categorized into four groups, reflecting the four trip types.

Modal split

For the modal split the cost component was implemented using a simple summation of costs such as ticket price, parking and fuel costs. The value of time (VOT)was determined by the VOT of the parts of a trip. A car trip consists of a single part (the drive), but a train trip consists of time for access and egress, waiting, transferring and in vehicle time. The costs of unreliability were determined by estimating the average early and late arrival of trips, based on a standardised log-normal distribution which is scaled based on the percentage of trip arriving on time and the time at which 95% of the travellers have arrived.

Monetary costs, time value of the trip and the costs of unreliability were traded-off based on a per characteristic basis train vs. car. A non-linear function was used in which large differences between car and train per component have a larger impact than small differences. This equation is presented in Equation 1, with: w_i being the weight for quality aspect i; and q_i being the value of that quality aspect, for train or car; and c determining the effect of the difference of a quality aspect between train and car. This results in quality aspects with a difference between car and train being weighted heavier than quality aspects which are almost equal.

$$modal\ split = \sum_{i \in S} w_i \cdot \frac{{}^{1}/_{q_{i,train}}{}^{c}}{\left({}^{1}/_{q_{i,train}} + {}^{1}/_{q_{i,car}}\right)^{c}}$$

With $S = \{costs, time\ value, reliability\}$

Equation 1

Mobility

The total demand for train transport was determined by the effect of the modal split on the number of choice passengers and the mobility of train captives. To reflect the inertia in travel choice (Chorus & Dellaert, 2009) and the assumption that a change in travel choice is caused by changes in the environment (Van Dalen, 2012), a delay in change from choice car to choice train traveller and vice versa was implemented.

Operations

For the operations the effect of incidents on the operations was estimated based on the causal model describing the links between incidents, primary and secondary delays.

Validation and verification

Validation and verification cannot prove that a model is correct and possible for all possible scenarios, but it can provide evidence (and build trust) that the model is sufficiently accurate for its intended use (Thacker et al., 2004). The model has been evaluated using a wide array of tests as suggested by (Sterman, 2000) and (Wolstenholme, 1989).

The structure of the model and the adequacy of the model were evaluated during separate discussions about it with two system experts. Dimensional consistency of the model and equations was verified, partial model testing was used to test and correct model parts. The presence of integration errors in the numerical results was disproved. Finally an extensive sensitivity analysis was performed on variables and model parts, to evaluate the sensitivity of model results to these parameters and determine the effect of uncertainty in the model. The sensitivity analysis was the main quantitative result of the model. The outcome of this analysis is discussed in the next section.

5. Simulation Results

Because of high uncertainty in the model, variables and structure, the model is not suitable for predicting and forecasting. Therefore the model was used for a structured analysis of the effects of uncertainty and sensitivity on the model results.

The univariate sensitivity analysis performed allows for a structured comparison of the model outcomes. When the model is sensitive to a variable or component of the system this can lead to two conclusions, or a combination thereof: (1) That variable or component of the system can be used to design a high leverage policy; (2) Because of the impact of this variable or component, uncertainty surrounding it must be reduced in order to improve the validity of the model. Whether conclusion one or two applies will depend on whether this component or variable can be influenced by stakeholders in the system and how much is known about this component, qualitatively and quantitatively.

Base Run

The results of the base run show a stable system, where the increase of train travel can be explained by the overall increase in demand for mobility. The modal split increases only slightly in favour of train travel, caused by an improvement of the quality of a train trip because of higher frequency services to deal with the increase in demand. The results of four of the key performance indicators of the system are shown in through .

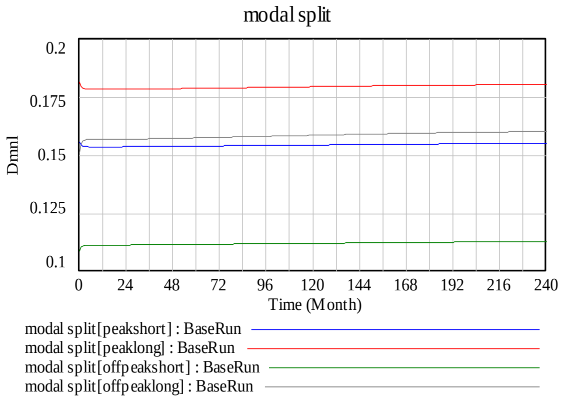

Figure 6: Development of Modal Split over time, per trip type.

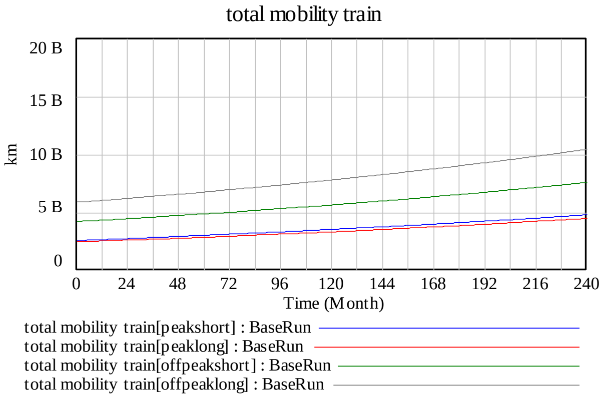

Figure 7: Total passenger kilometres travelled per year by train.

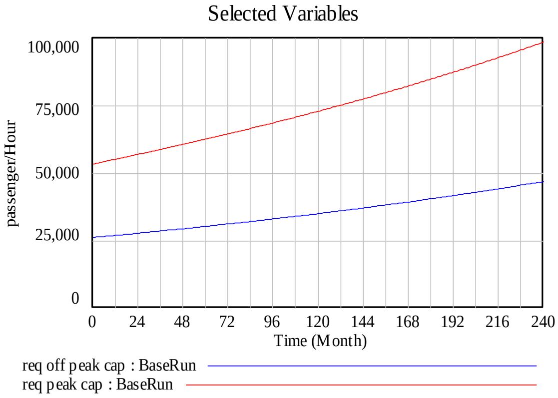

Figure 8: Required capacity in passengers per hour during and outside peak hours.

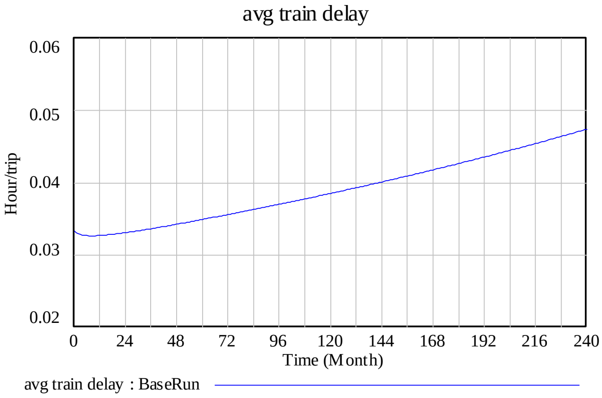

Figure 9: Development of average delay per train.

Sensitivity Analysis

For the sensitivity analysis 43 constants or variables were selected, that were of interest because of uncertainty about their values, because they can be influenced by actors in the system or because they represent a component of the system about which uncertainty regarding the structure exists. 21 variables were selected as criteria that indicate the performance of the main components of the model: modal split, mobility and operations. This resulted in 86 model runs, with their respective results combined in a single spreadsheet.

The model results were compared to the base run. When a 10% change of a variable resulted in a change of more than 10% for one of the criteria, this criterion was considered sensitive to that variable. A histogram of the results of the sensitivity analysis can be found in Figure 10. The results of this analysis have been grouped into four categories: external factors; reliability; effects of demand; and the trade-off function. The numerical results of the sensitivity analysis can be found in Appendix B.

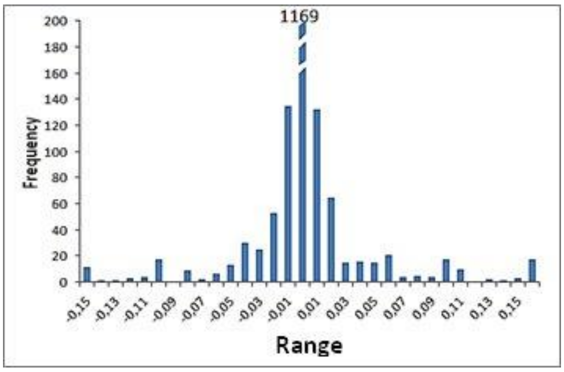

Figure 10: Distribution of results of the sensitivity analysis.

RELIABILITY IMPORTANT FACTOR IN MODAL CHOICE COMMUTE

Rescheduling costs during peak hours have the most impact on the total kilometres travelled by train in the sensitivity analysis. Additionally the modal split and passenger kilometres travelled by train is also sensitive to the predictability of train arrival times. The reliability ratio of the car compared to the train is too high outside peak hours to have effect, but during peak hours the train is a better match. Improvements of reliability will therefore mostly lead to increased usage of the train service during peak hours.

EFFECTS OF INCREASED DEMAND: MORE TRAINS LEAD TO HIGHER AVERAGE DELAY

Analysis of the feedback structure of the conceptual model in Section 3 already suggested that an increase in demand will have an impact on the performance of the rail network due to increased complexity of operations if the frequency of train services was increased. This was confirmed by the sensitivity analysis.

Growth of mobility leads to more train usage at the cost of more delays

The growth of mobility leads to an increased usage of the train for transport, but this is reflected in an intensified utilization of the rail infrastructure. The increase of the number of trains will lead to more incidents, and increased spread of delays. This will lead to an increase of the average delay of trains, curbing demand. This increase of delay and its effects can be explained by the causal model, namely loop 4 to 7 describing the relations between increased frequency and equipment usage and (in)direct incidents, infrastructure usage and delays.

Infra reliability and repair time major influence on average delay

The reliability of the infrastructure and the time needed to restore it in case of incidents is a major factor in determining the average delay. This is becomes more and more important when the frequency of trains is increased because it affects more trains and spreads more through the system.

TRADE-OFF FUNCTION VERY SENSITIVE TO VALUATION OF DIFFERENCE BETWEEN QUALITY ASPECTS

The overall model performance is very sensitive to the parameters of the trade-off function. This function is also one of the softest parts in the model. It represents a generalization of human behaviour. The way the trade-off of quality aspects are modelled can be seen as the most important part of the system in terms of influence it has on model outcomes and because uncertainty about the real-world decisions allow for different trade-off functions.

EXTERNAL FACTORS: QUALITY CAR TRIP IMPORTANT FOR ATTRACTIVENESS TRAIN
The external factors are variables that are determined outside the railway system and on which the stakeholders in the system have little to no direct influence. For most trips the choice is between taking the train of the car. It is therefore no surprise that characteristics of the car trip are important for the usage of the train service.

Raising speed limits leads to increased competition for the train outside rush hour for long distance trips
Increase of the average car speed will lead to increased competition for the train, especially on long distance trips performed outside rush hours. Since there will be little to no traffic jams outside rush hours, the main cause for this would be a raise of the speed limit.

Improvements of predictability of car arrival times will lead to reduced train usage
The other major car related factor that affects the modal split is the reliability of arrival time. If this reliability increases further this will negatively affect the portion of train users for all trip types. Improvements of the road networks, local, regional or national, that lead to an improvement of the predictability of a car trip will negatively influence train usage.

Time value of access and egress important for short distance trips
A change in the value of time of access and egress costs will lead only lead to a significant improvement of short distance train trips. This can be explained by the fact that in a short distance trip the ratio of access and egress time to in train time is much higher than for longer trips.

6. Value and Validity of the Model Analysis in a Complex Dynamic Network

Because of the separation of operations, management and oversight in the Dutch railway system, decision making will require the cooperation of stakeholders. The policy analysis and decision making process become even more complex when taking the institutional arrangements into account. None of the stakeholders is able to impose their own will upon the others. Any collective decision will therefore be the result of a process of consultation and negotiation, which allow actors to use all sorts of strategies to maximize their influence on the final decision (de Bruijn & ten Heuvelhof, 2002).

The decision-making also takes place in an environment that corresponds to the definition of a network: the stakeholders are interdependent, unable to impose their own problem definition, aims and information on others and not able to make a unilateral decision (de Bruijn & ten Heuvelhof, 2002). This poses a threat to a decision making process when the problems involved are contested and unstructured. De

Bruijn and ten Heuvelhof also list four main reasons why a policy analysis may not be authoritative in a network environment:

1. The quality of the analysis;
2. Stakeholders do not understand the analysis;
3. Stakeholders do not commit themselves to the way the analysis is carried out and therefore do not commit to the results;
4. The analysis does not match the game playing during the decision-making process.

The main remedy for the first reasons is improvement of the analysis. For the other reasons the main remedy involves improving communication about the analysis and improving interaction between the analysts and the stakeholders. In fact, inadequate communication between policy analysts and policy actors is one of the reasons for the limited impact that policy analysis has on policy making (Geurts & Joldersma, 2001).

In the following paragraphs methods will be discussed that can improve the validity of the analysis and the value of it to the decision making process. This will be done by discussing the ways the model can be improved, what knowledge gaps should be addressed, and how policy actors can be involved.

MODEL IMPROVEMENTS

Improving the model can be achieved by expanding the model boundaries and adding additional components to the model structure. Adding these components can help by improving the quality of the analysis because of the inclusion of additional feedback loops. Inclusion of concepts and models that are not yet in the model, that are deemed important by stakeholders, can also help convince them of the validity of the model.

Also during development of the model some concepts were implemented using the SD methodology that would be easier to represent in a different type of model. This resulted in a very complex structure of that part of the model. A hybrid combination of multiple modelling methods could help improve the validity of the model by providing more accurate results, but also reducing the complexity of the SD model.

An example of this is the calculation of unreliability of arrival times in a chain of transport modes: the effect of the unreliability of the arrival time of a train was used to determine the unreliability of a trip. Due to limitations of the SD approach and the simulation package, this was modelled using a single arrival distribution which values would be determined based on the probability of making a connection. This resulted in a distribution that would have the same properties of the distribution of arrival times for a trip, but would not take into account specific characteristics of such distributions such as the impact of service frequencies on delays when a connection is missed. During development of the SD model, a very simple model of arrival distribution was developed in an Excel spreadsheet. This model was used to calibrate a generalized version of the arrival distribution in the SD model. The spreadsheet model however did represent the actual distribution for a trip under specific conditions more naturally than the one in the SD model. It could however not be directly used in the SD simulation because the conditions would change over time. Implementing the simulation model in a package that would allow the import and export of values during simulation and the execution of other programs would allow the coupling of the model for policy analysis to specific and detailed models that could better represent the operational effects of policies.

RESEARCH KNOWLEDGE GAPS

During the modelling process knowledge gaps were encountered that limited the validity of parts of the model. Additional research into the these specific areas is required before the model can be improved to better reflect the real world system and thus improve the validity and authority of the model.

Trade-off Function

During sensitivity testing of the model it was found that the model results were very sensitive to the trade-off function itself, as well as the aspect of how heavily large difference are weighted. To improve the validity of the model it is suggested that more research is performed in determining which kind of trade-off function is most appropriate for the model. This trade-off function would have to take into account the modularity of the model, which supports adding any finite number of trade-off aspects by trading off the train to car values per quality aspect, to allow a weighted averaging regardless of the unit the quality aspect is measured in.

Effect of Utilization on Reliability

In the model increased utilization of the infrastructure results in an increase of delays because incidents affect more trains and because of smaller buffer times they spread more easily through the system. The effect of increased utilization of the network was not linked to an increase in unreliability of the arrival times of trains. The sensitivity analysis of the simulation model revealed that the model results were significantly influenced by the reliability of arrival times. Although the effects of unreliable train services on customer satisfaction has been the focus of many studies, quantification of the effect of operational aspects on the reliability of arrival times has not. A statistical study of the operational results of rail networks or a simulation study of such a system could improve the quantitative insight in this relation.

Trip Data

The parameters that were used for description of different trip types were extracted from the OViN database (CBS, 2011). Most of the trips of the database concerned car travel, and although the results were weighted for the frequency of trip types this posed some problems during implementation. For example the number of long distance trips was very limited, which may result in unreliable averages for the trip types. Furthermore some data such as the average speed had to be calculated from the data based on departure and arrival times and the distance travelled. The results of the model could be improved if more specific and reliable data was gathered tailored to the data needs of the current model.

INVOLVE POLICY ACTORS

To improve the authority of a policy analysis, resulting in trust in and acceptance of the results, interaction and communication between the analyst and the stakeholders is very important. Furthermore, most of the insight in a complex system is generated in the modelling process itself. Involving stakeholders can thus not only result in increased acceptance of the system, but also in enhancing the understanding of the actual decision-makers in the system.

In participatory policy analysis the focus is on the network perspective in policy making. It focusses on improving the process of communication between the policy analyst and the stakeholders in the network. The emphasis in this process is not on providing an analysis of policies options, but on increasing the problem solving capacities of the stakeholders. It is directed at improving as well as integrating the mental models of different actors in a policy network (Geurts & Joldersma, 2001).

Two ways of conducting participatory policy analyses using System Dynamics are group model building and gaming. Group model building focusses on integrating divided or subjective knowledge, different views and values, mediation and the generation of a shared system view (Vennix, 1996, 1999). Gaming focusses on improving the understanding of participants of the relation between the structure and the behaviour of the system by means of role-playing and interaction of stakeholders in a simulated environment (Lane, 1995; Geurts & Joldersma 2001). It is often supported by or based on a simulation model.

Both participatory modelling and gaming allow the transfer of knowledge acquired during the analysis to be transferred to stakeholders while avoiding some of the validation problems encountered in a ‘classical’ policy analysis setting. With participatory modelling validity is less important, as long as there is agreement between participants regarding the relations in the model it satisfies its purpose. With gaming key learning concepts identified during the modelling process can still be transferred, in an environment where the results of a formal modelling process will and can be endlessly scrutinized. Participating in a game can also be considered less of an obstacle by participants than committing themselves to the results of a policy analysis. This does not prevent the game from being able to influence the perception of the system, problems and solutions.

7. Conclusions and Recommendations

Modelling the rail system using SD facilitated a structured approach to system analysis, identification of the feedback structure of the system, evaluation of uncertainty and identification of directions for further policy analysis.

Analysis of the feedback structure of the system has shown that a further growth of passenger transport can both lead to shorter travel times and higher reliability of the rail network, but also to an increase of delays due to the added complexity of the operations.

This was confirmed by the quantitative analysis which has shown further that the reliability of infrastructure and the recovery time is a major component in the extent of this delay. Furthermore the effect of unreliability in a trip was quantified and was found to be of significant importance in determining the choice of travellers between the car or train. Finally it was found that characteristics of a car trip such as average speed and improvement of reliability of car travel was of significant effect on this choice. Improvements to the road network could therefore be a threat to the competitiveness of the train.

Because of network type of decision making surrounding policy design for the Dutch rail network, the validity, trust and authority of a policy analysis is very important. Because of the complexity of the system, unstructuredness of the problems and different stakeholders, performing an authoritative and acceptable policy analysis is difficult. The modelling process undertaken for this research has shown that in general System Dynamics can be valuable and is up to this task, but that for modelling part of the operational aspect of the system it is not the most suitable method.

This problem can be handled in three different ways: first as was done in this research, relations can be simplified and represented on a higher level of aggregation. Second the relations can be represented and estimated by using additional methods such intensive modelling and validation supported by experts, performing additional research to uncover empirical evidence to support these relations or perform additional simulation studies to support them. Thirdly more appropriate models or simulation could be coupled to the SD model to better represent these relations.

The high requirements for validity and acceptance of the model, due to the unstructuredness of the problems and the network type decision making, means that the first option is not viable. Simplification of the model would reduce the authority of the analysis and would give ample opportunity to criticize it. Performing additional research or developing additional models to support the SD model would be both costly and labour-intensive. The relative newness of System Dynamics for policy analysis in the rail sector in general, and in the Netherlands in specific might pose a problem to the willingness of making this investment.

Besides the classical usage of System Dynamics for policy analysis it can also be used in different ways, that would better fit with the problem, the environment wherein the policy analysis takes place, and be less costly while still staying true to the main purpose of System Dynamics: enhancing learning about complex dynamic systems. This leads to the following three recommendations for use of System Dynamics for policy analysis in the Dutch Rail Sector:

In the context of a single organization or department System Dynamics can be used as problem structuring method. Modelling of the system has supported a guided search into concepts and interactions, leading to a formalization of the interactions and assumptions about the system. Qualitative analysis revealed important trade-offs and feedback in the system. Implementation of the model revealed knowledge gaps and the need for data essential for any analysis of the system. System Dynamics can be used to research other problems as well and lead to a comprehensive overview and better understanding of the workings of the system.

System Dynamics can be used as a tool in a group model building process. Participatory modelling can be used for the creation of a shared problem perception. The causal diagrams are easy to understand and use, but also allow for representation of a complex system structure. They can be used to structure debate and better understand the effects of feedback. If such a process would result in a shared system view, the conceptual model can then be converted and simulated to allow quantitative analysis.

Because the needs for an authoritative analysis requires substantial research, development and validation of a model for classical policy analysis, this does not mean simpler, less substantiated models developed within one organization cannot be used in a multi actor environment. Many of the findings about the effects of feedback and the need for effective policies can also be represented in a game. This game can be developed based on a causal model, or be supported by a quantified simulation. Due to the nature of gaming the requirements for validity of the model will be less high. Important insights gained from an analysis, such as the importance of reliability in a train trip, can in this way still be conveyed to policy makers.

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