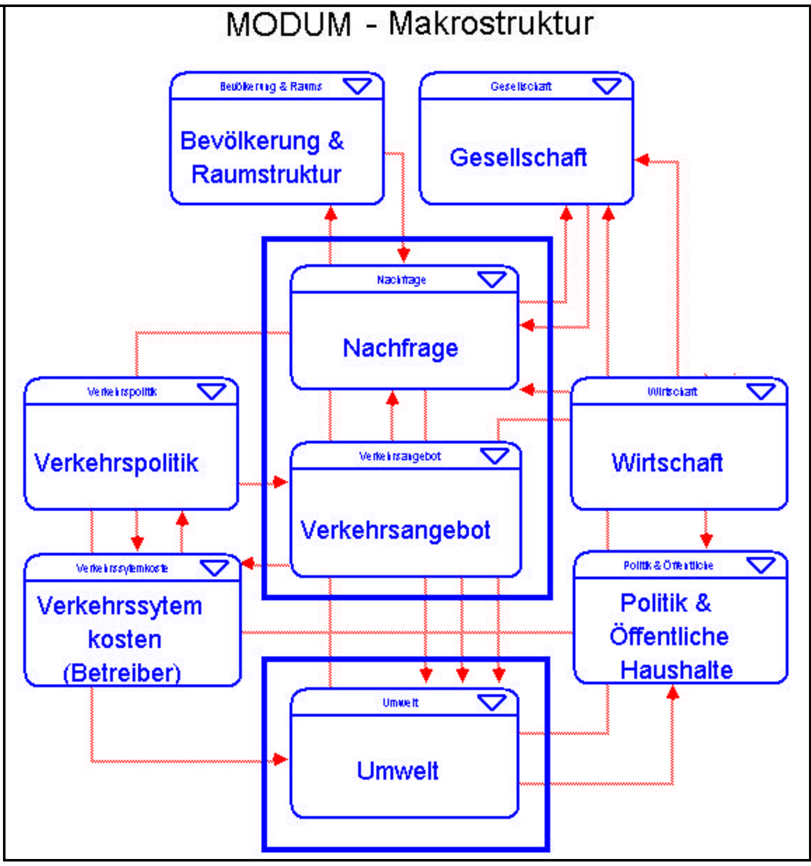

MODUM

Environment Mobility Model

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Abstract

This abstract presents the final results of a new approach undertaken in Swiss sustainable transportation research. The project MODUM is characterized by a participatory approach, by the integration of different disciplinary perspectives on the mobility issue, and by its (long-term) orientation towards sustainability.

The aim of MODUM (**Mod**ell **U**mwelt **M**obilität, english: Environment - Mobility Model) is to develop a system dynamic model in order to assess the impacts of interferences in the transport system on the environment and sustainable development. *System dynamic modeling* allows for reproducing self-enforcing and self-regulating processes and, hence, is particularly suited for investigating interactions within systems as well as medium- and long-term development.

The model was developed in close interaction with a so-called *„actor platform"*. This platform consisted of representatives of consumer organizations, the administration, and transport companies. Starting point were their "mental models", i.e. their personal perception of reality. Through a socalled "model moderation" process these mental models were rendered explicit in the form of system dynamic model elements (variables and relations between them). The model moderation enabled a structured discussion and lead to a system dynamic model which was implemented using the STELLA software. Thereby, the experience and input from the actors, data and information from scientific literature and statistics, as well as the professional background of the research team formed the basis for the quantification and calibration of the model.

The *structure of the (passenger transport) model* is built up by the following sectors: society (traffic generation, "soft part"), economics, politics and public budgets, environment and safety, and transport supply and demand. Core of the model are the interactions between transport offer and demand on the one hand and the impacts on the environment on the other hand. Feedback loops have policy parameters as their main input. The impacts of different sets of measures can be evaluated using various sustainability indicators (e.g. CO_2 emission level, land use for transportation infrastructure, energy intensity of the transportation system).

The *application of the model* is illustrated and discussed for three different scenarios: "BAU" (business as usual), "Free Flow" and "Demand Management". This last scenario has the most favorable impacts with respect to the environmental and economic sustainability indicators. The following figures show two examples of scenario runs.

Keywords

Sustainable Transportation – System Dynamics – Policy Model – Mental Modeling - Swiss Transport Research Conference – STRC 2001 – Monte Verità

1. Starting point

The mobility system is increasingly limited by environmental problems, bottlenecks in capacities and financing and impediments to political problem-solving as well. Due to growing interdependencies between these different fields and increasing complexity within the mobility system goal conflicts arise hindering policy decisions and the implementation of strategies towards sustainable transport.

2. Objectives

The aim of MODUM[1] (Environment - Mobility Model) is to develop a system dynamic model in order to assess the impacts of interferences in the transport system on the environment and sustainable development. Compared to some well known transport modeling approaches, such as e.g. „classical“ transport modeling (modeling of the traffic generation, distribution, modal split and assignment), econometric models or elasticity applications, the system dynamic approach adds feedback mechanisms to the model. These are most important for depicting, analyzing and evaluating the dynamic behavior of complex systems.

3. Research approach and methodology

System dynamic modeling allows for reproducing self-enforcing and self-regulating processes and, hence, is particularly suited for investigating medium- and long-term development as well as interactions within systems. The system structure is of a particular interest since it significantly determines the behavior of the mobility system. In the model, the level of mobility is not given from the outset but is considered a variable depending on structural relationships and feedback mechanisms. Therefore, knowledge about the causes of traffic generation as well as explanations of the mobility behavior of individuals, companies, and organizations form the most important basis for modeling the „environment - mobility“ system.

[1] The project has been funded by the Swiss National Science Foundation within the National Research Program “Environment an d Mobility” (NFP 41) and by the Bureau for Transportation Studies (GVF) as well. It has been finished by Summer 2000 (cf. Keller / Mauch / Heeb / Huber (2000): *MODUM – Model Umwelt Mobilität. Ein systemdynamischer Ansatz für die Schweiz*. Bericht C2 des NFP 41, Bern).

The model was developed in close interaction with several actors in the „environment - mobility“ system. For this purpose, a so-called „actor platform“ was established. In this platform, several organizations and institutions were participating: consumer organizations like the TCS (Swiss Touring Club), the VCS-ATE (Verkehrs-Club der Schweiz), the „KonsumentInnen-Forum“, the Swiss Road Transport Association (ASTAG), the Association of Pedestrians (ARF), transport companies like the SBB (Swiss Federal Railways) and the „Mobility Car-sharing Organization“ as well as the administration (the Bureau for Transport Studies (GVF) of the Federal Department of Environment, Transport, Energy and Communications (DETEC), the Federal Agency for Environment, Forests and Landscape (BUWAL), the Office for Public Transport of the canton of Berne). The model was implemented using the system dynamics software STELLA.

Mental modeling and *model moderation* were applied. *Mental models* are „tacit“ world maps which humans bear in their mind and which influence their behavior. An example of a mental model of an actor is shown in figure 1. *Model moderation*, i.e. the construction of the actors‘ mental models, on the one hand aimed at rendering transparent the different mental models by means of system dynamic modeling and, thereby, enabling a structured discussion, and bringing about a commonly shared comprehension of the system on the other hand. Model moderation was performed in several steps concluding with the system dynamic model. The method model moderation is illustrated in figure 2. After their elaboration, the different actors‘ mental models were presented to the entire actor platform and supplemented in a discussion. They formed the basis for the subsequent development of the „environment - mobility“ model by the research team. This holds for the passenger transport model. Based on this experience the goods transport model was developed by the research team on its own.

Figure 1 Example of a mental model of the action-system „environment - mobility“

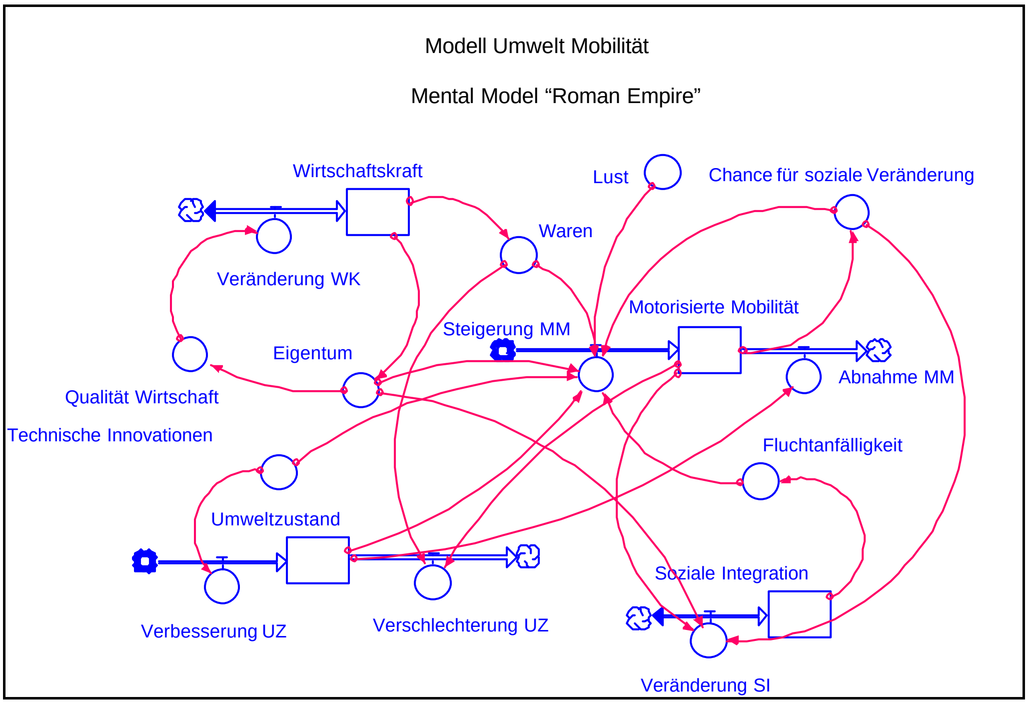
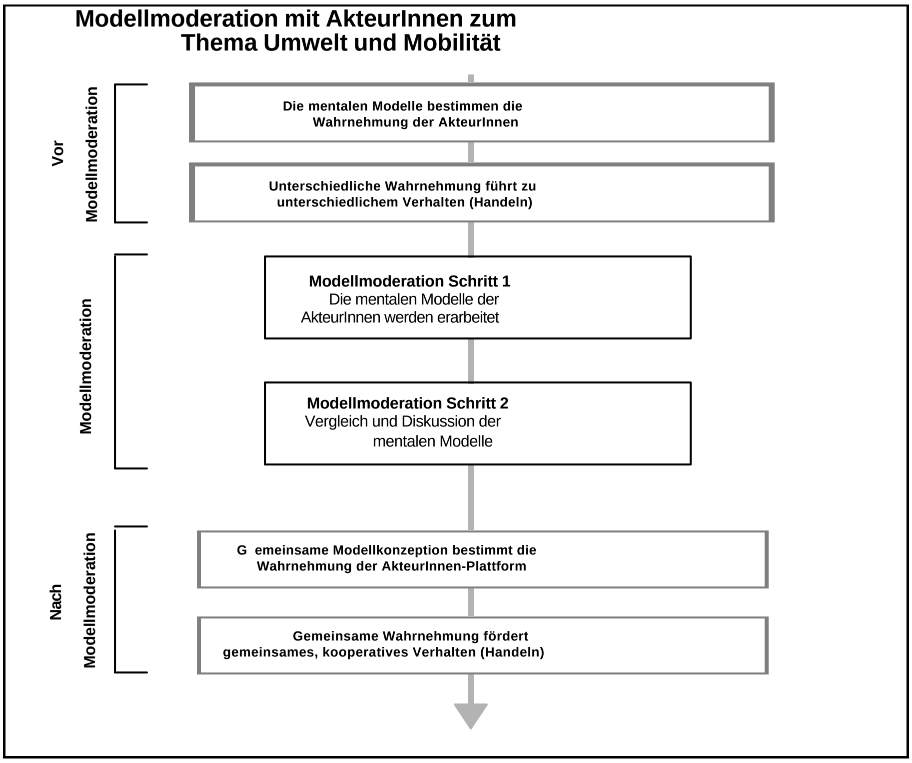


Figure 2 Method model moderation



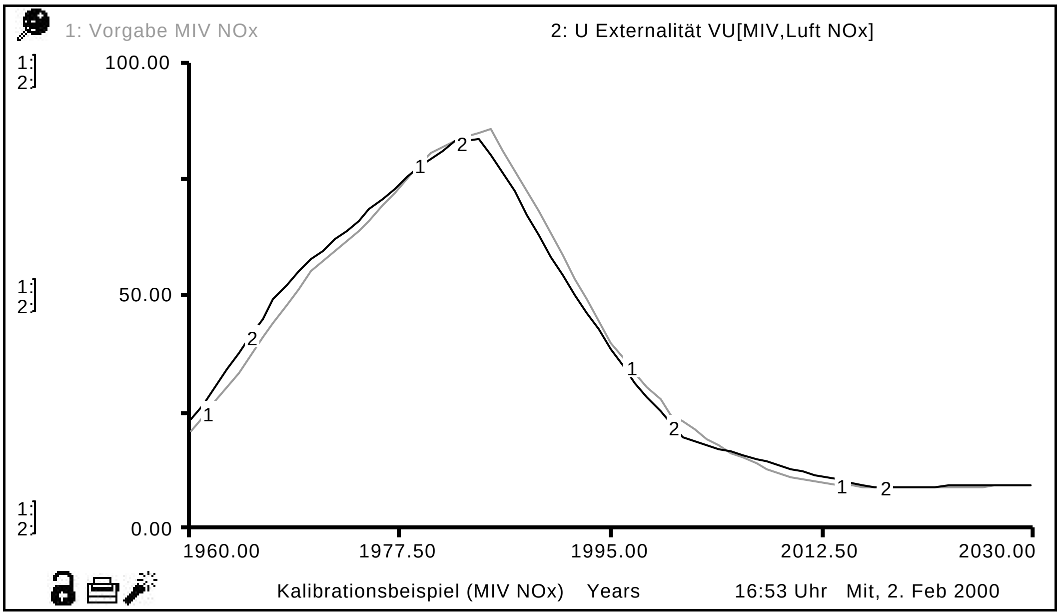
4. Research process

The *mental models* contributed, each of them from another point of view, elements to the model structure, such as parameters, statements on „clusters" of related parameters and structural relations and, thereby, added key statements regarding to the functioning of the „environment - mobility" system. Subsequently, these key statements from the mental models as well as the results of the discussions were integrated into a synthesis model.

This synthesis model was elaborated further by the research team (structure, structural relations, calibration, simulation runs) in an iterative process, whereby during the different phases of the project the model was (re-)discussed and valued by the actors within nine sessions in total with the platform. Towards the end of the research, it served the actors as a basis for developing and testing measures aiming at a more sustainable mobility. Thereby, it was not the impacts of single measures which interested primarily but bundles of measures integrated in scenarios.

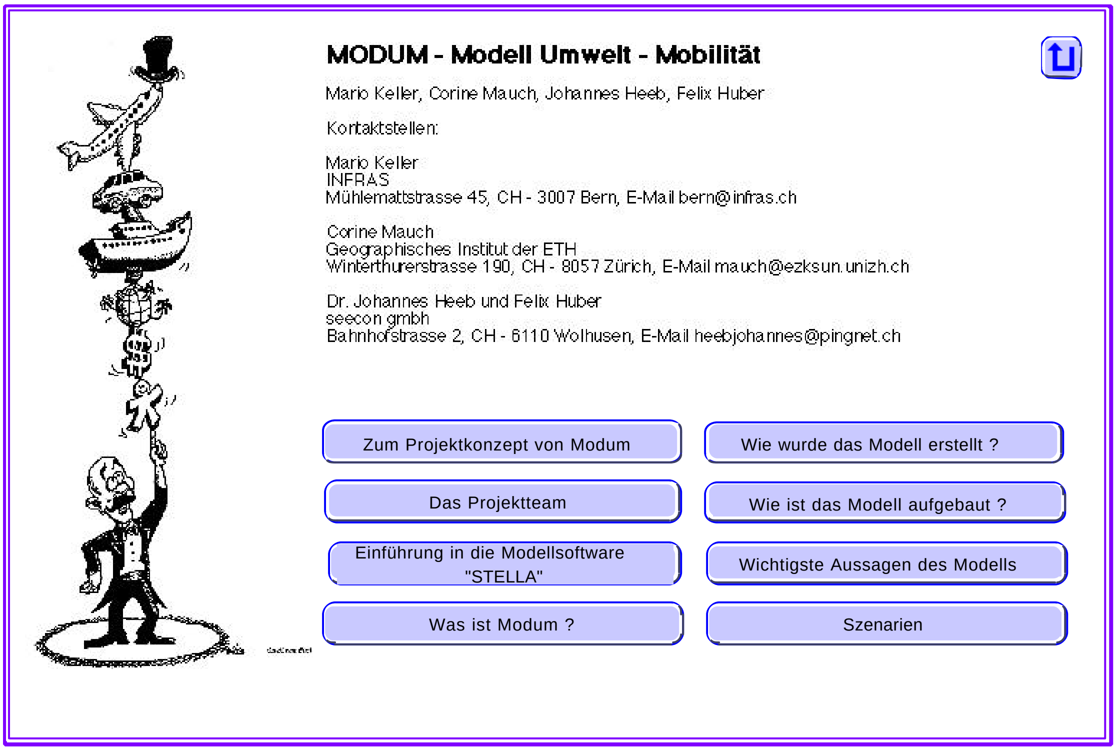
The experience and input from the actors, data and information from scientific literature and statistics, as well as the professional background of the research team formed the basis for the quantification and calibration of the model. A calibration example is shown in figure 3. The working process turned out to be the more difficult the more complex the functional relations and the stronger the feedback effects were. Regarding to the scenario formation, sensitivities of the parameters particularly had to be taken into account.

Figure 3 Calibration example



The resulting system dynamic model MODUM aims at evaluating strategies for change in the „mobility“ action-system with regard to sustainable development. Based on the experiences in the actor platform, a communication platform is now offered to the users of MODUM enabling a step by step approach to the model in the form of a „homepage“ and introducing them to scenario analyses. Figure 4 shows the starting page of this communication platform. By this means, users shall be enabled to explore the backgrounds of MODUM and, via the interpretation of the scenario runs regarding to sustainability, gain insight and understanding of the possibilities as well as the limits of regulating mechanisms in the „environment - mobility“ action-system.

Figure 4 Starting page of the communication platform



5. Primary results (passenger transport)

According to the project's objectives the research results are presented under the viewpoint of methodological aspects of model moderation and elaboration of the product „system dynamic simulation model" for valuation and forecasting purposes.

5.1 Actor platform and model moderation

The baseline of the model (macro-structure of MODUM) was set already in an early stage of the project by means of the model moderation process. It was based on the heterogeneous and complementary experience and knowledge of the actors regarding the „environment - mobility" system. The cooperation with the actors and model moderation primarily enriched the model concept with the „soft" parameters and structural relations in its „society" („soft") part. This result reaches beyond the achievements of transport models used hitherto. Nevertheless, this benefit opposites the fact that due to the cooperation with actors compared to traditional „expert-based“ modeling approaches larger time requirements resulted.

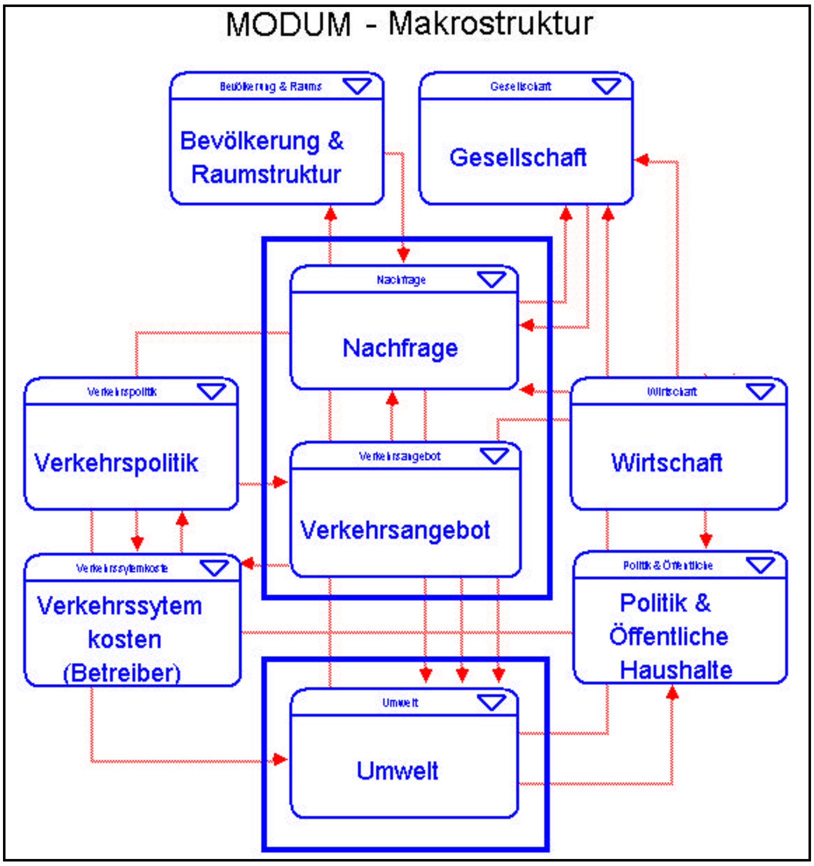
The research process showed that the consistent presentation of the model perceptions by means of system dynamics facilitated procurement, discussion and evaluation during the modeling process. On this basis, it was possible to build a plausible model structure reflecting the mechanisms of the traffic generation and to enable learning processes regarding to parameters, structural relations as well as, partially, quantified relations, and simulation scenarios. Nevertheless, the modeling process as well as the subsequent application of the model presume an optimal technique for communication. Based on this experience, a user-friendly communication platform in a modular design was constructed („homepage“).

5.2 The structure of MODUM (passenger transport)

The macro-structure of MODUM (see figure 5) is built up by the following sectors: society (traffic generation, „soft“ part), economics, politics and public budgets, transport finance, environment and safety, and transport demand. The core of this structure lies in the interaction between transport offer and demand on the one hand and on the impacts on the environment on the other hand. Thereby, population and economical development play an important background role due to their definition as external driving forces. Transport policy, in contrast to these, is not defined externally but in an interaction between the core sector (transport demand and offer) and a sector called transport policy. The same applies for the sector environmental impacts which retro-acts on the transport system via feedback loops (e.g. regulations or pricing policies). Likewise, the sector society which is mainly composed of „soft“ qualitative parameters is connected to other parts of the model by structural relations over-passing the separate model sectors.

In as much as the high aggregation level of the model permitted it, the parameters were differentiated according to the following dimensions: four population categories (employed persons, persons not engaged in formal employment, young persons/students, elderly people), three transport modes (public transport, private motorized transport, slow transport modes, i.e. bicycle and pedestrians), four types of environmental impacts (CO_2, NO_x, noise, area usage), and three aspects of safety (accidents, injured people, killed people).

Figure 5 Macro-structure of MODUM



5.3 Modeling process, elaboration of the model

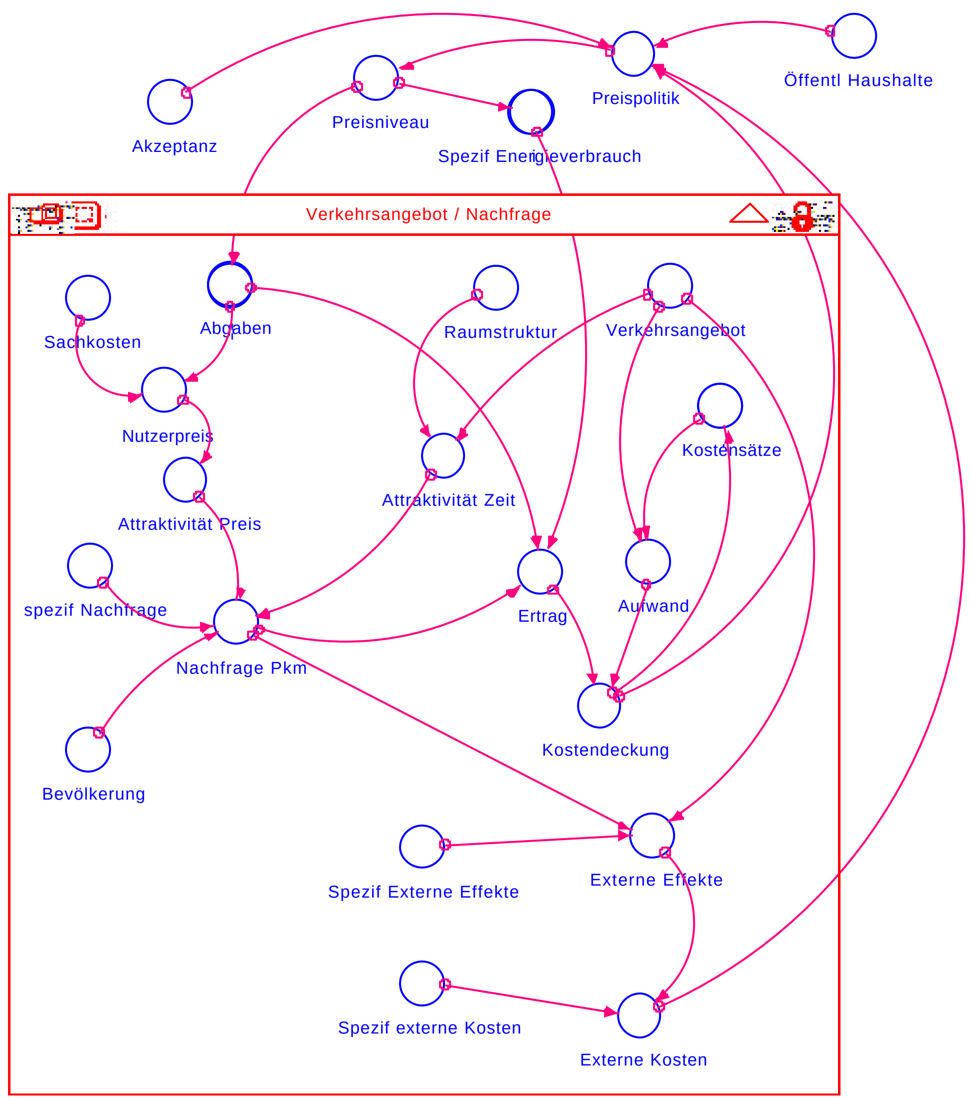
In a *first step*, a simplified passenger transport model was constructed outside of the system dynamic model and based on the classical approach of four stages (traffic generation, distribution, modal split and assignment) in order to reproduce physical transport demand which was considered as the „hard" part of the model. Hence, the so-called 106 MS-regions („spatial mobility") served as a spatial point of reference. Despite the use of this disaggregated spatial scheme the „hard transport model" nevertheless represents a highly aggregated model which is not suited for simulating distinct local traffic flows. The attractiveness of the transport system was represented by the length of the network and a capacity/length-ratio for the road system, and the supply (in terms of seat-kilometers) for the public transport system. Price and income development over time were taken as a basis for calculating the distribution of the transport demand among the different zones. In a *second step*, the dependency of the demand from the transport supply (prices, time attractiveness) was determined by means of a large amount of parameter variations and regression analyses. It then was integrated into the system dynamic model. In order to include some effects from spatial structure, an additional parameter for the „urban sprawl“ of a widely qualitative character was introduced. Furthermore, the development of the occupancy rates was taken into account. Eventually, this sector („transport supply / demand“) provides the physical description of the transport demand (in terms of pers-km resp. veh-km traveled) overall and per transport mode.

In the model sector „transport finance“ some feedback loops explicitly come into action. On the one hand the levels of taxes resp. prices determine the demand and—via some political measures—the level of cost-covering which, on the other hand, exerts an influence on the extent to which the transport system shall be expanded respectively the level of taxes shall be adapted in the medium and long term. For this purpose, costs (investment and operation costs) and revenues are defined for both transport modes (private and public) and put in relationship to each other.

In the sector „environment and safety“ the different external effects of the transport system (e.g. emissions in tons p. year or—for the safety aspects—number of accidents, injured or killed persons) are determined in a „classical“ way in a first step and subsequently applied for model calibration. In a second step, the externalities and feedback effects are calculated by the model itself and accordingly monetarized, i.e. transformed into external costs.

The model sector „society“ reflects the generation of traffic within the overall model. On the one hand, it results in an absolute *mobility quantity* (in number of trips per person and per day within the different population categories) and in a *modal split* related to the three transport modes („modal split soft“, trips which a person performs per day by one of the three modes considered (i.e. by „slow“ transport modes, by public transport or with a private automobile or motorcycle). This parameter, to which the attribute „soft“ was added, shall comprehend motivational aspects of the choice of specific means of transport. Evidence on the *social acceptability* of particular political measures (e.g. pricing policy, supply policy, regulations regarding to environmental and safety aspects) forms a third thread in the sector „society“. It consists mainly of „soft“ (qualitative) parameters and structural relations (e.g. values, environmental awareness, need for social interaction, individual degree of liberty, lifestyle, mobility-curriculum, prestige). For most of these „soft“ parameters and relations, qualitative information and data could be gathered, whereas quantitative data was rare.

Figure 6 Illustration of the mechanics of the pricing policy



Within the overall system (i.e. all sectors of MODUM), feedback mechanisms mainly operate through policy parameters. *Pricing policy* (see also figure 6) operates on the price level and, thereby, exerts an influence on transport demand and returns (e.g. level of cost-covering). Pricing policy in turn is steered by system parameters such as the level of cost-covering. *Supply policy* has an impact on the infrastructure for individual transport and on the operational offer for public transport which influences the attractiveness of the (two) transport systems and, hence, determines to a certain degree the modal split At the same time, it influences the costs of the transport system. Simultaneously, a usage/capacity ratio of the transport system results which again forms a steering parameter for the supply policy. *Regulatory policy* influences the safety level resp. determines the environmental impacts (e.g. air pollution, energy demand) and, in turn, depends on these impacts since the enactment of standards and threshold values is considered as a reaction to the actual state of the environment.

5.4 Scenarios and simulation (passenger transport)

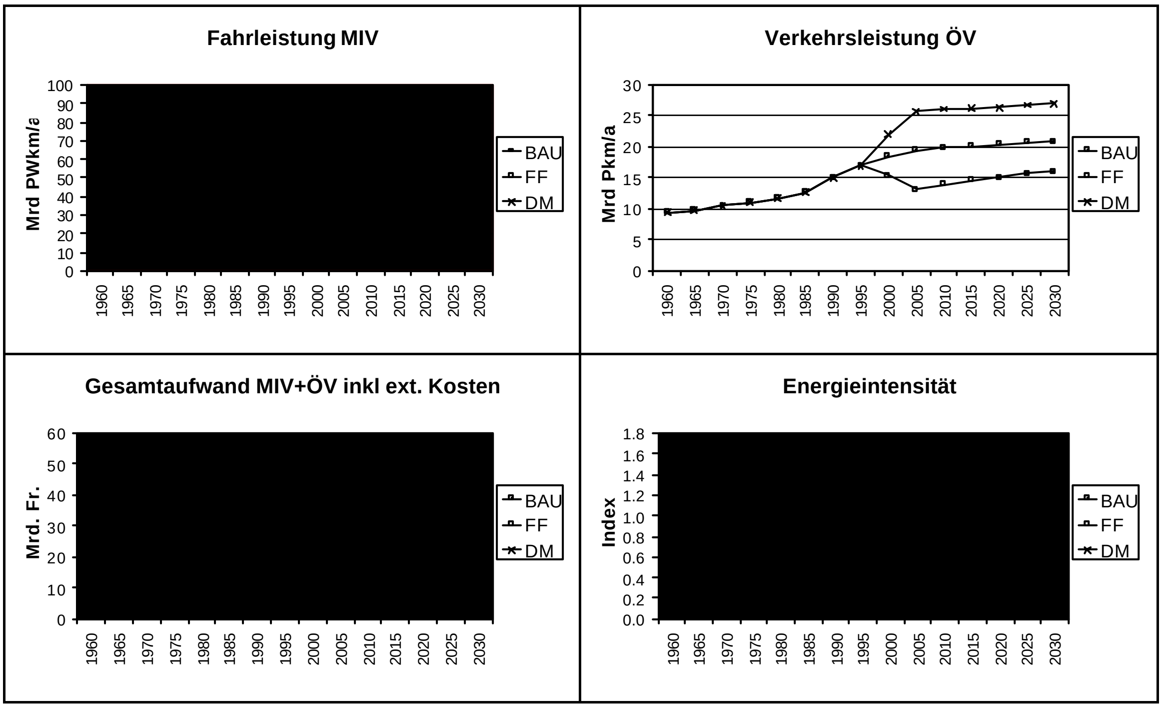
To some extent, the basic model (BAU, business as usual) depicts a trend-evolution taking patterns from some well known scenario calculations and serving as a basis for the calibration of the model structure. Three further scenarios are defined in order to facilitate the handling of the model, two of which are pre-defined („Free Flow“ and „Demand Management“). A further scenario gives the users the possibility to „set“ the steering parameters by themselves. Thereby, the levels „high“, „medium“ and „low“ are distinguished. Besides the possibility of running the model with full feedback interactions, a further path is offered where some of these feedback-loops can be eliminated and replaced by external steering parameters (predefined or self-defined). However, by proceeding this way the model will lose some of its dynamic character.

The qualitative assessment of the model result ensues by means of indicators reflecting the different dimensions of sustainable development. Three dimensions are distinguished: environment (Env), society (S), and economics (Ec). However, the applicability of certain indicators which presently are discussed also on an international level is limited in MODUM due to, among other factors, its high aggregation level. Rather „descriptive“ indicators are applied (e.g. pers-km traveled, seat-km offered) as well as indicators stemming from the three dimensions mentioned above, whereby the latter can not always be separated distinctively from each other (e.g. total emissions of NO_x and CO_2, surface consumption [Env], environmental awareness and awareness related to different transport modes [S], total costs as well as external costs and level of cost-covering [Ec]).

Simulation results on the one hand are tested by the impacts of the three scenarios onto specific indicators. On the other hand, the possibility is given to gain new evidence on the relevance and the importance of particular parameters and structural relations from a more comprehensive viewpoint (sensitivities, „leverage points“) mainly in the rather qualitative „soft“ model part „society“ which is more precisely differentiated and of which the results can be interpreted in quantitative terms only in a limited way.

The scenario „Free Flow“ (FF) resp. „Demand Management“ (DM) significantly raises resp. diminishes the total veh-km compared to BAU and the modal split changes as well (in FF in favor of road, in DM in favor of public transport). Both cases are steered through feedback-loops onto supply and pricing as well as cost-related parameters. This also affects the level of cost-covering whereby peaks are more important for individual than public transport. Total costs for mobility are highest in FF, whereas in DM they lie beneath the level of BAU. Likewise, despite a lowering level of emission of pollutants in all scenarios the external costs (mainly energy intensity, emissions, surface consumption) are lesser for DM than for BAU and, even more significantly, for FF. The observed fact of a faster change in user prices at a high price level compared to lower prices may indicate the dynamic reaction capabilities of the model. Figure 7 illustates some of the mentioned simulation results.

Figure 7 Selected simulation results in the three scenarios „BAU“ (business as usual), „FF“ (free flow) and „DM“ (demand management)



As for the interactions in the model part „society“, the following evidence could be found: (methodologically they stem from the iterative process of the elaboration of the model structure and model calibration; they reflect statements on „why“ certain evolutions can be observed). The BAU scenario shows a slight increase in the *mobility demand* (in trips per person and day) on different levels in all population categories (uppermost for employed persons, lowest for elderly people). This mainly results from an increasing demand for entertainment (due to decrease in social integration) and changes in lifestyle related to rising income, whereas an „opposite" evolution in social values (in direction of post-materialist values) is so to say „over-compensated".

The basic tendency for „*Modal Split Soft*" shows an increase in individual transport, no changes in public transport and decrease in slow transport modes (on different levels for the different population categories). This stands for a *substitution of walking and biking by car trips* in the context of only a slight increase in total mobility (trips per person per day). The general increase in „*Modal Split Soft*" for private transport means mainly results from a strong increase in car availability, in its attractiveness as well as in some powerful usage habits („mobility-curriculum") which, on their turn, „over-compensate" an opposite influence from the growing environmental awareness. The stability in public transport can be explained by a slow but steady decrease in the public transport related awareness which overrules the opposite evolution of a higher attractiveness and growing access to public transport (by means of a high availability of transport passes) in all population categories (except for the elderly people).

An increased „area shortage" in the BAU-scenario leads to a decrease in *acceptance* of political measures related to the offer for individual as well as for public transport. The slight tendency of increasing acceptance for slow transport modes directly reflects an increase in environmental awareness. As for the acceptance of pricing measures, its increase regarding to individual transport („user-payer principle") in the BAU-scenario can be explained by the growing environmental awareness on the one hand and an increase in the degree of individual freedom as well as a decrease in the level of cost-covering on the other hand. Furthermore, the decrease in the cost-covering level of public transport is responsible for a decrease in acceptance of price policy measures („further reduction of prices") in this field.

Summing up, it may be said that mainly „structural" issues turned out to be the dominant parameters within the „society" part regarding to the evolution manner of the transport system. In view of possible policy strategies this would primarily mean that—besides measures operating on the awareness of people—the main focus should be on „enabling" (resp. disabling) structures (e.g. the provision of an outstanding offer for public transport).

6. Critics and open questions (after part 1: passenger transport)

The main „stumbling stone“ for MODUM, and this can be taken as a result on the methodological level, turned out to be a specific *claim* formulated at the outset in the research concept. The idea was to combine a qualitative approach working in close interaction with the actors in the mobility-system (model moderation) with a rather „technical-quantitative“ modeling approach mainly aiming at forecasting. The objective behind this idea was to elaborate a system dynamic simulation model particularly related to a practical background and to the needs of the actors in the mobility-system. Due to several reasons, the link between the so-called „soft“ part (mainly societal interactions) and the „hard“ part (mainly technical and economical aspects) turned out to be a rather difficult and problematic task.

At the basis of this difficulty lies the question of how to interpret the produced data and curves. This must not only be seen in the context of linking „soft“ and „hard“ elements but in the basic idea of building a comprehensive model of the „socio-economical-technical“ overall system also reflecting feedback processes which, in the end, required „soft“ structural relations also in the so-called „hard“ model part. Therefore, from a viewpoint of „hard“ forecasting, some specific quantitative simulation results must not be overvalued. Hence, we can conclude from the research process that the idea of „hard“ forecasting and the model application as a „learning-tool“ producing plausible and meaningful „soft“ evidence seem to be difficult to combine.

In practical terms, the link between the „hard“ and the „soft“ model parts mainly were established through the feedback-loops which, at the same time, were particularly interesting for the model. Thereby, policy parameters were in the foreground. Unlike in other well known transport models, they represent the idea of explicitly including into the model important factors stemming from Switzerland‘s social and direct-democratic political system such as the acceptance of policy measures as well as their impacts on the system—and not to ignore socio-political realities while simulating policy-strategies. This objective could only be achieved partially mainly due to „technical“ reasons.

On the one hand, the connection of absolute values (such as pers-km or veh-km traveled, tons of NO_x p. a) with standardized qualitative parameters (e.g. high / low environmental awareness, high / low acceptance for specific political measures) turned out to be a problematic task. Mainly from the viewpoint of „hard“ data this represented a considerable source of „fuzziness“. On the other hand, some purely technical „measuring“ problems of conformity emerged insofar as e.g. the modal split was defined as „trips per person“ in the „society“-part, whereas in the „transport-model“, the modal split was expressed in terms of „pers-km“. These problems of conformity were even reinforced by the danger of implicit redundancies which automatically resulted from the combination of a relatively fine differentiation level in the „society“ part of the model compared to a rather comprehensive macro-economic aggregation level in the „transport model“.

Last but not least, all these difficulties culminated in the question which *target groups* should in the end best be addressed with MODUM. The model can be applied in a classical utilization manner well known in transport science and, thereby, requires some knowledge about modeling techniques from its users. However, some deviation from classical transport modeling will still take place due to the mentioned reasons. Likewise, the second application manner for MODUM—i.e. using it as a „learning tool“ in a group modeling process with an actor platform—only succeeded partially in the research process since beyond the more qualitative approach to the modeling issues, a minimum knowledge about the system dynamic modeling technique turned out to be a need. Namely the model part „society“ which primarily resulted from the model moderation process with the actor platform and which was intended as an important feature of the research process from the outset, might only unfold its full use under significantly different conditions than the classical, technical and primarily (simulation) result-oriented approach can guarantee.

Based on these reflections and experiences, the link between „hard“ and „soft“ model parts turned out to be problematic in MODUM. Two paths might contribute to solving the problem: First, a stronger orientation towards the classical quantitative modeling which mainly tries to take over the system dynamic element of feedback-loops. Such a path would be an issue to *traditional expert groups*. The second path mainly focuses on the model as a „learning tool“. Thereby, the model moderation approach bears some potential but still some cuts have to made from complexity, and ameliorations in communication should be envisaged.

7. MODUM and goods transport

Based on the experiences with the passenger transport model, the original intent to model the goods transports in the same fashion was dropped. It may be assumed that "soft" input parameters have a lesser importance for goods transports, and the "actor-platform" in fact was somewhat biased towards passenger transports. Therefore it was decided that the research team would develop the goods transport model on its own. Still, an answer had to be found on the fundamental question, which of two possible approaches should be adopted (towards "classic" quantitative modeling, or towards the application of the model as a "learning tool"). At present in Switzerland no (classic) quantitative model of goods transports exists that could be used as "reference model". Therefore, in analogy to the passenger transport model, the goods transport model rather corresponds to the second approach, but with the limitation that it is not based in the same extent on "mental models" of external experts. Therefore, the goods transport model is an implementation of tentative statements and hypotheses. It may serve as input to a debate of an "actor platform" on goods transport. "Mental models" of involved persons could then be incorporated to further adjust the model.

The goods transport model was implemented using the same software (STELLA) as the passenger transport model. Because it is more focused on internal needs, the approach adopted is more interactive as compared to the passenger transport model. The user has the possibility to change groups of steering parameters, and may alter "intensities" during the execution of the model.

7.1 Structure of the goods transport model

Contrary to the passenger transport model, the basic outline of the goods transport model is driven by classic indicators of goods transport, i.e. offer and demand. These indicators cause effects (mainly internal and external costs), which on their turn lead to interventions in the goods transport system. The demand issue is treated differently by focusing directly on the actual goods transport demand, expressed in tons to be transported and ton-km. The economic growth, the nature of the goods to be transported, and the production and distribution structures are the driving parameters. The total amount of ton-km is then distributed according to the attractiveness of the different modes of transport (rail and road). The attractiveness may, among others, be influenced by political measures. Such measures are interpreted as reaction upon the current state of the goods transport system and its impacts.

The main issues in the model design are, first, to which extent the policies related to transport and the resulting transport offer will influence economic growth and the spatial distribution of goods production (which in their turn induce traffic demand), and second, how the increase in transport in turn depends on the economic growth and the other factors generating transport demand.

Currently no clear picture can be drawn on the first issue, i.e. how transport offer influences different parameters like economic growth, the nature of goods to be transported, or the spatial distribution of goods production. Some put forward that the most common goal of transport policies is to change the modal split, as is the case for the Swiss policy on goods transit. No detailed model of economic activities exists that provides a quantitatively reliable description of this feedback of the transport offer on economic growth and production structures. Therefore, the goods transport model does not explicitly take into account this feedback mechanism. Instead, following the passenger transport model approach, economic growth is assumed being an external driving force.

Neither do consistent answers exist on the second issue, which addresses the relationship (if any) between transport growth and economic growth. An investigation of the transport intensity (ratio of ton-km to GDP) reveals that the elasticity decreased over the last 20 to 30 years, but still remains above unity. This means that no de-coupling of economic growth and transport demand growth has yet taken place. But the understanding even of this highly aggregated relationship is very limited. Therefore, the goods transport model assumes a simplified relationship between transport demand growth and economic growth. For this, an elasticity coefficient of 1.25 is used in the model, but its value may be modified.

This means that the goods transport model, too, is highly aggregated. It does differentiate between the transport modes rail and road, but there is no further spatial disaggregation and no further distinction between, for example, different categories of goods. The focus of the model is on the choice of the transport mode. This choice is modeled with a well-known modal split approach using a logit function. The attractiveness (or "utilities") of the different transport modes are parameterized with indexed price, time and quality levels. The calibration of the coefficients was done on the basis of known elasticities. Like the passenger transport model, the goods transport model computes various sustainability indicators.

Feedback mechanisms are again parameterized as a function of policy parameters. However, the extent of these feedbacks is not fixed, but instead ruled by steering parameters specified by the model user. For example, the user may define the policy on the construction of new roads between the two bounds "friendly" and "restrictive". If "friendly" is specified, the increase of road capacity is ruled by the extent of utilization of the current road capacities. The "restrictive" policy means no new roads are constructed at all, leading to increased overloading of existing road capacities, resulting in lower attractiveness and, more important, a lower transport quality (i.e. reliability). Other parameters may be specified in the same way, like the maximum allowed weight of road vehicles (which influences the productivity), the price level of road transport (taxes which are proportional to the amount of ton-km), the response of rail transport upon the price level of road transport, and the policy on rail transport offer. Besides these settings, by means of their elasticities the user may also specify the total transport demand, and the growth of passenger road transport. The latter uses the same roads as goods transport, and thereby influences road capacity and, correspondingly, the attractiveness of goods transport by road. Additional feedback mechanisms are included, for example, because the productivity of rail transport increases (for a fixed transport capacity) as demand increases, the attractiveness of rail transport and its competitiveness increases additionally.

7.2 Scenarios and simulations of goods transport

The model's outcomes are illustrated using different scenarios and sensitivities. The scenarios are "BAU" (business as usual), "road" (i.e., parameter settings favoring road transport) and "rail" (i.e., policies and measures in favor of rail transport). The share of rail transport steadily decreases for the "BAU" scenario (for the "road" scenario, this decrease is even more pronounced). In spite of this decrease of the relative share, the absolute demand (in ton-km per year) for rail transport still increases for the "BAU" scenario, but remains at its current level in the case of the "road" scenario. This stagnation originates from the fact that the productivity of the road transport sector increases with respect to its current level, caused by higher limits on the allowed load per vehicle on one hand, and the steady extension of the road infrastructure, leading to an increase of ton-km transported on the road. Nevertheless, the total traffic (in veh-km) on the road is similar for the "BAU" and "road" scenarios, although the extent of utilization of road capacities is higher for the "BAU" scenario, because of the more reservedly removal of bottlenecks. The "rail" scenario, on the other side, shows a pronounced increase of the modal split towards rail transport, partly because of more competitive prices, partly because of a higher attractiveness caused by new investments in infrastructure. This combination of policy measures succeeds in breaking the trend towards more road transport. The "rail" scenario also causes the modal split to remain on a higher level even after the period in which the policy measures are in effect. This is a consequence of the increased productivity of the rail transport system reached during that period. The subsequent effects are in close relationship to the higher modal split, i.e. in general more favorable in the case of more rail transport.

7.3 Conclusions

The time-dependent curves as predicted by the goods transport model basically are plausible. Some of the model behaviors presented here are indicative, above all the comparison of the relative effects of the different measures among each other. This is in line with the aim of the model, i.e. to contribute to the discussions between the different actors. However, the quantitative predictive power of the model is quite limited, because (similar to the passenger transport model) some quantities have been parameterized using indicators for which no possibility to calibrate exists, and which are difficult to justify and to communicate (e.g., "transport offer" or "transport quality"). This confirms the main finding of the passenger transport model, i.e. it seems impossible to predict with sufficient accuracy the results of an evolutionary process describing such a broad field as all relationships between transport and environment. This again means that it seems necessary to question the original intent to develop, using a system dynamic approach, an integral strategy model which also has sufficiently reliable quantitative results. If reliable quantitative predictions are required, it probably would prove to be more successful to drop the requirement of an integral modeling approach, and instead try to improve classic quantitative models by introducing some feedback loops, as well as enhancements or refinements where needed.

The system dynamic approach is more suited for applications as a "learning tool". The "language" of system dynamics helps to structure complex questions using common conventions, even though the latter might take some time to get familiar with. The system dynamics approach hence primarily is a thinking tool which helps to visualize connections and to discuss possible ways of acting. Used in this way, the model reflects the personal perception of those involved, rather than "the reality". It proves almost impossible to reach at the same time the aim to obtain results that are quantitatively reliable and of general validity. In correspondence to using a system dynamics model in such a way, its general audience consists of actors that have to prepare a decision or are interested in the general relationships. The MODUM passenger transport model has been used by the "actor platform" in this sense. The corresponding goods transport model, that has been developed by the research team on its own, can serve as an input to such discussions. The use of the MODUM models by anybody not involved in this study might be questionable, since such users lack the required knowledge of the background, and at the same time might not be confident about the validity of the interactions and connections within the model. However, for those involved in this study, the model may, even though it is mainly suited as a "learning tool", contribute to find and formulate appropriate strategies.