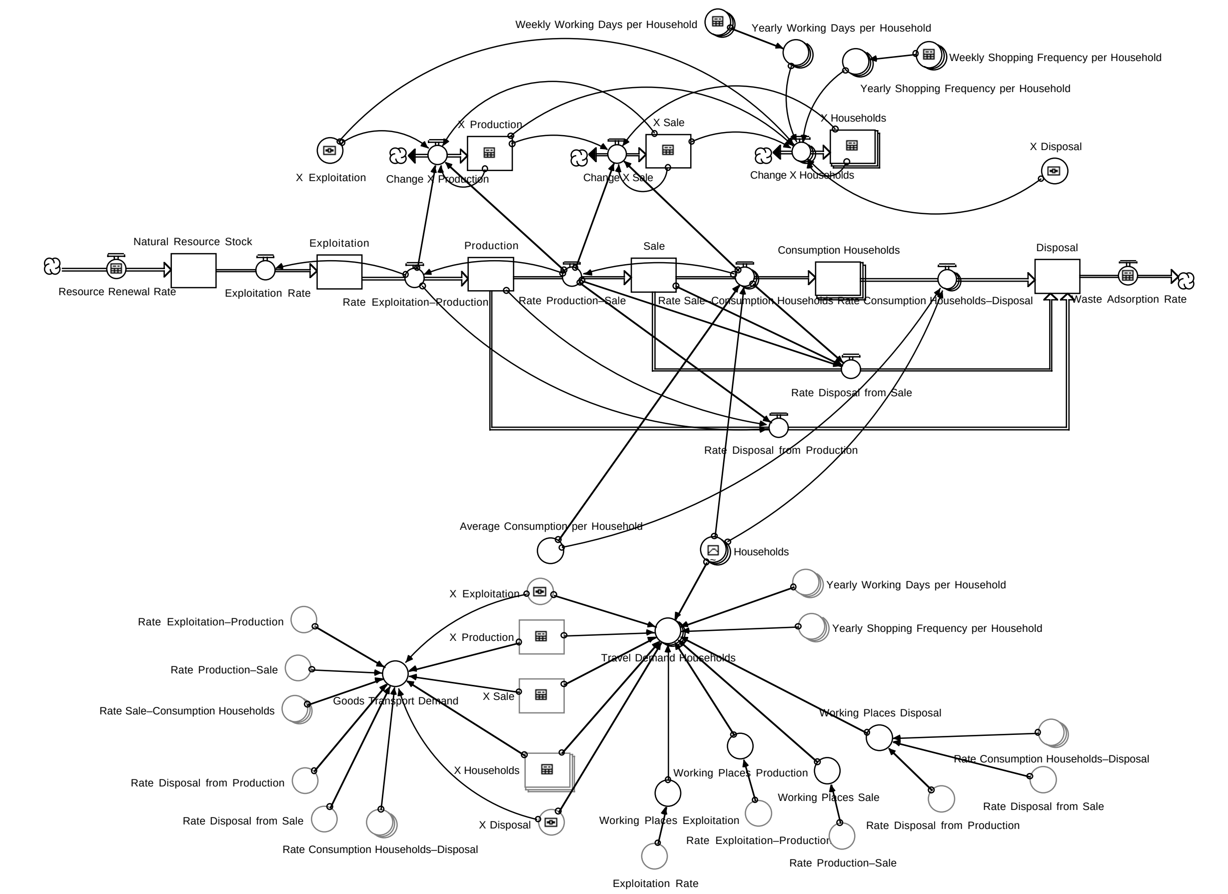

System Dynamic Modelling of Transport and Land use - A First Model Draft

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System Dynamic Modelling of Transport and Land use - A First Model Draft

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Abstract

Transport and land use form, in the context of sustainability, a complex system with many feedback mechanisms. Therefore, system dynamics is a suitable approach to develop a model framework that allows simulation of the behaviour of such a connected system structure. The agent based system dynamic model, presented in this paper, is a first draft of a modelling process that aims to develop a tool that allows the evaluation of sustainability promoting policies in the field of transport and land use.

Keywords

Transport – Land use – Sustainability – System dynamics – Agent based modelling – Swiss Transport Research Conference – STRC 2001 – Monte Verità

1. Land use, transport and sustainability

One of the overall aims of any research is promoting the quality of life. This life, in some sort of a less romantic way of understanding, contains nothing other than different activities at different places at different times, from birth until death. Some of the most central are activities such as being at home, work, education, shopping and leisure. Since these different activities in most cases take place on the ground[1], they are linked consequently to different type of land use: land used for agriculture, forestry, settlement etc. Now, as life contains different activities at different places, it also includes transport of the considered persons: they travel, have to travel between the different activity places. The mentioned activities and also the transport of persons induce goods transports: resources are needed for food production, for construction and operating of buildings (being at home, work) and transport systems, for health care etc. With regard to the whole life cycle of these goods such as resources, food, non-food articles, waste materials etc. their transport starts in the environment (exploitation of resources) and also ends there (disposal and deposit of waste materials). Therefore, human life, based on land use, activities, and transport of persons and goods, is connected with the environment. According to the behaviour of the people, seen just as individuals in households, firms or as members of governmental or non-governmental organisations, the results are impacts not only on the society and economy, but also on the environment. With regard to the concept of sustainability, one has to search for the facilities to arrange transport and land use as the bases of activities and life, with intention to raise quality of life with regard to the ecological, economic, and social dimension including the intergenerational dimension (see e.g. World Commission on Environment and Development, 1987, United Nations, 1993). A sustainable system handling and system management of the transport and land use system has to be addressed by policies. The model presented in this article, is a first very simple and highly aggregated draft in the context of a PhD-Thesis[2] at the Institut für Verkehrsplanung und Trans-

[1] Of course there are some activities, which are not directly linked to land use, such as flying with a plane etc. In this case the expression "space use" would be more accurate.

[2] This PhD-Thesis - "System Dynamic Simulation of Transport and Land Use - Evaluation of Sustainability Promoting Policies", or in the original German version "Systemdynamische Simulation von Verkehr und Flächennutzungen – Evaluation nachhaltigkeitsfördernder Massnahmen" – aims to develop a model tool of transport and land use with regard to sustainability (social, ecological and economic aspects) using the system dynamics method.

porttechnik, Strassen- und Eisenbahnbau (IVT) ETH Zürich and goes in that direction by an agent based system dynamic modelling approach.

2. An Agent based System Dynamic Modelling Approach

2.1 System Dynamic Modelling Approach

For the integration of an overall complex and connected system that includes ecological, economic and social aspects with transport and land use in its core, system dynamics is a well suited method, since it is a topic independent method and is not limited by applicability only in a specific area. As it allows the simulation of any system during time ($t_0 \rightarrow t_1 \rightarrow t_2 \rightarrow t_3 \rightarrow ... \rightarrow t_n$), long term and thereby intergenerational aspects can be included in the modelling process. Further the interactive effects of the system parts can be simulated by so called feedback loops. In this case the system dynamic approach was used to design a highly aggregated model draft for the simulation of transport and land use, which in a further step could be disaggregated in a modular way[3].

2.2 Agent based approach

Since one merit of system dynamics is the possibility of integration and analysis of feedback loops, and since much feedback loops have their effect via agents (e.g. interdependency between transport and land use), the combination of a system dynamic and an agent based approach offers many opportunities in modelling transport and land use in the context of social, economic and environmental aspects. Hence the system dynamic approach and the designed system structure has to include the most important agents as parts of the system itself. Behaviour in transport and land use as customer (decision and choice behaviour) and citizen (politics and policies) are to be marked as the central dimensions of the agents actions. Through a clear definition of the reasons of the considered actions of these agents, one can

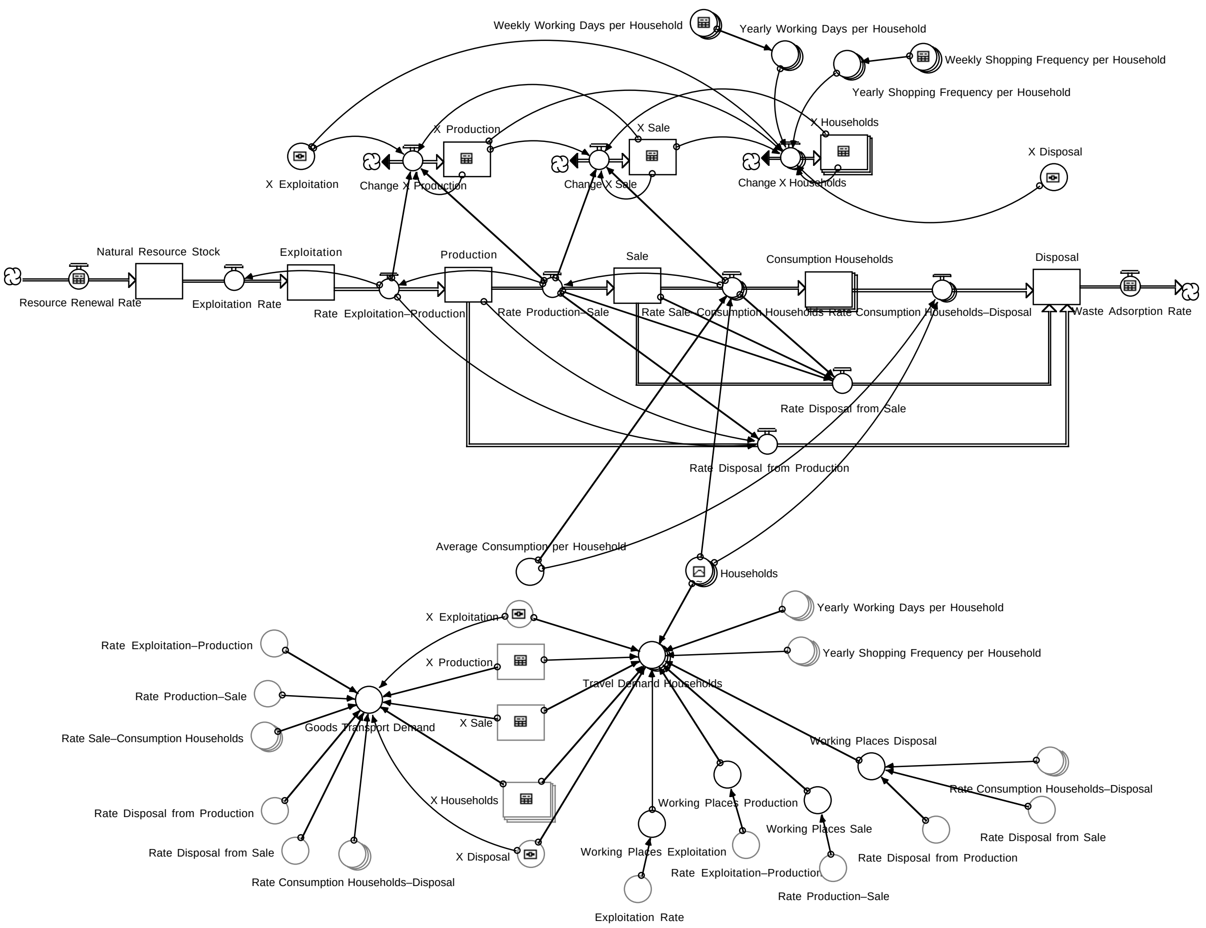
[3] For further information about the system dynamics method see e.g. Bossel (1994), Hannon and Ruth (1994) or HPS (2000a); for information about the use of system dynamics in the field of transport planning see Abbas and Bell (1993).

obtain a transparent system structure that promotes the plausibility of the model framework. Furthermore, the integration of agents allows not only a transparent modelling of decision and choice behaviour, but also of the resulting benefits for the modelled agents. This can be seen as a medium for the evaluation of social aspects like e.g. fair chances for everybody (every agent).

3. First Model Draft

The first model draft (see Figure 1) was designed using the software STELLA (HPS, 2000b) and is a only qualitative and not quantitative data based model draft. It was developed upon the idea of creating a system that links human life, as a sequence of activities, and the life cycle of goods, including the different processes, to a networked system.

Figure 1 First Model Draft



3.1 Model elements

The model includes the following elements:

- 1 unspecified resource flow:

  This resource flow has its source in the environment (*resource renewal rate*) and passes, starting from *natural resource stock*, the 5 processes *exploitation*, *production*, *sale*, *consumption* and *disposal*. It finally ends at its origin, the environment (resource sink: *waste adsorption rate*). Some parts of the resources are flowing as waste materials directly from the processes production and sale to the disposal.

- 8 agents:

  They can be subdivided into:

  - 4 firms:

    Each of this firms represents one of the 4 processes *exploitation*, *production*, *sale* and *disposal*, has a certain site (*x exploitation*[4], *x production*, *x sale* and *x disposal*) and a certain number of working places (*working places exploitation*, *working places production*, *working places sale* and *working places disposal*).

  - 4 household types[5] corresponding to the 4 firms as working place:

    - households, whose members work in the exploitation firm (see 3.2);
    - households, whose members work in the production firm;
    - households, whose members work in the sale firm;
    - households, whose members work in the disposal firm.

4 "x" represents abscissa.

5 In the figure only one element *households* can be identified. As this element is implemented as array in the model, it includes all 4 types of households (the same can be said about the elements *consumption households* and *x households*, which refer to the element *households*).

Besides the resource flow related process (*consumption households*) and the site (*x households*), some further aspects concerning the households are integrated in the model by the parameters *average consumption per household*, *yearly working days per household, weekly working days per household, yearly shopping frequency per household,* and *weekly shopping frequency per household*.

- 3 activities:

  Accordingly to the above described agents 3 types of activities can be identified in the model:

  - being at home;
  - work;
  - shopping.

- 2 transport demand indicators:

  The transport demand indicators integrated in the model are:

  - travel demand households;
  - goods transport demand.

While the unspecified resource flow representing the life cycle of goods can be identified clearly in the figure of the model, the human life has to be understood as the chronology sequence of the 3 activities being at home, work and shopping of the 4 types of households.

3.2 Model assumptions

The model is based on the following assumptions:

- The land area is 1-dimensional with a range from 0 to 200 [].

- The in- and outflows concerning the processes exploitation, production and sale is regulated as follows:

  inflow = outflow · 1.1 with a lag of 1 year

- The numbers of working places are assumed in relation to the inflows to the processes:

  Working places exploitation = inflow to exploitation · 0.1

  Working places production = inflow to production · 0.2

  Working places sale = inflow to sale · 0.4

  Working places disposal = inflow to disposal · 0.1

- The production and sale firms optimise their site based on the distance to the previous and the following process or agent, weighted with the resource flows value (see Hidber et al., 1994, p. 7.7ff) (e.g. production):

$$\text{"X\_Production"}(t) = \text{"X\_Production"}(t - dt) + \text{"Change\_X\_Production"} \cdot dt$$

$$\text{"Change\_X\_Production"} =$$

$$\frac{\text{"X\_Exploitation"} \cdot \text{"Rate\_Exploitation - Production"} + \text{"X\_Sale"} \cdot \text{"Rate\_Production - Sale"}}{\text{"Rate\_Exploitation - Production"} + \text{"Rate\_Production - Sale"}}$$

$$- \text{"X\_Production"}$$

- The exploitation and disposal firms do not optimise their site (it is set by the model navigator, see 3.4).

- The population is represented by households (not individuals).

- The households optimise their site, in analogy to the production and sale firms, based on the distance to the working and shopping place, weighted with the numbers of ways for work and shopping, but with no regard to any resource flows. It is assumed that one person per household goes for work (48 weeks per year; 4 weeks were assumed as average time of vacations), and one person per household goes shopping (52 weeks per year).

- goods transport demand is calculated as the sum of the product of flows and the according distances, with no regard to the possibility of any collecting tours on the disposal side, but including the ways from the shops etc. to the houses of the consumers.

- The decision interval of the several agents is set to 1 year.

- There are no special measurement units defined.

3.3 Model limitations

With regard to the model draft, the following aspects are not considered in the model:

- 2-dimensional area aspects;
- zonal specifications such as in area planning;
- buildings;
- formation and failure processes of firms;
- competition processes between firms (only one firm for each process is modelled);
- transport infrastructure;
- transport agents (including induced flows of resources such as energy consumption etc.);
- different transport modes;
- government and governmental institutions;
- monetary flows and prices;
- recycling processes;
- detailed time aspects such as duration of activities or traffic congestion etc.;
- detailed socio-demographic aspects;
- detailed employment or unemployment aspects;
- behaviour adaptation processes of the agents (e.g. more shopping ways in case of a central site of the households).

Furthermore, the model in the presented version is not yet calibrated and validated. The model parameters have been set to initial values, which permits some qualitative simulation results.

3.4 Steering mechanisms

For the simulation the following steering mechanisms can be used to navigate the model:

- Sliders:

  Exploitation and disposal site in the land area can be chosen by sliders.

- Lists:

  The following parameters can be set in lists:

  - initial site of the production firm, the sale firm, and the households;
  - work and shopping behaviour parameters of the households;
  - resource renewal rate and waste adsorption rates.

- Graphs:

  The numbers of the households during the simulation period can be defined by a graphical input device for each household type.

4. Simulations and results

For four different model runs the most interesting results are presented here.

4.1 Default Run

Concept

The default run starts from an initial spatial separation of the households and firms and especially the exploitation and disposal firms. During the simulation, it is expected that the other entities will prefer a more concentrated pattern.

Parameter values

The parameter values chosen (see 3.4) for the default run can be seen in Table 1.

Table 1 Default run parameter values

Process/Firm	Exploitation	Production	Sale	Disposal
Initial site values	200 constant during simulation	120	60	150 constant during simulation

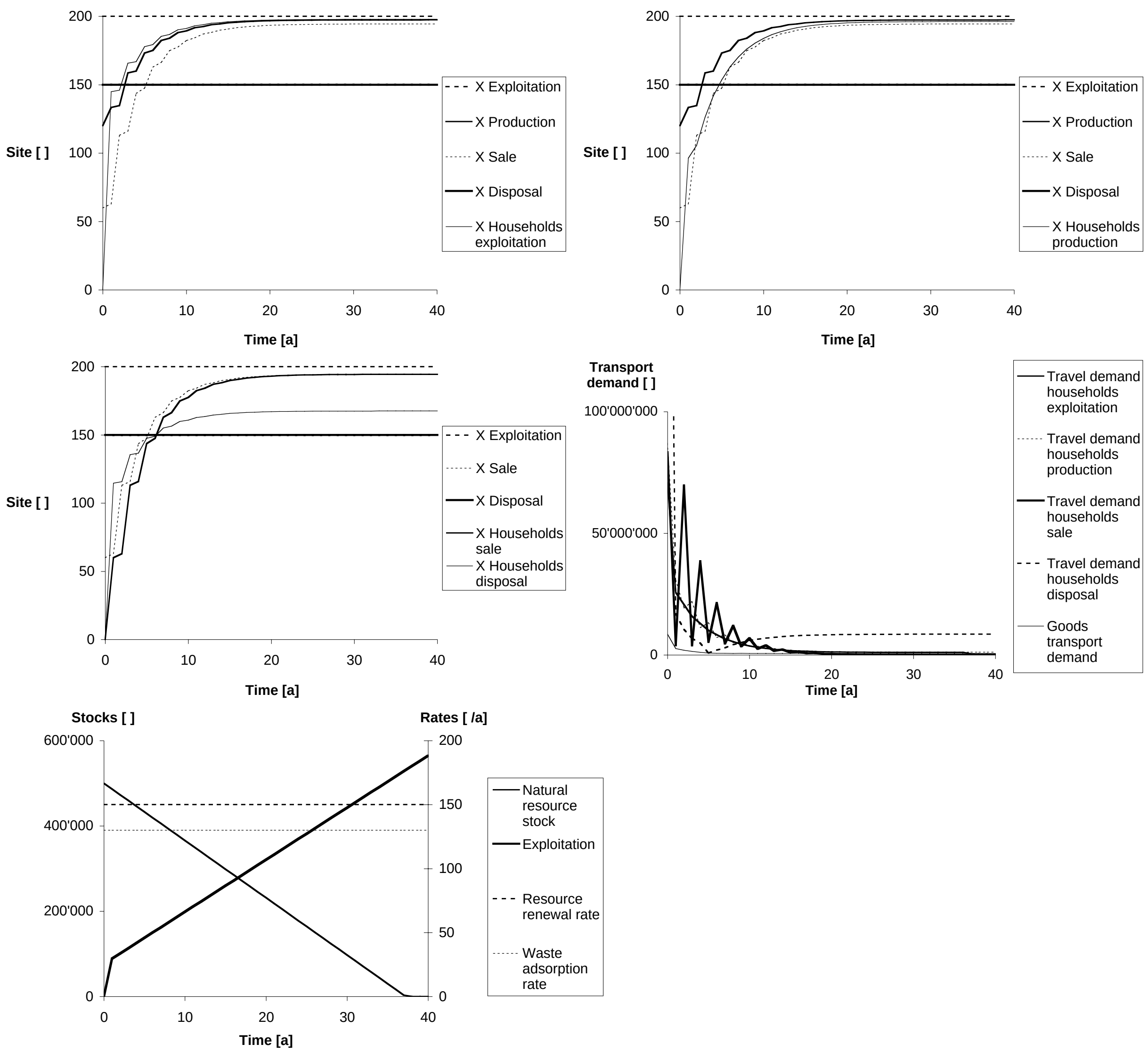
Households	Households Exploitation	Households Production	Households Sale	Households Disposal
Number of households	600	1700	2000	800
Initial site values	0	0	0	0
Behaviour Parameters:				
Weekly working days	5	5	5	5
Weekly shopping frequency	3	3	3	3

Environmental Parameters	Resource renewal rate	Waste adsorption rate
Values	150	130

Results

The results of the default simulation are shown in Figure 2. They show the expected concentration process, as it can be observed in urban areas. The households, whose members work in the exploitation, production and sale firms, choose their residental site close to the working and shopping place (in the case of the households working in the sale firm it is the same site). Due to the location of the disposal firm, the households working in that firm find their optimal site in a more outlying area in comparison to the other households, which results also in a comparatively higher travel demand. Generally the travel and goods transport demand decreases accordingly to the process of spatial concentration. Since this model draft does not respect the use of resources by transport, the decrease of the natural resource stock remains constant during the simulation process accordingly to the constant number of households.

Figure 2 Results of the default run



4.2 Big Distance between Exploitation and Disposal Run

Concept

With the big distance between exploitation and disposal run it should be possible to show how the mobile households and firms (production, sale) react, when the exploitation is at the one end of the space and the disposal at the other.

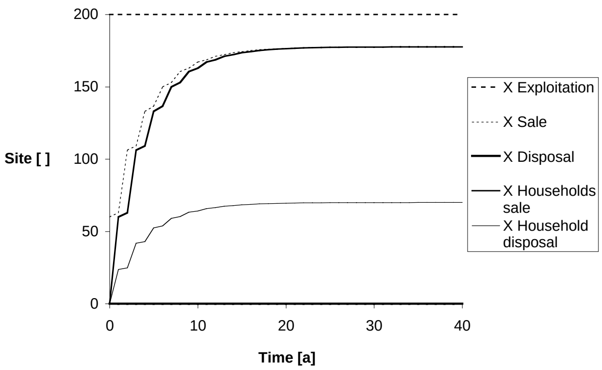
Parameter values

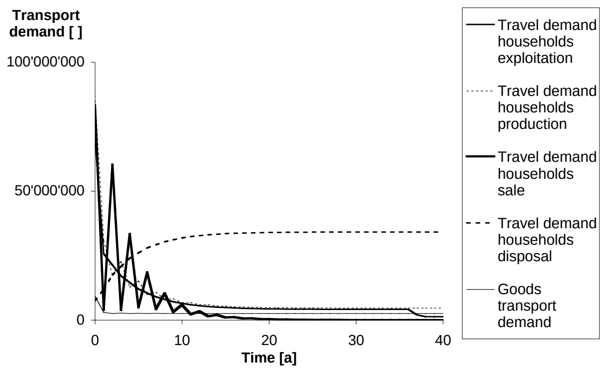
There are no further changes with regard to the default run, only the initial site value for disposal is 0 (stays constant during the simulation).

Results

Figure 3 shows the results which differ most from the default run. It can be noted that the big distance between exploitation and disposal leads to a more dispersed land use with regard to the previous run. The households working in the disposal firm choose their site in the country, what leads to much more travel demand. The land use is not totally dispersed and this is due to the fact that the households do not choose their site with regard to waste transports.

Figure 3 Results of the big distance between exploitation and disposal run





4.3 Less Shopping Run

Concept

Based on the spatial conditions of the big distance between exploitation and disposal run this simulation aims to show the effect of a different shopping behaviour of the households.

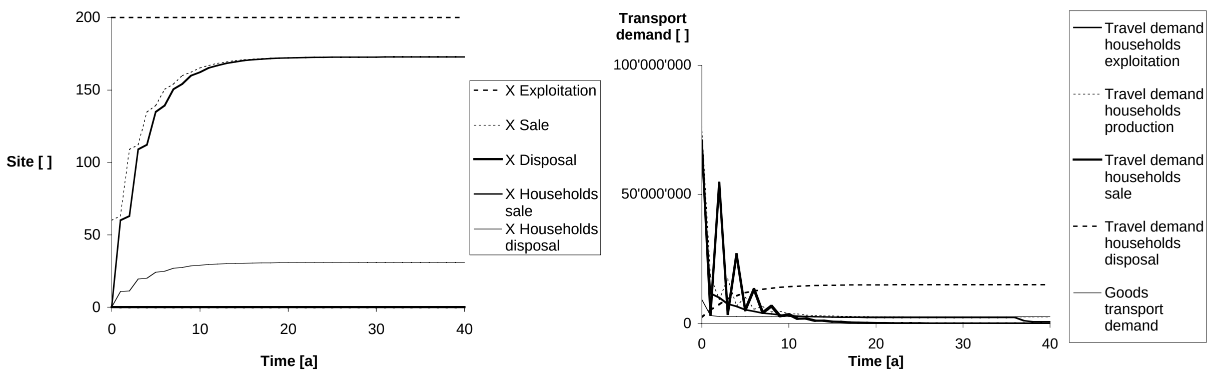
Parameter values

With regard to the big distance between exploitation and disposal run, the weekly shopping frequency is set to 1 (instead of 3) for each household group. The initial site value for disposal is 0 and constant during the simulation.

Results

Figure 4 shows the results which differ most from the previous runs. There is a remarkable influence of the household's shopping behaviour: A reduced shopping frequency by the household working in the disposal firm results in a site choice much closer to that of the previous run. The consequence is a reduced travel demand.

Figure 4 Results of the less shopping run



4.4 Non constant Population Run

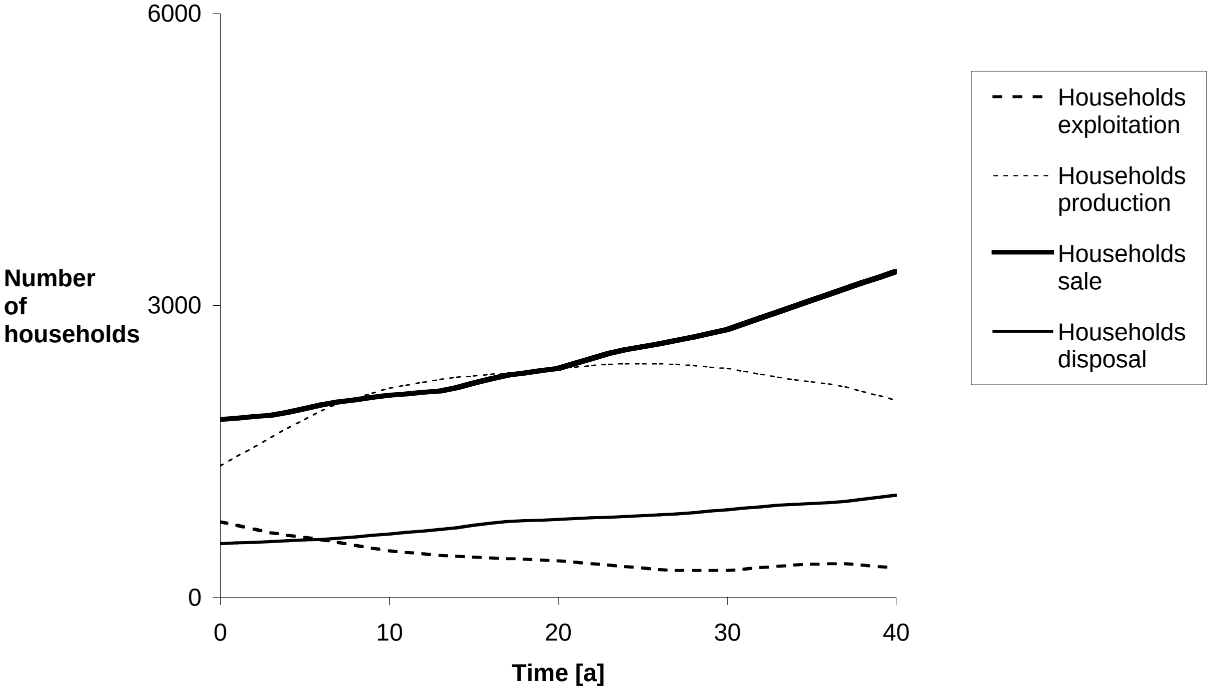
Concept

It can be expected that some changes concerning the population size and the number of households cause a different travel and goods transport demand. This effect should be shown by this run.

Parameter values

This model run starts with the same parameter values as the default run with the exception of the number of households. Their values during the simulation can be seen in Figure 5.

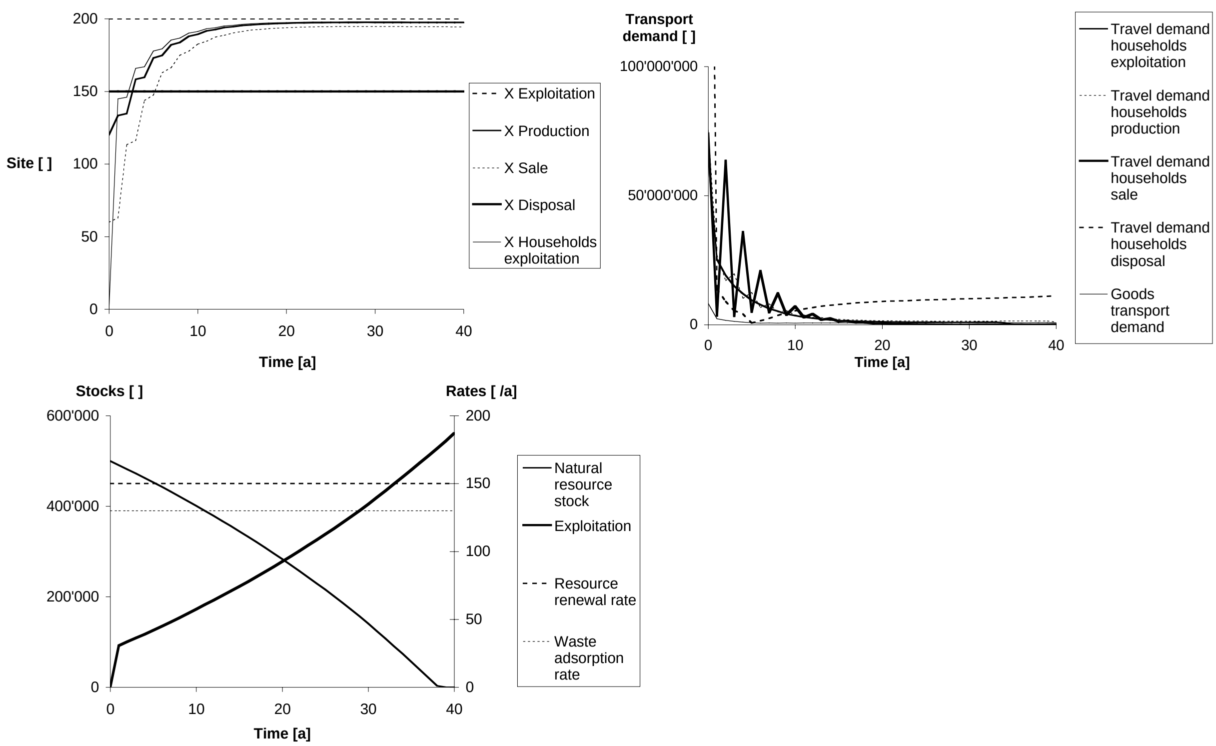
Figure 5 Number of households during the non constant population run



Results

There is no big influence of the number of households on the concentration process and the travel and goods transport demand (see Figure 6). A respectively bigger demand of resources and of goods transport is compensated by the household's site choices close to each other.

Figure 6 Results of the non constant population run



5. Conclusions and Outlook

The agent based system dynamic model draft here presented is able to show in a simple way the interaction between households, firms, transport, land use and the environment. According to the initial set of site and behaviour parameters for the households and firms, the simulation results in optimising the sites of these agents due to their location to each other. It also shows the possibility to develop a framework that is based on the connected relation of passenger and goods transports. However, it is a very limited first draft, therefore the significance of the simulation results is also limited with regard to the overall aim of a simulation tool that allows the evaluation of sustainability promoting policies. So the model has to be further developed step by step, by reducing the limitations mentioned in 3.3. The main focus should be pointed on the integration of a 2-dimensional space that includes land use (resource exploitation, agri-culture, industry, services, reside, disposal), transport, and the buildings and infrastructure connected to them (e.g. railways, roads), and on the substitution of the households by a more detailed population model. The goods flow shown in Figure 1 has to be differentiated into resources for construction, food, non-food articles, fuel, electricity and services. The transport system ought to be represented by at least public transport and individual traffic with regard both to passenger and goods transport. Moreover, the government with its institutions and functionality has to be represented as policy agent. In order to take into account the monetary aspects with money stocks and flows, it would be a good deal to evaluate the financial situation of the modelled agents. However, according to the number of integrated aspects, the number of agents to be modelled will rise. The forthcoming modelling process will point out, how far this aspects can be integrated into an overall model framework of transport and land use in the context of sustainability.

6. References

Abbas, Khaled A. und Michael G. H. Bell (1993) System Dynamic Applicability to Transportation Modelling, *Transportation Research*, **28A** (5) 373-400.

Bossel, Hartmut (1994) *Modellbildung und Simulation*, Vieweg, Braunschweig/Wiesbaden.

Hannon, Bruce und Matthias Ruth (1994) *Dynamic Modeling*, Springer Verlag, New York.

Hidber, Carl, Eugen Meier, Zlata Oblozinska und Jean-Pierre Widmer (1994) Verkehrskonzepte, Vorlesungsunterlagen, IVT ETH Zürich.

HPS (2000a) *An Introduction to Systems Thinking*, High Performance Systems, Inc., Hanover, NH.

HPS (2000b) STELLA® Research 6.0, Software, High Performance Systems, Inc., Hanover, NH.

United Nations (1993) *Agenda 21 Earth Summit - United Nations Program of Action from Rio*, United Nations Department of Public Information, New York.

World Commission on Environment and Development (1987) *Our Common Future* Oxford University Press, Oxford UK