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Causal Loop Model to Describe Transport System's Effects on Socio-Economic Systems

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Abbreviations

CLD Causal Loop Diagramming

GNP Gross National Product

LOS Level Of Service

Number

Structure of the paper

In chapter 1 the overall problem description will be given. In the 2nd chapter the applied method will be introduced and the process of CLD-model developing will be illustrated. In chapter 3 some transport related findings of the work will be discussed with regard to their impacts on the key indicators *quality of life* and *resource consumption*. In chapter 4 an overall conclusion will be drawn and fields for further research will be shown.

1 Introduction

All things around us are part of an overall system, and all these elements are connected together. These relations are flows of information and/or flows of materials. Together flows and elements form systems like economy, ecology, culture and so on. It becomes obvious, that transport of goods and passengers are an essential part to ensure the functioning of societies. But it is also important to realize that transport cannot grow to infinity. There must exist self-stabilizing properties in a system to prevent infinite growth.

The question is: "How does the transport system connect all system elements like economy, business management and other areas of socio economic systems together; where are natural barriers that means system immanent barriers; and how is the overall system behaviour over time?"

The main purpose of the work was to identify the structure of today's western oriented life style and economy - to depict this structure by applying causal-loop-method and to use this information on one hand as a discussion base to talk with experts of several disciplines and on the other hand to understand and estimate the overall system behaviour over time.

Every model is an abstraction of reality. The model building process is highly creative and there are no well-defined rules how to set up a model. But it's necessary to define system borders and the model context at the beginning of a modelling exercise. For the model presented here the following assumptions were made:

1. The model should be valid for a spatial bordered region (like a village, a town, a country, a continent, the world); so the areas for housing, food-production, transport facilities and so on are limited (closed system).
2. A western life style oriented "value"-system is assumed, i.e. consumer society; the believe in everlasting growth of GNP, and so on.

The following picture of the developed model shows major cause-effect-relations embedded in the context declared above:

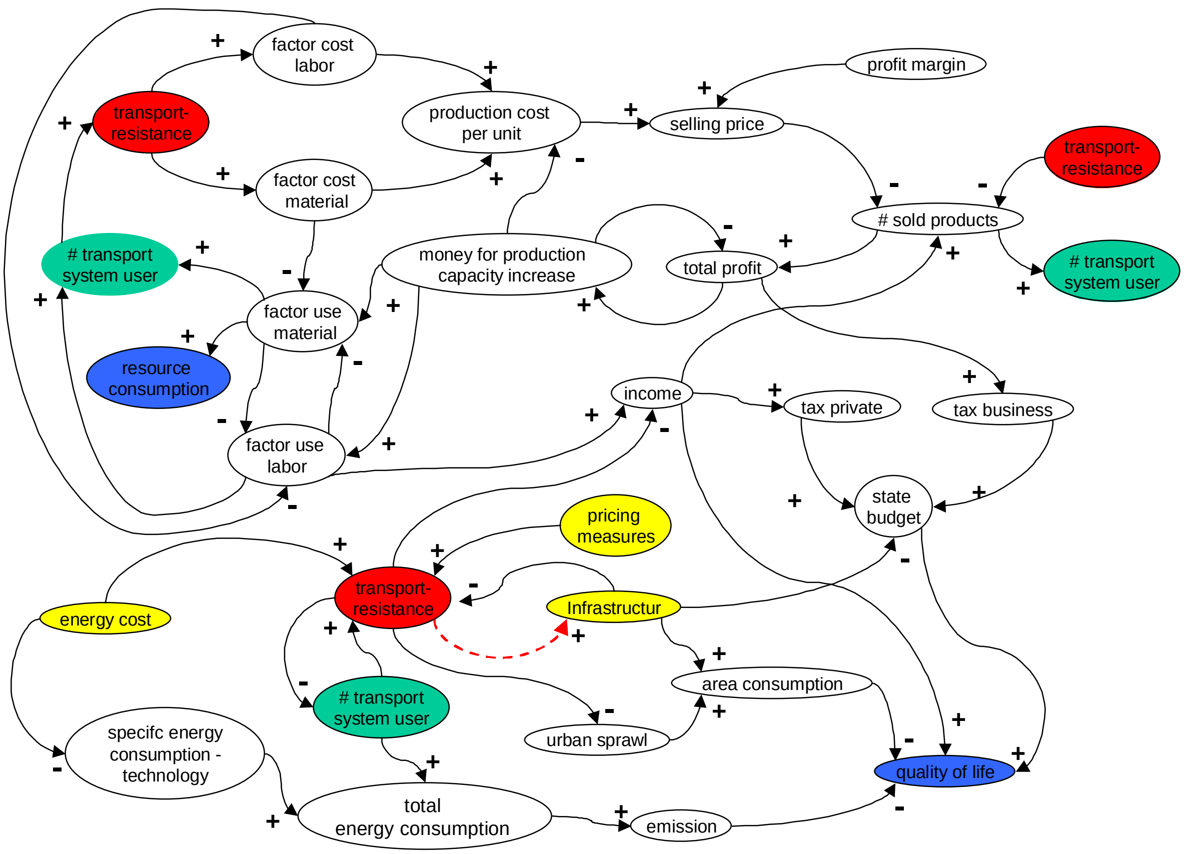

Figure 1: causal-loop-model

Source: Emberger G., Interdisciplinary view of impacts of transport policies on socio-economic systems, Dissertation, University of Vienna, Institut für Soziologie, 1999, page 30

In the following chapter first the process and the methodology will be explained, in the subsequent chapter transport related issues will be illustrated.

2 Methodology

To get new problem insights the causal-loop-diagramming (CLD) technique was chosen to describe the overall system behaviour. Because of the complexity of the underlying problem the author started by identifying the key-elements of the system and their interrelationships. The state of the art of several disciplines and their main theories were translated into the causal loop diagramming language.

Involved disciplines are:

- Transport planning, depict in the diagram through the entities *number of transport system user, transport resistance, energy cost, pricing measures* and *infrastructure*. It must be mentioned, that the elements *# transport system user* and *transport resistance* are always one and the same elements through the whole diagram.

  The reason for doubling them was twofold:

  1. To reduce the number of in- and outgoing arrows → clearness of diagram and
  2. from transport planning point of view there exist two major distinctions for trip purposes a) commuting trips - expressed through *# transport system user* in the upper left corner and b) leisure trips - expressed by the entity in the upper right corner of the diagram.
- Land use planning, expressed by the elements in the lower right corner of the diagram,
- Business administration - production, depict in the upper left corner,
- Business administration - market, shown in the upper right corner and
- Economy shown in the middle right corner of the diagram.

The process was carried out by a careful abstraction work - the chosen level of hierarchy of the model elements had to be nearly the same. Another requirement on the selected elements is the constraint that between two elements there must exist a clear defined positive or negative cause-effect-relation. If there exists no clearly defined cause-effect-relation the element must be a "Meta"-system and therefore it must be split into its sub-elements - in this case the hierarchy level was chosen wrong. On the other hand the number of elements should be as small as possible to help the reader to understand the system as a whole. The introduced model consists of 26 elements.

In the CLD there are 3 different types of elements:

1. autonomous elements - these elements are used to steer the overall system behaviour. Corresponding to the scope of the paper only transport related policies/measures are in this group: ***pricing measures, energy cost, infrastructure***
2. indicator elements - these elements describe the state of the art of the overall system, respectively the response of the overall system caused by changes of autonomous elements: ***quality of life, resource consumption***
3. influenced elements - these elements are influenced through cause-effect-relations: all other elements

If a CLD is designed based on the rules mentioned above, it has some useful characteristics, i.e. it is possible to derive quantitative results from a qualitative model. By applying the “depth-first-search algorithm” [1] onto the CLD, statements how (positive or negative) a specific measure influences a specific indicator over a specific path could be derived.

This information was calculated for all existing paths between autonomous elements and indicator elements. For example there exist 3658! different paths from *energy price* to *quality of life.* Also the information, how many elements have to be visited along the way through the model and how long the minimum and maximum time lags are, were calculated and stored in a database. The longest path from energy price to quality of life visits 22 different model entities; the shortest one reaches the target after 3 steps. The maximum time lag derived from the model was 52 years, the shortest one 7 years (based on expert estimation).

All these information, calculated directly from the CLD provide a feeling how the whole system behaviour would be. Short-term dominant loops, which influence the human decision-making process, can be made explicit and understood. Also "wrong" decisions based on the recognition of only simple cause-effect-relations could be explained. On the other hand the CLD can help to identify long term cause-effect-relations in the underlying system and their de- or stabilization characteristics. In a dynamic system the identification and the following elimination of vicious cycles (positive feedback loops - destabilizing characteristics) must be a major goal of our society.

During history research disciplines have developed their own language and point of view of reality. One negative effect of this separation and specialisation is that there exists no “meta-science” which links and assesses research results of different disciplines into an overall system view. To overcome this problem the CLD approach was chosen by the author.

Firstly the different languages of the involved sciences had to be studied; secondly major theories, laws and dogmas had to be identified and thirdly they had to be translated into the CLD-language on a very high abstraction level. By creating a so-called *initial CLD* first insights into the overall system structure and behaviour could be derived. Then, in a next step, this *initial CLD* was checked and verified through interviews with experts of involved disciplines.

This validation process was performed in the following way: At the beginning of an interview the method of causal loop diagramming was explained to the interview partner by using simple, intuitively understandable examples. After this phase the interview partner was able to understand mental models depicted with causal loop diagramming technique. In a next step, the interviewee was shown the part of the *initial CLD-model* that corresponds to his discipline. This part of the model was discussed then in detail and corrected where necessary.

This process included answers of the interviewee to the following questions:

- Do the displayed cause-effect-relations represent the main theories/dogmas of your science?
- Is the direction of cause-effect-relation positive or negative?
- How long do you think is the minimum and maximum time lag between cause and effect of the two model entities?

After finishing this process, the rest of the model was introduced to the interview partner and interfaces and connections to other sub-systems respectively sub-elements of the whole model were discussed. In total ten experts of touched science disciplines were interviewed during the validation phase. Most of them seemed to be very interested and confirmed that they got new insights into the underlying problem.

3 Transport system related findings

As mentioned in the introduction, urban sprawl (caused by existing transport system) and transport related emissions are responsible for a reduction of quality of life in the so-called 1st world. To solve these problems different transport policies could be applied. These policies can be classified in 3[1] main categories:

1. pricing measures, which influence the organization of existing transport systems (parking fees, taxes, road pricing, fare prices and so on)
2. energy cost, which influence the technical innovation concerning vehicle fleets, and
3. infrastructure investment respectively new construction of e.g. highways, subways or high speed trains.

All these measures have in common that they influence the *transport resistance* in a specific direction. As shown in the CLD-model a transport policy leads via the model element *transport resistance* to a change in the *number of transport system users* (decrease or increase) or changes the *personal income*.

In the following two inherent aspects of the causal-loop-diagram will be discussed in more detail:

a) Economy of scale effect

If for example the *fuel price* goes down, *transport resistance* goes down and the factor cost for labour and material goes down, too. That can be seen in the upper right corner of the CLD, expressed by arrows marked with the “+”-sign. Because of different reaction speed of these cost changes (labour cost decrease has a longer time lag than material cost decrease) and because the change in material cost is more cost effective, labour becomes, seen relatively, more expensive compared to production material. This fact results, by assuming a substitutional production function, in a substitution of *factor use labour* through *factor use material*. By walking further through the CLD-model it can be seen, that not the whole potential of labour substitution takes place because of the expansion of production output and following from that, more labour and material would be demanded. In a long-term point of view this everlasting economic growth (expansion of production output) is not possible

[1] Generally there are only two major transport policy categories: monetary and capacity policies. Because of the different system impacts the monetary policies are split into *pricing measures* and *energy cost*. A more detailed justification of this issue is provided in [2].

(model assumptions point 1) – so the conclusion is that there must be a structural error in the existing system. But this structural error is apparently accepted because the negative effects (increase of *resource consumption*) are far away (in space and time) from the causing factor (decrease of *transport resistance*).

Expressed in shorter way: A decrease in transport resistance, caused by infrastructure construction or any other transport related policy which reduces *the transport resistance*, produces a decrease in employment by a simultaneously increase of resource consumption.

b) Infrastructure effect

Another interesting finding derived from the introduced CLD-model concerns the system elements *infrastructure* and *transport resistance.* Normally a policy measure should be an autonomous decision, based on scientific knowledge and made by responsible politicians. Decision makers define also the direction and height of a specific measure implementation. This characteristic of an autonomous decision is expressed in the CLD as an entity with only outgoing arrows. As mentioned at the beginning of this chapter, 3 different categories of transport related measures/policies exist. 2 are pricing measures and one is *infrastructure*. Let's focus on *infrastructure*: there exists a dashed arrow starting at *transport resistance* and ending at *infrastructure*. Per definition infrastructure is therefore no longer an autonomous policy because it is influenced by a system element. At least in Austria and in Germany there exist official laws and guidelines which ensure that if the transport resistance, measured in LOS, falls under a specific threshold, construction of new transport infrastructure must be executed. These laws only exist for road traffic. From system dynamics' point of view the duty of construction of new *infrastructure* mentioned above together with the change in the *number of transport system users* is a vicious cycle and leads therefore to an exponential growth of mechanical transport effort.

In reality the system behaviour described above comes to light as the "concentration" and "decentralization" process. A faster, more energy-consuming transport system enables on one side the concentration of production facilities and also makes possible the existence of shopping centres (economies of scale). On the other hand this transport system promotes settlement decay and induces an additional demand for motorized physical mobility. The vicious circle is closed and works with all its negative impacts on quality of life and sustainability.

4 Conclusions and further outlook

To understand system behaviour over time and to steer a dynamic system it is necessary to identify the main system components and their cause-effect-relations. In other words – it's essential to know the structure of a system to estimate the system behaviour over time.

Human beings are, caused by their evolution, not able to understand complex dynamic system behaviour without using an adequate tool. Spatial and time dimensions of human interventions in ecological systems need to be expressed in an explicit manner: CLD seems to be a suitable method.

Only from an observing point of view outside the investigated system a neutral judgement on interventions is possible. Most transport planners are not able to distinct between their own intra-personal experience of being a member of a transport system and system effects of the implementation of transport policies on a transport system as a whole.

Most of transport planning activities are irreversible. They induce long-term effects in economy, land use and many other system areas.

Negative feedback loops enable self-stabilizing system behaviour. The lack of such structures must be detected; appropriate frameworks should be promoted and established.

The number of interventions in a dynamic system increases the system-inherent complexity and reduces the goal-oriented steering of a system.

Without knowledge about system behaviour over time an acceleration of system speed is irresponsible and dangerous.

The time scale chosen for policy assessment must fit to the underlying problem.

The CLD depicted here should be seen as a starting point for a broader discussion and the derived findings should be improved. New viewpoints from other disciplines should be included and their impacts proved against the overall system behaviour. The next logical step must be the further development of the qualitative CLD-model towards a quantitative stock-flow model. To realize this plan additional research is needed. This process might deliver valuable insights about overall system behaviour and will ensure a development towards a viable society.

5 References

1. Wirth Nikolaus, Algorithmen und Datenstrukturen, B.G. Teubner Verlag, Stuttgart, 1983, 3. Auflage

2. Emberger G., Interdisciplinary view of impacts of transport policies on socio-economic systems, Dissertation, University of Vienna, Institut für Soziologie, 1999