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A group multicriteria decision aid and system dynamics approach to study the influence of an urban toll and flexible working hours on the congestion problem.

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Abstract

The effect of an urban toll and flexible working hours on traffic crowding in cities is analysed by means of a framework based on a methodology in which system dynamics and group multicriteria decision aid are combined. The basic model, which extends a congestion model described by K. Small, examines the behaviour of driving car commuters with respect to their home departure times to office during the morning rush hours. Several strategies for urban toll combined with working time flexibility are investigated as well as the possible use of the benefits induced by the toll for transforming the vicious circle of crowding into virtuous circles, e.g. promoting alternate transport means.

1. Introduction.

A major problem nowadays in Western countries is the so called congestion problem. It is clear that the road network is no longer sufficient to handle the traffic. Especially the traffic crowding in the cities resulting in large traffic jams in the morning and the evening have reached a level far above the acceptable limits.

In this paper we try to understand potential solutions for this problem through the combination of several techniques of operational research such as system dynamics and multicriteria analysis. Our starting point is a simple congestion model introduced by K. Small (1992) based on the trade-off between two cost-functions: the time people spent on road when driving to the office, and the pressure of the schedule people are "suffering" to get at time at the office (9 a.m. in our model). The major supposition in this model is that every car commuter from the suburbs defines his personal strategy for leaving home by calculating this trade-off.
With our model we try to apply Small's theory and to extend it in such a way that it would enable us to propose possible solutions allowing an influencing on the trade-off made by the car commuters.

In the next section we briefly explain the techniques used in the model. In the third section the basic assumptions of the model are discussed. Finally, the last section consist of a first model which has still to be validated and which is partially under construction.

2. Multicriteria decision making and system dynamics.

Our everyday experience learns us that tackling socio-economic and environmental problems is a very hard thing to do. System dynamics with its focus on structuring a problem seems an appropriate technique to help us to understand the basic mechanisms of these complex problems. However, most “analysts” use system dynamics only to understand the problem and to make a long term forecast. Afterwards the model is never used again. Some of the authors: J.P. Brans *et al*. (1998) proposed to go beyond what most system dynamic users do by introducing a method to control this socio-economic or environmental system based on control theory and multicriteria analysis.

Important questions in the construction of a system dynamic model are: for who is the model intended, which policies should be examined, etc. (see e.g. G.P. Richardson and A.L. Pugh (1981)). In relation to these two question Brans *et al.* proposed to use a multicriteria analysis with the following purpose: the decision maker (i.e. the person using the results of the model) will have to make a choice between several policies simulated by the model. Most of the time this choice will depend on the outcome of different variables, which may not all have the required value or behaviour. Hence, a choice must be made between different policies which are validated on several, possibly conflicting, criteria. It is at this stage that the multicriteria techniques can help the decision maker. Which multicriteria method is used, is not essential at this stage, in principle any method can be used.

Once the decision maker has determined its policy, this policy is implemented as well in the model as in reality. It is now that the control and monitoring phase starts. A constant interaction between the real data and the expectations of the model takes place. Though if the behaviour of the variables in the real world are diverging too much from those expected in the model a warning signal occurs, meaning that the policy was not the appropriate one or that the model was too restrictive. In this way they were able to construct a decision support system for complex socio-economic problems.

However, an important lack in the structure of their method, which was later on remarked by C. Macharis (1999), is that the system itself can incorporate choices (i.e. the system itself is making choices between several options) and that these choices are governing the system and its behaviour. In our model we will incorporate such a “decision-motor” based on the multicriteria method PROMETHEE introduced by J.P. Brans and P. Vincke (1985), which we have transformed in such a manner that it could be used in our model. However, we are not working with one decision maker within the system but with a large number since the decision makers in the system are nothing but the car commuters. Hence, we must introduce some kind of statistical decision making which would lead to a distribution of choices or percentages of decision makers choosing a particular option.

The transformation of the PROMETHEE method is necessary since this gives a ranking of the several choices and not a percentage or a distribution. If we now suppose that the car commuters are all alike and all think more or less in the same way, one can transform the Promethee-I ranking into a distribution by means of the following expression:

$$\text{probability of choice A} = \phi^+(A)(1-\phi^-(A)) \qquad (2.1)$$

where $\phi^+(A)$ and $\phi^-(A)$ respectively stand for the power and the weakness of the choice A (for more explanation and detail on the Promethee method we refer to J.P. Brans and B. Mareschal (1994)).

3. Basic assumptions of the model.

A first assumption we made is that of an idealised city, in which the car commuters get immediately from their house on the highway and from the highway to their job. In a much more advanced stadium of the model the bottleneck effects rising up at the entrance and exit of the highway should of course be incorporated in the model. We also suppose that there is only one highway to this city, and that every car commuter must take this highway. Although this is a large simplification it seems to be good approximation of the reality.

In this model we are only interested in the morning traffic jams. Hence the model is constructed in such a way that it leads to an iteration process (by resetting the levels and certain crucial variables on their initial value), each iteration representing a day from 6 a.m. till 12 a.m. Of course if we want to fully implement flexible working hours without any limit on the time to start 24 hours should be modelled, including also the traffic jams in the evening. The integration step of the model represents 6 minutes, which implies that in our model every 6 minutes a bunch of people are leaving from their home. Hence, the distribution of departures is known every 6 minutes. The iteration interval (360 minutes) and the time step (6 minutes) can easily be adapted in the model such that extending the length of the iterations to 24 hours should not be to difficult.

After each iteration we make the hypothesis that every decision maker asks himself the question in the evening at what time he will leave in the morning, taking into account the past situations and traffic jams the days before, and making the balance between the several criteria through the use of the cost-functions.

A final and more technical assumption is the one with respect to the “decision-motor”. In the model we suppose that the “decision-motor” generates the statistical decision making process in an appropriate manner. Presently it is too early at this stage of the model to confirm this. Validation tests should be performed in order to calibrate this “decision-motor” and its inclusion in the system dynamic model.

4. The iterative system dynamic model.

As already mentioned the model is constructed in such a way that it generates an iterative process. In fact if one considers a single day the main process of people leaving home, getting on the highway and then arriving at their job is a so called open loop problem (blue part of fig.1). However, in reality the car commuters take into account what the traffic jams would be, using there daily experience, in their decision-process on leaving home. Of course they are making a guess, expecting that the situation would be the same as yesterday and the day before, etc. This leads to the creation of certain habits which is translated into a kind of optimal departure distribution. This effect can easily be verified experimentally: the day after a long holiday, traffic on highways becomes chaotic; after a week or so the distribution of departures has converged towards its optimal shape. Hence, the study of this departure distribution through an iterative process could learn us something about this convergence.

It is clear that if we can influence the departure distribution in such a way that the number of people on the road at the same time decreases, a part of the traffic jams will dissolve and the congestion will also diminish. So the question remains: how can we influence the distribution of departures in an appropriate way ?

A first approach is to try to modify the cost-functions by implementing several strategies. To modify the time spent on road directly it would be a hard task, since this can only be done by investing in infrastructure (such as enlarging and adding highways). Moreover this solution would not be sustainable in the sense that after a while the same problem would arise again. A real sustainable solution can in our opinion only be generated by changing people's habits.

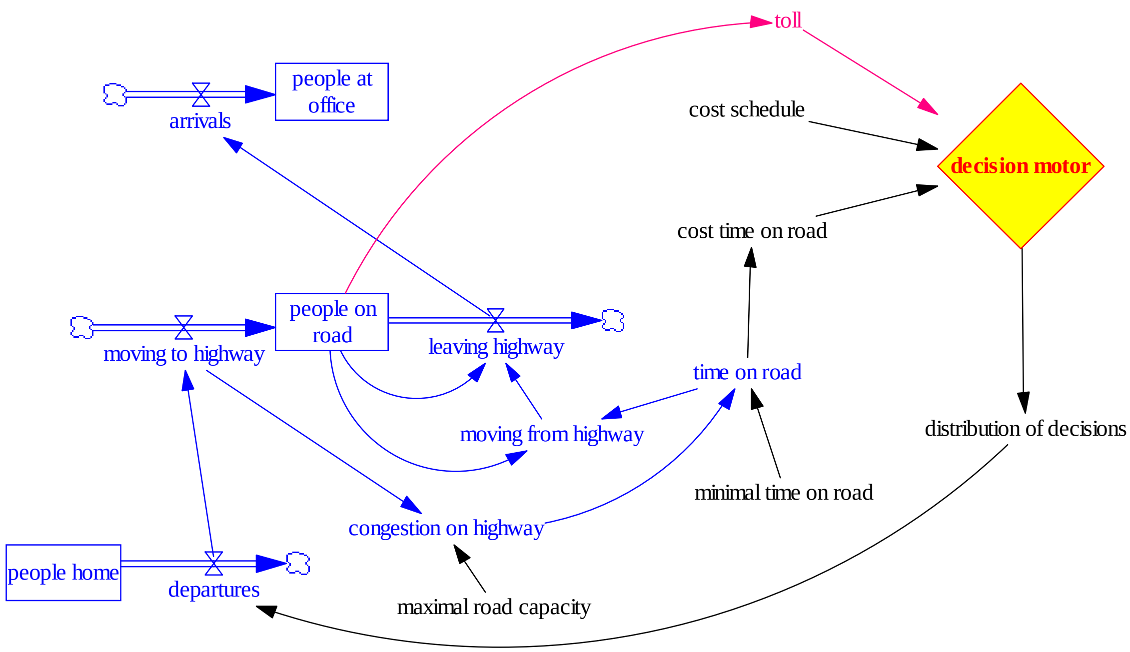

Figure 1: Sketch of the model.

The people's habits with respect to the departure time are in fact imposed and restrained by the second cost-function namely the pressure of the schedule: people must be at time at their job or they are penalised and can even lose there job. By giving them some freedom with respect to the working schedule through the introduction of flexible working hours the fear of being too late at their job will disappear. Hence, the weight of the cost-function pressure of schedule in the decision-process will decrease, which determines the distribution of departures as can be seen in the above figure.

However, by only allowing flexible working hours, the effect on the morning jams would probably be marginal since habits of people are very inelastic by definition. Hence, an incentive should be created in such a way that affects them deeply, namely their wallet. This can be done by adding a new cost-function namely a toll when entering the city depending on the degree of congestion at that time starting from a given threshold (in pink in fig.1).

The introduction of this third cost-function corresponds to the introduction of a control loop, the intensity of which can be regulated. In this way we are able to control the system and to guide it to a desired level. If this toll is well chosen (i.e. if the intensity of the control loop is well determined) the people will get the incentive to leave earlier or later in the morning. However, it is an absolutely necessity that this toll is combined with flexible working hours, otherwise the effect of the toll will be practically nonexisting. The taxes collected through the toll can then be used to increase the investments for a better public transportation network which on its turn would create an incentive for people to leave their car home. However, the influence of the public transportation has not been included in this model, because it is beyond the scope of this model.

5. Conclusions.

In this paper we have tried to demonstrate on the traffic problem the necessity to combine several techniques with system dynamics modelling. This necessity is imposed by the nature of the problem itself since there are different time scales. Although we were not able to present simulation results here, due to the fact that several parts of the model need to be validated, the basic structure of the model is clear and allows us to understand the process which cause the traffic jams in the morning.
One may conclude that if one wants to "solve" (partially) the traffic problem, it is the departure distribution, created by some statistical decision process of the car commuters from the suburbs, which should be spread out by introducing new cost-functions for these decision makers.

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