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# SIMTRANS (Freight Transportation Simulation Model)

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**Key words : freight transportation – market analysis – rail – road – Co2 – Kyoto – Emission credit policy – causal loop analysis**

**ABSTRACT :** The authors have been asked by the French Ministry of Transport, to develop a System Dynamics model which could help analyze the dynamics of the French freight transportation market (Road – Rail – River). A little later, the model was modified and used to analyze the possible consequences, on that same market, of the Kyoto proposed Emission credit policy.
Both models are explained here, but in addition we show how an « ex post » causal loop analysis can help, in this context, to have experts understand better the numerous and often contradictory simulation results.

## 1 - INTRODUCTION

This paper could be subtitled : « to model, to apply, to convince ».

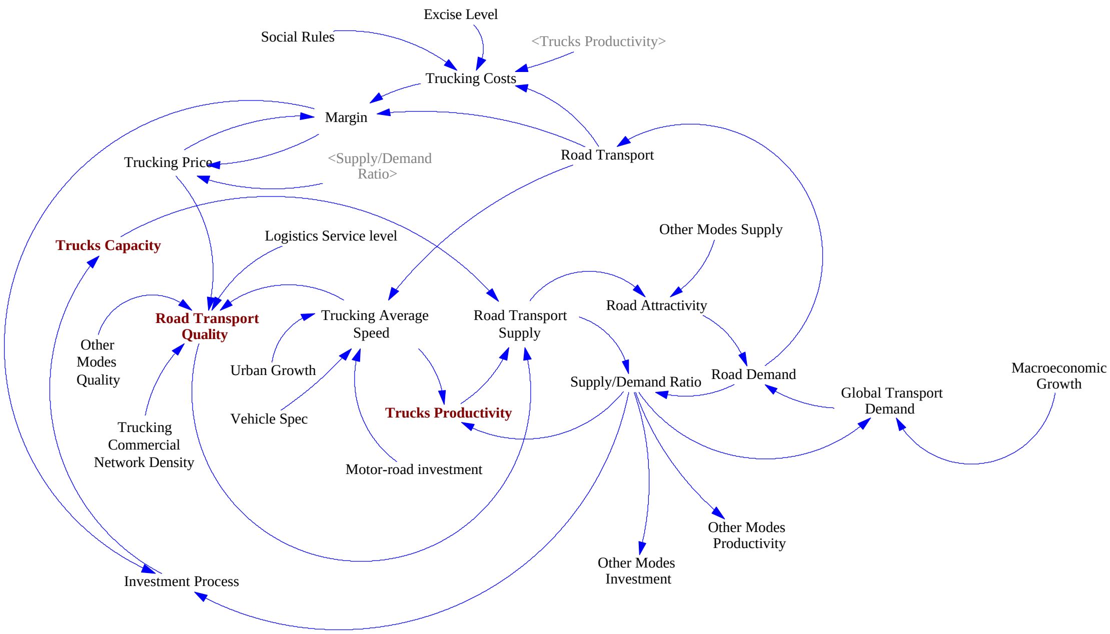
Many System Dynamics models have been built in the last 40 or more years, some simple, some very complex, most of them good in the sense that they did have a meaning, a purpose, were thoroughly tested … yet not that often used in practice. Hence many of these models did not outlive the involvement of their creator.
One of the reasons for this gap between good models and often-used models has been and still is the difficulty to show their usefulness and convince people that they do bring them knowledge they did not have.
Let us admit straight away that we, long term System Dynamicists, have often been faced with this same situation, namely the difficulty to show practically and quickly (managers are in a hurry) the long term knowledge and system understanding brought by our models.
In the case of the present model, however, we were asked not only to develop it and to show practical realistic simulations, also to apply it in a specific context of general interest (Kyoto agreements), but essentially we had to find a way of showing, quickly, simply and convincingly, using the main elements of the model, some of the probable long term consequences of decisions, situations, events and evolutions.

Therefore, this paper has three parts which correspond to the above mentioned consecutive actions.

## 2 – SIMTRANS : a French Freight Simulation model

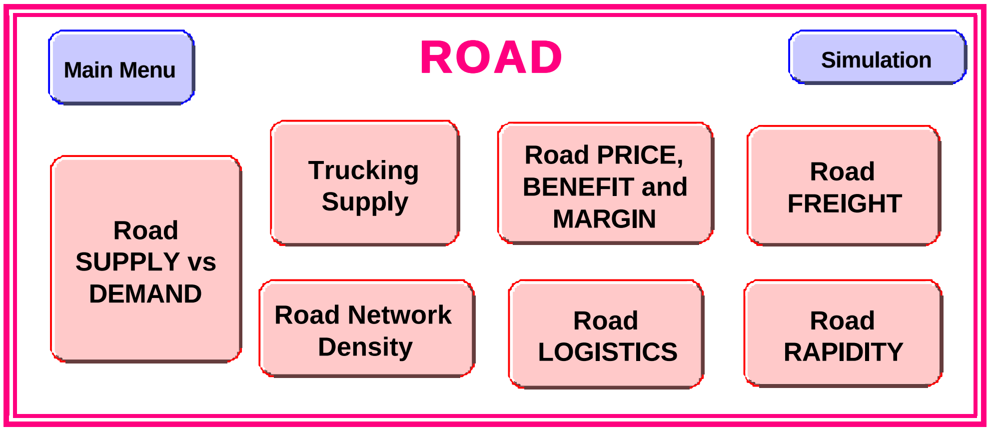
We describe the development and some uses of a System Dynamics model of French freight land and river transportation structure (which means freight transported in France by French and non-French operators).
This model, asked and paid for by the French Ministry of Transportation, is a global forecast tool of transportation and modal split between three types of competitive freight transportation : road, rail and river. It is based on a supply-demand « meso-economic » desegregated analysis.
Beyond its forecasting possibilities, SIMTRANS has been used to test numerous scenarios, concerning both the macroeconomic environment and transportation policies. It can and has been used to understand the efficiency and/or limits of policy decisions, including « one-way » single minded policies such as increasing excise taxes without a corresponding network investment policy. It is also being used to analyze the impact on freight transportation structure of sudden disturbances such as oil crises, strikes in some or all transportation modes, etc.

The following is a simplified causal diagram of the model, showing only one mode of transportation (road).




Basically, the model contains 4 main sectors :
3 sectors describing the behavior of each transportation mode,
1 sector corresponding to the economic environment, containing 7 different freight and product types (agriculture, energy, chemicals, metallurgy, etc.)

Each transportation sector is defined by the following main variables, which are in fact whole sectors by themselves




We have considered that variables defining most freight transportation can be characterized by three main properties :

How much (quantity)
How efficient (productivity)
How good (quality)

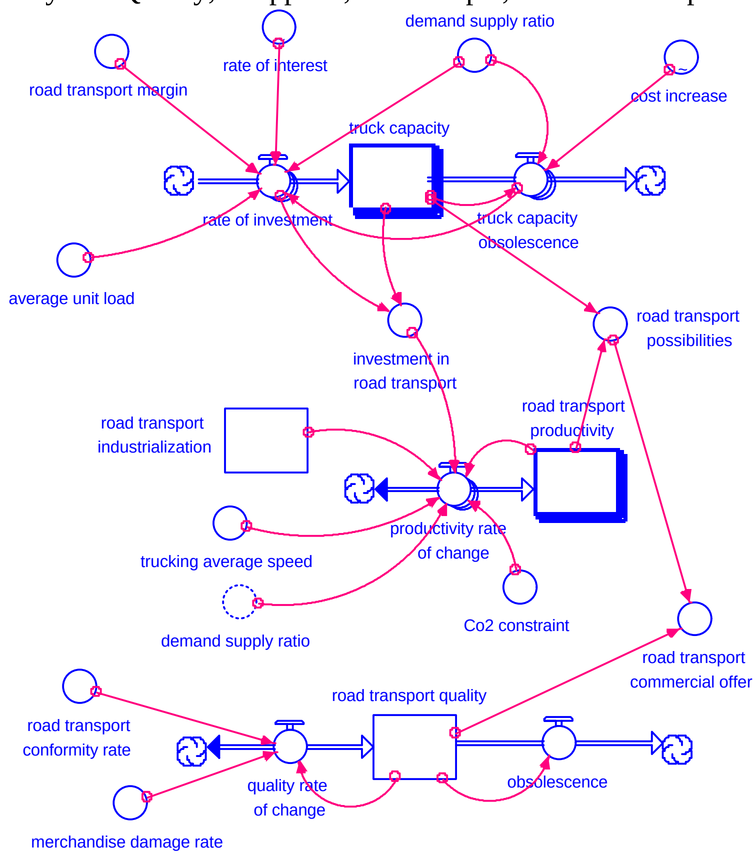
These triple defining properties apply to the amount of freight transported, to the commercial network density, to logistics as well as to rapidity. For example, road (as well as rail or river freight) is defined by available (and variable) Transportation Means, Freight Productivity (also a variable) and Transportation Quality.
The supply concept is very important for the transport industry. Transport cannot be stocked, and it is not possible to produce capacity « just in time ». What we need is an overcapacity, because shippers must believe that transport companies which they deal with are always able to bring the whole capacity into play. But in fact, supply is a combination of capacity, productivity and quality.

Capacity is basically a loading (usefull) « tonnage » of vehicules, barges, waggons etc..
It is typically a stock depending on enterprises' behaviour. This level variable can be used with more or less efficiency, which we shall call « productivity » in the model. It represents the distance (kilometers) the available capacity can and does move per unit time.
It depends on the supply/demand ratio on the market and some structural parameters.
That is to say that speed-regulations, quality of infrastructure, vehicle perfomance, allow a certain productivity , whether the market will use it or not.
The physical supply is the result of the multiplication of capacity by productivity, that is to say that you could produce a certain quantity of tons-kilometers.

Quality is a basic variable of transportation competition, and therefore explains the modal split.
We consider two types of quality parameters.

The first category is the direct « quality » of the supply. What we describe is in terms of « conformity » (the right thing in the right place), and in terms of « no damage » to shipment.
We consider that the percentage of damage and no conformity is equivalent to a decrease of the supply.

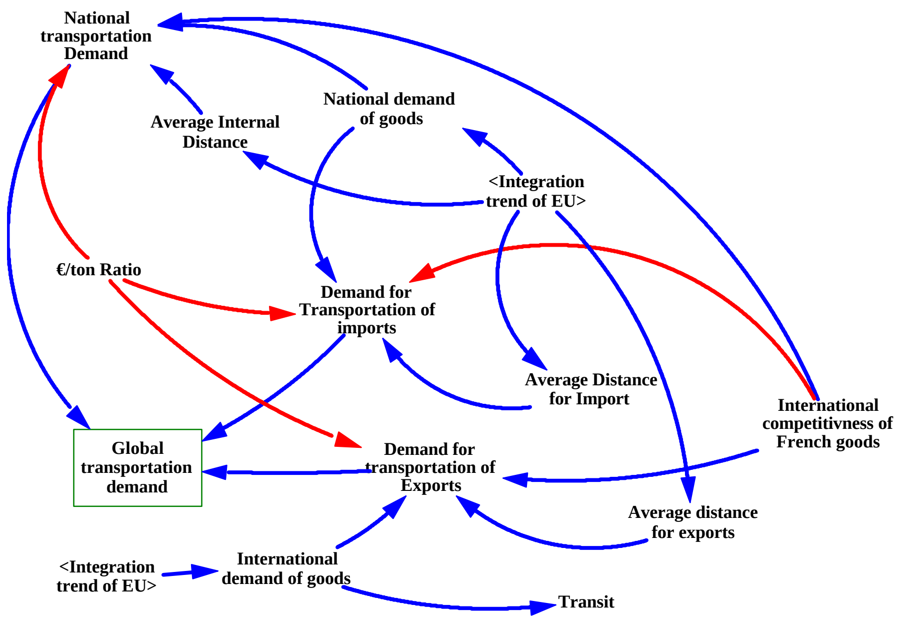
The following diagram gives a rough idea of the way we have modelled this triple concept of Means, Productivity and Quality, as applied, for example, to Road Transport.




The second type of quality concept is more complex. It represents the way we compare rail, road or inland navigation.
The problem is to combine different quality items such as price, price change, rapidity, network density, etc… in a globally attractive combination for each mode. Each quality index have not the same weight for the different modes. For example, we can imagine that prices are very important for inland shipping, rapidity for road and rail, etc…
The calibration of this part of the model is extemely important and combines statistical and experts analyses.

The « demand » sector attempts to deal with the diversity of exchanges. Transportation in France is the result of domestic trading, which means resident demand satisfied by French goods, importation goods driven by national demand, and French exportations driven by international (in fact mostly EU) demand.
The global level of exchange between other EU nordic countries and the Iberic peninsula and Italy, also generates a « transit » traffic through French territory.
Each basic economic sector has its own dynamics, both national and international, caracterized by specific ratios (average distance, $/ton ratio, international competitiveness, etc..)

The next causal graph shows the principles behind our sectorial forecasting process of demand.

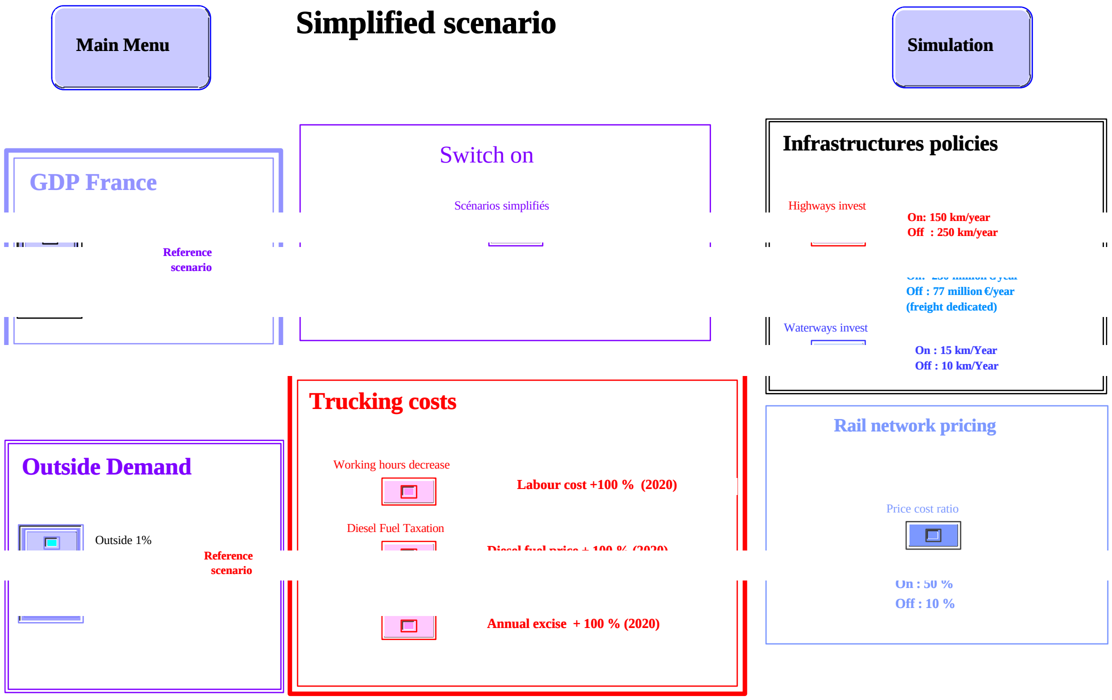



In addition, we take into account the fact that the energy sector has links with the transportation sector - trucks use oil -, and that certain sectors have links among themselves. For example, fertilizers and chemicals have links with agriculture, and agriculture is linked with food industry.

The model can be used easily (Stella user friendly interface) by students or politicians (simplified inputs) or by professionals (differentiated inputs for each of the 7 economic sectors).

Three different ways to use the model have been defined :

- A "detailed" mode, where one can describe through graphical inputs a forecast over 20 years of most of the input variables of the model such as macroeconomic and freight sectors forecasts and transportation policy hypotheses.
- A "semi-detailed" mode, where the 7 freight sectors are endogenous.
- A "multiple-switch" mode, where the user has to choose between different ready-made macroeconomic packages and government actions.




## Simplified mode control panel

The « simplified » mode is very useful to explain what is or is not possible in terms of transportation policy objectives.
For example, it is frequently suggested that a change in the road pricing policy, which would include accounting for external costs, would modify the modal split. Our simulations show that this assumption may be incorrect. An increase of the trucking labor cost (through lower allowed working hours) and a high level of excise tax, do not produce a significant change in the modal split.
On the other hand, with a new infrastructure policy, such as freight dedicated investment on railroad, and lower highway investment, the modal split could change significantly, although it would take some ten to twelve years.
The best practice policy is probably a narrow path for a government. For example, if the cost/price ratio for railroad infrastructure reaches an average of 50% rather than 10%, all the benefits of the above mentioned policy package would be lost for rail.

## 3 – SIMTRANS Co2 : Emission permit policy analysis

The SIMTRANS model has been adapted and used to try to answer the following question, asked by the French Energy and Environment Governmental Agency (ADEME) : what does the Kyoto proposed Emission credit policy do to the freight transportation sector, and conversely, which policy concerning this sector is likely to have an effect on the emission of Co2.

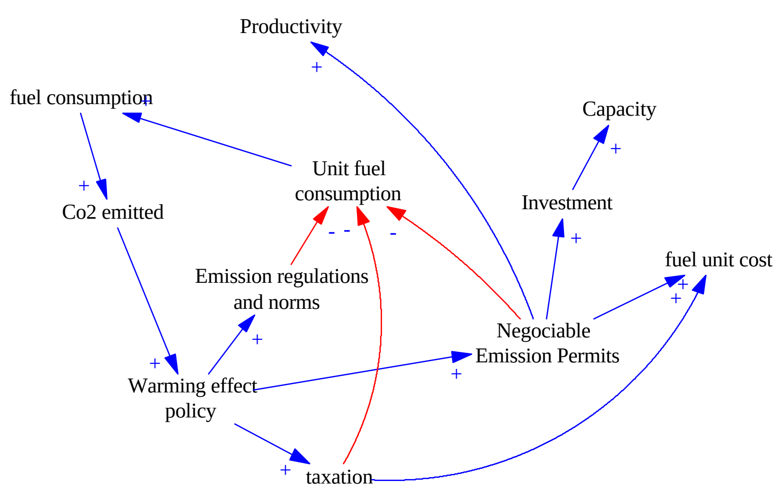
In March 2000, the Commission launched the *European Climate Change Programme (ECCP)* to prepare additional policies to ensure that the EU achieves the 8% cut in Co2 emission by 2008-2012, as compared with the level of 1990, a cut to which it is committed under the Kyoto Protocol. The latest data show that Co2 emissions are increasing rather than decreasing, and that the 8% reduction goal will not be met if no additional measures are taken. And transportation emissions are growing in OU at even a higher rate.

*As stated in the Commission's November 2000 Green Paper on security of supply, in 1998 energy consumption in the transportation sector was to blame for 28% of emissions of $CO_2$, the leading greenhouse gas. According to the latest estimates, if nothing is done to reverse the traffic growth trend, $CO_2$ emissions from transportation can be expected to increase by around 50% to reach 1 113 billion tonnes in 2010, compared with the 739 million tonnes recorded in 1990. Once again, road transportation is the main culprit since it alone accounts for 84% of the $CO_2$ emissions attributable to transportation. However, internal combustion engines are notorious for their low energy efficiency, mainly because only part of the combustion power serves to move the vehicle.* (*source:*WHITE PAPER 2001 "European transportation policy for 2010 : time to decide")

According to the ECCP, one strong policy strategy would consist in a internal EU greenhouse gas emission trading scheme.

It is this proposed strategy that we were asked to analyze through the use of an adapted version of SIMTRANS.

A simplified causal diagram is shown below, which will be combined with the causal diagram of SIMTRANS.

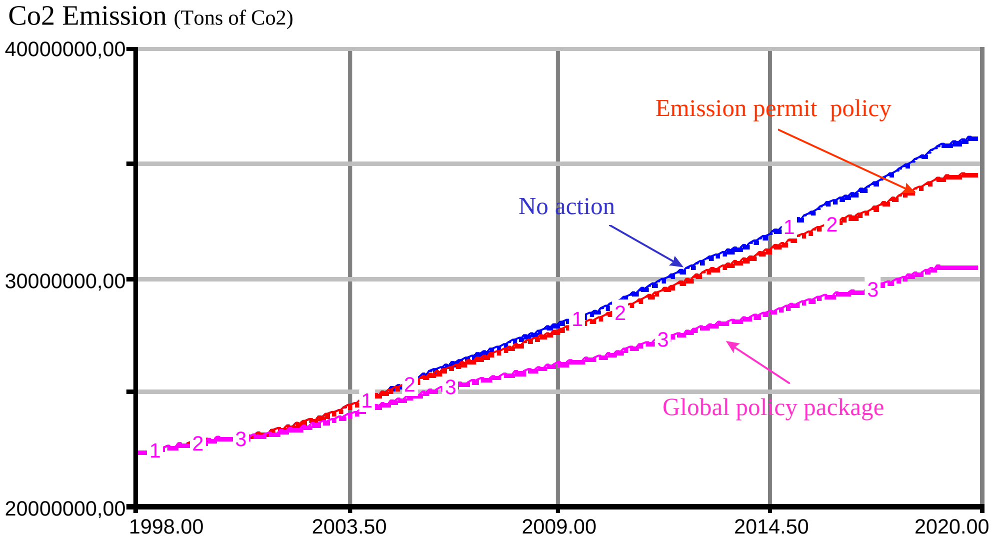



**Simplified Causal Diagram of Co2 and Emission Permit addition to SIMTRANS**

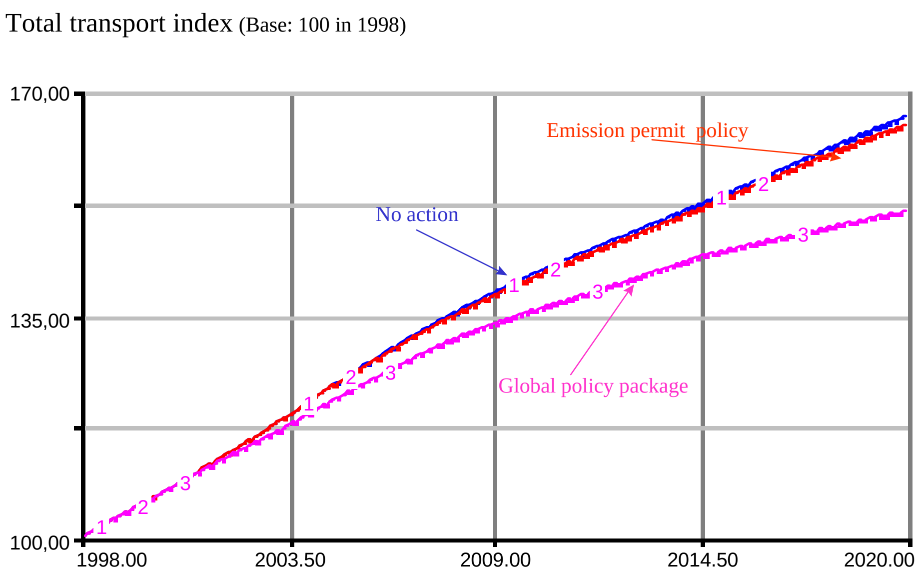
This portion of the SIMTRANS Co2 model contains two parts :

- a permit allocation sector, which models various policies for allocation of permits, their use, their sale or acquisition (buying). The allocation itself can be free (or not), periodic, recursive, diminishing, etc.
- an Energy consumption and saving sector which shows possible links between permit allocation and use, and change in driving habits, capacity usage and productivity, etc., such links being either voluntary or imposed on the freight transportation sector.

The French national program against climate change projected a carbon tax which represents a fuel excise of 0,053 € per liter. Using this model has shown that a permit trading scheme, based on such a value of permit price, has no real impact on road transportation and modal split. Neither does the impact change drastically with higher Co2 permit price levels.
Curve 2 in the following graph shows such a profile – with an emission credit price of 0,9 €/liter - which is not very different from the passed trend (curve 1). Note that this "price" is not an average one for the trucking industry, but a **marginal** fuel cost. This marginal cost "appears" when the level of Co2 emission becomes higher than what is allowed. Note also that such a value, which may appear high, is not very far from the changes of the average diesel fuel price witnessed during the last two years. We know that economists are anticipating an impact on producer behavior when average costs are significantly lower than marginal ones. They consider that marginal costs drive the pricing behaviour. But, in the market competition, other variables are very important. There are many feedback loops (see 4 – Causal Loop Analysis) which potentially can and are likely to counteract the "initial price effect".
For example, a difference between marginal and average fuel costs will accelerate the willingness to buy new and more efficient trucks. It will generate a new interest for drivers training, and probably increase the capacity of new trucks and put the emphasis on the management of capacity utilization. After some time, our model shows that these "induced, so-called secondary effects" could become very important and may more or less rapidly and completely compensate the initial effect of increasing the marginal cost above the average one.
On the other hand, we have tested the effect of a policy package with excises, labor rules, investment expenses, etc.. Curve 3 indicates that such a global policy « package », which includes Co2 emission trading plus the following policies : decrease of working hours, diesel fuel taxation and railroad infrastructure investments (cf : presentation of « Simplified mode control panel »), could be efficient.



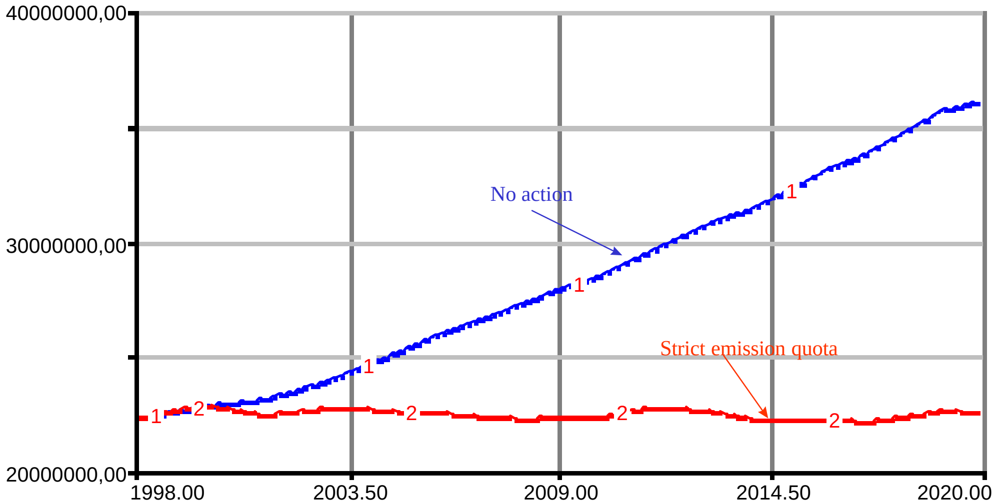

**Comparative graphs of Co2 emissions**




**Comparative graphs of total transport index**

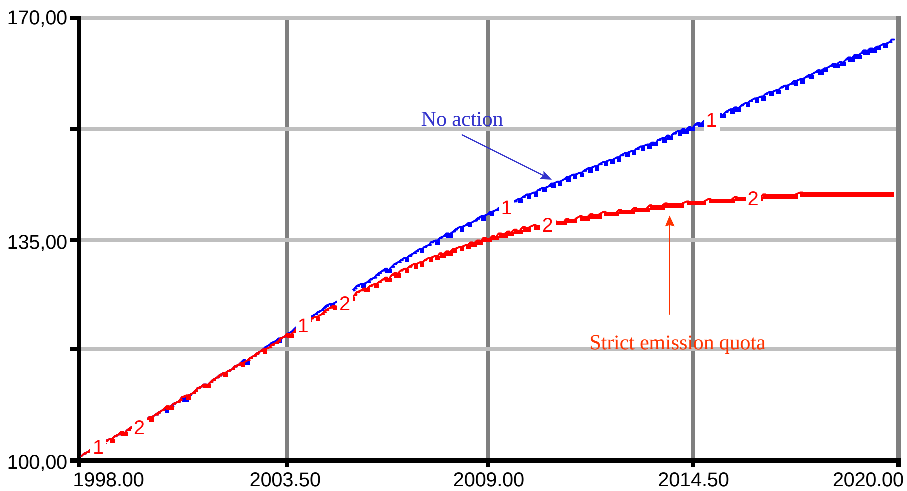
It will be of no surprise to find that a policy applying a strict quota on Co2, specific to the road transportation sector, plus an internal emission trading policy, would be efficient, but might probably generate a global deflation impact on economy. Such a policy would be drastic : trucks would not be allowed to produce more than a maximum level of Co2. It is likely that the industry could imagine strategies to save energy, use bigger trucks, increase the allowed maximum load, replace old engines, etc.. But when reaching the maximum allowed Co2 level, there would be no other solution than to cancel whatever remaining freight transportation was yet to be done, which really means decreasing the level of supply. Such a scenario (see next graph) would lead to a « transportation crisis » : for the first time since the XIXth century, the transportation system would not be able to satisfy demand. This could lead to a decrease of the GDP, a scenario which could be analyzed only by means of a totally different model, which would have to take into account social and political repercussions, among others. Such a model is yet to be built.

Co2 Emission (Tons of Co2)




**Comparative graphs of Co2 emissions**

Total transport index (Base: 100 in 1998)




**Comparative graphs of total transport index**

## 4 – Causal Loop Analysis

Causal diagrams generally constitute the first step in a coherent analysis of a problem, and they are generally drawn first, before formalizing and quantifying a model. Also, in a « System Thinking » type of approach, simple causal loops are drawn, and their behavior and possible effects are described.
In the present case, due in part to the complexity and size of the model, and the resulting difficulty in explaining both the model and its behavior modes, we were led to come back to a complete causal loop analysis after the model was built and used extensively. The purpose of such an « a posteriori » complex loop analysis is twofold :

- to help analyze and explain the various possible behavior modes of the system being analyzed,
- to show long term feedback loops whose existence and effect are very often not expected and/or ignored.

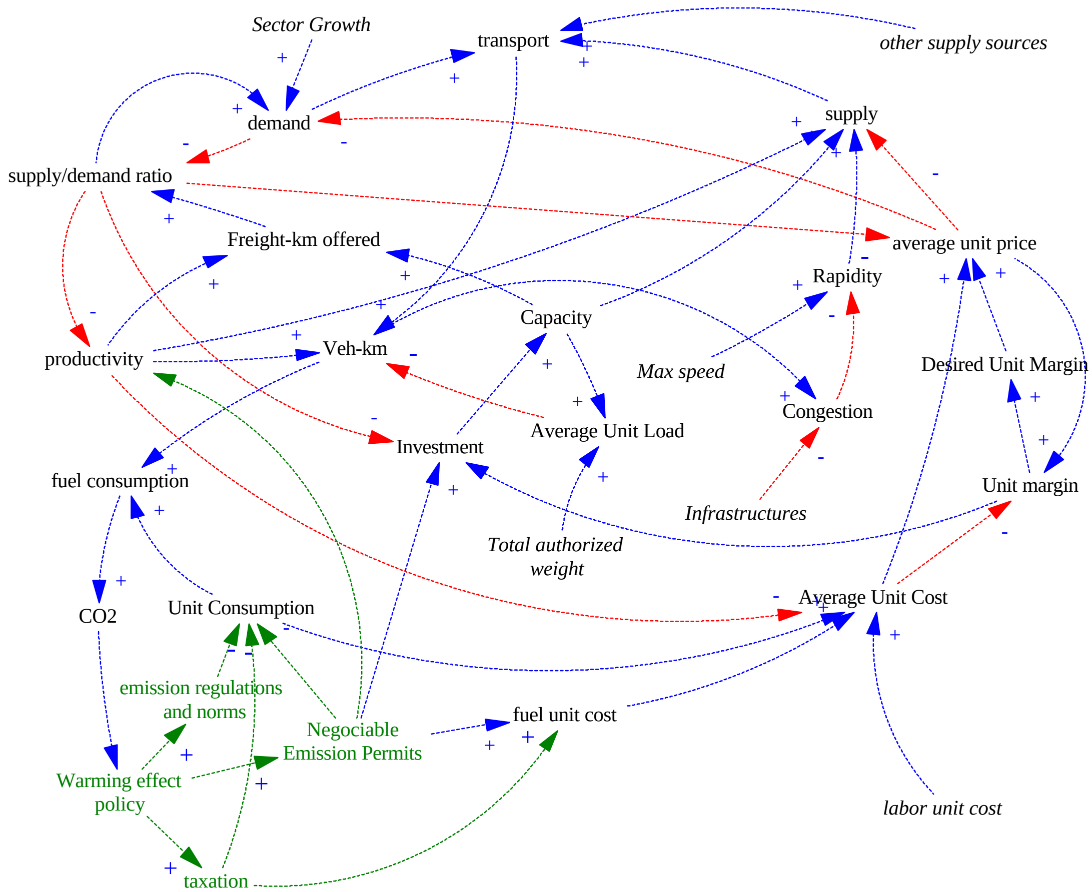
In practice, such a loop analysis is based on a causal diagram drawn after the complete model has been built, tested and extensively used. Hence both modelers and to a certain extent users of the SD model know what really lies behind each causal variable and behind the causal arrows. We have experienced that during such « a posteriori » causal analyses, frequent switches from causal to dynamic models are very useful and help understand both the general structure and the details of a model.
In a real model, even if limiting oneself to a one page causal diagram such as the Causal Diagram of SIMTRANS Co2, loops easily number by scores or hundreds. For the purpose of analysis and understanding, there are three types of loops :

- Short loops (meaning that few variables are involved) which may have short or long term effects. Such loops are easy to explain, most often they are self-evident and experts as well as model users do not feel that they get much benefit from their description and analysis, rather that they are wasting their time.

- Long loops (involving at least 10 variables or more) : some may have short term effects, others being rather long term, but in both cases these dynamics do correspond to expected behavior. The analysis of such loops is useful because the corresponding effects are generally a mix of many loop behavior types, and a loop by loop decomposition helps understand what was possibly expected, hoped for or forecast through intuition, but was too complex to be rationally and simply analyzed and explained.

- Long loops (in general very long loops), with long term and sometimes counterintuitive effects, but whose existence is ill perceived, or ignored or forgotten. To show and analyze these loops one by one, showing also how they can combine effects, has proven to be very effective in the process of convincing users, experts and clients, that their problem is in effect a complex one and that long term consequences of decisions are, and can be forecast and taken into account.

For example, here is the causal diagram drawn after SIMTRANS Co2 was used :

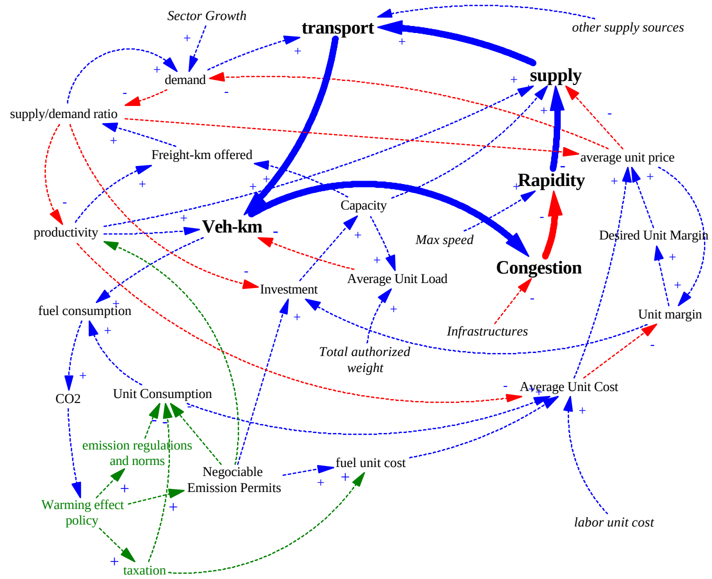



**A general Causal Diagram of SIMTRANS Co2**

Applying the Vensim loop analysis, we find that there are some 200 loops within this causal model (for example, 159 of them go through the Fuel Consumption variable). As already mentioned most of the short term loops are easy to analyze, and correspond to one's knowledge, experience or intuition. But many loops, mostly those with long term dynamics, are not evident, are seldom taken into account or are even ignored. These long term loops are the most « interesting » and are of utmost importance, since their effect occurs late in the whole process, when the initial cause is long-forgotten and not traceable any more. Although unavoidable and often troublesome, these long-term effects seem hard to understand or at least unclear, since one cannot come back to the initial cause of disturbance. As can be noticed, the generally ignored long term loops are not only long term in the dynamic behavior sense, they are also long, that is they involve many interconnected variables, which is one reason for the difficulty of dealing with them.

Let us give some examples :

The loop shown in heavy lines in the following diagram, is a relatively long term one, but it is evident, and graphically short. It says that a lot of transportation leads to traffic congestion, hence to a slow down of traffic as well as transportation supply…a stabilizing loop. But that loop is well known, felt every workday, and showing it to experts of the field is of no use, and is even counter effective.

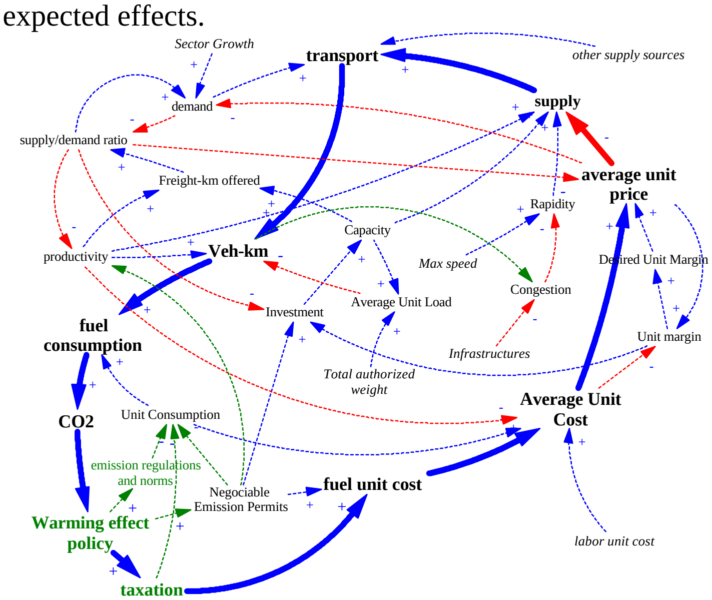



**A long-term « evident » feedback loop**

The following loop is less evident because it involves many variables, hence it is less intuitive and requires the help of tools such as the Vensim loop analysis one. Nevertheless, its potential effect is not surprising since it corresponds to the hoped for effect of taxation on emissions of Co2.

Taxation leads to increased fuel prices, which tends to increase freight transportation prices, and decrease the supply of transportation, hence the amount of vehicle-km and the total consumption of fuel. The corresponding decrease of emission of Co2 is the desired effect of that negative loop, but it would also tend, if one is not careful about this effect, to weaken the taxation rules.

This could be a relatively fast (one or two year time constant) feedback loop, which does correspond to the expected effects.

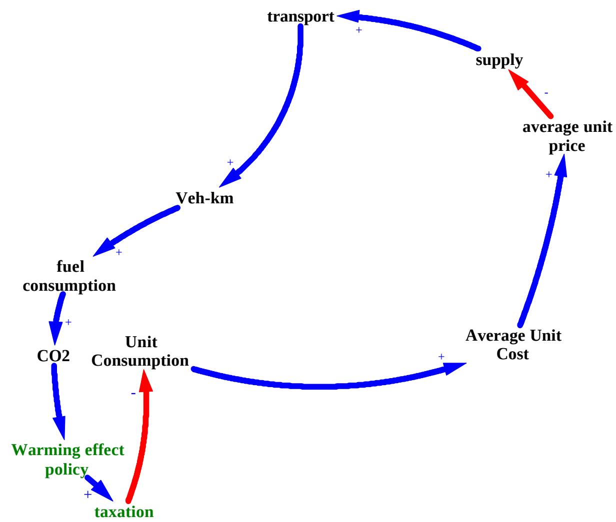



**A relatively fast and hoped-for feedback loop**

On the other hand, the next diagram shows a very similar loop whose effect would be contrary to the one shown in the previous loop. Taxation would lead to an increase of fuel unit cost, but also, a little later and progressively, to a reduction in unit consumption, hence to a decrease of average unit cost of transportation. This positive feedback loop may, in the long run, compensate the previous stabilizing loop. The right questions to be asked would be :

- what would be the respective increase of unit cost and decrease of unit consumption,
- what are the approximate time constants of each link, in particular how soon would the unit consumption start to decrease ?

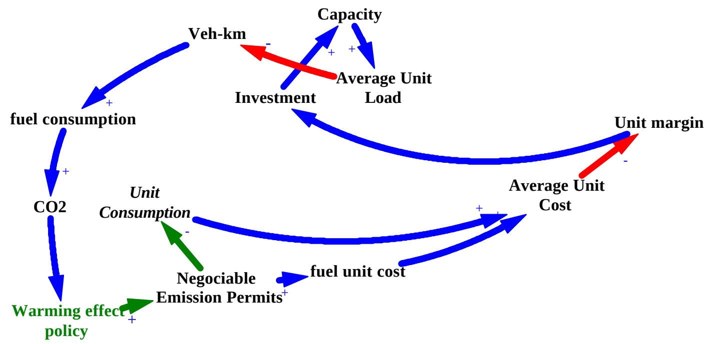
Only experts of the field can possibly answer such questions (trying to do so results generally in an increase of their own expertise), but the simulation model itself constitutes a means of checking the reliability of the new data.




**A slower positive feedback loop, potentially counteracting the previous one**

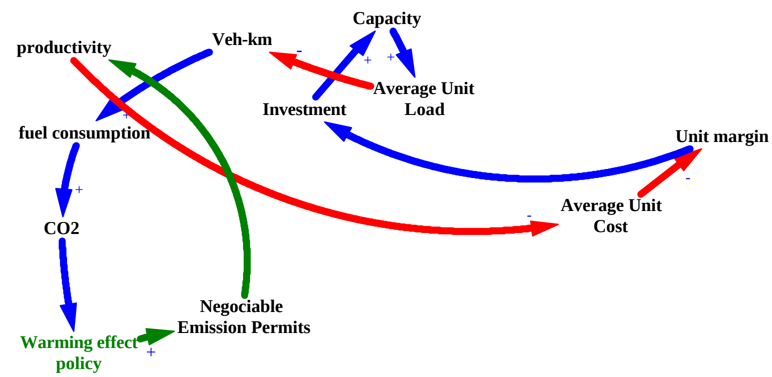
Let us show a few more long term, sometimes counterintuitive, loops which often appear in counteracting pairs.

The following diagram shows such a pair of counteracting loops, which are both long term since they involve slow moving Investment, Capacity and Average Unit Load variables. Creating Emission Permits may thus have a long term favorable effect on the emission of Co2, but also, and first of all, a negative consequence on that same Co2 emission variable.

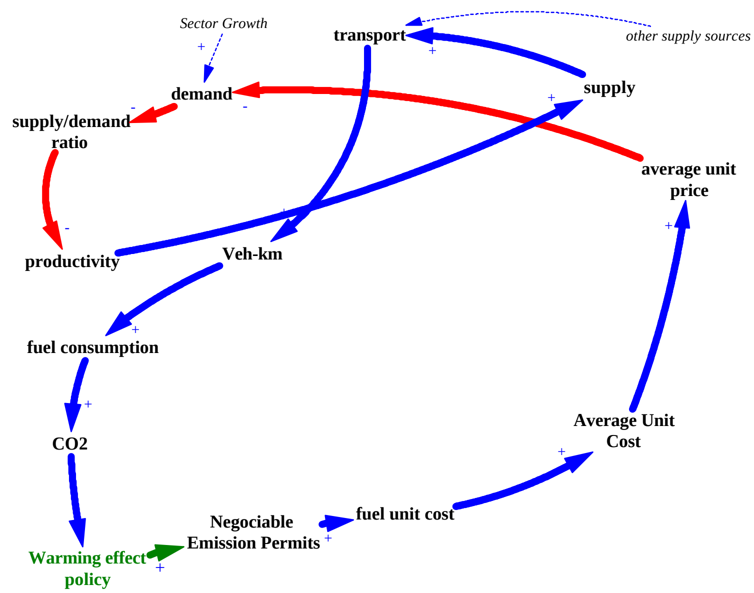



**Two long term counteracting loops**

The following two loops are potentially favorable to a decrease in Co2 emission, but the effect can be particularly slow in the first case,




and even counterintuitive in the second case (below) since it involves both offer and demand, but through an indirect productivity effect (if demand decreases, this will have a negative effect on productivity, hence on supply, but only after a long delay)




Making such loops explicit does not solve problems, but it helps analyze and understand long term hidden, sometimes counterintuitive effects. But in order for such an analysis to be really useful, these loops and the corresponding causal diagrams must be based on a well tested and thoroughly understood complex dynamic model.

In a way, such a combination could be called an « ex post Complex System Thinking ».

## 5 - CONCLUDING REMARKS

The reason for asking to build a model often comes from the desire to have a new demonstration or discussion tool. SIMTRANS Co2 did fulfill the aim of the client Agency (ADEME), namely to show there could be other ways of reasoning beyond linear logical and non global thinking. In addition, the user did wish to have new tools available, in order to test various political scenarios.

Although both aims were fulfilled, it is to be noted that a discussion between experts of the field (Co2 emission policies) became possible and fruitful only on the basis and around simplified causal diagrams, such as the few shown in this paper. We were astonished to watch experts discuss, argue and learn from qualitative dynamic behavior which would seem obvious and banal to any System Dynamicist.

For example, one such debate went around the likelihood of the system to adapt to changes of cost. It did not seem at all obvious that an increase of cost (fuel price for example), or for that matter any other constraint on the system, could lead more or less slowly, to changes in behavior modes (innovation, driving and truck loading habits, structural logistics, etc.) and to investments which would result in an increase of total fuel consumption.

We tried to show that progress in understanding a system's complexity and possible modes of behavior, results from a simultaneous use of detailed dynamic models and simulations, causal diagrams made « ex post », and individual feedback loops extracted from such diagrams but confirmed through simulations. This triple set of thinking tools does seem to be usefull, perhaps even essential, as a « convincing » tool.

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