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Impact of Freight Transport Costs and Pricing on Logistical Systems

- A System Dynamics Modelling Approach (the SANDOMA Model) –

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Abstract

The aim of this research is to evaluate the possible impacts of an increase in freight rates on traffic in a logistical perspective. At the present time road pricing appears as a key issue for current public policies in Europe in a context of an increasing concern for sustainable development. However transport costs take part in several kinds of trade-off decisions that affect a complex logistical system, involving the whole production and distribution organisation. A complete analysis of their role in the logistical organisation needs a systemic approach in order to be able to evaluate the impacts of a significant freight rates increase on traffic. In addition costs are not considered as the only decisive factor in the organisation, and some qualitative attributes are taken into account. The SANDOMA model is thus designed to evaluate the impacts of public policies on freight flows and for a pedagogical use.

Keywords: freight transport, transport costs, public policy, logistics, system dynamics modelling

Introduction

The work and results presented herein are part of a PhD research carried out at the French National Institute for Transport and Safety Research, completed in June 2003. The title of this PhD research is “Impact of Freight Transport Costs on Logistical Systems with a System Dynamics Modelling Approach – The SANDOMA model”.

Road freight transport costs and pricing appears to be a key issue in current European transport policy debates. It takes place in a context where congestion, safety, pollutant emissions seem to be getting worse, and with an increasing concern for sustainable development, public health and a better quality of life. According to the last White Paper of the European Commission – “So unless major new measures are taken by 2010 in the European Union so that the Fifteen can use the advantages of each mode of transport more rationally, heavy goods vehicle traffic alone will increase by nearly 50% over its 1998 level” (p.13). The enlargement of the Union seems to reinforce this problem of road freight traffic growth. Firstly acceding States have seen a sharp increase in their road traffic at the expense of other modes since the beginning of the

90’s, secondly their trades have literally exploded and they are expected to keep on growing in the next decades.

The following figures remind us of much the land freight traffic has grown in Western Europe since 1970. Furthermore this growth is only due to road freight transport (+325%), since railway traffic and inland waterways have remained more or less stable. As a result their modal share has drastically diminished; indeed rail freight transport represented a 32% modal share in 1970, but only 15% in 2000. On the contrary, the road modal share has increased by 23% (reaching a 78% market share).

Table 1: Freight Transport in Western Europe (thousand million of tonnes-km)

	1970	**1980**	**1990**	**2000**
Rail	255	242	234	275
Road	439	674	970	1426
Inland waterways	104	106	107	126

Source: ECMT 2002

All types of measures that are able to encourage a modal shift from road to alternative modes and also to reduce road freight traffic increase are to be considered. The White Paper thus offers a set of measures combining road pricing, revitalisation of alternative modes and investments in the trans-European transport network. The increase of road freight rates thanks to adequate policy measures is considered as one of the tools to be placed at the heart of current public policies.

However the role played by transport costs in the whole organisation of freight flows is not simple. It can be analysed from very different perspectives as in the complex problem of the modal choice, but it is rarely analysed as a key element in the shippers’ organisation. And yet the logistical organisation of the shippers, which is understood herein as the whole production and distribution organisation, can directly be put into question according to some current traffic trends. In other words it seems that the current freight traffic increase can be partly explained by recent logistical trends. This research focuses on this issue and how road pricing can be able to reduce freight traffic growth in a logistical perspective. It appears from the results of this PhD research that the role played by transport costs is quite complex, as they are implied in many feedback loops, non-linear and delayed relationships between numerous variables involved in the logistical system.

The scientific issues in which this PhD research fits and the objectives of the work is explained with further details hereafter by looking at each term composing the thesis title. The model that was built using a system dynamics modelling approach is also briefly presented, and to finish some of the main results coming from the analyses of the simulations are detailed.

1. Logistical Systems and Freight Traffic Growth

As indicated in the title, logistical systems were studied. First of all, the following two definitions of logistics are suggested:

- Logistics is currently defined as the ability to make available the right product in the right quantities at the right place in due time, and at the cheapest cost;

- Logistics aims at optimizing the circulation of physical flows as well as information and financial flows, from the production of raw materials to the delivery of the finished product to the final consumer.

This second definition fits in a more recent and modern conception of logistics, in other words the logistical organisation is conceived as a complex system made up of flow circulation. With this definition logistics is also understood in its widest sense since it takes into account the whole production and the distribution organisation; in comparison to its beginnings, i.e. in the 60's, logistics was mostly limited to physical distribution. This is the second definition that was retained for this research. Without going into details here, we will explain why focusing on logistical systems is important to understand some of the current traffic trends, and then to evaluate the possible impacts of a significant increase in freight rates on these trends.

According to recent studies which have been carried out since the beginning of the 90's[1], logistical organisations seem to *consume* more and more transports resulting in traffic increases, which are usually measured in tonnes-km and tonnes loaded.

At the present time, the way European shippers tend to organise their production sites as well as their distribution networks would generate more traffics. How?

- By relocating their production units (e.g. in Eastern Europe, North Africa or Asia);
- By concentrating their production sites;
- By specialising their production sites (for example national multi-product sites can be replaced by pan-European sites dedicated to one product but with larger merchandise area);
- By developing the sub-contracting of intermediate stages of the production process;
- By centralising their distribution structures (with less distribution levels in the network);
- With the concentration and growth of large retailers;
- By implementing pan-European distribution structures (eventually with the so-called European Distribution Centres, i.e. serving more than one country);
- By generalising just-in-time practices in the production as well as in the distribution system.

[1] See for example BERNADET (1998); McKINNON & WOODBURN (1993 and 1996).

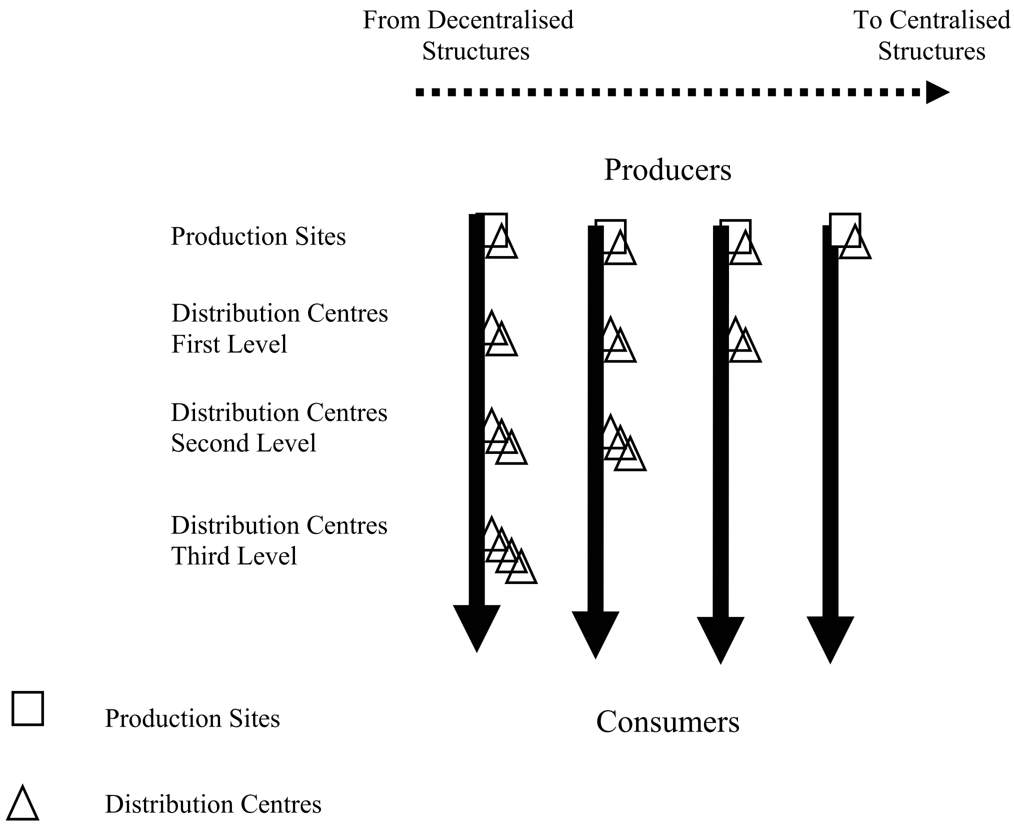
From all these changes, different kinds of impacts can be expected on freight flows:

- increased international freight transport;
- increased transport links in the production process;
- longer average distances of transport for primary distribution;
- longer average distances of transport in the distribution network;
- but decreased number of distribution links;
- and possible consolidation of freight flows;
- smaller and more frequent shipments;
- more requirements for a high transport quality of service.

To summarize, these changes would increase the average travel distances, and thus contribute to raising tonnes-km, and also in some cases the number of trips and thus tonnes-lifted. Furthermore they would favour road transport that is especially more able to meet quality requirements such as flexibility, reliability etc., as these attributes weight more and more in these complex organisations.

The two following figures illustrate some of these changes that the logistical organisation is currently facing. These examples concern the distribution networks.

Figure 1: Distribution structures in Western Europe



Adapted from Bouteiller and Kobler (1998) and Janssen (1993)

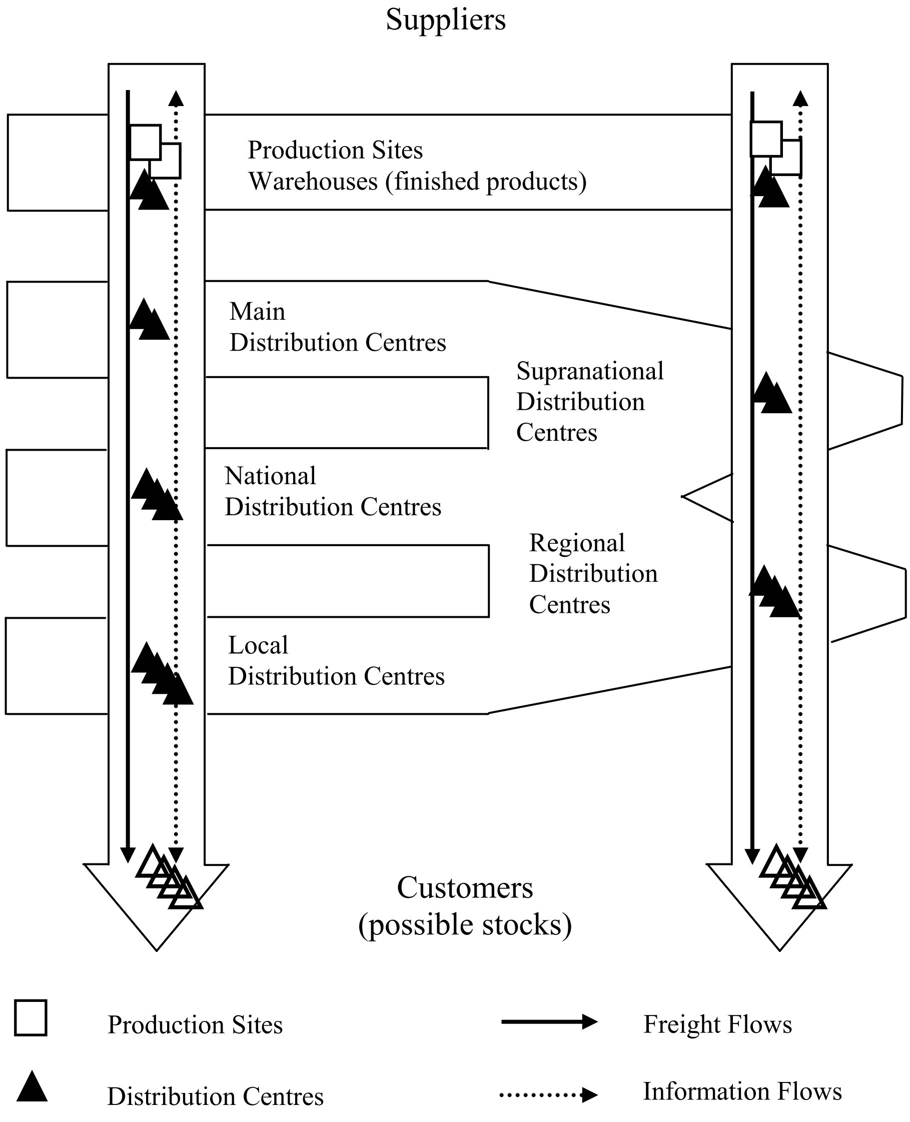
This figure indicates that distribution structures tend to be more and more centralised with less distribution levels and less stocks. The traditional structure which counts four levels appears to be quite obsolete today in Europe. The one with two levels seems to be at the present time the most used, with one level corresponding to the national one and another one to the regional one (or sometimes the first level corresponds to either a national or a regional one whereas the second one is a local distribution level)[2]. As to the most centralised distribution structure, it would thus correspond to direct deliveries from the production sites to the customers.
The term *distribution centre* was intentionally chosen as a distribution centre can be either a warehouse or a depot or even a platform with hardly any stocks that is to say dedicated to transhipments. A platform can usually replace a storage centre located at the second or at the third level.

However we must be aware that this decreasing number of distribution centres is also linked to a move towards supranational structures instead of national ones, with centres serving more than one European country. This evolution illustrated by the following

[2] See for example FLEISCHMANN et al. (1998); CRANFIELD CENTRE FOR LOGISTICS & TRANSPORTATION (1994).

diagram can be compared to a change in the geographical scale that affects the logistical organisations. It is said that time is a key issue in logistical organisations (with the circulation of material as well as non material flows going faster and faster), but spatially organisations have also to be adapted to supranational regions, involving thus quite complex changes even in the freight flow structure.

Figure 2: Traditional and pan-European distribution structures



Adapted from Bouteiller and Kobler (1998)

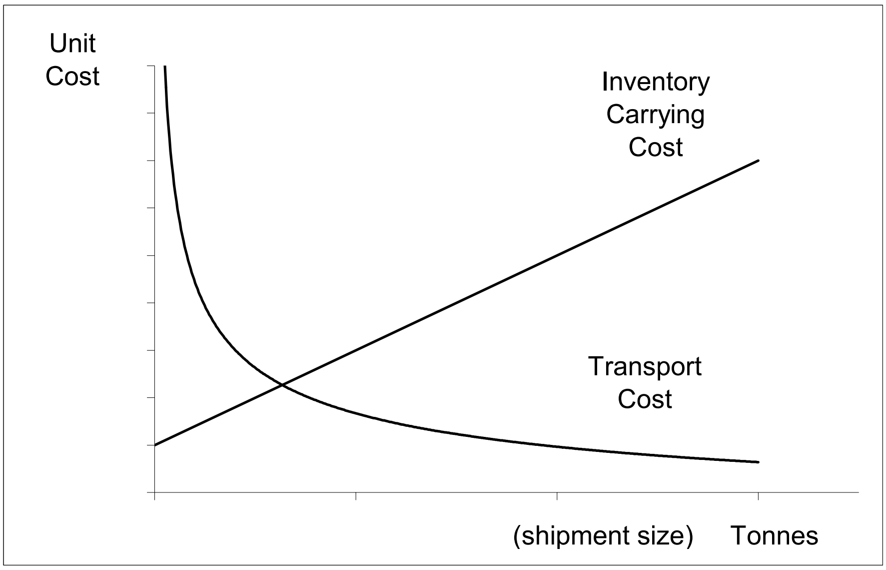
These changes concern mainly large manufacturers and large retailers, but they are the sign that European production and distribution systems are currently facing a vast transformation. Obviously it is linked to the progressive opening up of larger markets since the end of World War II beginning with the GATT agreements in 1947. This has lead to intensive trades between countries in Western Europe, and more recently since the 80's to the well-known phenomenon of globalisation. These points cannot be developed in this paper, but it is obvious that globalisation urges manufacturers to adapt their production system and their distribution networks to larger merchandise areas. Furthermore it makes emerge areas that correspond to pan-European regions instead of national ones. Even if the traffic is still closely related to the economic growth, it seems that nowadays it is necessary to analyse the recent trends in the logistical systems to understand the freight traffic demand well. This point is the crux of this PhD research.

2. The Role of Transport Costs in Logistical Systems

It appears that road transport costs and rates are directly in question in the recent logistical evolutions, and this is why an analysis of the impacts of transport costs and road pricing on the logistical systems appears to be crucial. Transport costs are questioned in different ways. First of all, road freight rates are incriminated since their level seems to be quite low regarding other transport modes and the negative external costs that they are assumed to generate, but are not taken into account. Furthermore as the road is the dominant mode, road rates are used as a reference according to the White Paper (p.25), and the current logistical organisations would thus be based on these low prices. In other words road transport rates would be partially responsible for these recent trends in logistical organisations which tend to generate more traffic.

It is obvious that transport costs play an important role in logistical organisations, and at different levels of the system, as they clearly take part in several kinds of trade-offs that involve production and distribution costs. These trade-offs are related to short-term decisions that are mostly of tactical concern, but also include medium and long-term decisions that are thus more strategic. For instance, some operational decisions, i.e. short-term decisions, will determine the average stock level in a warehouse with the size and frequency of shipments. An optimum compromise has to be found between transport and inventory carrying costs, indeed the higher the shipment size is the lower the transport cost is but the higher the stock level is and consequently its cost. This is illustrated with the following curve.

Figure 3: Inventory carrying cost versus transport cost according to the shipment size



An example of a strategic decision involving transport can be the number and the geographical area covered by warehouses, so choices that concern the structure of distribution networks. Indeed transport organisation and costs are directly affected by these decisions, as the structure of the network will determine the number of the transport links, the average distances to be travelled, possible flow consolidations, etc.

The logistical organisation implies decisions in which transport costs can intervene, and leads to determining:

- the number and location of production sites;
- the degree of specialisation of production sites;
- the degree of centralisation of the distribution networks, with the number of levels in the structure;
- the number, the geographical location and the role assigned to the distribution centres (platforms only for transhipments, warehouses or depots with stocks);
- size and frequency of shipments.

As a result transport costs are appreciated differently according to the actors:

- from the operators' viewpoint, transport costs are mostly operating costs which can be broken down into driver wages, fuel price, truck taxes, etc.
- for public policies they are considered as a key tool to reduce traffic increase and as a possible leverage for modal shift;
- from the shippers' point of view, the role of transport costs appears far more complex. On the one hand, they correspond to freight rates but on the other hand they also result from the logistical organisation from which shippers' decisions may have a strong influence, as it was explained above. This is why they can be seen as the origin as well as the result of their logistical organisation. It appears thus that a complete analysis of their role in the production and distribution

organisations needs a systemic approach, as they are involved in many feedback loops. They justified the necessity of using a system dynamics approach for the construction of the model.

3. Presentation of the SANDOMA model

The objectives of the model called SANDOMA[3] are:

- to highlight the complex link existing between the evolution of freight flows and current changes in the logistical systems;
- to help understand the role played by transport costs in logistical organisations as they are involved in different kinds of trade-offs (and as they are considered as a key tool for public policies).

These two points help evaluate the possible impacts of a significant increase in road freight rates on the logistical systems and consequently on freight flows. Such an increase can be induced by adequate transport policies. In the model freight flows are measured in tonnes-kilometres (tonnes multiplied by kilometres) and tonnes-lifted as usually in statistics. They are also characterised by average haul lengths, number of transport links in the networks, shipment size and frequency, possible flow consolidation, or even the total distance travelled by one product from the production site to the final consumer. On the basis of these characteristics, further analyses of the modal choice can be carried out, but it was not in the scope of this research. Modal choice is one aspect of the shippers' logistical organisation, and can be considered as one of the final decisions to be taken at the end of the whole organisation process. For this research it was essential to focus on logistical trends that deeply affect freight flow structures, in order to highlight some of the factors responsible for the actual freight traffic growth.

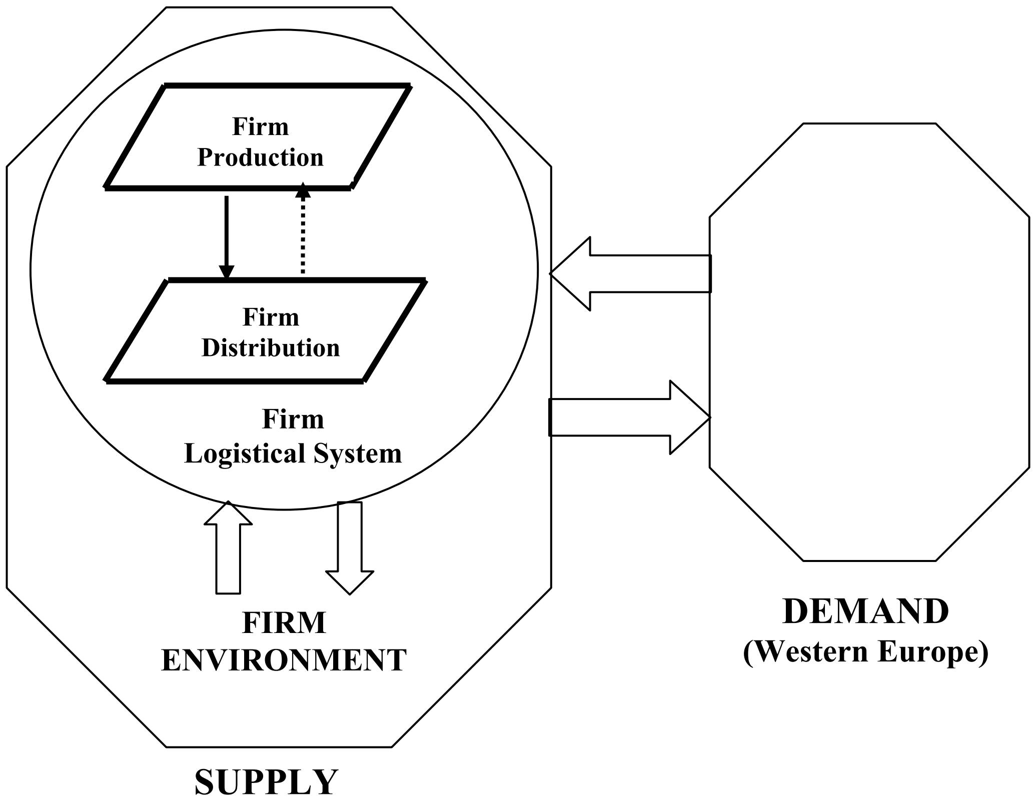
The role of the model is primarily pedagogical and explicative, as it must help understand mechanisms which are hidden behind the measures of freight traffic. It also helps analyse the actual role of freight transport costs in logistical organisations, and thus the possible impacts of a rise in freight rates on traffic that are so often questioned.

The model was thus designed to be used for the evaluation of public transport policies, but it can also be applied to a real case with a specific economic sector to be analysed.

The basic model architecture can be sketched as in the following diagram.

[3] SimulAtioNs Dynamiques pour un Outil d'aide à l'intelligence des flux de MArchandises

Figure 4: Basic architecture of the SANDOMA model



The model is intended to simulate the evolution of one firm which supplies one type of finished product (only one is simulated at the least) in Western Europe, and all its logistical system at a horizon time of 25 years. In other words its production system and its distribution system, from the production sites to the final customers, are taken into account. This firm is constantly interacting with its economic environment that takes place in a supply system also interacting with a demand system.

The model itself was divided into 16 parts that are obviously interlinked, as follows:

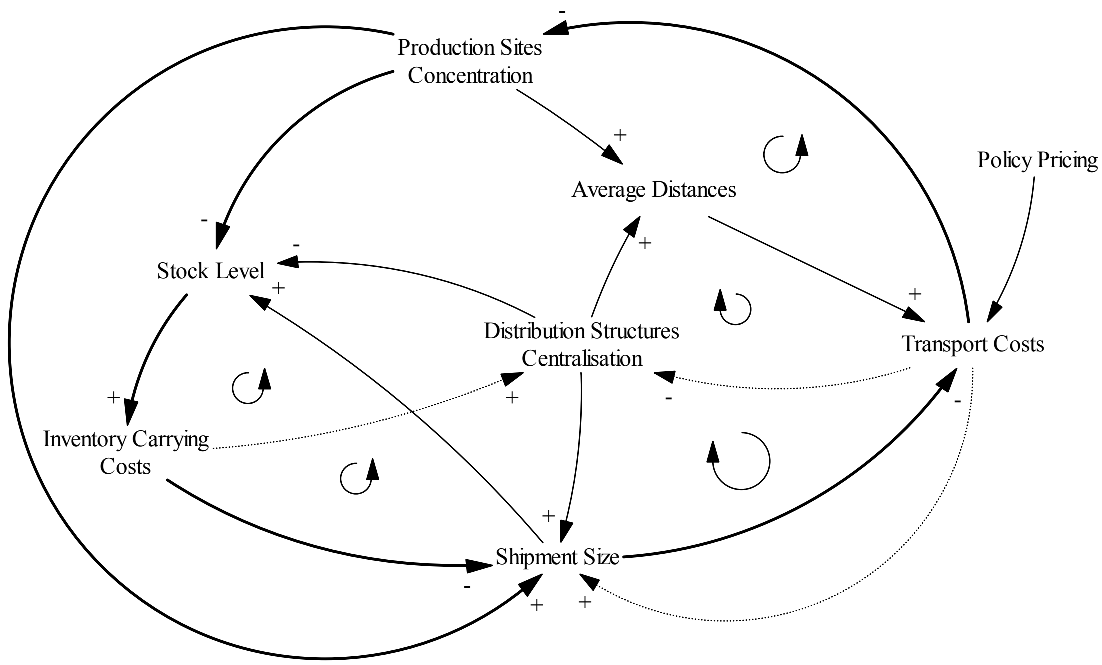
- Western Europe demand;
- Supply and sales;
- Production structure in Western Europe;
- Investments and divestments in Western Europe;
- Production of the firm;
- Firm production facilities;
- Firm product price and costs;
- First level of the distribution structure of the firm;
- Centralised distribution structure (small customers);
- Decentralised distribution structure (small customers);
- Distribution network costs (small customers);
- Distribution structure (large customers);
- Intermediate distribution centres (large customers);
- Firm freight flows in Western Europe;

- Firm transport and inventory carrying costs;
- Imports.

All the organisation of the firm can be simulated, its production as well as its distribution systems, as the number, capacity and costs of the production sites, the distribution networks with a more or less centralised structure, the average distances of transport at the different level of the networks, the number of transport links, the shipment size and frequency, or even the total distance travelled by each product from the production site to the customer, etc. Obviously transport costs are involved in many trade-offs influencing several kinds of decisions to be taken at different levels of the organisation.

The model counts about 400 variables, and it is based on the following feedback loops which appeared to be quite complex as dynamical hypotheses.

Figure 5: Basic feedback loops of the SANDOMA model



This diagram is related to freight flows from the production sites to the final customers. It presents the basic feedback loops in which transport costs are involved. For instance, a more centralised distribution network tends to increase distances and consequently transport costs, which in turn influence decisions related to the distribution structures. In addition a more centralised structure with less distribution centres tends to diminish the global level of stocks in the network. It appears then that in some cases the average size of shipments is raised to counterbalance the stock reduction in order to decrease the shipper's transport costs (as road freight rates tend to decrease with the shipment size). Without going into further details, these few examples taken from the previous diagram show some of the most important feedback loops of the model. They can give an insight into the complexity of the role of transport costs, of which effects on the logistical organisation are neither direct nor linear.

4. Scenarios and Results

Results can be clustered according to two different issues which were analysed by using different sorts of scenarios. The first one concerns the impacts of current logistical trends on freight flows, and more especially the consequences of the concentration of the economic activities and of specialisation of sites on traffic. The second one deals with the valuation of the possible impacts of a significant increase in freight rates on logistical organisations and consequently on freight flows.

Secondly, the model was used in two different manners. It was applied to a specific case which is the production and the distribution of eggs in Europe. This case was taken from reality with actual data from the economic sector, and also directly given by professionals and the firm which was studied in detail. Results of the simulations validated the model and provided a good understanding of the current organisation; it also gave insights into the possible evolution of the organisation of the economic sector. The model was also applied to different types of products with well-defined characteristics (added value, weight, demand, etc.) quite realistic but not coming from a real case as for the eggs. These kinds of simulations were mostly designed for a pedagogical use of the model.

Concerning the effects of the concentration and specialisation of the activities (production and even distribution centres), the results confirm some analyses that assume that they tend to increase significantly haul lengths, and thus tonnes-km measured in statistics. However the model also shows how important the flow consolidation is, due to the reduction of the transport links inside the distribution networks (simultaneously with the concentration of activities). Furthermore this consolidation tends to raise the average shipment size which can thus partially or completely offsets the transport cost rise resulting from longer distances.

In the model, large and small customers have been distinguished. Actually large customers correspond to large retailers or wholesalers; they have very different types of organisations (and costs) in comparison to a small retailer or a small firm for at least two reasons. Firstly as they are able to put pressure on some of their suppliers, they are also able to influence the logistical organisation of their suppliers to make them meet their requirements (fast replenishments, bigger shipments, flexibility, etc.). Secondly as large manufacturers they have the ability to concentrate and consolidate large freight flows, in that way they are able to make substantial transport cost reductions. Large retailers have already made a great decrease in stock levels and inventory carrying costs thanks to a high stock turn-over. The next step is obviously to keep on reducing distribution costs by decreasing transport costs thanks to flow consolidation. The simulations clearly showed that the transport cost rise due to longer distances cannot compensate for the transport cost reduction induced by flow consolidation, which is allowed for by concentrating activities and the huge volumes generated by large shippers.

Concerning the possible impacts of an increase in freight rates, which would come from public policies via taxes or specific social regulations for example, it seems that even if it is significant (more than 60% over 25 years) it is not really able to influence the concentration of activities and consequently the trend in haul length increase. This assessment can be explained in two ways:

- Transport costs are a major factor in the logistical organisation for some products that are of low added value for example (as in the case of the production and distribution of eggs that is also a perishable good). As a result the whole organisation of such product tends not to concentrate a lot the distribution sites (the break-even point depends on many variables depending on the characteristics of the product but also on the production system, the volume of sales, etc.), and to keep the average haul length quite short. Consequently, whenever transport rates are raised it seems that there is no flexibility in the system to adapt itself to this change. Depending on the case study, if possible the frequency of the shipments is reduced and thus the size is increased leading also to higher stocks. But most of the time the average shipment size is quite high for these products, and sometimes already corresponds to a full truck load. So another response is a lower price margin and eventually a price increase (depending also among other of the economic environment and the competition).

- At the contrary, products for which transport costs do not seem to play an important role in the logistical organisation are not very sensitive to a sharp rise in rates. Usually just-in-time practices are widely used and the most frequent response to such a rate increase is again larger shipments with a lower frequency. But if it was the shipper’s advantage to concentrate activities, which implies longer haul length, most of the time it is still his advantage not to change such an organisation when freight rates are raised. This result was not really intuitive but appears logical with the simulations of the model.

Conclusion

SANDOMA seems to be the first model in Europe that looks at freight transports using system dynamics modelling with a micro-economic approach. This choice was made to highlight mechanisms that underlie freight traffic trends under the influence of the increasing complexity of the logistical systems. It was also made to understand the actual role of transport costs in the logistical system, since they are considered as a key issue for the Common Transport Policy.

Obviously not all the results can be developed in this paper, but some of them have been underlined. Even if the consequences of public policies aiming at increasing freight transport costs do not seem to lead to the expected results, we must keep in mind that the concentration of activities also allows for flow consolidation. This trend tends to raise haul length and thus tonnes-km, but it also has a strong impact on the consolidation of flows, and yet this point cannot be statistically measured. However such a trend is of great importance as it changes the *structure* of the flows, and needs to be further analysed from different perspectives including environmental, and the use of vehicles (types, average load, etc.).

We hope to have in the future the opportunity to improve the SANDOMA model and to use it for further analyses of freight traffic in Europe. Systems dynamics modelling proved to be a powerful tool to help understand complex logistical trends and to analyse the role of transport costs that are key issues for current transport policies.

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