Simulating Regional Logistics: the North-Western Italy Case-Study

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Abstract: The fast-pace development of trades with the Far East is giving the Mediterranean Sea the chance of becoming a major logistics hub. In the Mediterranean-front E.U. regions, public and private investments are aimed at this opportunity by integrating transportation networks, sea ports, and inland logistics platforms. With specific regard to North-Western Italy, a model based on System Dynamics has been simulated to help decision and policy makers in the task of planning and directing the investment effort. The model provides impact analysis of freight traffic flow trends in the region on the medium and long-term, as a result of the interaction between exogenous variables and different case-scenarios for road and railroad infrastructure investments.

Key-Words: Logistics, Transportation, Infrastructures, Complexity, System Dynamics, Modeling, Policy

1 Introduction

Logistics increasingly impact on the competitive advantage of industrial systems because the cost of transportation and distribution does not affect product quality and value.

Globalization of trades, fast-growing Asian economies and delocalization of production sites require southern Europe to increase capacity and attractiveness for containerships crossing the Mediterranean Sea from the Far East to northern Europe and to the Americas through the Suez Canal.

Mediterranean ports are keen to become hubs to transiting flows, but major benefits to the region may be obtained from added-value logistic operations. In this sense, negative environmental factors due to increasing traffic flows may be compensated by local economic and social development.

1.1 North-western Italy outlook

To a smaller scale, the north-western Italy area (particularly, Piedmont and Liguria regions) perfectly suits the problem.

The region is a major crossroads of commerce and mobility at the intersection of the European Corridors V Lisbon-Kiev, and XXIV Genoa-Rotterdam, with a strong manufacturing environment and a good level of infrastructures: roads, railroads and logistic platforms.

However, the growing traffic flows face infrastructures congestion and inefficient logistic services.

To a better insight, the expansion of the deep port of Genoa (as well as other Liguria's harbors) is limited by the mountains that wildly separate the Tyrrhenian Sea from the large and wealthy plain to the north, where most of the largest and productive cities in Italy are located.

Yet, port operations need more and more space due to the growing usage of containers. Capacity, handling efficiency and value-added logistic services are the key factors to attract containership traffics to a port than to another.

Liguria and Genoa have very deep water to host mega-containerships, but spaces for logistic services are unavailable: inland harbors have to be created north of the mountains as an integrated logistics platform system.

Local governments and private entities have just started the investment process aimed at being part of the game of global traffic flows [1]. But this is still underway and partly behind schedule compared to some competitor regions in Spain and northern Europe.

Disadvantages for the process to be successful are inherent with the geographical positioning constrained by the Alps, and with the economic environment based on small and medium logistic players. Indeed, the most important weakness is that no strategic planning has been done to lead the task.

1.2 The location problem for the inland harbor

In such a context, the development of logistics in north-western Italy still requires plans and directions to invest in effective inland logistic platforms.

The candidate hosts of an appropriate dry harbor for Genoa are the nodes close to the city of Alessandria (between Genoa and Milan) and the city of Novara (between Torino and Milan).

The first one is closer to Genoa, but the second is also at the intersection with the east-west corridor V and has intense commerce relationships with northern-European ports, such as Rotterdam and Hamburg. The longer distance to Genoa is actually irrelevant, since handling and customs lead-times have high incidence on the total transportation time to the site.

In both areas chaotic and unplanned logistic investments have been performed or are underway in the field of transportation infrastructures and logistics businesses. The actual capacity of five million square meters of logistic platforms is supposed to be tripled in a few years.

2 Modeling for policy design

To support the capacity expansion planning process in a coordinated and effective manner, a simulation model has been developed out of a research study aimed at understanding the complex system of logistics in the region [2].

In particular, the problem of locating the dry harbor is influenced by non-linear and recurring interactions with a number of variables related to g/local traffic flows. The model is designed to capture the status of the logistic system and to forecast future dynamics.

The model is based on the System Dynamics approach [2]. System Dynamics is a computer-based simulation method that allows the modeler to graphically represent a system of differential non-linear equations and to have the computer do the discrete-step computational effort over a preset time frame [3].

The outcome of the simulation is the set of curves that describe the behavior of all variables on the time axis. Validation of the model is based on historical data and sensitivity analysis. This allows understanding the overall dynamics of the system, the influence of independent and dependent variables to the problem, and, finally, to support decision making and testing policy design by making simulations of different case-scenarios [4].

Before entering the regional logistics model in details, a few notions of System Dynamics are presented. References are provided for more information.

2.1 Glimpse of System Thinking

The System Dynamics theory is jointly related to system thinking: causes and effects are not linear in time and space, but multiple feedback loops interact as variables of a complex system.

Typically, a Causal Loop Diagram is a graphical qualitative representation of the relationships between interrelated factors affecting a system and, obviously, its problems.

Figure 1 is a Causal Loop Diagram example of a simplified problem of freight traffic growth in a logistics platform: the reinforcing loop (letter “R” in the graph) illustrates the exponential increase of traffic because, the more the handling efficiency – and its cost for customers –, the more the volumes, which, in turn, allow for even more efficiency as an effect of scale, and consequently more traffic, leading to a virtually infinite positive escalation.

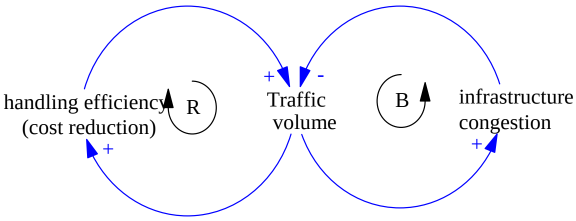

Fig. 1 - Example of Causal Loop Diagram

Yet, one or more balancing loops usually limit exponential growth. Thus, the infrastructure congestion loop (letter “B” in Figure 1) reduces the traffic volume expansion up to an equilibrium point, which is the maximum capacity of existing infrastructures [5]. A balancing loop usually creates an oscillation in the dynamics of the system, especially if a delay occurs between the cause and the effect (Exhibit 2).

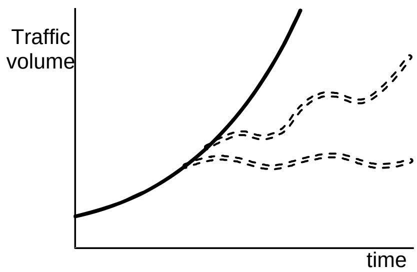

Fig. 2 - Goal seeking for the ‘traffic volume’ variable

2.2 System Dynamics modeling and computer simulation

The causal loop representation requires defining all variables and mutual relationships in a system.
Then, to obtain a quantitative outcome and analyze the system behavior, it is necessary to translate the influence diagram into a computer-compliant “System Dynamics model” enabling calculations of a number of simultaneous feedbacks (several software packages are available, such as iThink, High Performance Systems, Hanover HA, U.S.A.; Vensim, Ventana Systems, Harvard MA, U.S.A.; Powersim, Model1Data, Bergen, Norway).
The computer-simulation model involves physical variables considered as stocks and flows, as well as writing the equations for all the relationships between variables to have a system of both linear and non-linear differential equations.
Figure 3 is an example of “stock&flow” diagram, which describes the process of supplies coming in an inventory. The equations for the example are provided below (please note that the syntax may change depending on the software package).

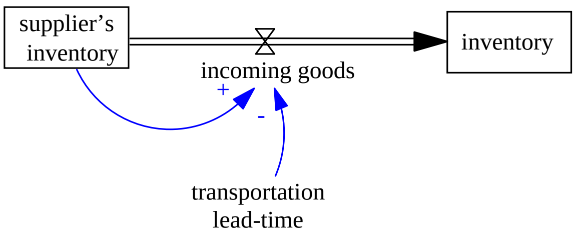

Fig. 3 – Example of stock&flow diagram

Stock: *inventory* = *INTEG (incoming goods) dt ; INITIAL: 0* (1)
Flow or rate: *incoming goods* = *supplier’s inventory / transportation lead-time* (2)

This example shows that System Dynamics allow analyzing complex situations by using fairly simple software tools that can be learnt and applied to practical problems [6].

3 Case-study modeling and simulation

Basically, the strategic problem of localizing a new logistics platform to serve as a dry harbor for Genoa is about investigating the following main traffic flows:
- the quantities of goods related to the port of Genoa;
- the quantities of goods from and to Genoa that cross the inland region, but bypass local logistic operations (transiting traffic flows);
- the volumes of goods from and to the port that take advantage of inland logistics operations (stocked traffic flows).

The model design and simulation aims are the following.
- Assessing the necessity and worth of creating a new logistics inland port. This is measured in terms of optimal capacity compared to the actual available one.
- Determining the degree of concentration, or fragmentation, of logistics spaces and how to adjust investments between the two mentioned geographical areas, namely Alessandria and Novara. This can be done also by investigating the type - collaborative or competitive – of dynamic relationships between the two sites.

3.1 Qualitative modeling: the causal loop diagram

The influence diagram (model and simulation are partly presented in this paper due to space constraints; please ask authors for complete graphical representation and system dynamics model) drawn to qualitatively capture the system feedbacks between traffic variables can be mainly subsumed into five areas, namely: 1) the sea traffic feedbacks between real sea traffic and port capacity; 2) the inland transiting traffic feedbacks that involve infrastructure connections with the sea port of Genoa; 3) the inland transiting traffic flows that do not involve the port, i.e.: east-west and north directed flows; 4) the traffic flow stocked in Novara for added-value logistic operations; 5) the traffic flow stocked in Alessandria for added-value logistic operations.
Several loops exist within and between all areas. For example, the sea traffic area includes the balancing loop that assures the ‘satisfaction of potential traffic demand’ (Figure 4).

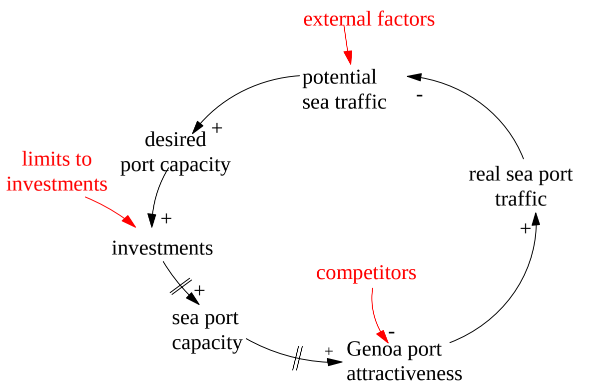

Fig. 4 – Feedback loop describing the dynamics of satisfaction of potential traffic demand

The variable ‘Potential sea traffic’ represents the demand to be fulfilled, which is driven by exogenous factors related to Far-East traffic trends. The more the ‘Potential sea traffic’, the more is the ‘Desired port capacity’. This, in turn, triggers investments in port infrastructure projects that, with a delay for construction, lead to the increase of real ‘Sea port capacity’ and attractiveness for traffic flows. As a consequence, the growth of real traffic volumes fulfills the demand and the ‘Desired capacity’, thus reducing investments and attractiveness in the next period. The recurrence of the loop creates an oscillating goal-seeking behavior.

Similarly, in the transit areas of the model the main feedbacks loops are the balancing one that illustrates the process of fulfilling the desired capacity of inland logistics platforms, and the reinforcing one representing the relationships between capacity and infrastructure congestion. The latter feedback is somewhat counterintuitive: the more the capacity, the more the attractiveness and so the traffic leading to congestion.

The model also includes loops across different areas, such as the dynamic relationship prey-predator between the Novara and Alessandria regions, as well as the oscillating influence between congestion and attractiveness.

3.2 Quantitative modeling: stock&flow diagramming

The stock&flow model declines three main systems of factors, namely: freight flows, investments in infrastructures, attractiveness and traffic shares.

Basically, those factors are part of a general feed back: site attractiveness, which depends on both actual traffic flows and potential demand and infrastructure availabilities, is the source of traffic flows coming in and out a site and, in turn, of site appeal itself.

Traffic flows are divided into sea traffic and inland traffic flows, decomposed into transiting and stocked quantities for both sites (Figure 5 is provided as a sample of the complete model). The potential traffic share that goes to Genoa is not an exogenous variable, since it is conditioned by port infrastructures, by Novara’s inland port attractiveness, as well as by the appeal of north-European ports. Real traffic flows are determined by comparing demand and infrastructure offering; only part of those flows are stocked for logistics operations. After goods have been processed they get out of the inland platform and become transiting flows. In the model, because of a primary distribution vocation, Novara’s lead-times are shorter than in Alessandria where longer added-value manufacturing operations are traditionally made. Here, the smaller turnover is calibrated by a greater economic unit value.

As far as investments are concerned, a large quantity of exogenous variables (independent) have been taken into account with regard to projects that are planned or yet underway in the region from 2007 to 2016.

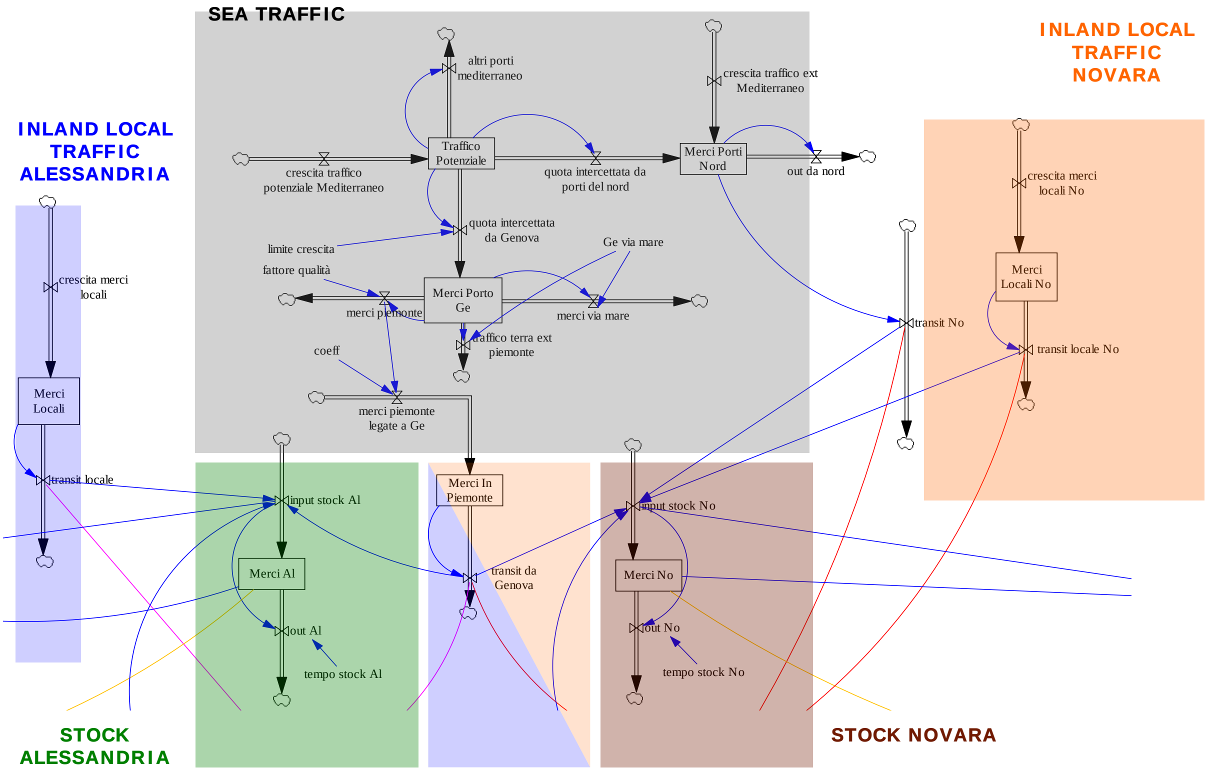

Fig. 5 – Overview of the stock&flow logistics model: the system of freight flows

Those include local road and railroad network optimizations, as well as large projects planned to bore new tunnels through the mountains (Lötschberg, third pass from Genoa, etc.).
On the contrary, investments in logistic platforms are the output variables in the model aimed at providing support for decision making, namely the size and point in time for required investments. The focus is on the total investment and on its repartition between the two sites as well as on their effects over time.
There is no space here to provide explanations of other feedback areas in the entire model, but details and complete model equations can be requested to the authors.

3.3 The model simulation

3.3.1 Inputs and outputs

The inputs to the model are the size and the timing of investments in both geographical areas (i.e. Novara and Alessandria). The first are referred to as the capacity dimensioned as TEU per month TEU is the twenty feet equivalent container unit. The timing, expressed in months, is referred to as the date when the additional capacity will be available as the result of planned and in progress logistic platform projects.
The most important output is the cumulative curve of stocked freight over the simulation timeframe. Also, since larger quantities do not necessarily involve greater return on investments, to better analyze the profitability of different case-scenarios Net Present Value evaluations have been introduced using third party sources that allow determining value generated from processed stocked goods [7].
Thus, the comparison of incremental values of both freight and NPV cumulative curves gives more significant results than their total values.

3.3.2 Timeframe and model validation

The simulation provided runs for a 21-year timeframe, from January 2000 to December 2020. The unit time step is a month.

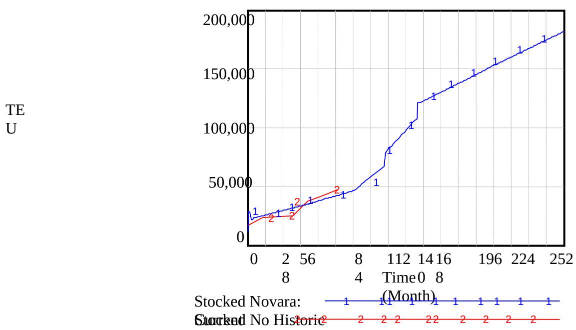

Fig. 6 – Model validation for variable stocked freight in Novara

The first five years of simulation results are compared to available historic data series in order to retrospectively validate the entire model (sample is in Figure 6. From January 2005 results are supposed to anticipate future trends.
Also, a sensitivity analysis has been performed for input variables and this has demonstrated the model substantial robustness.

3.4 Simulation results and policy design

The Vensim software simulations have been performed by reiteration. The investigated problems (namely: opportunity of the dry harbor, its degree of optimal distribution, and the timing to make investments) are non independent, but, for computational reasons, have been first calculated by assuming independency. Then, after local optimizations have been obtained, such values have been applied to sub-problems up to a general stability status.
The presented values are the ones associated with the global optimal solution. They are the results of two main hypotheses: as time passes by, investments for enhancing the Genoa port capacity are progressively continuous as well as trade relationships between the port and the inland platforms.
Following are the policy-making directions provided by the simulation with regard to the analyzed problem and sub-problems.
Main problem: opportunity of expanding the capacity of an inland harbor. Here output cumulative curves for total freight and NPV of total investments increase monotone (Figures 7).
Under the assumption of unlimited financial

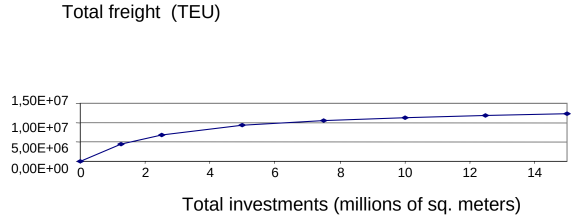

Fig. 7 – Curve of total freight as a function of increasing investments

resources, the optimal investment would be the one associated with the maximum surface available. Yet, it is clear that effectiveness and profitability decreases as total investment grows.
Sub-problem 1: optimal degree of concentration or fragmentation of inland harbors. Figure 8 shows how the maximum quantity of stocked freight is obtained when the total investment, worth 10 million sq. meters, is equally shared between both sites. Directing investments to only one site would

result in penalizing the total stocked traffic benefits. By applying the bisection method, the optimal investment repartition is 41% to Alessandria and 59% to Novara. Similar results are provided by analyzing the NPVs.

TOTAL FREIGHT [teu]

Alessandria	DISTRIBUTION OF TOTAL INVESTMENT				
100%	5,12E+06				
75%		1,04E+07			
50%			1,127E+07		
25%				1,12E+07	
0%	0,00E+00				7,11E+06
	0%	25%	50%	75%	100%
	Novara				

Fig. 8 – Quantity of stocked freight as a function of investment sharing between Novara and Alessandria

In case circumstances require concentrating capacity, further analyses suggest that more investments in Novara cause less harm than enhancing capacity solely in Alessandria.

Sub-problem 2: timing for investing in inland harbors. Inland logistic platforms are made available after construction projects have been completed. In the best-case scenario considered in the simulation, the first additional capacity will be on hand no earlier than January 2009, while projects will accomplish no later than 2014. The more investments are delayed, the more potential traffic share is absorbed by competitors and, thus, the more cost-opportunity.

Figure 9 shows the NPV as a function of the time (in months) when additional capacity is available in both sites. From the simulation data, the obvious concept of anticipating investments is confirmed, but still Novara takes the lead in effectiveness.

4 Conclusions

This work presents a model to provide fundamental policy directions for planning logistics investments, with regard to the need of creating a dry harbor in north-western Italy to support Genoa's shipping operations. In particular, this considers the dilemma of locating a new major logistic platform with choice between two sites, namely: Novara and Alessandria.

The simulation analysis indicates that the best results for the overall system are obtained when investments are equally shared between both sites

NPV (€)

Alessandria	Novara 108	Novara 144	Novara 180
108	**1,54E+09**	1,38E+09	1,14E+09
144	1,50E+09	1,35E+09	1,10E+09
180	1,37E+09	1,22E+09	9,92E+08

Fig. 9 – NPV of investments in additional capacity as a function of time

and anticipated as soon as possible, with priority to the Novara's platform.

In general terms, this work is aimed at providing a decision making tool based on scientific evidence; to this end, the System Dynamics method is used to provide a simple and informative method for policy makers.

The model basically provides approximate future behaviors of the variables affecting the system because quantitative results are based on historical data validation.

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