A MODAL CHOICE MODEL FOR EVALUATING THE IMPACT OF INCREASING AUTOMATION IN CONTAINER TERMINALS

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ABSTRACT

The aim of this paper is to define a model for the modal choice between road and rail transport taking into account the increase of rail attractiveness resulting from the increasing of the number of container terminals equipped with automated handling systems. The considered automated handling system is the automated multilevel handling system developed within the RCMS EU project, that is, a multistory storage building, equipped with electric AGVs, remote controlled elevators and remote controlled ceiling cranes. This automated system makes possible to access to a specific container without the necessity of reshuffling and to load/unload containers to/from trucks and trains directly under the storage structure, allowing a significant reduction of the loading/unloading time.

In order to define the modal choice model, the systematic utility and the perceived utility are provided and the flows of freight delivered via rail or via road are determined with a binomial Logit model. Moreover, the threshold distance between seaport and inland terminals beyond which automation has a significant impact on modal split is evaluated.

As a case study, a European port hinterland network is considered and some scenarios are analyzed, assuming that an increasing number of terminals introduces automation.

The paper shows that the introduction of automation in container terminals has significant consequences on modal split. In particular, as the number of automated terminals increases, the rail mode becomes more competitive and the threshold distance between seaport and inland terminals, at which the modal split is equally distributed between road and rail modes, significantly decreases.

Keywords: Freight transportation, Modal shift, Automation

INTRODUCTION

The 2011 Transport White Paper (European Commission, [1]) sets out a target of 30% of freight moving over 300 km by road to transfer to other modes (e.g. rail or waterborne) by 2030, and of more than 50% transfer by 2050. Nevertheless, presently, most freight at intra-European level is transported by road and the share of this mode of transport has increased over recent years, further accentuating the polarization of the modal split. As a consequence, the increasing flows of road freight transport have generated high levels traffic congestion with significant environmental and social spillovers, such as environmental pollution, road network congestion and increase in the cost of transport. Therefore, measures are needed to achieve a more sustainable split between road and rail of medium/long distance freight transport.

In order to make rail more attractive, the level of organization of integrated transport chains should be increased. This can be achieved by the introduction of automation aiming at a more efficient handling and management systems in the modal change, both in seaports and in inland freight terminals. Indeed, increasing the efficiency of transport chain nodes means improving the efficiency of the transport chain itself. Therefore, nowadays, the concept of handling and storage containers by automated equipments has become more and more important for terminal containers managers and many conventional equipments, such as Quay Cranes or Yard Cranes are becoming semi-automatic or fully automatic. In turn, there are also more advanced systems based on Automatic Stacking Cranes and Automatic Guided Vehicles, up to full-automated multi-storage installations. These technologies, that nowadays are not very widely spread due to their high infrastructure cost or due to the absence of the traffic demand and of the operational conditions that could justify the investment, will be probably more widely applied in the future decades to deal with the demand of high performance in containerized freight transport.

In this framework, to model and predict the future trends, the effects of automation must be explicitly taken into account modelling the modal choice between road and rail transport on the inland chain of containerized maritime freight shipments. According to the assumption “rational user” for shipper, the choice of transportation mode is an integrated balance, namely the perceived utility, of different factors such as monetary expense, travel time, flexibility, reliability, safety, and a certain attitude concerning the image the user has of each transport mode and the vision of its future evolution. With this assumption, the “rational user” chooses the mode he perceives as the best, that is the one with the maximum utility.

In doing so, the present study starts from the premise that a consequence of rising level of automation is a variation of modal shift towards more sustainable modes of transport, particularly rail. Therefore, the aim of the present paper is to provide a model for evaluating the modal shift towards rail transportation that can be achieved by the introduction of automated handling systems in two or more connected terminals. In particular, a model for assessing the attractiveness of rail transport at a network level is developed and the effects of the variation of rail attractiveness, for instance due to quick loading/unloading operations, are assessed. The network level choice model is design for evaluating the modal split in a wide area gathering more terminals that can be equipped with automated handling system or not.

Some case study scenarios are considered, assuming that automation is presented in one or more terminals. The generalized cost functions of monetary cost and time (the so-called systematic utility) and the perceived utility for rail and road transport are evaluated and the percentage of freights that are delivered by train and via trucks in the different scenarios are estimated. Moreover, the threshold distance between seaport and inland terminals, beyond which automation has a significant influence on rail attractiveness, is also determined.

The paper presents a review of the main literature on freight transport choice models, pointing out the substantial differences with the proposed approach. Then, the detailed description of the dynamic modal choice model between road and rail transport is presented. A case study is finally introduced to point put the capability of the proposed model.

LITERATURE REVIEW

The present paper falls into the research field freight transport demand and modal choice modelling, especially developed to face the problem of the enormously unbalanced modal split in Europe.

In such a literature, there are many references to the importance of inland transport connecting ports to their hinterlands. Already in 1998, Van Klink and Van Den Berg [2] defined rail transport and intermodality as an instrument for port competition. In the following years, Notteboom et al. [3] and Woodburn [4] identified a clear trend involving the growing level of integration between maritime transport and inland freight transport systems with a door-to-door corridor approach, whereas, Ianic et al. [5] developed a method for estimating savings in externalities that could be achieved by substituting truck with rail freight services (about 30%). Therefore, at present, freight transport by rail is mainly based on port rail connections with the hinterland, and, to ensure that rail transport successfully increases its market share of intra-European traffic, it is necessary to have a good understanding of what determines modal choice on the door-to-port and port-to-door legs.

Therefore, many researchers deal with the problem of modelling modal choice. In such a framework, the models usually considered are static models modelling the utility randomly perceived by users (Feo-Valero et al. [6], Liu et al. [7], Liu et al. [8]) that do not consider the evolution of costs over time, as well as of the effect of the increase of the total demand.

Nevertheless, a different model proposed by Ferrari [9] introduced a dynamic model that is based, like the static models, on the paradigm of random utility, but introduces a dynamic cost function, considering the evolution over time of costs, due to technological and organizational changes in transport modes, and takes into account the delay in users' reaction to the changes in the supply system. Nevertheless, such a model analyzes modal choice on particular inland corridors, whereas the modal split behavior at a port hinterland network level seems to be neglected.

In turn, since many terminals are moving towards more advance automation, research is facing this new tendency. Many studies investigated the effect of automation through simulation models (Liu et al. [10], Zhen et al. [11]) and schedule models (Lau et al. [12]), comparing the transport efficiency and stacking capacity of different cargo automated handling technologies.

Martín-Soberón et al. [13] presented a methodology to identify the most suitable automation solution for a given port container terminal, whereas Anghinolfi et al. [14] proposed a planning procedure for serving freight transportation requests in a railway network with fast transfer equipment at terminals. Nevertheless, the importance of automation in modal choice has not apparently been analyzed as it deserves.

This paper aims at moving some steps forward in filling the above mentioned gaps by proposing a modal choice model between road and rail that takes into account the role of automation in users' choices. The model presented in this paper assumes that users choose the freight transport mode, at a given time instant, on the basis of the perceived costs of the various alternatives in previous instants. The dynamic evolution of the modal split is due to the fact that these costs vary over time as a consequence of the variations in freight flows, of the users' attitudes, and of other characteristics of the transport modes, such as reliability. Nevertheless, the presented study extends that model, taking into account the effects that the introduction of automated handling system in ports and inland terminals have on the modal split and analyzes the problem at a network level.

PROBELEM DESCRIPTION

This paper deals with the problem of evaluating the modal split in a port hinterland network gathering more terminals that can be equipped with automated handling system or not.
The considered automated handling system is a multilevel handling system developed within the RCMS EU project [15], that is a multistory storage building, equipped with electric AGVs, remote controlled elevators and remote controlled ceiling cranes (Fig.1), which makes possible to access to a specific container without the necessity of reshuffling.

FIGURE 1 The RCMS automated handling system.

In particular, the AGVs carry containers between the different storage positions inside the building, whereas the elevators transfer the loaded and empty AGVs between the different building floors. Finally, the ceiling cranes, on the ground floor of the building, support the gate-away terminal operations, loading trucks and trains. In this way, the traditional handling systems, such as RTG and RMG, can be decommissioned and the phase of moving containers from quay to the yard is no more necessary. Moreover, the terminal handling capacity and efficiency can be increased evidently and the terminal full potential is reached, reducing the need of large yards. From the freight transportation point of view, this automated equipment allows a significant reduction of the time for loading/unloading to/from trucks and train. In particular, the rail mode is the transport mode that is expected to have major benefits from the introduction of this technology thanks to the possibility of loading/unloading simultaneously containers to/from wagons of the train directly under the storage structure.
Therefore, the dynamic choice model proposed in this paper aims at identifying the improvement in railway attractiveness at network level and the threshold distance, between seaport and inland terminals, beyond which automation makes rail transport more attractive than road one. In order to do that, the freight flows dependent expressions of the transport monetary cost and time (making up the so-called generalized cost) for rail and road transport are first determined and then applied to the mode choice problem. In this framework, the assumption of “rational user” is considered to model the shippers who regularly send freights between territories by means of the transport mode they deem to be the best. It is supposed that, to make their choices, shippers arrange the transport alternatives in a set, namely the choice set, and assign a perceived cost to each alternative: higher costs make the alternatives less preferable.

However, transport cost changes over time due to the growth of the freight flows, which increase the node congestion, and to the transport mode characteristics. In this context, a key role is played by the delay with which users shift from a transport mode to another one, deemed more convenient. Such a delay is due to many factors, including the limited knowledge of the different alternatives or a poor confidence in the future possibilities of transport modes, to difficulties in adapting the logistical organization, or simply to a certain inertia in changing habits.
Therefore, the presented paper, models transport cost as dynamic functions taking into account the cost reduction due to the optimization of loading/unloading operations achievable by means of the increasing automation in container terminals. In particular, the present study is developed considering two possible modal choices: road or rail. Intermodal transport is neglected since the focus of the paper is on the transport from a seaport to a set of inland terminals. Furthermore, it is considered that the cost term related only to the container travel by road and rail between two terminals do not depend on terminal automation and on freight flow. Therefore, it is reasonably assumed that automation has effects only on the costs related to the congestion in the nodes, that is the handling costs. Another important assumption is that the railway infrastructure has the sufficient capacity for receiving the increased number of trains related to the new rail attractiveness.
In next section the model is described in detail.

MATHEMATICAL FORMULATION

The presented dynamic model considers the hinterland network of a seaport, hereafter indicated as o, that is connected with a set of inland terminals, whose generic element is indicated as d. The freight transport between each o/d pair is carried by N alternative transport modes. The transport network is schematically represented by a graph whose links, each of which connects the origin with one of the destinations, as shown in Fig. 2.
The behavior of the system is evaluated during a sequence $k = 0,1, \dots, K$ of unit time intervals (e.g., one year).
Let $T_{od}(k)$ be the total amount of containerized freight exchanged between o and d in k, and carried the N transport modes. It is assumed that $T_{od}(k)$ varies over time at rate r tending to an asymptotic value $T(K) = T_{od}^{max}$, and can be modeled as

$$T_{od}(k+1) = T_{od}(k) \left[1 + r\left(1 - \frac{T_{od}(k)}{T_{od}^{max}}\right)\right] \qquad \forall d \qquad (1)$$

Then, by denoting $x_{od}^{i}(k)$ as the proportion of $T_{od}(k)$ that uses mode i, it is possible to write the freight flow on mode i directed to the destination d as $f_{od}^{i}(k) = x_{od}^{i}(k)T_{od}(k)$. With this definition, it is possible to write, for each destination d and for each mode i, the *systematic* transport cost as a function $V_{od}^{i}(f_{od}^{i}(k))$ of the freight flow f_{od}^{i}, and then consider that each shipment is assigned to the transport mode which minimizes such a cost. Moreover, it is worth remarking that this expression is valid for a limited period of time, during which it is supposed that the relation between characteristics of transport modes and freight flow remains substantially unchanged. As mentioned, according to the assumption “rational user” for shipper, the choice of transportation mode is an integrated balance, namely the perceived utility, of different factors such as monetary expense, travel time, flexibility, reliability, safety, and a certain attitude concerning the image the user has of each transport mode and the vision of its future evolution. With this assumption, the “rational user” chooses the mode he perceives as the best, that is the one with the maximum utility. Therefore, since the mode choice process is not completely known, it turns out that the costs are better represented as perceived utility stochastic variables $U^i_{od}(f^i_{od}(k))$ with a known distribution characterized by the expectation $E\left[U^i_{od}(f^i_{od}(k))\right] = V^i_{od}(f^i_{od}(k))$.

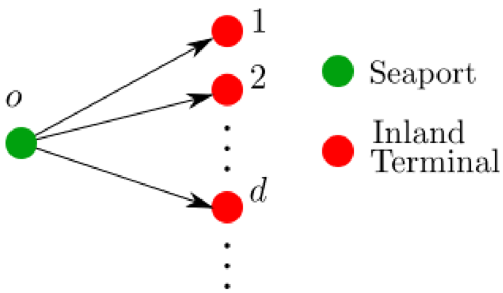

FIGURE 2 Network example graph.

Then, let $y^i_{od}(k+1)$ denoting the fraction of $T_{od}(k+1)$ that would be delivered to the destination d by means of the mode i, selected on the basis of the mode utilities "experienced" during the time period k. Such a portion can be estimated, by assuming that $U^i_{od}(f^i_{od}(k))$ is a Gumbel stochastic variable, as

$$y^i_{od}(k) = \frac{\exp\left[V^i_{od}\left(f^i_{od}(k)\right)/\theta\right]}{\sum_{\mathrm{j}=1}^{n} \exp\left[V^j_{od}\left(f^t_{od}(k)\right)/\theta\right]} \qquad \forall i \in N, \forall d \qquad (2)$$

Nevertheless, due to the delay with which users switch from a transport mode to another, only some of those who deem mode i better than that they are using at time k, will actually change mode at time $k+1$. Hence, the real modal shift between two consecutive time periods results to be only a fraction $\beta \in [0,1]$ of the potential one, that is

$$x^i_{od}(k+1) - x^i_{od}(k) = \beta\left(y^i_{od}(k) - x^i_{od}(k)\right)$$

Therefore, for all the o/d pairs, the fraction of freights that choses the mode i in $k+1$ results to be

$$x^i_{od}(k+1) = x^i_{od}(k) + \beta\left(y^i_{od}(k) - x^i_{od}(k)\right) \qquad (3)$$

where coefficient β, assumed to be time-independent, is a measure of the speed with which users change transport mode: the higher β is, the quicker users are to switch.
It is worth noting that the potential shift y^i_{od} in $k+1$ is a function of the systematic utilities $V^i_{od}(f^i_{od}(k))$, $\forall od$, $\forall i$, evaluated in k.
For what concerns the analytic expression of the transport cost $V^i_{od}(f^i_{od}(k))$, it can be defined differently for *highly automated terminals* and *traditional manual (or semi-automated) terminals*.
Then, let h indicates if a terminal is highly automated ($h = a$) or traditional/sei-automated ($h = t$).
Then, for each mode $i \in N$ and for all the o/d pairs, the cost can be expressed, as

$$V^{i,h}_{od}\left(f^i_{od}(k)\right) = \alpha^i_1 tw^i + \alpha^i_2 tc^{i,h}_o\left(f^i_{od}(k)\right) + \alpha^i_3 tc^{i,h}_d\left(f^i_{od}(k)\right) + \alpha^i_4 cw^i + \alpha^i_5 cc^{i,h}_o\left(f^i_{od}(k)\right) + \alpha^i_6 cc^{i,h}_d\left(f^i_{od}(k)\right) + V^{i,h}_0 \qquad (4)$$

where:

- tw^i is the transport time for moving containers from the seaport o to the inland terminal d by the transport mode i;

- $tc_o^{i,h}(\cdot)$ is the unloading/loading time at the origin port o from/to the mean of transport i;
- $tc_d^{i,h}(\cdot)$ is the unloading/loading time from/to the mean of transport i at the terminal of destination d;
- cw^i is the cost for moving the container from the seaport o to the inland terminal d by the transport mode i;
- $cc_o^{i,h}(\cdot)$ is the unloading/loading cost from/to the mean of transport i at the origin port o;
- $cc_d^{i,h}(\cdot)$ is the unloading/loading cost from/to the mean of transport i at the terminal of destination d;
- $V_0^{i,h}$ is a model estimation residual that could take into account other factors influencing the systematic utility, such as comfort, reliability, safety, and so on;
- α_ℓ^i, $\ell = 1,2,\dots,6$, are coefficients expressing the importance users assign to each term.

It is worth noting that it is assumed that tw^i and cw^i do not depend on the freight flow and on the degree of automation.
Moreover, it is worth saying that also "mixed" configurations can be represented by the model in Eq. (4), for instance when the seaport is highly automated and the inland terminal is not, or vice-versa.
For what concerns the analytic expressions of the time terms, it is supposed that they can be expressed by linear functions of freight flow as

$$tc^{i,h}\left(f_{od}^i(k)\right) = t_0^h + a^h f_{od}^i(k) \quad (5)$$

whereas the monetary handling cost can be expressed via quadratic functions of freight flow ([16]) as

$$cc^{i,h}\left(f_{od}^i(k)\right) = b^h\left(f_{od}^i(k)\right)^2 + c^h f_{od}^i(k) + e^h \quad (6)$$

being a^h, b^h, c^h, and e^h, $h = \{a, t\}$, parameters to be estimated.
Summarizing, the complete model basically consists of Eqs. (2) - (6) which provide the costs and freights splits and by Eq. (1) which provides the input of the system. In other words, it is possible to say that the future split depends on the present costs and results to be a first order non-linear discrete-time system.
In the next section the model is applied to a real case study.

CASE STUDY

The case study considered is the hinterland network of La Spezia seaport in North-West Italy, depicted in Fig.3. This seaport is connected at national level with the inland terminals of six Italian Regions (Lombardy, Emilia Romagna, Veneto, Piedmont, Liguria and Tuscany), where there the main freight origins/destinations are located. The inland terminals can be reached via rail or road ($N = 2$) and the relevant distances from La Spezia seaport are reported in Tab. 1.

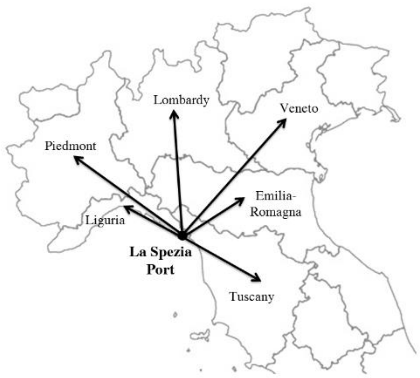

FIGURE 3 La Spezia seaport hinterland network

La Spezia seaport has handled 1.3 million TEUs in 2015. In the considered numerical analysis, only the import freight flow, consisted of $T_{od}(0) = 652.665$ TEUs in 2015 (about 50% of the total) is considered. The destination distribution of the import freight flows is reported in Tab.2, whereas the present modal split is shown in Tab.3. The present state, hereafter addressed as *scenario 0*, is characterized by the absence of automated handling systems in the seaport and in the connected inland terminals. Therefore, two different scenarios representing possible evolution of the seaport and inland terminals equipment are considered:

- scenario 1, in which the automated handling system is introduced only in the origin seaport of La Spezia;
- scenario 2, in which the automated handling system is introduced also in the inland terminals of destination.

For both scenarios 1 and 2, it is assumed that the automated handling system produces a growth of the freight flows up to 35% in ten years, that is $T(10) = T_{od}^{max} = 881.000$). Such an assumption is based on the hypothesis that all the capacity increase due to the automation[1] is saturated in the considered time horizon.

For what concerns the relations between the monetary cost and number of transhipments in terminals, they can be evaluated taking into account the results in [16], where some curves, characterized by different kinds of terminal design and handling system characteristics, are reported. In the following, the expression of the loading time and costs are provided for the considered terminal.

In doing so, to keep the notation simple, the index k is drop. Then, considering the present La Spezia seaport handling equipment, consisting in 8 RMG (Rail Mounted Gantry) cranes and 11 RTG (Rubber Tired Gantry) cranes and taking into account the results in [16], the loading/unloading costs in Eq. (6) can be expressed as

$$\begin{aligned} cc^{rail,t} &= 3.2 \cdot 10^{-6}\left(f_{od}^{i}\right)^2 - 2 \cdot 10^{-2} f_{od}^{i} + 63 \\ cc^{road,t} &= 2.7 \cdot 10^{-6}\left(f_{od}^{i}\right)^2 - 2 \cdot 10^{-2} f_{od}^{i} + 63 \end{aligned} \tag{7}$$

whereas the loading/unloading costs in an automated terminal result to be

$$cc^{rail,a} = 1.42 \cdot 10^{-6}\left(f_{od}^{i}\right)^2 - 1.4 \cdot 10^{-2} f_{od}^{i} + 50 \tag{8}$$

[1] Source RCMS project

$$cc^{road,a} = 1.8 \cdot 10^{-6}\left(f_{od}^{i}\right)^{2} - 1.4 \cdot 10^{-2} f_{od}^{i} + 50$$

TABLE 1 Distances from national destinations (average distances between destination terminals)

Destination	Distance by road (km)	Distance by rail (km)
Lombardy	221	250
Emilia Romagna	170	163
Veneto	292	328
Piedmont	162	151
Liguria	156	156
Tuscany	150	150

TABLE 2 Import freight flow destinations (source: La Spezia Port Authority)

Destination	%	TEUs import
Lombardy	27.1%	176.872
Emilia Romagna	29.6%	193.189
Veneto	11.7%	76.362
Piedmont	2.5%	16.317
Liguria	11.3%	73.751
Tuscany	13.0%	84.846
Other	4.8%	31.328
Total	***100%***	***652.665***

TABLE 3 Current freight flow modal split (source: La Spezia Port Authority)

Destination	TEUs imported by rail	TEUs imported by road	Road	Rail
Lombardy	68.450	108.423	61%	39%
Emilia Romagna	58.729	134.459	70%	30%
Veneto	16.418	59.944	79%	21%
Piedmont	6.853	9.464	58%	42%
Liguria	0	73.751	100%	0%
Tuscany	0	84.846	100%	0%
Other	0	31.328	100%	0%
Total	***150.439***	***502.226***	***77%***	***23%***

Analogously, the expressions of the loading/unloading time in Eq. (5) are

$$\begin{aligned} tc^{rail,t} &= 0.5 + 9 \cdot 10^{-3} f_{od}^{i} \\ tc^{road,t} &= 0.25 + 3 \cdot 10^{-3} f_{od}^{i} \end{aligned} \qquad (9)$$

for the present terminal configuration, and become

$$tc^{rail,a} = 1.5 \cdot 10^{-2} + 3 \cdot 10^{-3} f_{od}^{i} \qquad (10)$$

$$tc^{road,a} = 1.5 \cdot 10^{-2} + 2.6 \cdot 10^{-3} f_{od}^{i}$$

with the introduction of automation.

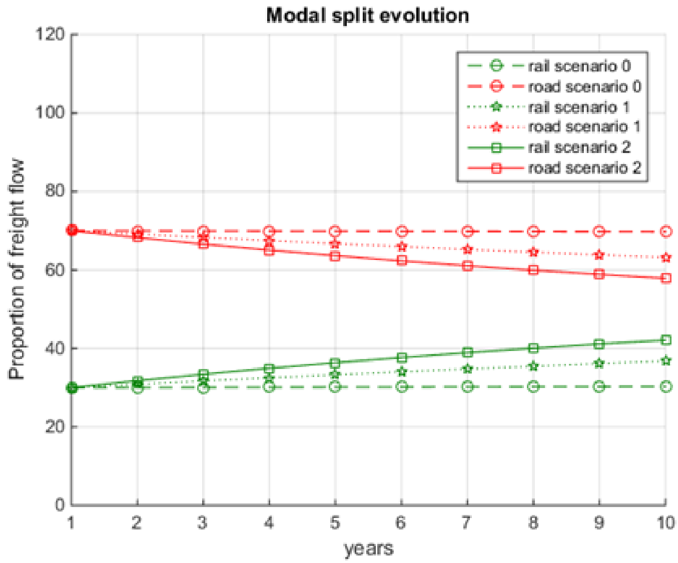

FIGURE 4 Modal split for Veneto

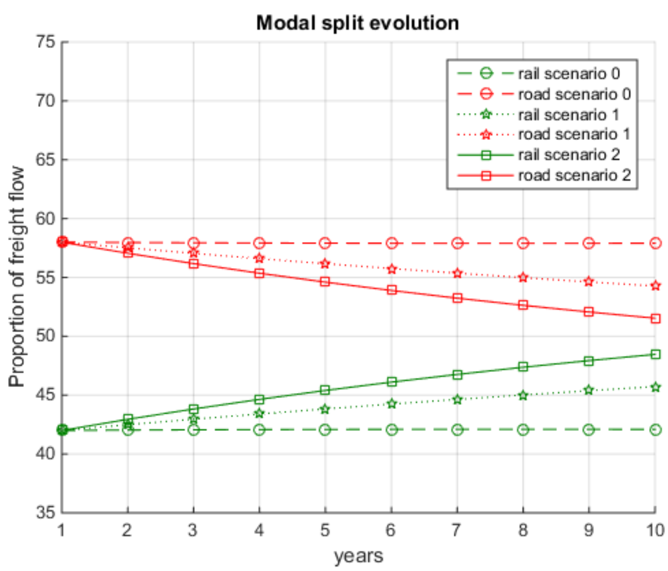

FIGURE 5 Modal split for Piedmont

The costs cw^h (€/km per TEU) for rail mode and road mode are 0.125 and 1.25 respectively[2]. The coefficients $V_0^{i,h}$ and α_ℓ^h estimation is performed by means of MSE procedure aiming at determining the best coefficients for the perceived utility that determines the known current modal split, that is those relevant to the La Spezia o/d pairs for which all the parameters of Eq. (4) are known at a time. Note that the terms $V_0^{i,h}$ includes the effects of factors such as comfort, reliability, safety, etc., which could not be estimated due to lack of relevant data.

[2] source: HPC Hamburg Port Consulting GmbH

All the coefficients values are non-positive, as they represent cost in the utility function. The alternative specific constant $V_0^{i,h}$ is equal to zero for the road mode and positive for the rail mode, since La Spezia seaport is characterized by a significant percentage of freight moved by rail mode, in comparison with other Italian seaports.

RESULTS

In this section are discussed the results obtained by the application of the above model, and the evolution over time of the modal split for each scenario and each destination is analyzed.
For this purpose, were analyzed the results of scenarios 0, 1 and 2 for two different destinations: the furthest destination (Veneto, Fig. 4); and the destination with the highest initial rail modal split (Piedmont, Fig. 5)
For all the considered destinations, the introduction of the automated handling system in the seaport guarantees a significant improvement of rail attractiveness (scenario 1). Moreover, the increasing adoption of automated handling systems also in destination terminals contributes to move another step towards the choice of rail mode (scenario 2). In Fig. 5 it is worth noting that the present configuration is characterized by a slight decrease of the percentage of freights choosing rail. Such a phenomenon is due to the congestion that makes the loading time and costs on trains increasing faster than the truck ones in the present terminal configuration (see Eq. (7) and Eq. (9)). On the contrary, with automation the loading cost on trains increases more slowly that the truck one (see Eq. (8)) while the loading time is similar for the two transport modes (see Eq. (10)).
As regards the forecasted split at the end of the considered period, $K = 10$, the relevant values are reported in Tab. 4. Moreover, the total modal split variation with the increasing of the distance of the destination terminals in $K = 10$ is depicted in Fig. 6 for the three scenarios. In such a figure, it is easy to note that the threshold distance that makes rail and road equally chosen is significantly reduced by the introduction of automation.

TABLE 4 Freight flow modal split

		Scenario 0		Scenario 1		Scenario 2	
Destination	**TEUs import**	**Road**	**Rail**	**Road**	**Rail**	**Road**	**Rail**
Lombardy	238.777	65%	35%	56%	44%	53%	47%
Emilia Romagna	260.805	70%	30%	63%	37%	57%	43%
Veneto	103.089	78%	22%	70%	30%	62%	38%
Piedmont	22.028	58%	42%	54%	46%	51%	49%
Liguria	99.564	93%	7%	83%	17%	71%	29%
Tuscany	114.542	93%	7%	83%	17%	71%	29%
Other	42.293	100%	0%	100%	0%	100%	0%
Total	***881.098***	**77%**	**23%**	***68%***	***32%***	***62%***	***38%***

CONCLUSIONS AND FUTURE DEVELOPMENTS

In this paper, it has been shown that the freight transport mode choice process in a port hinterland can be modelled as a non-linear discrete-time dynamic system. In this framework, the effects of changes in technology and organization of the various transport modes have been evaluated over time and, in particular, it has been shown that the introduction of automation in container terminals has significant consequences on modal split.
The achieved results, obtained by applying the proposed model to a real world case study have shown that as the automation level increases, the rail mode becomes more competitive and the

threshold distance between seaport and inland terminals at which the modal split is equally distributed between road and rail modes significantly decreases. Moreover, this model could be useful to support the infrastructure manager in making decision about the prioritization of automation investments at seaport terminals and intermodals terminals. The analysis of the economic aspects and of the investment costs, as well as the comparison of the performance of the different existing automated handling systems, is conducted within the RCMS project; the interested reader can refer to [15].

Works are in progress to conduct a sensitivity analysis of the utility function parameters, to consider the effects of congestion on road and railway lines, as well as to study the stable and unstable equilibrium points of the system with respect to the parameters weighting the transport time and costs in the systematic utilities.

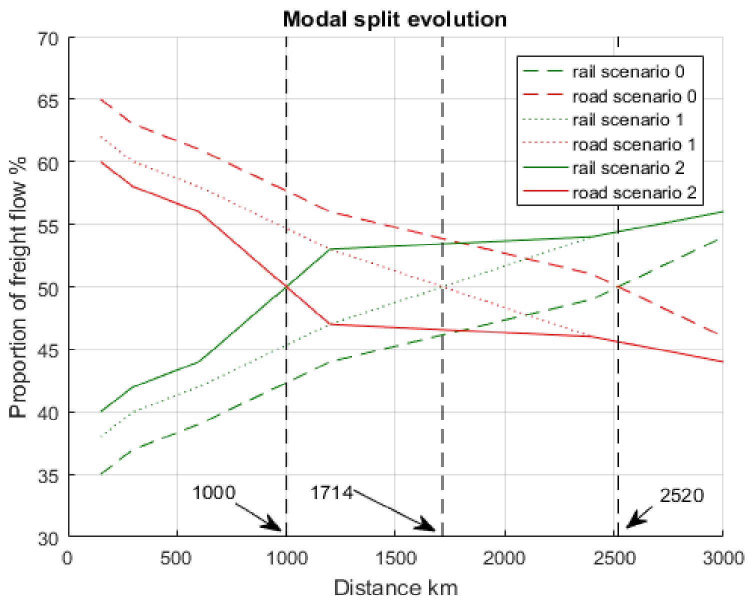

FIGURE 6 Modal split with respect to the increasing destination distance in scenarios 0, 1 and 2.

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