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A RAIL NETWORK OPTIMIZATION MODEL DESIGNED TO MODEL FREIGHT NETWORKS AT A MACRO LEVEL

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ABSTRACT

The rail freight network optimization model presented in this paper was developed as a support tool for planning and policy decisions involved in the improvement of rail networks on a regional and national level. It is based on a strategic traffic assignment model designed to model macro networks with a high aggregation level, being exclusively designed for freight traffic. The model contemplates road and rail transport modes, and considers two different types of cargo: intermodal cargo, which is generally transported in containers and is easily interchanged between different modes at intermodal terminals; and general cargo, which represents all the remaining cargo. The optimization process is based on a local search heuristic which delivers good solutions in a reasonable computing time, with the quality of each network improvement solution being assessed based on the reduction of the total generalized costs and CO2 emissions. This freight network optimization model is innovative in the fact that it is not limited, allowing for both the improvement of existing links as well as the construction of new ones, and not having a limit on the number or variety of network improvement possibilities. Its adaptability to different conditions is emphasized when the model is applied to a network under two different investment scenarios, by delivering considerably different solutions adapted to the conditions of each scenario.

Keywords: network optimization, freight transport, traffic assignment.

INTRODUCTION

While freight transportation is an activity that plays a crucial role in the everyday life of any modern economy, being critical to a large part of the economy, it usually gets less attention in the academia than its passenger counterpart. This is probably justified by the fact that it is not as appealing to policy makers and the general public as passenger transportation, but also because it is a considerably more complex subject, due to the multiplicity of goods transported, the complexity of the freight supply chain and the difficulty in getting the needed data. While it may be less appealing and more complex than passenger transportation, it is important to study freight transportation using models specifically made for it, in order to account for its distinct characteristics and for the fact that the network investments needed to improve freight transportation can be considerably different from those aimed at improving passenger transportation. Due to that, the network optimization model and the associated traffic assignment model that are presented in this paper have been developed specifically for this type of transportation, although they may be combined with passenger models in the future, in order to create a model for the whole transportation system.

The presented model, developed in the scope of a broader project (Maia and Couto, 2011), uses a strategic planning traffic assignment model (Crainic and Laporte, 1997) designed to model macro networks with a high aggregation level. This assignment model does not require very detailed data inputs, with the outcome of its application being the estimation of the movement of freight at a regional, national, or international scale. It considers road and rail transport modes, being intended to simulate medium and long distance flows of inland transportation. The model contemplates two different types of cargo, namely general cargo and intermodal cargo, in order to make a distinction between the cargo that may be easily interchanged between different modes at intermodal terminals, which is generally transported in containers, and the rest of the cargo. The above characteristics make this traffic assignment model particularly suited for the planning and policy decisions that are going to be performed by the network optimization model (Wigan and Southworth, 2006).

As for the optimization process in itself, it is quite flexible and innovative, allowing for both upgrades in the quality of existing rail and intermodal terminal links as well as the construction of new ones, not having a limit on the number or variety of improvement solutions. This is achieved by defining a set of possible link levels for each link type, according to the users' preferences, including the mere possibility of building a link. As for the quality of each network improvement solution, it is assessed based on the reduction of the total generalized costs and CO2 emissions, with the weight given to each of those parameters being defined by the user according to its preferences. The optimization model is based on a local search heuristic and tries to meet a balance between efficiency and effectiveness, by delivering good solutions in a reasonable computing time.

This paper is structured in six sections. After the introduction, there is a background section, containing a brief literature review on the subject of freight traffic assignment and network optimization models. The third section is dedicated to the traffic assignment model, while the fourth section is devoted to the network optimization process. The fifth section describes an application of the network optimization model, with the sixth and last section being dedicated to the final conclusions.

BACKGROUND

Freight Traffic Assignment Models

The different traffic assignment techniques that are presented in the literature can be divided in four big groups: All-or-nothing (AoN), Equilibrium, Stochastic-multi-flow and Stochastic-equilibrium (Jourquin, 2005). The two factors whose usage determines to which of the four groups a model belongs are the existence of capacity constraints imposed by congestion (Equilibrium and Stochastic-equilibrium models) and the use of a variable perception of costs

(Stochastic-multi-flow and Stochastic-equilibrium models). Capacity constraint models are those in which the capacity of links is limited, including time penalties due to congestion when certain limits of traffic are exceeded. As for the variable perception of costs, it reflects whether the mode and route choice decisions are made uniquely based on the lowest generalized cost, or if some stochasticity is included, reflecting a variable perception of costs and consequently spreading the traffic through different modes and routes. The most commonly used assignment techniques for freight traffic assignment models are the AoN and the Equilibrium techniques, with Stochastic-multi-flow models being seldom used. As for Stochastic-equilibrium models, and according to the authors' best knowledge, their use in this area of study has been limited, probably due to their complexity.

Although there are many different models present in the literature, with many being created for just one specific work, there are two major freight traffic assignment models that are worth mentioning, due to their importance and extensive use. Those are STAN, which was developed in 1990 in Canada (Crainic *et al*, 1990; Guélat *et al*, 1990), making use of an Equilibrium assignment technique, and the NODUS software, which was developed in Belgium a few years later (Jourquin and Beuthe, 1996; Beuthe *et al*, 2001; Jourquin, 2005) and that has been employed using all the three most common assignment techniques: AoN, Equilibrium and Stochastic-multi-flow. The fact that various techniques were used with the NODUS software shows that each one has its own advantages, which should be considered when choosing which type of technique to use. An AoN technique is the most straightforward, being best suited for cases where other assignment techniques are considered too complex or simply not fit for the proposed approach (Jourquin and Beuthe, 1996; Beuthe *et al*, 2001). Regarding the use of the Equilibrium assignment technique, it is best suited for congested networks, where congestion effects are taken into account by admitting cost penalties when traffic is close to the capacity (Crainic *et al*, 1990; Guélat *et al*, 1990). As for the Stochastic-multi-flow, this technique distributes the traffic by different possible routes, ensuring that the path with the least generalized costs never receives the totality of the traffic. This is a valuable feature when dealing with strategic aggregated models, where the generalized transportation costs are just an estimation of the average costs, not being able to incorporate many factors that have a decisive influence on the modal or route choice, such as the shipment size (Abdelwahab, 1998), the frequency of service (Shinghal and Fowkes, 2002), the service quality (Andersen and Christiansen, 2009) and the existence of an integrated door to door logistic chain (Vanek and Smith, 2004). As for the method used to perform the distribution of traffic, the Logit formulation has consistently been chosen to address this problem, due to its versatility and convenience (Oum, 1979; Jourquin, 2005; Tsamboulas and Moraitis, 2007).

Network Optimization Models

The aim of a network optimization model is to find out how the transportation network should be improved, in order to minimize or maximize (as applicable) the appropriate indicators, defined by the user. The optimization parameters can vary from case to case, and have to have an associated quantitative indicator, in order for them to be objectively analyzed. Many different parameters can be used in order to assess the quality of each solution, namely the total generalized cost, the robustness of the network and its environmental impact (Santos *et*

al, 2010). As for the network improvement operations that may the performed in order to optimize the network, they can be improvements in the quality of existing links or the construction of new links from scratch, which each specific improvement operation having an associated investment cost in order to quantify the investment made in a given network improvement scenario. Having well defined network conditions and improvement possibilities, as well as the corresponding costs, are the basic ingredients needed for the development of a network optimization process able to optimize the way in which the investments are made, in order to minimize or maximize selected parameters. Most of the research found in the literature on the subject of network optimization was performed using two types of models: the discrete network design problem (DNDP) (Arnold *et al*, 2004; Yamada *et al*, 2009; Santos *et al*, 2010) and the continuous network design problem (CNDP) (Zhang and Lu, 2008). While the former tends to concentrate on the addition of new links, and the latter on the (continuous) improvement of existing links, it is also possible to use a discrete approach allowing for both the addition of new links and the improvement of existing links (Santos *et al*, 2010). Due to the considerable complexity of the transportation networks and to the discrete nature of most models, there is no practical analytical solution for this problem, which leads to the adoption of heuristic techniques. Several techniques have been successfully used to address this kind of problems, predominantly metaheuristics such as tabu search, simulated annealing and genetic algorithms (Crainic, 2000; Arnold *et al*, 2004; Yamada *et al*, 2009; Santos *et al*, 2010).
While there are various network optimization models made specifically for freight transportation, they tend to focus on the optimization of specific equipment such as intermodal terminals (Arnold *et al*, 2004), or to be limited, by only allowing for either the creation of new links or the improvement of new links, or by having a limited search space (Yamada *et al*, 2009), with only a limited number of improvement possibilities.

FREIGHT TRAFFIC ASSIGNMENT MODEL

Model's General Attributes and Computation of the Shortest Paths

The presented model is a strategic freight traffic assignment model, being based on a previous model developed by the authors (Maia and Couto, 2012), which was upgraded in order to allow for the introduction of separate link characteristics for each type of cargo, and for the introduction of congestion in rail nodes. It considers two different types of cargo: general cargo and intermodal cargo. The latter represents the share of freight that can be easily transferred between modes at intermodal terminals, namely containerized cargo, with the general cargo representing all the other cargo. The model was developed for the assignment of traffic on road and rail networks, but apart from the links representing those networks, it also includes other type of complementary links. Those include intermodal terminals that establish the connection between the road and rail networks, as well as virtual links that are included to represent congested rail nodes, which are an important limitation to the capacity of rail networks. It also includes connector links, which make the connection between the road network and the centroids that represent the traffic generating regions. Each link has a set of attributes, with some of them being inherent to the link, namely its length and capacity, while others depend on the vehicles that use those links, which may be different for each type of cargo. Those are the average speed, vehicle capacity, cost per distance and CO2 emissions of the vehicles, and the value of time for each type of cargo. The calculation of the generalized cost per unit of cargo is constituted by a vehicle cost component and a time cost component, and is given by equation 1:

$$Generalized\ cost\ per\ unit\ of\ cargo = \frac{Length * Vehicle\ cost\ per\ distance}{Vehicle\ capacity} + \frac{Length}{Average\ speed} * Value\ of\ time \quad (1)$$

Based on the defined generalized costs it is possible to calculate the shortest path (with the least generalized costs) between any given pair of nodes for each type of cargo. The shortest path algorithm that is employed in the model is the Floyd-Warshall algorithm (Floyd, 1962) with path reconstruction, which computes the value of the shortest paths between all the nodes, as well as the path in itself (the links used in each shortest path).

Assignment Process

With all the model's basic features properly defined, it is now possible to describe the assignment process, whose main features are resumed in figure 1.

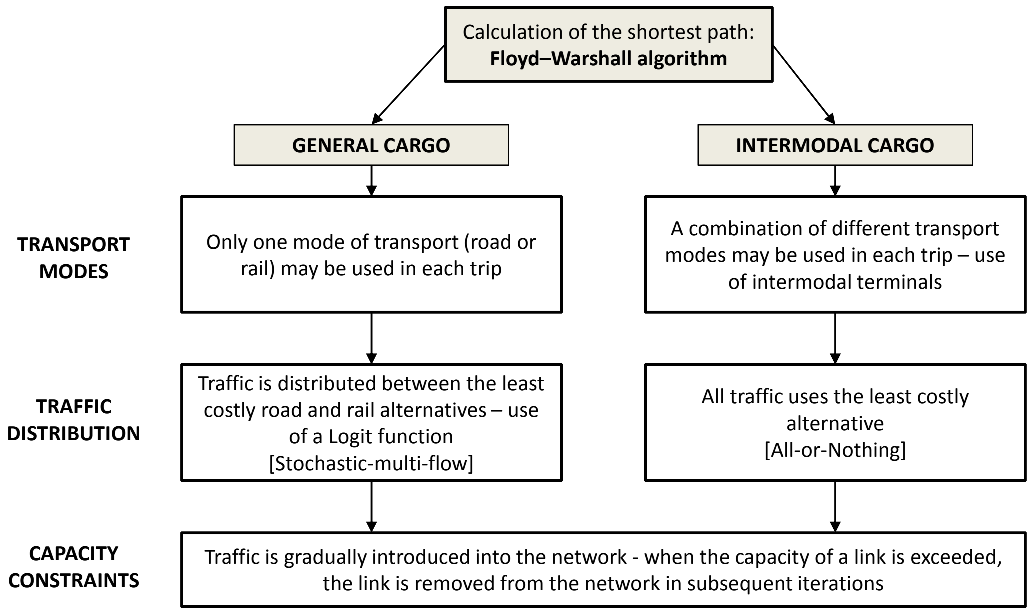

Figure 1 - Assignment process

As it can be seen in figure 1, there are different assignment techniques for the two different types of cargo, mainly due to the fact that only intermodal cargo is allowed to use intermodal terminals, which is a solution already applied to other studies in this area (Beuthe *et al*, 2001). This means that, while intermodal cargo may use more than one mode of transport per trip, general cargo is limited to using the same transport mode in each trip, which is reflected in the traffic distribution techniques that are used for each type of cargo. In the case of general cargo, as each trip may only use one mode of transport, there is a clear mode choice decision between the least costly paths using road and rail transport. This allows for the distribution of traffic between the two modes, using a Stochastic-multi-flow technique, which is implemented using a Logit function (Tsamboulas and Moraitis, 2007) that gives the percentage of traffic using each mode. As for intermodal cargo, its traffic is assigned to the least costly path between the origin and the destination, which may include intermodal terminals. This is done using an AoN technique, which allows for road and rail links to be used indifferently in every trip, as long as they are part of the absolute least expensive path.

Although the model does not consider capacity limits on road links, due to the fact that congestion is mostly observed in and around urban areas (Jourquin, 2005) and not on intercity routes, it considers it on rail links and intermodal terminals. This is justified by the fact that the capacity of rail links and intermodal terminals is relatively rigid, with empirical evidence showing that rail links are more likely to be used to capacity than their modern intercity road links counterparts. Given that most of the capacity problems in rail networks are due to specific point in the network, such as congested rail junctions, the model allows for the introduction of congested rail nodes with a limited capacity. As it can be seen in figure 2, which displays the technique used to model rail nodes (Crainic *et al*, 1990), the model considers a virtual link that represents the total capacity of the rail node.

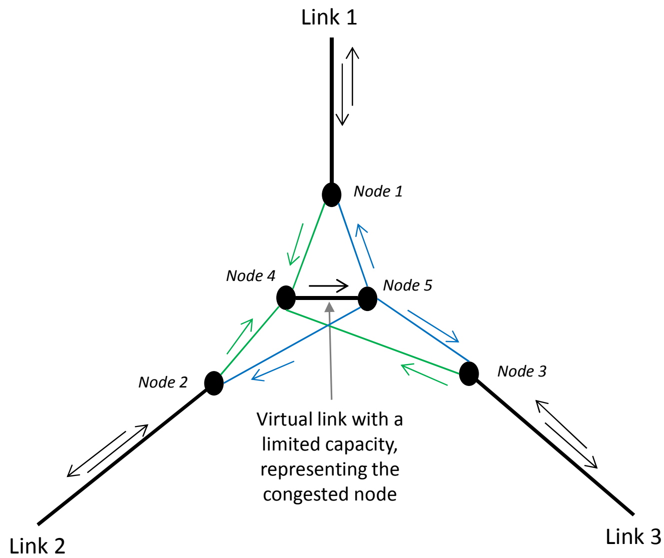

Figure 2 - Congested rail nodes scheme (example of a congested rail node with 3 rail links converging on it)

It is important to notice that what is defined in the network is the physical capacity of each link, which means that the capacity that is left for freight trains is the total capacity minus the flow of passenger trains. That flow is obtained by assigning an origin/destination (O/D) matrix of passenger trains to the rail network, using the shortest distance path.

Although the model includes capacity constraints, this is not done by using an equilibrium model. The total freight flow is gradually inserted into the network, with the user defining in how many interactions is the traffic flow introduced into the network. If any new link has reached its capacity after each iteration, it is removed from the network and the shortest paths and traffic distributions are recalculated. This process continues until all the traffic is assigned to the network.

NETWORK OPTIMIZATION MODEL

Overview of the Optimization Process

The first step in the development of a network optimization process is the definition of the adopted network structure, defining all the possible link levels and network improvement possibilities. The solution employed in this model is a network structure where the links have a limited number of discrete quality levels, which each level corresponding to a different link type. Link's quality levels can vary from zero, which corresponds to the mere possibility of building a link, to the highest level, corresponding to the best possible link quality. Each link level has an associated set of characteristics for each type of cargo, which may be freely defined by the user. This network structure allows for both the improvement and the construction of new links, permitting unlimited improvement possibilities. The model allows for the improvement of rail, intermodal terminal and virtual links, meaning that all the links which are related to rail transport may be improved, in order to meet the goal of the model, which is the optimization of rail networks. All the possible improvement operations that are defined by the user have to have an associated cost, in order to quantify the money that is spent in each improvement scenario.

The factors that are considered for the assessment of the quality of each network improvement solution are the total generalized costs, and the total emissions of CO2. The total generalized cost reflects the economic costs that are supported by the freight carriers, and according to which they make their transportation decisions. As for the total emissions of CO2, they quantify the total CO2 emitted by all the vehicles transporting freight, serving as a measure of the environmental impact caused by freight transportation. The quality of each improvement solution is measured based on the minimization of both of this parameters. Given the existence of more than one optimization parameter, it is necessary to define the weight that is given to each one of them, which is something that is defined by the user according to each case's planning priorities.

After having the network structure, improvement possibilities, and quality assessment parameters well defined, it is possible to develop an optimization process. This process generates network improvement solutions which, respecting a given budget, optimize the previously defined quality parameters. Except for small-size instances, this network optimization process is extremely difficult to be solved to exact optimality using an analytical process, which means that an heuristic has to be used. Due to its nature, the heuristic process may not guarantee the absolute best possible solution, but it will scrutinize the search space in order to find the most satisfactory solution possible, with the quality of the obtained solutions being dependent on the quality of the heuristic. In this model, after studying various alternatives and having consulted with specialists in the area, the authors have decided to use a local search heuristic which, being a relatively straightforward heuristic, delivers good results for this type of problem.

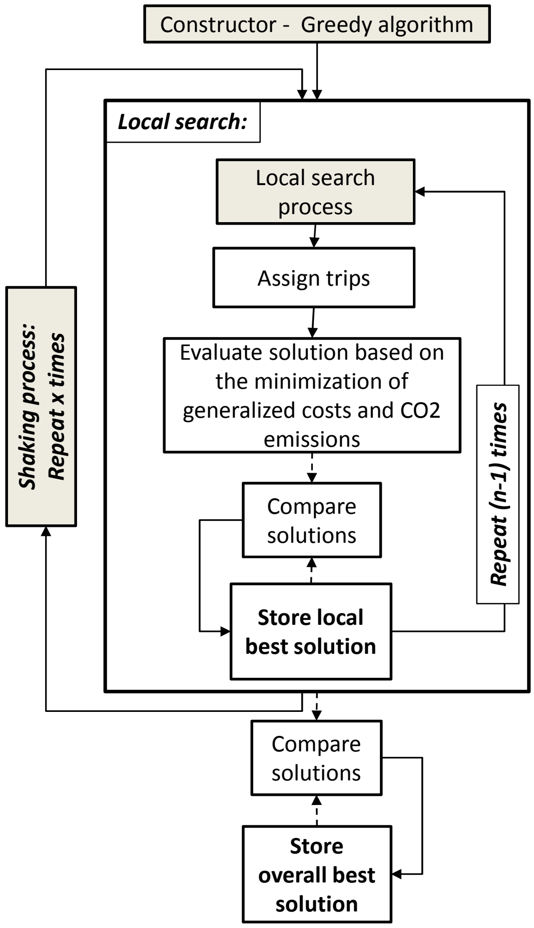

Figure 3 - Optimization process

As it can be seen in figure 3, the optimization process starts with a constructor, creating a reasonable initial solution, which is done by using a greedy algorithm. Based on that initial solution, the model runs two different cycles: an inner local search process, and an outer shaking process. The local search process tries the optimize the solution by searching for better solutions on the search space vicinity of the initial solution, while the shaking process is used to make the solution "jump" to a different point in the search space, in order to avoid being stuck in a local optimum.

Constructor Algorithm

The constructor process is based on a greedy algorithm, which iteratively improves the links with the highest perceived improvement benefit to their maximum possible level, until there is no more available budget for improvements. The formula that is used to measure the perceived improvement benefit of each link, which was freely defined by the authors, is the following:

$$Improvment\_Benefit = \left(1 + \frac{Volume\_of\_Traffic}{Link\_capacity}\right)^2 * Volume\_of\_Traffic \quad (2)$$

As it can be seen in equation 2, the improvement benefit for each link is proportional to the volume of traffic that uses the link and to the relative utilization of the link. The authors considered that links with higher volumes of traffic should be improved first, because their improvement benefits a higher share of the total traffic. Also, the relative utilization of each link is also important, as links which are over their capacity will benefit the most with a capacity increase, allowing them to be used by more traffic. If an improvable link has no traffic passing throw it, which is the case in links which represent the mere possibility of building a link, the model attributes it an improvement benefit marginally bigger than zero, as an improvement in such a link may be beneficial. The algorithm iteratively improves the links with the higher value of improvement benefit to their maximum level until there is no more budget available to make new improvements, constructing an initial network optimization solution.

Local Search Algorithm

The algorithm that is used for the local search process, which is the core of the whole optimization process, is schematized in figure 4.

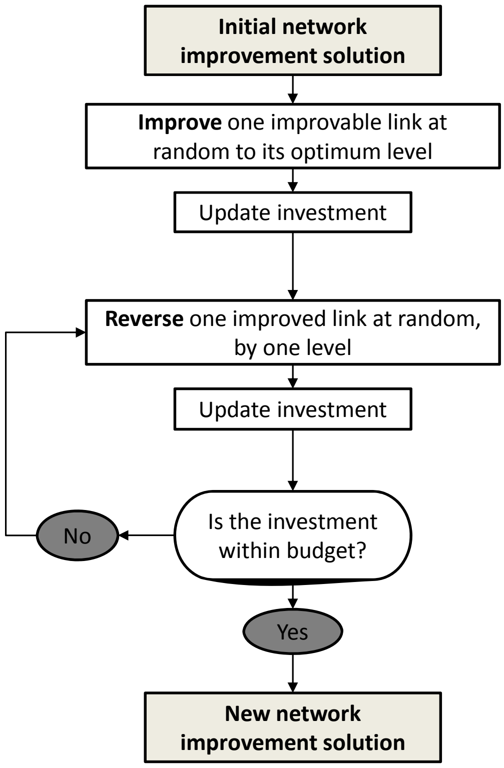

Figure 4 - Local search process

The local process takes an initial network improvement solution and makes a small change in it, by proposing a new solution in the search space vicinity of the initial solution. This is done by improving an improvable link at random to its optimum level, and then iteratively reversing a link at random by one level, until the investment is within budget. Each link's optimum level corresponds to the best possible level a link can reach, without unnecessarily improve its capacity. This means that the optimum level for a link which does not need more capacity is the best possible link level within its capacity bracket. The optimum level for a link which needs more capacity is the best possible link level in the next capacity bracket. The new solution is then tested to see if it is better than the current solution, in which case it becomes the new current solution, and this cycle is repeated by as many times as defined by the user, as it can be seen in figure 3.

Shaking Algorithm

In order to avoid being stuck in local optimums, the model has a shaking algorithm that makes the solution that comes out of each local search process “jump” to a different place in the search space, from where a new local search process can be performed. This process consists in the reversal of two thirds of the improvement operations that were originally done, followed by the iterative improvement of random links to their optimum level, until the budget is reached or exceeded. An improvement operation corresponds to the improvement of one link by one level, with the relation between the number of reversal operations and the total number of original improvement operations being something that may be calibrated according to the type and size of the network under analysis. This process creates a new random solution, which is significantly different from the original solution, and that will likely have left its original search space vicinity, avoiding being stuck in local optimums. Due to the fact that the shaking algorithm only stops when the budget is reached or exceeded, most of the improvement solutions that will come out of this algorithm will exceed the available budget, at least slightly. This is however not a problem, due to the fact that the ensuing local search process will correct this, by reversing as many links as needed until the total network investment is within budget.

APPLICATION OF THE MODEL

Description of the network and considered scenarios

In order to test and evaluate its performance, the developed model was applied to a network created by the authors, which is schematized in figure 5.

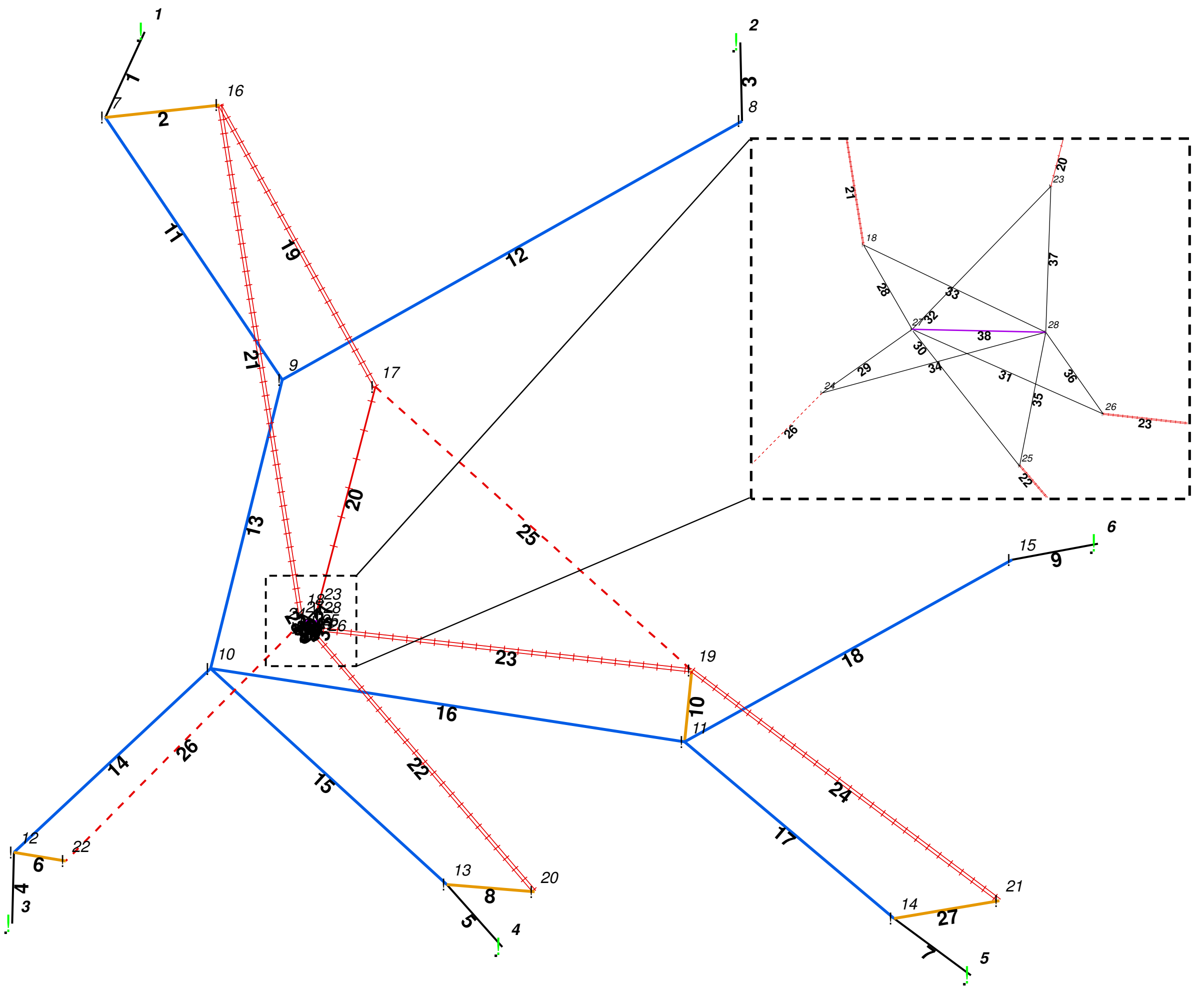

Figure 5 - Network map

It is a relatively simple network, with six traffic generating poles (centroids), which are represented as large green dots, road and rail links, which are the plain blue and crossed/dashed red lines respectively, and four intermodal terminals, which are links 2, 6, 8 and 27, represented in orange. Links 1, 3, 4, 5, 7 and 9 are connectors which link the centroids to the road network, with the concentration of nodes in the convergence of links 20, 21, 22, 23 and 26 representing a congested rail node, as exemplified in figure 2, where the virtual link is link 38. There are various possible link levels for each link type, as it can be seen in table I, and only some of them are used in this network.

Table I - Summary of links

		LINK TYPE				
		Type 0 - Connector	Type 1 - Road link	Type 2 - Rail link	Type 3 - Intermodal terminal	Type 4 - Rail node virtual Link
LINK LEVEL	0	-	-	Possible link	Possible link	-
	1	Centroid to rail	Road link	Non-electrified single line; Max. train length = 450m	Intermodal terminal - capacity level 1	Rail node - capacity level 1
	2	Centroid to road	-	Electrified single line; Max. train length = 450m	Intermodal terminal - capacity level 2	Rail node - capacity level 2
	3	Port to rail	-	Electrified single line; Max. train length = 750m	Intermodal terminal - capacity level 3	Rail node - capacity level 3
	4	Port to road	-	Electrified double line; Max. train length = 450m	Intermodal terminal - capacity level 4	Rail node - capacity level 4
	5	Zero cost connector - for rail nodes	-	Electrified double line; Max. train length = 750m	-	Rail node - capacity level 5
	6	-	-	-	-	Rail node - capacity level 6

By consulting figure 5 it is possible to see that links 25 and 26 are represented as dashed lines, which means they are level 0, representing just the possibility of building a link. All the other rail links are level 4, with the exception of link 20, which is level 2. As for the intermodal terminals as well as the virtual link representing the congested rail node, they are all level 1. The O/D matrices with the demand for freight between the six centroids as well as the movement of passenger trains, which are all inputs of the model, can be consulted in table II.

Table II - O/D matrices

O/D	General cargo(ton) / Intermodal cargo(ton) / Passenger trains(trains)					
	1	2	3	4	5	6
1	0 / 0 / 0	0 / 0 / 0	40000 / 0 / 0	25000 / 0 / 7	22500 / 55000 / 5	35000 / 0 / 0
2	0 / 0 / 0	0 / 0 / 0	30000 / 0 / 0	20000 / 0 / 0	27500 / 0 / 0	15000 / 0 / 0
3	40000 / 0 / 0	30000 / 0 / 0	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0
4	25000 / 0 / 7	20000 / 0 / 0	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0
5	22500 / 55000 / 5	27500 / 0 / 0	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0
6	35000 / 0 / 0	15000 / 0 / 0	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0

The values that were considered for the network improvement costs, attributes of the different links levels and O/D matrices were chosen by the authors for this specific application, being reasonable indicative values. For the sake of simplification, the link attributes for both intermodal cargo and generalized cargo were considered equal, with both types of cargo being measured in tons. Regarding the definition of CO_2 emissions, they were quantified as grams per km in the road and rail links, and as grams per moved ton of cargo in intermodal terminals. As for the links capacity, in the case of intermodal terminals it is measured in tons of moved cargo, while in rail links and congested rail nodes it is measured in number of trains.

Application results and discussion

The network optimization model was applied to the network under the following conditions: regarding the assignment process, the traffic was introduced into the network in 20 interactions; as for the optimization process, each local search process consisted of 50 cycles, and the shaking process considered 50 shaking cycles The optimization program took approximately 16 minutes to finish in a dual core 2.5GHz processor, which is a reasonable amount of time for a network of this size with this relatively high number of improvement possibilities. The relative weights that were given to generalized costs and CO2 emissions minimization were 2 and 1, respectively, and two different scenarios were considered: one with a total available budget of 250 million monetary units, and another with a total budget of 500 million monetary units.

Table III - Results of the optimization process

	Scenario 1						**Scenario 2**				
Total investment (million monetary units)	247						484				
Percentage of reduction in total generalized cost	-0.1390%						-3.5632%				
Percentage of change in total CO2 emissions	-1.9433%						-23.8656%				
Combined weighted improvment percentage	-0.7404%						-10.3306%				
Improvment solution	Id	Link type	Original link status	Improved link status	Levels of improvment		Id	Link type	Original link status	Improved link status	Levels of improvment
	1	0	2	2	0		1	0	2	2	0
	2	3	1	1	0		2	3	1	3	2
	3	0	2	2	0		3	0	2	2	0
	4	0	2	2	0		4	0	2	2	0
	5	0	2	2	0		5	0	2	2	0
	6	3	1	1	0		6	3	1	1	0
	7	0	2	2	0		7	0	2	2	0
	8	3	1	1	0		8	3	1	1	0
	9	0	2	2	0		9	0	2	2	0
	10	3	1	1	0		10	3	1	1	0
	11	1	1	1	0		11	1	1	1	0
	12	1	1	1	0		12	1	1	1	0
	13	1	1	1	0		13	1	1	1	0
	14	1	1	1	0		14	1	1	1	0
	15	1	1	1	0		15	1	1	1	0
	16	1	1	1	0		16	1	1	1	0
	17	1	1	1	0		17	1	1	1	0
	18	1	1	1	0		18	1	1	1	0
	19	2	4	5	1		19	2	4	5	1
	20	2	2	5	3		20	2	2	2	0
	21	2	4	4	0		21	2	4	4	0
	22	2	4	4	0		22	2	4	4	0
	23	2	4	4	0		23	2	4	4	0
	24	2	4	4	0		24	2	4	5	1
	25	2	0	0	0		25	2	0	5	5
	26	2	0	0	0		26	2	0	0	0
	27	3	1	1	0		27	3	1	3	2
	28	0	5	5	0		28	0	5	5	0
	29	0	5	5	0		29	0	5	5	0
	30	0	5	5	0		30	0	5	5	0
	31	0	5	5	0		31	0	5	5	0
	32	0	5	5	0		32	0	5	5	0
	33	0	5	5	0		33	0	5	5	0
	34	0	5	5	0		34	0	5	5	0
	35	0	5	5	0		35	0	5	5	0
	36	0	5	5	0		36	0	5	5	0
	37	0	5	5	0		37	0	5	5	0
	38	4	1	2	1		38	4	1	1	0

The results and improvement solutions obtained for each scenario, as well as the type and original level of each link, can be consulted in table III. The solutions obtained for each of the

two scenarios are considerably different, which reflects the complexity of the network optimization process, as a bigger budget allows for more ambitious network interventions.
In the solution obtained for scenario 1 the virtual link 38, which represents the congested rail node, is improved in order to have a higher capacity, which is justified by the fact that in the original network configuration this node is congested. Also, rail links 19 and 20 are improved to their best possible level, in order to reduce rail transport costs. By contrast, on the solution obtained for scenario 2 the rail node link is not improved. This is justified by the fact that the higher available budget allowed for the construction of link 25, which is a new rail link that diverts rail traffic from the congested node, meaning that it no longer needs a capacity improvement. The construction of this new rail link, combined with the improvement of rail links 19 and 24, makes the rail mode much more competitive for certain routes. This causes a sharp rise in the amount of cargo that uses intermodal terminals 2 and 27, which therefore need to be improved in order to accommodate for this traffic growth.
The obtained results were in line with what was expected, with the model demonstrating the necessary adaptability needed to handle a problem as complex as this optimization problem. This is patent in the very different outcomes that were obtained for the two scenarios, which are justified by the fact that the bigger budget of scenario 2 enabled the adoption of a radically different solution.

CONCLUSIONS

In this paper, an innovative network optimization model is presented, being subsequently applied to a network, under two different scenarios. The model is conceived for a strategic level of planning, modeling the major road and rail links, as well as specific congested rail nodes and intermodal terminals. It is an innovative model in the fact that it is not limited, unlike existing freight network optimization models which are usually limited by only allowing for either the construction or the improvement of links, or by having a limited search space. This model allows for both the improvement of existing links as well as the construction of new ones from scratch, and can be applied to very different networks without a limit on the number or variety of network improvement possibilities.
The practical application of the model produced satisfactory results, highlighting the model's adaptability, as it was able to optimize the network investment according to the available budget for each of the two tested scenarios, by delivering considerably different solutions.

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