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Performance indicators for planning intermodal barge transportation systems

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Abstract

Various indicators are used to qualify the performance of intermodal transportation systems. Some of these are found in public documents, usually providing global measures such as total flow volumes, profits, and share values. While of great interest, such measures are not sufficient to support a fine analysis of different operation strategies, commercial policies, and planning methods. Additional measures are used in the scientific literature to address these issues. Our first goal is to review the performance indicators found in scientific literature and to qualify them with respect to tactical planning of intermodal barge transportation systems. We extend this analysis to include revenue management policies, a topic generally neglected in freight transportation. We also discuss procedures to generate problem instances that provide the means to analyze planning methods and system behavior based on these performance indicators.

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Keywords: freight intermodal transportation; barge transportation; performance indicators; tactical planning; revenue management

1. Introduction

Intermodal freight transportation is generally defined as moving cargo loaded into some type of boxes, the well-known containers, by a series of at least two transportation modes or carriers, without handling the cargo, containers being moved from one mode (vehicle) to the next in intermodal terminals, e.g., ports and rail yards (Bektaş and

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Crainic, 2008; Crainic and Kim, 2007). It is a core economic activity supporting for a large part national and international trade. As such, it is a well-known and intensely investigated application field in operations research and transportation science. Planning and management of activities at the strategic (e.g., market development and location and dimensioning of facilities), tactical (e.g., service and capacity planning) and operational (e.g., dispatching and resource management) are both essential to the economic and operation efficiency of intermodal transportation systems and stakeholders, and complex processes in their own right. This resulted into a rather rich collection of models and methods aiming to optimize operations, service and resource utilization for intermodal freight transportation carriers. Not all components of the industry received equal treatment, however. We are thus particularly interested in such a less studied branch of the field, namely barge intermodal freight transportation systems (inland water transportation), which is gaining interest as a component of environment-friendly modal shifts.

The study we undergo, and the results presented here, focus on the tactical level decision-making problems and concern, in particular, the scheduled service network design (SSND) with asset management considerations. There are very few service network design models and methods proposed for barge transportation yet, but one observes raising interest for the topic, including within freight forwarders and carriers, mainly due to modal-shift public policies and increasing concerns in the public and shippers alike with respect to the environmental impact of other modes of freight transportation. This translates for barge carriers into a new motivation and willingness to have a higher level of competitiveness, to devise a different way of designing their services, and to explore new customer-service strategies offered by the revenue-management concepts.

Many studies assess existing decision-support tools, policies and practice or proposed service network design models and solution techniques, generally through comparison of optimization or numerical simulation results. The transportation system is generally modeled through network-based formulations with assumptions regarding the underlying physical network and infrastructure, characteristics of available assets (fleets of vehicles, terminal resources, capacities, etc.), and future demands (demand forecasts). Test instances are then generated, hopefully with reference to actual practice, the corresponding SSND formulations are solved, and solutions and characteristics of the corresponding operation plans are analyzed and performances are evaluated. Performance indicators thus play an important role in the analysis of models, methods, results, and corresponding policies.

Performance indicators are broadly used, in practice and research, to characterize the performance of a given transportation system under current (e.g., the annual activity and financial reports of carriers) or proposed (e.g., optimization and simulation studies) operating conditions. They are, of course, also widely used to validate and evaluate models and solution methods, as well as the corresponding results and strategies. Many such indicators are found in official documents and the scientific literature, as shown in the following. Yet, there is no general framework for analyzing the interest of particular performance indicators in the context of specific problem settings, generating appropriate problem instances, and choosing the most representative indicators. Nevertheless, it is commonly accepted that, some indicators give more insights than others when evaluating the performances of a transportation system or methodology, and some critical ones may be singled out. In the same time, the performance indicators can only be computed if specific information and data are collected for this purpose. Our goal is to contribute toward addressing this issue.

The contribution of the research presented here therefore is to propose a classification and analysis of the performance indicators generally used to evaluate tactical planning solutions in freight transportation, aiming to identify adequate ones for SSND with revenue management considerations. The performance indicators analyzed herein may be applied to assess performances of different modes (maritime, rail, etc.) supporting container transportation systems; we illustrate our study with an inland navigation system. We also give some insights in the way the necessary test instances are generated for a general network barge transportation system.

The structure of the paper is as follows. We give a brief description of the general SSND problem in Section 2, together with corresponding literature and specific issues related to the introduction of revenue management considerations in the tactical planning problem. Section 3 gives the first steps toward a general classification of performance indicators and identifies a number of particular ones related to the problem studied here. The description of a general procedure to generate problem instances for SSND models of general barge transportation networks is the focus of Section 4, followed by Section 5 where numerical results and an analysis of the different performance indicators are presented. The paper ends with conclusions about the presented study.

2. Problem characterization

Service network design formulations (Crainic 2000) are extensively used to address planning issues within many application fields, in particular for the tactical planning of operations of consolidation-based modal and multimodal carriers (e.g., Bektaş and Crainic 2008, Christiansen et al. 2007, Cordeau et al. 1998, Crainic 2003, Crainic and Kim 2007). Building such a plan involves principally selecting the services to operate and their schedules or frequencies, and routing the demand through the selected service network. Most service network design models proposed in the literature consider the resources required to perform the services (vehicles, power units, drivers, etc.) and the different types of customers only indirectly, however, which is increasingly inadequate to reflect the operation strategies of a broad range of transportation systems.

One observes a recent trend in the field aiming to introduce more explicit resource-management considerations into tactical planning models (e.g., Andersen et al. 2009a,b, Bilegan and Crainic 2014, Crainic et al. 2013, Kim et al. 1999, Lai and Lo 2004, Pedersen et al. 2009, Sharypova et al. 2012, Smilowitz et al. 2003). These so-called scheduled service network design with resource (or asset) management take the form of mixed-integer formulations defined on time-space networks (except Sharypova et al. 2012, working with continuous time). The schedule length (e.g., a week), which will be repeated during the planning horizon (e.g., the season), is divided into periods (e.g., the day), and the terminals are duplicated to have a time-labeled copy within each such period. The set of time-labeled terminals makes up the set of nodes of the graph. In the basic problem setting, demand is then defined in terms of commodities, that is, given quantity of freight available at an origin node at a given period to be moved to a given destination node within some duration restrictions. Potential services (mode, speed, etc., may further characterize the service) from a terminal at a given period (departure time) to a different terminal and time period are making up the set of design arcs of the model. Holding arcs, for freight and resources waiting at a given terminal for one period, are included between two consecutive copies of the same terminal. Service arcs are generally characterized by a capacity limiting the total quantity of flow transported (sometimes, commodity-specific capacities are also included), as well as by a fixed cost to be paid if the service is included in the final design (i.e., it will operate) and a unit commodity cost. Only the latter characterizes holding arcs. Resources, vehicles of a single or a low number of types, support the operations of the services. In the current state-of-the-art, a unit of resource is required to operate each selected service, and it may operate at most a service at each time period. Resources are allocated to terminals out of which they operate and where they return according to various rules and restrictions (e.g., the number of periods they may be out of their home terminal).

The scheduled service network design (SSND) with resource management formulation then includes three sets of variables representing decisions on service selection (arc, binary), demand transportation (arc-based continuous commodity-specific flows), and resource-to-service assignment (binary; path/cycle formulations have also been proposed, e.g., Andersen et al. 2009b, Crainic et al. 2013, Pedersen et al. 2009). The objective function generally minimizes the total cost of the system made up of the total fixed cost of selecting services, the total cost of flowing the demand, the total fixed cost of the used resources, and their respective operating costs. Other than the application-specific restrictions (e.g., number of resources by terminal), the constraints making up the formulation are enforcing the conservation of flow and the balance of services (number of services/resources incoming at a node equal the number departing the node) at nodes, the linking (and capacity) relations between flows and services, the assignment of a single resource to a service and of at most a service to each resource, the time limits on the route of a resource and the transportation of demand.

To perform our experiments in the present study, we use the SSND model proposed by Bilegan and Crainic (2014). The model follows this general framework but also includes a representation of the revenue management strategy used by the firm. Revenue management is a well-known set of concepts, strategies, and methods aiming to determine the most appropriate fare for each customer at the moment the reservation is made (Talluri and van Ryzin 2004). Used broadly for passenger transportation and in the tourism industry, its utilization within freight transportation is still in its infancy (Bilegan et al. 2014). Consequently, there is little expertise on how to include such concepts into the tactical-planning methodology. In their pioneering work, Bilegan and Crainic (2014) propose to proceed by including several types of customers (on the demand side) and several levels of delivery service (on the provider side). Each level of delivery service (e.g., fast or slow delivery) is associated with a specific fare for each origin-destination pair of terminals in the system. The overall objective of the SSND model proposed is to maximize the net profit.

Therefore, two types of customers, and consequently two types of demand are considered in the present study, regular – corresponding to the regular traffic on the network (following long-term contracts or advance bookings with customers); this demand has to be always satisfied –, and punctual or "spot" demand. We stress here that the main difference between the two types of customers lays in the degree of confidence associated with each. We consider the former, the regular customers, to be quite sure (this is a classical assumption for most of the traditional SSND models); we consider the latter, the punctual or "spot" customers, to be associated with a higher degree of uncertainty (the demand values used could come from the aggregation of several small and sporadic customers using the transportation capacity of the network in place). Consequently, the solution of the optimization model will never deny regular demands and will, in addition, allow for part of the irregular customers to be integrated at the tactical level, to offer more flexibility to the proposed solutions. Two types of such irregular or, so-called, punctual demands are considered depending whether a punctual demand must be served in its entirety if accepted (full punctual demand) or whether only a fraction of it might be served (partial punctual demand). The relative ratios of punctual to regular demand volumes, as well as the ratio of the fares (e.g., fast delivery fare with respect to the slow delivery fare), constitute determining factors for the profitability of the firm and they are addressed when analyzing numerical results in Section 5.

3. A first step towards a taxonomy of performance indicators

In this section, we present an analysis of some of the performance indicators generally used for validating and evaluating service network design models, and the corresponding results and strategies. In order to keep the presentation short, only a few recent scientific papers are cited. We selected those with a high relevance to the present study, in particular some developing models for intermodal barge transportation at the tactical level. We consider them to be quite representative of the existing literature in this field, although we do not claim having performed an exhaustive search in this direction.

Andersen and Christiansen (2009) used a set of performance indicators to qualify rail freight services. The authors computed the number of contracts served and the number of vehicles used. The total profit was also evaluated, computed as total costs subtracted from the total revenue obtained from the served contracts. Andersen et al. (2009a) also looked at the number of vehicles in use, as well as at the number of service departures per week and the duration (number of hours or time periods) of service operations, repositioning moves, and holding vehicles at nodes. Braekers et al. (2013) focused on the average cost reduction and vessel capacity utilization, as well as on weekly profit and cost, the weekly number of transported containers, and the percentage of empty containers transported. It is worth noticing that, in addition, they used a particular indicator giving the percentage of volume transported by barge out of the total volume of demand, since some of the demands could be transported by road in their problem setting. In Caris et al. (2011), average and maximum waiting times, and average turnaround time at the port of Antwerp were used as indicators. The authors also computed the average and maximum capacity utilization at the port of Antwerp in terms of berthing capacity of the port. Sharypova et al. (2012) calculated the ratio between the number of vehicles used and the total number of vehicles in the fleet, the percentage of containers transshipped between vehicles with respect to the total number of containers transported in the system, and the percentage of direct services out of the total number of services chosen as optimal solution of the SSND model. Lo et al. (2013) developed a two-phase stochastic program formulation for ferry service network design with stochastic demand for passenger transportation. They used the notion of service reliability to differentiate demands and introduce uncertainty into the mathematical model. Total cost was used in comparing their new formulation with the conventional one. They also decomposed it by different secondary indicators: ad hoc cost (cost of ad hoc services added only when needed, subcontracted or outsourced to a third party), waiting cost (passenger waiting time penalties) and regular services operation costs.

We propose a first classification of these different performance indicators based on their relevance and meaning from the service providers' perspective, as well as from the customers' perspective. Thus, we consider that the first and most important category is the one grouping indicators directly giving information about the economic impact of the tactical planning decisions (e.g., costs, profits). The second one includes resource-utilization performance indicators, giving information particularly useful to service providers and other stakeholders directly involved in transportation and handling activities. Last but not least, a third important category, especially from the customers' point of view, is the one concerning quality-of-service performance indicators. Inspired by the set of performance indicators cited above, we present a classification based on these three main criteria in table 1. The performance indicators collected in the preliminary analysis are to be found in the upper part of the table, while the lower part displays additional indicators responding to the need of evaluating SSND models with revenue management considerations, as explained in more detail hereafter.

When differentiating types of customers and fares, we need to understand how the system behaves when different values of some key parameters are used (e.g., different ratios of Regular/Punctual customers, different ratios of slow/fast delivery type demands, etc.). This type of analysis also provides a better understanding of what are the most suitable circumstances under which specific planning methods (e.g., revenue management policies) should be applied to obtain the best outcomes. This is why, when introducing revenue management concepts in service network design models, new performance indicators are needed, in particular for evaluating their absolute/relative economic performance, the resource utilization levels and the quality-of-service offered (e.g., the ratio of accepted demand with respect to the total demand, etc.). Moreover, in order to develop more insights into the behavior of the system, several different indicators can be calculated with the purpose of understanding where the effectiveness of the solution comes from, how resources are distributed and used, how freight consolidation is performed, etc.

Table 1. A first classification of performance indicators used for tactical planning of intermodal barge transportation systems.

Economic impact	Resource utilization	Quality-of-service
Total profit	Number of vehicles in use	Number of contracts served
Total cost	Number of open services	Waiting time in intermodal terminals
Average cost reduction	Operating hours of services	Waiting time at other terminals
Ad hoc services cost	Operating hours for repositioning	Average turnaround time
Waiting time cost	Duration of holding vehicles at nodes	Time on intermodal services
Regular services cost	Number of vehicles used/fleet size	Handling in intermodal terminals
	Vessel capacity utilization	Waiting time at borders
	Berthing capacity utilization	Containers transported by barge
	Number of direct services/total services	Empty containers transported
	Ratio of transshipped containers	
Net profit increase	Number of less-used vehicles	Volume of rejected partial punctual demands
	Number of empty vehicles	Volume of rejected full punctual demands

When analyzing the way resources are used, we focus particularly on the number of empty and less-used vehicles. The empty vehicles are the vehicles used in the transportation plan without any cargo (repositioning moves); the less-used vehicles indicate vehicles whose average capacity usage is less than 20% (the value of this parameter may be changed with respect to the service provider requirements). The service suppliers could decide not to open services whose capacity is less used, which would probably lead to a different solution and plan; this could be confirmed by introducing the corresponding constraints in the mathematical model and by comparing the subsequent solutions thus obtained.

Another indicator that has to be introduced is the percentage of accepted/rejected punctual demands (TEUs) out of the total volume of demands (regular and punctual). As we differentiate demand by category of customers, we are looking at how much of the demand, in terms of TEUs, is accepted/rejected in each category of punctual demands (partial and full punctual demands). This indicator is related to the quality-of-service offered by the carrier, and gives an idea of the capability of the system to discriminate between high-profit and low-profit demands.

4. Test instances generation

We now turn to how the problem instances are set up and how the data characterizing the transportation system are randomly generated. To represent the reality of a general network, we consider a set of ports and the physical links (water navigation infrastructure) between them representing the physical network, like the one represented in Fig. 1. Without loss of generality, we classify ports into two categories, i.e., main ports and secondary ports. The main ports stand for the deep-sea ports (e.g., port A in Figure1) and the secondary ports represent the inland ports. An Origin-Destination (OD) pair is called a main OD-pair, if it is related to at least one main port. It is considered a secondary OD-pair otherwise. We make the assumption that all ports have enough berthing capacity to hold vehicles (in operation or not), and sufficient space to store containers. We also assume that the handling machinery at each port is efficient enough and the duration of servicing a vehicle, for loading and/or unloading activities, is equal to one time period. A single type of vehicle is considered with a capacity equal to 100 TEUs. We make the assumption that the transit time from one port to any other consecutive port is one time period (the distance between any consecutive ports in the physical network is considered to be almost the same). The fleet size is assumed big enough to satisfy all demands.

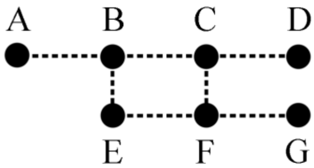

Fig. 1. A general physical network.

Every demand is characterized by an OD-pair (its origin and destination ports), its availability time at origin (the earliest time the demand is available and ready for transportation), a delivery type (slow or fast) characterizing the maximum delivery time within which the demand has to be transported to its destination (in number of time periods), a volume (in TEUs) and a category differentiating the type of customer or the type of contract (regular or punctual, as explained in Section 2).

We assume that demands between main OD-pairs occur more often than demands between secondary OD-pairs. In terms of availability time in port, demands for main OD-pairs may arrive at each time instant. To restrict the problem size, demands for the secondary OD-pairs may occur at time instants belonging to a specified set (e.g., every two time periods). Moreover, we allow only 10% of the secondary OD-pairs to be chosen in a test instance. These 10% are randomly picked up with a uniform distribution from the complete list of possible OD-pairs. For each OD-pair and availability time in port (randomly generated), two demands, one with fast delivery and the other with slow delivery type, are set. This results in a balanced number of demands requiring fast and slow deliveries within the same test instance.

The volume of each demand is randomly generated between 0 and a maximum value (usually less than the capacity of a vehicle) according to the uniform distribution. In order to generate a well-balanced combination of regular and punctual demands within a test instance, we generate first the set of demands to be used, without specifying their category. Thus, we fix the total volume of demand in the instance. Then, the volume of punctual demands is specified by a percentage (p) over the total volume of demand, the remaining percentage (1-p) corresponding to the total volume of regular demands. We may thus generate instances with a fixed total demand but with varying proportions of main to secondary OD-pairs and regular to punctual ratios.

The maximum delivery time for each demand is computed (in terms of time periods) according to the distance between the origin and destination of the demand and the corresponding delivery type (fast or slow). As a general rule, we assume that a demand associated with a slow delivery would agree to be delivered within a time two times longer than the delivery time required by a fast demand between the same origin and destination. We set the fast delivery time by ensuring feasibility with respect to some of the less time-consuming potential services that could serve that demand. The different delivery types and thus the different types of demands are associated to different fares classes. A low-fare corresponds to a slow delivery demand type and a high-fare is associated with a fast delivery demand.

In the following section we give some numerical results obtained when solving the SSND problem for random test instances with data sets generated by this type of procedure.

5. Numerical results and analysis

We now illustrate how, using a set of problem instances generated as described above, the performance indicators may help analyzing the output of an SSND model with asset and revenue management considerations. We compare two mathematical models, a traditional one in which customers are not differentiated, called SSND in the following, and the new SSND-RM model proposed by Bilegan and Crainic (2014), incorporating revenue management concerns, namely different categories of customers and different fare classes. The main difference between the two models is that the first one deals with regular demands only (all the demands have to be satisfied), while the second one takes into account both regular and punctual demands. As explained in Section 2, the SSND-RM model allows potential increase in performance when partially or totally refusing some of the less profitable punctual demands. Following the procedure described in Section 4, demands are generated randomly for each test instance. We run the program and solve the two service network design problems (SSND and SSND-RM) for 20 different instances.

The performance indicators used here are a selection of indicators displayed in table 1, for each of the three main categories identified: economic impact, resource utilization and quality of service. The main indicators used are the net profit and total cost. For the latter, we also identify and calculate some of its components. In terms of fixed service operating costs, we use the cost of opening a service, called service-start cost. In terms of unit costs we use container-transportation, container-handling, container-holding (holding in the storage yard of a terminal), and in-port vehicle-holding costs. In terms of resource utilization, we compute the number of empty and less-used vehicles, as well as classical indicators such as the number of open services, the number of vehicles used by these services, and the average used capacity of those vehicles. Finally, we add two particular indicators required to study the incorporation of revenue management into the SSND related to the different categories of demands, which can be either partially or fully accepted or denied. The percentage of rejected volume of partial punctual demands and of full punctual demands out of the total volume of demands is denoted *p/all* and *f/all* respectively.

The average values (over the 20 instances) are displayed in table 2. These relative values of the performance indicators denote an increase or a decrease of the corresponding absolute value of an indicator when the solution of the SSND-RM problem is compared to that of the classical SSND.

Table 2. Performance indicators (relative values) with fare ratio (fast delivery/slow delivery) = 1.5.

	R=4P	R=2P	R=P	2R=P	4R=P
Total cost decrease (%)	4.00	6.91	10.18	12.85	16.83
Transportation cost decrease (%)	2.79	5.16	7.42	9.14	12.05
Handling cost decrease (%)	3.08	5.37	8.03	9.62	13.15
Holding-containers cost decrease (%)	2.90	-5.19	4.79	6.28	23.36
Holding-barges cost decrease (%)	-33.33	-27.85	-51.90	-39.56	-53.25
Service-start cost decrease (%)	5.60	10.23	14.05	18.28	21.78
Net profit increase (%)	2.68	4.07	6.28	8.42	10.29
Capacity usage increase (%)	3.54	5.00	6.92	9.30	10.87
# Open services decrease (%)	5.60	10.23	14.05	18.28	21.78
# Used vehicles decrease (%)	5.17	9.41	13.44	17.12	20.53
# Empty vehicles decrease (%)	24.66	34.25	55.07	63.24	72.97
# Less-used vehicles decrease (%)	10.83	27.33	36.48	48.67	54.72
Rejected demands volume p/all (%)	1.39	2.30	3.92	4.33	6.36
Rejected demands volume f/all (%)	1.55	2.84	3.66	4.82	5.96

The proportion of regular and punctual demands out of the total volume was varied between these five sets of instances. The five columns of the table correspond to five different ratios for the regular versus punctual demand categories. For example, “R=4P” indicates that the corresponding column displays the values of the performance indicators when in the SSND-RM problem setting the total volume of regular demands is approximately 4 times as large as the volume of punctual demands. In the same way, “R=P” means that the volume of regular demands is almost equal to the volume of punctual demands and, for the last column, “4R=P” means that we have 4 times as large volume for the punctual demands as for the regular ones. Recall that the total volume of demands (regular plus punctual) is maintained equal, and that only the ratio between the two general categories is varied. As shown in the table, the SSND-RM model always provides a better solution with respect to the performance indicators calculated here. This trend is even more accentuated when we increase the proportion of punctual demands. Fig. 2 shows that the same hierarchy in the value level of the different measures is observed for the five different ratios of regular to punctual demands, for almost all the performance indicators considered. This is a first confirmation of the fact that the measures (performance indicators) employed are consistent with the behavior of the system and with the variation of the value of some parameters (e.g., regular/punctual ratio) used when generating test instances.

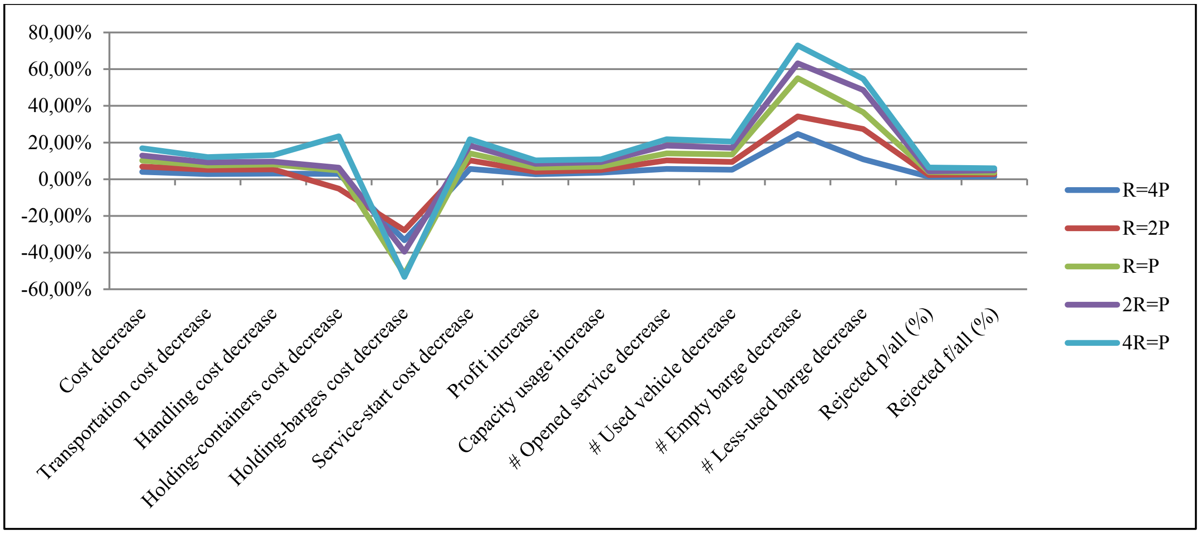

Fig. 2. The value hierarchy of demand category ratios (R/P) for different performance indicators

To be more precise, Figures 3 and 4 present trends of relative values of costs and profits. As shown in Fig. 3, the SSND-RM strategy always offers better solutions, in terms of cost decrease and profit increase. A rising trend appears when we increase the proportion of punctual demands as well. Furthermore, the slope of profit increase is smaller than cost decrease. This phenomenon comes from the fact that less money is obtained from the satisfied demands, as more demands are refused when increasing the ratio of punctual demands.

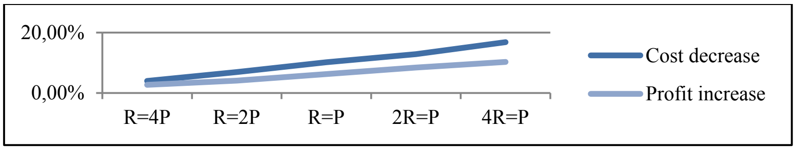

Fig. 3. The trends of total cost decrease and net profit increase when increasing the ratio of punctual demands.

We present in Fig. 4 the trends of different cost components when increasing the ratio of punctual demands out of the total volume of demand. One can notice that some of the cost indicators have very similar behavior compared to total cost decrease: service-start cost, transportation cost and handling cost relative value indicators. This implies that the analysis of only one type of indicator (e.g., the total cost decrease) gives reliable and consistent information about the behavior of the system and the related components having the same trend do not necessarily need to be calculated.

A somewhat different comportment is observed for holding-container cost and holding-barges cost decrease, which have irregular trends. For the holding-barges cost decrease, its irregularity can be explained by the fact that barges are active (in-service) most of the time. Hence, only a small amount of the total cost is spent on holding barges in ports. The relative values of this performance indicator being computed on such small values, the fluctuation is larger compared to other indicators. We can also notice some correlation between the holding-containers cost and holding-barges cost, their trends being in opposite directions.

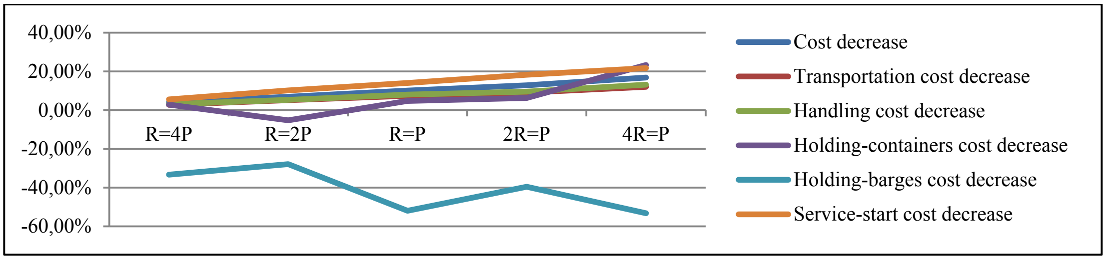

Fig. 4. The trends of different cost components indicators when increasing the ratio of punctual demands.

For the resource utilization, as more punctual demands can be denied, more services and vehicles can be saved. For the same reason, the routing of demands on services is more flexible and efficient. The number of empty barges is getting smaller and the capacity usage is increased. All these trends are shown in Fig. 5, where the resource utilization and quality-of-service performance indicators values and trends are displayed. In this figure, we can also observe that more punctual demands are rejected to maximize the revenue associated with the SSND-RM solution.

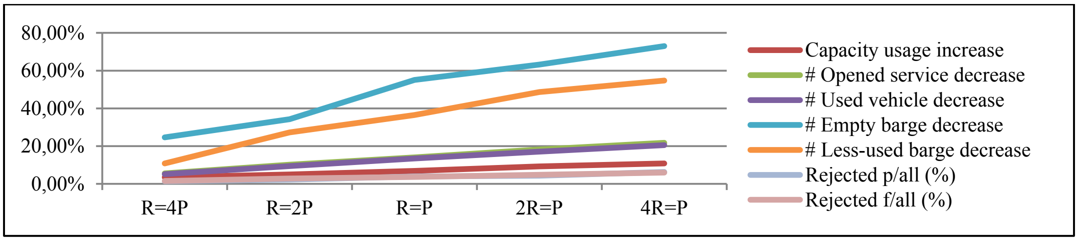

Fig. 5. The trends of resource utilization and quality-of-service indicators when increasing the ratio of punctual demands

When comparing the two strategies and models (SSND and SSND-RM), we evaluate the performances in terms of costs, revenues, resource utilization and quality-of-service. The introduction of revenue management concepts results in better network and asset utilization. Using a large range of performance indicators results in a better understanding of the transportation system behavior. The numerical results presented in this section confirm our intuition that an important increase in net profits may be derived from better resource utilization and more flexible flow distribution and demand satisfaction, while maintaining a high quality-of-service, at the tactical planning level.

6. Conclusions

Performance indicators are broadly used to characterize the performance of transportation systems and to validate and evaluate models and solution methods, corresponding results and strategies. It is also known that some indicators give more insight than others and one would like to single out the critical ones for particular problem settings. This is particularly meaningful when new problem settings are analyzed, as are the emerging needs for tactical planning for container barge transportation with revenue management strategies. Yet, there is no general framework for analyzing the interest of particular performance indicators in the context of specific problem settings, generating appropriate problem instances, and choosing the most representative indicators.

We proposed a first classification and analysis of performance indicators generally used to evaluate tactical planning solutions in freight transportation, and identified a number of adequate ones for scheduled service network design models with resource and revenue management considerations. We also provided insights into the generation of adequate test instances to study these planning issues in the general context of container barge transportation systems.

The numerical analysis of the results of comparing a classical SSND formulation and a model integrating revenue management strategies has shown the interest of the instance-generation procedure and performance-indicator study in the context of SSND-RM for container barge transportation. The initial insights provided by the study into the behavior of such systems under varying conditions of demand stratification and customer-service strategies (in terms of load acceptance) are a clear indication of this interest. They are also a first step into more comprehensive studies of such intermodal systems and modeling approaches, studies that we plan to undertake in the near future.

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