SHORT TERM CONTAINER FLEET MANAGEMENT : ISSUES, MODELS AND TOOLS

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1. INTRODUCTION

Freight transportation activities have undergone numerous and significant modifications for the past twenty years, prompted, in particular, by the growing utilization of containers. Using containers offers obvious advantages of rationalization of shipment, higher security, simplicity of handling, facility for multimodal transportation, etc., but it also introduces new planning and operating problems, or exacerbates old ones, such as the management of the fleet, the determination of multicarrier transportation routes, empty container balancing, etc. The high cost of procurement, maintenance, handling and transportation of containers further designate the adequate management of the container fleet as a very relevant problem for international container shipping firms.

It is interesting to note the relationships between these issues and those related to the use of intermodality in long distance transportation, which has also been, and still is, the subject of important developments. Intermodal systems offer the combined advantages of several modes of transportation, such as rail and road (including warehousing and door to door service), while using the most efficient and economical means for each part of the journey. Prompted by the advent of the container, intermodal systems are flourishing, even if they require the utilization of complex and expensive transshipment facilities ([21]). In this context, Operations Research models and methodologies offer useful instruments that a company may use to analyze, evaluate and plan its strategic, tactical and operational policies. These models and methods are now often integrated into interactive-graphic decision support systems, which allows users with no operations research or computer science background to take full advantage of the flexibility and power they offer. Of course, such systems have to rely upon reliable information systems and up-to-date databases for optimum performance ([1], [3], [16]).

Dejax and Crainic [9] review the literature on fleet management models in freight transportation, and note that relatively little effort has been dedicated to the development of specific models for the planning of the land distribution and transportation of containers, although this is an important component of the overall operations of an international shipping firm, with significant impact on both its economic and service performance [10].

The objective of this paper is to introduce the important problem of the satisfaction of the empty and loaded container transportation demands on a short-term, day-by-day, basis. Our goal is to describe the problem, to analyze its main characteristics, and to propose a first modelling approach. We first summarize the general land container transportation problem and the methodology already developed. We then present the context and main issues related to the transportation of containers and to the routing of the vehicles which perform these operations. Finally, we propose a general modelling approach and indicate directions for future research.

2. GENERAL PROBLEM AND METHODOLOGY

Arriving ships bring in containers loaded with imported goods, as well as empty containers returning from previous exports. Loaded containers must be transported, by using appropriate modes and vehicles, to their final destinations. Empty containers may either stay at the port for a while, or be immediately dispatched wherever they are needed for subsequent operations. After import and unloading, the empty containers present at a customer site may either be transported back to the port of origin, or be positioned to any other depot (port or inland terminal) in prevision of known or forecast future requirements. This "return" shipment may, but more often than otherwise will not, be made by using the same vehicle that has been used for the initial movement from the import port to the customer. Similarly, exporting customers require empty containers to be delivered to them. These containers may be delivered either from the future export port, or from any other convenient location (usually, a depot). After being loaded, containers are transported to the export port, and are loaded on ships together with empty containers sent abroad to cope with the world-wide imbalance in the supply/demand of certain container types. Finally, direct shipments of empty containers are made on a regular basis between depots, to cope with the surplus and deficits of container supplies and demands in various regions due to the geographic imbalance of imports and exports. To insure these container movements, the "land" (non-maritime) distribution and transportation system makes use of various modes, such as rail, truck, barges and mixed modes which usually consist in a "long" railroad shipment and a second movement by truck.

The overall problem that the container shipment company faces is to take a series of interdependent decisions in order to satisfy demand, while aiming to meet global objectives regarding the level of service and the minimization of its costs. All the concerned activities do not belong, however, to the same management decision level, nor do they require the same data for their planning and execution. Hence, Crainic, Dejax and Gendreau ([6], [7]) propose an integrated multilevel methodology which aims to assist the planning and management of these activities, while considering the relevant relations and interdependencies. The methodology relies upon a hierarchical approach that involves models and methods aimed at problems at several levels of planning, and is summarized in the rest of this section.

2.1 The Strategic/Tactical Level

The first planning level is concerned with the global determination of the general design and operating characteristics of the system for a given planning period (typically, six month to one year long): the location of the facilities (ports, inland terminals...) to be used for intermodal transshipments and for the collection, storage and distribution of the container fleet, the allocation of customer zones to these facilities for import and export movements of each type of containers, and the optimization of flows in all directions, including the interdepot empty balancing flows. (See [10] for a detailed analysis of this problem.)

The objective of this exercise is to minimize the total operating cost: the cost of opening and operating the facilities, plus the various transportation costs. It is noteworthy that, in practice, this strategic/tactical logistics problem may have to be solved repeatedly since container shipping companies do not often build their own depots; rather, they use facilities available from other modes (e.g. ports and rail yards). It is then a question of deciding which facilities to use, according to the demand and the cost structure particular to the specific planning period.

Crainic, Dejax and Delorme [5] have proposed the location-allocation model of this problem, for which several algorithmic approaches have also been explored (e.g. [4] and references therein).

2.2 The operational level

The operational planning level is concerned with the satisfaction of demand on a (typically) short term basis, while relying on the logistics structure and operating policies determined at the strategic/tactical level. At this stage, decisions are made concerning the allocation of empty containers to customers, the actual interdepot movements of empty containers, and the transportation of empty and loaded containers. One has to make sure that the day-to-day empty container requests are satisfied, while planning for forecast customer and safety stocks requirements, and that the most efficient routes and means of transportation are selected and used for moving empty and loaded containers to satisfy these demands.

Major factors that characterize the planning and management problems at this level are related to the dynamic and stochastic environment inherent in the actual operations of the system. This is particularly true of the data concerning the availability of, and demands for, empty containers, which are known for certain only on a short term basis and cannot easily be forecast ([13]). The random variations of operating times (travel, loading and unloading, etc.) further increase the stochasticity level of empty and loaded container transportation activities.

Ideally, one would like to develop a single mathematical model to represent and optimize the short-term distribution and transportation land operations, in order to fully account for the interactions between the multiple elements of the system and the various decisions to be made. Given the intrinsic complexity of the problem, this is however not conceivable in practice. The solution proposed by Crainic, Dejax and Gendreau [7] is to break down this large problem into two separate sub-problems: an empty container allocation problem, and an empty and loaded routing problem for both vehicles and containers. Specific models are then proposed to solve each of these problems.

The allocation problem is concerned with the determination of the empty container movements to satisfy customer demands and to reposition part of the fleet in preparation of future (expected and forecast) requests. To cope with the random aspects of the system and with the impact of current decisions on future ones, the model ([8]) is a dynamic, stochastic multicommodity minimum cost network flow formulation, which fully responds to the complexity of the specific problems which arise in this area, particularly the space and time dependency of events and the uncertainty of supply and demand data, plus specific operational characteristics such as substitutions, relationships with partner companies, imports and exports, massive equilibration flows, etc. In practice, it should be used as a rolling horizon model (over a planning horizon typically covering a period from one to two weeks), only the decisions corresponding to the first period (say one day) being actually implemented.

The routing problem is concerned with the generation of the actual, possibly multimodal, routes needed in order to satisfy the movement requests of empty and loaded containers between customers and depots. The description of the main characteristics and variants of this problem, and of the general modelling framework that we propose to represent it, constitutes the object of this paper.

3. THE ROUTING PROBLEM

Fleet management problems at the operational level are encountered in many different contexts, particularly motor carrier and rail transportation. Most published work, however, focuses on one transportation mode, and is directed either towards empty vehicle redistribution problems ([12], [17]) or the combined loaded and empty movement optimization ([18], [19], [20]) with possibility to turn down unprofitable demands. Indeed, these formulations address systems and issues that are closer to the empty container allocation problem than to the present one. Vehicle routing problems (for a recent survey of methods and studies relative to vehicle routing issues see Golden and Assad [14]) are a more appropriate reference, although they differ in many ways from the context of the container routing problem.

During each planning period, containers must be moved from where they are available to where they are needed. Requests for loaded container movements are determined by the commercial commitments of the company towards exporting customers, and are supplied by the company's Management Information System, while requests for empty container distribution and repositioning are determined by the allocation model. These transportation operations must respect all the commercial (e.g., customer-determined transportation mode choices or specific carrier agreements), technical (e.g., container type - vehicle type matching), and operating (e.g., pick-up and delivery schedules) rules and regulations of the company, while attempting to minimize total cost.

A major characteristic of the problem is the strong interrelationships, in terms of productivity and economic efficiency, as well as in operational terms, that exist between the construction of container routes and the management of the fleet of vehicles used to move them. Consider that, since containers cannot move on their own, the simplest operating policy is to dedicate a vehicle to every container movement, and to assume the corresponding cost of the empty vehicle traffic. This is quite obviously a very inefficient policy. Indeed, substantial savings can be realized by generating multi-stop vehicle itineraries and by suitably matching container routes to vehicle itineraries.

This simultaneous building of container routes and generation of vehicle itineraries is "naturally" performed when the container shipping firm owns (or controls) the carrier company. Moreover, it is beneficial even when the shipping firm does not own the vehicle fleet, since it may then negotiate better tariffs in exchange of more "complete", closed routes for the carrier's vehicles. Hence, the container routing problem is, in fact, a combined container route, vehicle itinerary generation problem. This problem may be further complicated by the presence of more then one carrier company for which vehicle itineraries may be generated, and of other carriers (railroads, typically) that offer services for fixed tariffs.

The container routing problem is also characterized by its dynamic and stochastic environment.

The dynamic characteristic emerges from the fact that requests for movement arise dynamically over time, from the inherent duration of transportation activities, and from the necessity to explicitly consider the effect of current decisions on future ones. Indeed, longer vehicle itineraries that correspond to several sequential container movements, cover not only current transportation requests but also future ones. In fact, most of the time, such itineraries cover only one current request, their initial one, all the remaining requests belonging to later periods. Hence, current decisions on vehicle itineraries impact significantly on the dispatch of containers and on the means of transportation available in following periods. And that impact may be further stressed by the stochastic characteristics of the system.

The main sources of uncertainty are the variations in the demand and supply of empty containers, in the transportation times between customers and terminals or ports, and the duration of operations at customer sites or at terminals. In the allocation model, empty container demands and supplies are explicitly considered as stochastic and thus, while current period requests are sure, most of those indicated for later periods are uncertain. Moreover, uncertainties may be observed even in loaded movements, especially for requests further in time, due to variations in ship arriving dates, delays in transportation activities, etc. Hence, the routing problem has to consider stochastic container movement requests, especially when a long planning horizon is contemplated, since the degree of uncertainty increases as one considers events further away on the temporal axis.

4. MODELLING APPROACHES

A solution to the routing problem described in the previous section relies on the simultaneous construction, at each period of the planning horizon, of (eventually) multimodal routes for the empty and loaded containers to be moved from their origins to their destinations, and of vehicle itineraries, for the controlled transportation modes, which insure the physical transportation of these containers. In so-doing, we need to coordinate all the transportation operations over a finite horizon in order to satisfy the transportation demands at minimum cost. Figure 1 illustrates the main information sources and expected results of a routing model.

We present in this section a general framework for such a combined container routing - vehicle itinerary building model. But first, we briefly describe the main data categories that have to be considered at this planning and operating level.

4.1 Basic Data and Modelling Principles

The routing model relies on several main data and information categories. Foremost of those are:

- The *demand for movements*, mainly defined by its origin and destination, its temporal (pick-up/delivery windows, earliest pick-up or latest delivery times, etc) and load (type and number of containers to be moved) characteristics, and the technical (type of vehicle required, particular transportation mode(s) or commercial agreement ...) constraints .

- The *planning horizon*. Dispatching decisions are taken in real (or quasi-real) time, and vehicle departures may occur at any moment during working hours. On the other hand, there is no theoretical limit on the length of a vehicle itinerary. Consequently, the planning horizon is theoretically continuous and infinite. From a practical point of view, however, an appropriate length limitation and discretization (e.g., 7 to 10 days long with 1 or 1/2 day periods) has to be made. Several elements have to be considered in determining the length of the planning horizon. In particular, it is supposed to be long enough to include the next set of ship arrivals and departures, and to allow the coherent, system wide, building of vehicle itineraries. Thus, it should permit circuit itineraries of a given (three or four, for example) minimum number of container movements. On the other hand, practical considerations (e.g. labor contracts, safety regulations, etc.) limit the actual length of vehicle itineraries and thus of the planning horizon.

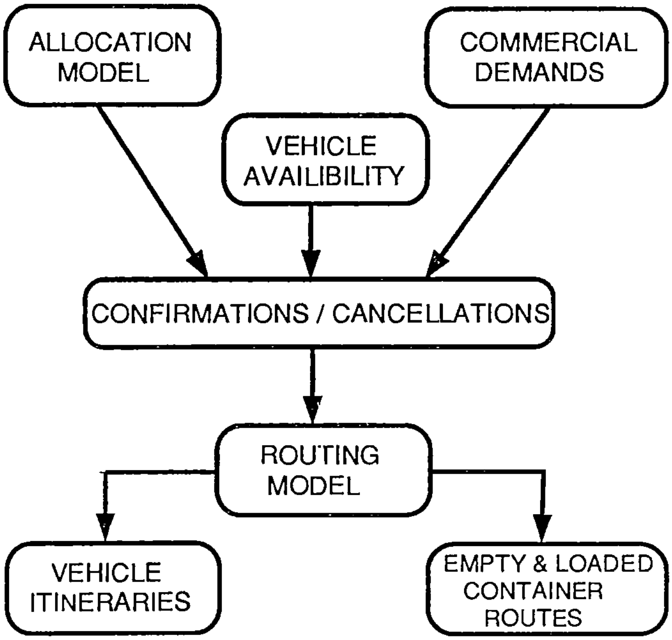

Figure 1 : Combined Container and Vehicle Routing Model

- The *transportation mode*. A general definition of a mode of transportation includes the type of infrastructure and vehicle (physical mode), the capacity (number of containers and total weight), the physical (container types that may be loaded, ...) and technical (speed, ...) characteristics and the various costs.
- The *dynamic transportation network* that represents the network on which the planning and optimization of the transportation operations are performed. It is a "copy" of the real (infrastructure) network for each period of the planning horizon. Nodes represent customers, depots, ports, intermodal facilities, etc. Each link (called segment) represents a modal path, at a given starting period (this means that parallel links may be required to represent the transportation options between two nodes of the network). Links are also used to represent other interperiod relations, such as the holding of containers at nodes
- The *costs*. Different costs must be considered for the planning of the transportation operations, including fixed and variable costs, for each type of container and compatible transportation mode, empty vehicle movement costs, operating costs at customer sites, depots, ports, intermodal facilities, etc. These costs are not always easy to estimate truthfully, especially since transportation costs vary strongly with the type, number and weight of the containers moved, the transportation mode, the distance, the carrier contract options, and the transportation commercial agreements.

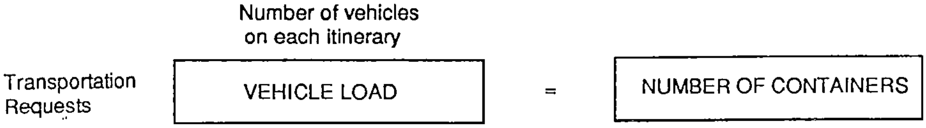

Figure 2 : Structure of the Simple Route Model

A route is considered *simple* if it contains at most one segment of a transportation mode for which itineraries may be build built by the company. On the other hand, a route is *complex* if it may contain several segments of one or several modes for which itineraries may be built. Dejax, Benamar, Crainic and Gendreau ([11], [12]) detail these formulations.

In the one mode model, we suppose that all the container routes are simple, and that we control only one transportation mode. Container shipments using other transportation modes are not explicitly considered in the formulation (except for costing purposes). This is, for example, the case when the container shipping company controls the organization of transportation by trucks of given characteristics, while railroad shipments are subcontracted to a railroad firm.

We propose a generalized set partitioning formulation where the columns represent the set of vehicle itineraries; each column indicates the number of containers the vehicle may load on the itinerary, and the associated decision variable gives the number of vehicles using the itinerary. The rows correspond to the transportation demands to be satisfied. The structure of the simple model is represented in Figure 2.

Note that the container routes do not explicitly appear in this model; they are implicit in the definition of the vehicle itineraries. This is due to the fact that the itinerary segments are components of the container routes. This simplifies the problem and allows us to consider only vehicle itineraries in the column generation process.

For the multimode model, we suppose that there are several controlled transportation modes and, consequently, we assume the existence of complex container routes. We propose an extended set partitioning model with two types of columns and rows. The first column type represents the container routes, and the number of containers to be moved by using each selected route. The second set of columns represents the vehicle itineraries, the corresponding decision variable standing for the number of vehicles taking each specified itinerary. The first row type represents the segments corresponding to the controlled transportation modes (the other segments are considered implicitly for costing purposes), while the second row type represents the transportation demands to be satisfied. Figure 3 illustrates the structure of the multimode model.

Let us make these definitions more precise. For a given request, a *container route* is a sequence of intermodal transshipment points, with modal transportation segments between two such points. If the demand concerns one container movement, only one route will be used; otherwise, several routes just may be used simultaneously to satisfy the demand.

A vehicle can be used to perform different container transportation sequences. For a given mode, the *vehicle itinerary* represents a sequence of segments performed by the same vehicle along its journey. On each segment, one or several containers are moved. The vehicle may also move empty.

Ideally, in order to achieve the minimum possible transportation cost, it might be desirable to plan the vehicle itineraries to be as long as possible. Practically, however, one has to consider the above mentioned limits on the length of vehicle journeys, the length of the planning horizon, and the constraints imposed by the stochasticity of some of the elements of the problem. Indeed, although container movements and vehicle itineraries being initiated in a given period have to be deterministic, a significant number of future period requests are stochastic. Hence, vehicle itineraries may also be stochastic, and several modelling approaches are then possible. One may, for example, build "open" itineraries, to be completed when additional information is available in future periods. A different approach, which may be more "acceptable" in practice (truck drivers and owners would rather have the whole route before leaving), is to build itineraries that contain stochastic requests in future periods. These itineraries are then adjusted when the stochasticity is resolved. The adjustment may simply be to run empty if the request has not materialized, or the actual routing of the vehicle may be modified. In all cases, the planning horizon has to be limited and hence ending conditions have to be included into the formulation.

To summarize, the informations needed to solve the routing problem at every starting period of the planning horizon are the known and forecast transportation requests, the dynamic network structure, the vehicle itineraries built at the previous periods and still active, the availability of means of transportation. With this information, the decisions to be made for every (beginning of) starting period consist of the selected container routes on which containers are to be dispatched, the vehicle itineraries to be initiated, and possible modifications to some vehicle itineraries initiated in previous periods.

4.2 Modelling Framework

A number of interesting and important modelling questions are still open relative to the stochastic formulation and algorithmic resolution of the container routing model. However, in a first attempt at modeling and solving this complex problem, we now consider the deterministic case for a heterogeneous container fleet and several transportation modes and vehicle types. The output of the routing model will be a list of container and vehicle movement orders, for each period of the planning horizon. This list describes completely the empty and loaded container movements to be executed in order to satisfy the customer demands, as well as the itineraries to be operated by the vehicles of the mode(s) operated or controlled by the firm.

We propose a general set partitioning approach combined to a solution methodology based upon column generation techniques. These approaches have proved to be satisfactory in several transportation planning contexts, including the modelling and solution of complex vehicle routing problems (see [15], for example).

Two model variants according to the modal characteristics of the container routes are briefly described. Indeed, we distinguish between two types of container routes.

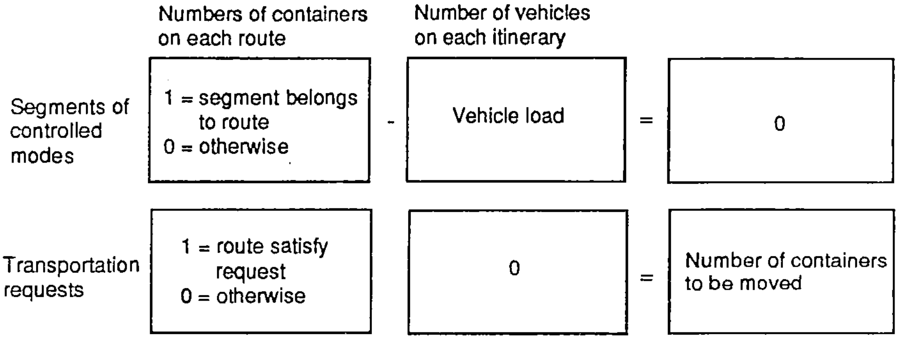

Figure 3 : Structure of the Complex Model

The formulation of the complex model clearly shows the container routes. The most important characteristic of the multimodal land transportation by containers also appears in this formulation: the joint consideration of the container routes and of the vehicle itineraries, and their strong interactions in terms of costs and operations.

For both problems, we are developing appropriate solution methods that include column generation techniques for the construction of routes and itineraries. It is interesting to note that to solve the second model requires the generation of two types of columns, and that the generation of vehicle itineraries may also generate new segment rows, thus inducing a two-dimensional growth of the constraint matrix at each iteration.

CONCLUSIONS

We have described the main characteristics and difficulties involved in the problem of routing empty and loaded containers and the vehicles needed to transport them. This is a complex problem, mainly due to its dynamic and stochastic nature. We have proposed a general modelling approach, described two specific formulations for the deterministic case, and have sketched some promising avenues for the development of efficient solution techniques for the proposed models.

To our knowledge, these are the first models specifically addressing the empty and loaded container routing problem. We are still in the process of exploring, as comprehensively as possible, the various modelling issues related to this very interesting and important problem. This allows us to highlight the originality of the problem and to explain the differences which may be observed between our modelling framework and formulations for routing problems arising in different contexts.

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