Optimal Fleet Planning for an Industrial Shipper of Bulk Products in Three Steps ¹

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Abstract

This paper describes the methodology how to deal with strategic, operational fleeting decisions in an integrated framework, by addressing optimal fleet planning problems from shippers' industrial point of view. Fleeting decisions are complex, imply significant sunk costs, savings potential; they set the basis for routing and scheduling, and consequently the operational costs of the fleet, key inputs for optimal fleeting. The main result is a three-step procedure in order to find simultaneous solutions to an optimal fleet plan that is consistent with scheduling realities - and costs. The process iterates between a mixed integer problem used as a front end, based on cost estimate inputs derived from simulated feasible schedules for the candidate ships.

Keywords: Strategic planning, Systems Dynamics, Supply Chain management, Facilities planning and design.

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1. Introduction

The shipping industry has a monopoly regarding transportation of large volumes due to its structural competitive advantage in terms of the interrelated shipping costs of bulk materials. When quantities are substantial, products can be stored and shipped in bulk, marine transport turns out to be the cheapest, and sometimes the only feasible mode. Oil refiners, chemical manufacturers, cement producers, grain traders ship most of their bulk products from the manufacturing / loading facilities to distribution centers or customers by sea. Efficient marine industrial operations require proper fleeting, planning, scheduling and routing of cargo movements.

Sea transportation managers have usually two options: contract shipping services through sea freight markets, based on cargo movements needs or hire a fleet of ships optimizing shipments accordingly. The first option is known as “spot” hiring; in this case the freight (usually in $ per unit of cargo moved) includes all interrelated costs. The second option known as charter hiring implies “in-house” management of fleet routing and control over the scheduling with the objective to ship cargoes at minimum cost. In line with Stopford (1991) “a time charter gives the charterer operational control of the ships carrying his cargo, while leaving ownership and management of the vessels in the hands of the owner”. When on charter, the owner of the ship receives freight rate payment (time-charter or charter-hire) per day of operation, being liable to the operating costs (crew, maintenance, repair). The charterer directs the commercial operations, covering voyage expenses, mainly fuel, port fees. The latter are fully determined by the voyages performed. “Spot” hiring is similar to hiring a taxi, whereas a charter hire resembles mainly the principles of car renting. Time charter rates are usually standardized, quoted by organized brokers in a competitive environment.

Charter hiring a ship is a substantial financial commitment as daily time charter costs can amount to thousand of dollars. Operating ships under a chartering scheme requires skills, organizational competencies to deal with the phases of ship vetting, chartering, contracting, managing. Significant savings can be expected when the chartering and scheduling policies exercised, not only minimize idle time of ships but also maximize fleet utilization. On the contrary, sub-optimal chartering policies that result in low fleet utilization may have a negative impact on transportation costs, financial performance, and competitiveness.

The decision to adopt a “spot” or “time-charter” strategy depends on the scale of operations, frequency, complexity of shipments, maturity level of the shippers’ “know-how”. Organizations involved in large scale marine supply chains will opt for a time charter in order to: a) secure their sea transportation needs without substantial exposure to market fluctuations; b) optimize their transportation costs by total supply chain management.

In any case, ship operators - either owners or charterers - have complex, extensive planning problems to address, ranging from long-term (strategic) to mid-term (tactical), and short-term (operational) levels. Globally, planning-, scheduling decisions involve problems of optimal size, mix, routing plans, operational
policies. For a ship investor this process involves mainly investment decisions, driven by projections regarding the evolution of freight rates and ship prices, where the interrelated fleet allocation and scheduling policies determine profitability. The owners’ goal is to maximize cash-flow. For a charterer the main drivers are forecasted shipping needs and vision regarding the evolution of shipping (freight) costs. The shippers’ or charterers’ objective is to serve their volume transportation needs at minimum cost.

The methodology presented is highly relevant to a (large) industrial shipper who faces the aforementioned challenges. The shipper, is assumed to have perfect information regarding the production and consumption patterns, be entitled to design the fleet type, mix, size, and ultimately execute the transportation of volumes from production to consumption harbors. By owning both production and consumption facilities transportation decisions do not influence total inventory costs. In this context the shippers’ objective is the design of a long-term fleeting plan, as well as a set of optimal schedules for the interrelated fleet of ships in the short-run, that serve dry bulk cargoes during the planned period at minimum cost. In line with Simchi-Levi, Chen and Bramel (2005, pp. 3) regarding the classification of strategic, tactical, operational levels in logistical decisions of production - inventory systems, the model provides a three-step methodology that uses heuristics to address strategic ship fleeting, jointly with operational ship scheduling.

Section 2 highlights the relevant literature on ship scheduling; section 3 presents the framework for decomposing the problem and the interrelated solution; section 4 discusses the algorithm; section 5 concludes the paper.
2. Literature Review

Transportation routing and scheduling have been widely discussed in the literature (Christiansen et al., 2007). Most of the work regarding vehicle routing can be adjusted to solve ship problems (Christiansen, Fagerholt and Ronen (2004)), which remain fundamentally different from other transportation modes. The reasons, summarized by Christiansen, Fagerholt and Ronen (2004, p.2) are: 1) ships pay port fees; 2) they operate internationally; 3) they can be diverted at sea; 4) ship-type and size determine port compatibility; and 5) ship voyages span usually long-time periods.

The ship scheduling problem corresponds mainly to the pickup and delivery of bulk cargoes at minimum cost for a pre-configured network and fleet. The objective is to find a set of routes for the ships, where each voyage begins in the loading port, ends in a port of discharge, serving specific needs without violating the ships’ (or fleets’) capacity and the interrelated time window constraints. In contrast to the “classical” vehicle routing problems the loading or discharging of a ship is often time consuming. Therefore, ship dispatchers design schedules that do not imply long idle times in port, particularly waiting time during weekends. The balance between service time and the ports’ operating hours makes the scheduling problem different from the vehicle routing problem. Their objective is to optimize fleet utilization by maximizing the throughput of tons transported for each vessel, while minimizing non-productive time.

Within the fleet scheduling framework, similarities exist between mid-term ship planning and shift scheduling problems, where permanent staff satisfies some percentage of the average planned demand, while temporary staffing planning serve the remaining mainly seasonal demand. When demand varies from one time period to the next or when different products are assembled in a flexible environment, it is necessary to reposition the workforce to maximize use of equipment and manpower (Bard and Wan, 2006). In similar ways, when necessary to respond to demand fluctuations or forecast misses, ships are repositioned or additional shipping capacity is chartered (contracted) from the market. In the contrary, when excess capacity is available, ship operators try to improve utilization by moving ships (at a cost) or by recovering costs through chartering-out (leasing out to another shipper).

Fleet planning problems are critical for the design of efficient marine logistic systems: the goal is to determine the fleet size, mix and chartering strategy that will deliver the shipping needs at a minimum total cost over the corresponding period. Christiansen, Fagerholt and Ronen (2004) review the benefits from decision-support systems in the maritime industry. Despite their recorded success in reducing the cost of shipping operations (Fagerholt and Lindstad (2000)), comparatively few applications exist in the literature; the bulk of research centers upon the tactical, upon operational side, dealing mainly with routing and scheduling for a given fleet. Xinlian et al. (2000) address the sizing and deployment problem, with a cost minimization objective function, as an optimal timing decision.

Fleet planning determines the selection of ship types, size, specification, aiming to empower dispatchers
to set-up plans that ensure the transportation of all cargoes from their loading port to the port of destiny, while achieving the common target of both strategists and operators to minimize costs. Although it is usual to distinguish between planning and scheduling problems, there is a strong interplay between the two in the sea transportation framework. The decisions made at planning level affect those made at scheduling levels and vice versa. Strategies regarding fleet sizing and mix set the general policies and operational capabilities at tactical, operational levels. From a revenue generating perspective the ship owner’s tactics fix the commercial, operational capabilities of chartering and planning departments. From a cost minimization perspective actions at the tactical level influence capacity requirements and costs for supply chain operations. This information on revenues and cost provides the much needed feedback for “high-level” decisions. On the one hand demand estimates for shipping services and representative routing schedules are necessary inputs when designing an optimal fleet; on the other hand the choice of fleet size, type, mix of ships spans the set of feasible routes and schedules. Agarwal and Ergun (2008) present a model for dealing in a unified framework with the problems of ship scheduling and network design in liner shipping. Similar challenges in service networks for delivering express packages are presented in Armacost et al. (2004); optimization methods are developed for simultaneously determining aircraft movements and package flows that minimize aircraft ownership and operating costs.

In this paper we propose a framework for optimal fleeting, while taking into consideration the impact of scheduling. Although neither closed solution nor any performance / convergence metrics are available, the contribution of the methodology is threefold: a) it can be customized as it does not have any specific system requirements; b) replaces empirical rules in an “operationally-friendly” way; and c) provides a coherent framework for optimizing decisions consistently across all levels of operations.

3. Problem Description

Contractual commitments in shipping are usually long-term, in the range of a couple of months to years. Ships can be owned or leased (chartered); respective time charter rates are usually traded in freight markets. All ships cannot visit all harbors because of physical constraints; harbor specifications impact their loading, unloading, cargo carrying performance. Once a ship has been chartered, the hire (chartering) costs become sunk and fixed. The charterer (operator) directs the commercial operations, pays all voyage expenses, which promotes the saturation of ship capacity, as a measure to reduce the unitary cost of transportation. The daily costs of chartering a fleet of ships can amount to tens of thousands of dollars, which means that sizing the fleet optimally and improving fleet utilization can be translated into significant cost savings.

The planner works on finding routes that serve cargo flows, meet constraints, minimize the sum of transitions between ports, while keeping transportation costs at minimum possible. “Switching costs” regarding the change of fleet size and type are usually high, thus there is no interest to modify the fleet
configuration in the short-term; therefore, the scheduling process considers the time charter costs as “sunk” and ignores them. Inventory and the network structure are taken as exogenous; volumes transported correspond to internal flows (from production to consumption sites), and therefore do not influence capital and inventory costs (both are excluded from the model).

Actions concerning fleet size and composition shape the entire chain by determining the ships available, interrelated routes and schedules. However, the set of potential schedules and the interrelated demand for shipping capacity are essential inputs for the design of the optimal fleet; otherwise the required inputs are built on assumptions based on representative routes.

In most cases no tractable optimization methods exist. To solve the problem we use the following three step heuristic approach where the selection of the optimal size and mix of vessels is indirectly dependent on scheduling decisions. They, as treated in step 1, influence the ship cost and performance data, determined in step 2. The pre-selected vessels generate feasible solutions - and interrelated voyage cost data - which reflect their competitiveness and are consumed in step 3. Although in theory the optimal fleet should be determined simultaneously, the approach presented decomposes the problem in three modules. The solution proposes a heuristic procedure that iterates between a mixed integer module in step 3 and the simulated schedules for a set of fleet candidates in step 1. The cost inputs for step 3, calculated in the intermediate step 2, are based on the simulated plans in step 1. Feedback loops will ultimately ensure consistency between the three steps. The gains from this approach arise from: 1) the reduction of complexity but also of need for sophisticated solutions in the scheduling part that do not always “pay-off”; 2) the compatibility of the proposed approach with the existing processes of each business; 3) the low implementation costs as no specific systemic requirements are necessary.

The outcome of the methodology presented is a solution to the real industrial ocean cargo shipping problem, as defined in Mehrez et al. (1995), providing: a) the number and size of ships to charter in each time period during the planning horizon; b) the number and location of transshipment ports to use; c) the proposed routes for each ship in the fleet from ports to customers. Karabakal et al. (2000) present a similar methodology for determining the optimal location scenarios that uses a mixed integer programme as a front end to simulation. They develop a heuristic procedure that iterates between a Mixed Integer Programme for optimal network selection and simulation until both models agree in a particular location policy.

3.1. Step 1: Gantt Charts of feasible dispatch and scheduling plans

The first building block of our methodology is ship pre-selection, in order to generate feasible ship schedules that satisfy demand, within the interrelated time windows for loading, unloading. Due to the restrictions and uncertainties discussed previously, it is hardly possible for the dispatcher to make plans for more than three voyages ahead. Practically, this means that the generated plans have a maximum horizon
of a couple of months.

The listing of all ships under consideration as potential candidates triggers off the process. Following the pre-selection of a set of possible considered fleet configurations, dispatchers manually or with the usage of tools generate feasible schedules for each ship with a medium-term view of a couple of weeks and draft the interrelated routes in Gantt charts (Figure 1). They take into account ships and ports constraints, due to draft limitations, different operating hours, and rules regarding continuation during nightfall or weekends. The objective is to simulate for each fleet configuration candidacy a set of ship voyages that fully serve the transportation flows of the representative demand profile, for the period under consideration. Based on these inputs the voyage characteristics for each vessel-route pair are computed. The impact of inventory, as well as constraints of the specified transportation flows and network are reflected in the turnaround time of vessels and their loading/unloading performance.

Marine dispatchers often use hand-drawn Gantt charts, with an horizon of up to four-six weeks. As the underlying assumptions change they search for acceptable, feasible arrangements and reschedule dynamically. They mainly use heuristics or rules of thumb to minimize idle time and maximize the throughput of tons transported for each vessel. Usually the global cost impact of their decisions is not fully available while cost optimization is an option only when constraints are not tight. By managing speed, exercising slow steaming options, ships save fuel, avoid unnecessary waiting times or port costs.

In Figure 1 an extract presents an Excell based programme for ship scheduling developed and used successfully in the sea transportation bulk commodity industry. The toolset used to run scheduling is not a blocker for this step. However, a computer based approach will make the exchange of data required efficient and reliable. As a principal, database centric applications are encouraged because they can: a) to a certain extent ensure the consistency of information used throughout the company; b) synchronize with the existing systems at reasonable cost. A similar methodology is used in Brown et al. (1987), and Bausch et al. (1998) where a decision support system is presented for a fleet of coastal tankers and barges that transport liquid bulk products among plants, distribution centers, industrial customers. In the service industry Armacost et al. (2004) generate a set of feasible routes for combinations of aircraft routes and the corresponding flow of packages, which is the input to their set-covering model.

Mixed integer programs, supported by “off-the-shelf” software, existing best-practices or “custom-made” tools can be used to automatize the simulation of feasible plans. Either manually or based on computer systems, the outcome is a schedule for each fleet configuration candidacy, specified network, transportation flows.

3.2. Step 2: Cost inputs

Each ship has a set of technical characteristics: capacity, maximum draught, range of possible capabilities (speed, loading and unloading rates), as well as the interrelated fuel consumptions during the phases of
Figure 1: Step 1: Generating feasible schedules for candidate fleet configurations using Gantt charts in Excel.
operations. The technical characteristics regarding specific fuel consumptions determine fuel (bunkering) costs for each ship-destination pair. All the aforementioned data are consumed by the ship information matrix of the **voyage calculator module**, which generates voyage durations, costs per ship and route. Duration is the sum of time at sea and ports; steaming time is the quotient of distance with speed; loading and unloading time is based on ship, port capabilities. The voyage calculator allocates the fixed cost of each vessel (operating or chartering) to each destination based on the voyage duration, adds the interrelated variable costs (fuel, port fees), and divides total costs by the cargo transported. This yields the unitary cost (per metric of cargo transported) for each ship-pair destination. Globally, costs depend directly on the size and carrying capacity of the vessel. Usually there is an increasing relationship between total costs and size - and on the contrary, due to economies of scale - a decreasing relationship of unitary costs and size.

The above methodology provides a general framework for voyage cost calculation, but does not incorporate the impact of network constraints (time windows, silo constraints). Therefore the above estimates have to be modified according to actual operating data. Theoretical steaming times can be used as reference for comparing the performance of different ships in different routes.

In order to obtain voyage and cost data for each fleeting scenario, we feed the voyage calculator with round-trip inputs from step 1. For all simulated schedules the voyage calculator computes the average data for each ship and destination pair using this estimator for its calculations.

The revised loading / unloading times are compared with the respective ones derived from the nominal rates. In case of significant discrepancies (more than 15%) data regarding shore capacities are matched with the outcomes in step 1. Ultimately for each ship and destination the voyage calculator generates a matrix that includes steaming time, loading-unloading duration, fuel, port costs and feasible ship-port links. The simulated outputs incorporate the impact of physical (i.e. a ship cannot enter a port due to specific draft restrictions) or inventory constraints (a facility with low storing capacity will imply significant waiting times and prolong the unloading period). As the number of scenarios increases, the voyage data estimators are expected to converge to the mean loading, unloading and steaming times per ship and destination.

Summarizing, the model consumes the following inputs and calculates for each ship $o$ the voyage cost estimate $FREIGHT_{ijo}$, from loading port $i$ to discharge port $j$:

- $FCOSTS_o$: time-charter hire in monetary units per day. It reflects the total lease cost for operating the vessel, including operating expenses (crew, maintenance, insurance) and owners’ financial costs (capital repayment, interest, return on equity, amortization);
- $C_o$: net carrying capacity of the vessel (in tons or the respective volume metric, as determined by the cargo to be carried), excluding the weight of fuels and other consumable;
- $V_o$: speed of the vessel (usually in knots);
The voyage cost per metric of cargo shipped, for one full shipment, from loading port \( i \) to discharge port \( j \) for ship \( o \), is then given by the formula:

\[
F_{REIGHT}^{ijo} = \frac{1}{C_o} \frac{d_{ij}}{V_o} [FCOSTS_o + K_{oFS}] + \frac{1}{r_m} [FCOSTS_o + K_{oFP}]
\] (1)

Then, the optimal capacity that minimizes the cost per ton shipped for the one destination problem is given by the first-order condition:

\[
\frac{\partial F_{REIGHT}}{\partial C} = 0 \Rightarrow -\frac{1}{C^2} \frac{d}{V} [F(C) + K_{FS}(C)] + \frac{1}{C} \frac{d}{V} [F'(C) + K'_{FS}(C)] + \frac{1}{r_m} [F'(C) + K'_{FP}(C)] = 0 \Rightarrow (2)
\]

\[
\frac{[F(C) + K_{FS}(C)]}{C} = [F'(C) + K'_{FS}(C)] + \frac{T_p}{T_s} [F'(C) + K'_{FP}(C)]
\] (3)

where \( T_P \) and \( T_S \) denote the time spent in port and steaming respectively. Assuming \( K_{FS}, K_{PS} \) are fixed (say \( K_F \) and \( K_P \)) and taking a first order linear approximation for the freight - capacity relationship \( F(C) = AC + B \) we get the following optimality condition regarding ship capacity:

\[
\frac{T_p}{T_s} = \frac{B + K_F}{A} \Rightarrow (4)
\]

\[
C_{opt} = \sqrt{\frac{T_s \times r_m \times [B + K_F]}{A}}
\] (5)

The above relationship has several interesting implications:

- “the longer the haul, the bigger the vessel”;

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3 As discussed, \( r_l \) for each load port and ship depends on the technical capabilities of the ship and port; it is computed by averaging the loading times for the specific ship - load port pair, from all the simulated schedules in step 1.
the optimal vessel is an increasing function of the geometric average of loading and unloading rates;

- a large vessel in a port with poor unloading capabilities might be uncompetitive compared to a smaller one;

- “the bigger ship, the cheaper voyage cost” does not hold;

Based on the different inputs for each ship-port pair, as derived from the scheduling simulations in step 1, a full cost matrix per ship, load port and destination is computed in step 2, consumed as an input in the next step. Extracts from the cost matrix are displayed in Figure 2.

3.3. Step 3: Mixed Integer Programming for fleet choices

Voyage costs have a direct impact on the transported by each vessel quantities, which have feedback effects on the size of the fleet. The objective of the tactical fleet sizing mixed integer module is to
minimize total sea transportation cost using the following inputs, as estimated in the previous steps:

- **CAPACITY** <sub>o</sub>: transportation capacity of vessel <i>o</i> per round trip; (equals <i>C_o</i> if no port or capacity constraints apply)
- **CONNECT** <sub>ij,o</sub>: binary variable determining the feasibility of vessel <i>o</i> to load in port <i>i</i> (or production site) and discharge in port <i>j</i> (or consumption site);
- **DURATION**<sub>ij,o</sub>: round trip duration from port <i>i</i> to port <i>j</i> for vessel <i>o</i> (outcome of step 2);
- **WT<sub>o</sub>**: Vessels’ <i>o</i> time availability for the user specified time interval (planning horizon);
- **FCOSTS<sub>o</sub>**: daily time-charter hire in monetary units per day for vessel <i>o</i> in the user specified time interval;
- **vFREIGHT**<sub>ij,o</sub>: cost matrix per ship and destination pair including the *variable* freight cost for ship <i>o</i> and route <i>i</i> \(\mapsto\) <i>j</i> (load port <i>i</i> and discharge port <i>j</i>), as calculated in step 2;

The outcome determines the required trips for vessel <i>o</i> and each load port, destination pair <i>(i, j)</i>, for the user specified time horizon <i>WT_o</i>. The routes serve the transportation inflows <i>D_j</i> for each discharge port <i>j</i>, as used in step 1 to generate the feasible schedules. They are set by the business needs and considered as an exogenous input into the planning process. <i>X_o</i> is a binary output that activates the selection of a ship; **ROUTES**<sub>ij,o</sub> are binary variables determining whether vessel <i>o</i> will serve site <i>j</i>, from site <i>i</i> and **BIG**(<i>M</i>) is a large integer used for computational ease<sup>4</sup>. The model formulation is given by:

\[
\begin{align*}
\text{min} & \quad \text{cost} = \sum_{ij,o} vFREIGHT_{ij,o} \cdot ROUTES_{ij,o} \cdot C_o + \sum_o \hat{X}_o \cdot FCOSTS_o \cdot C_o \\
\sum_{ij,o} ROUTES_{ij,o} \cdot C_o \cdot CONNECTIVITY_{ij,o} & \quad < \quad \hat{X}_o \cdot BIG(M) \\
\sum_{ij,o} ROUTES_{ij,o} \cdot DURATION_{ij,o} & \quad \leq \quad \overline{WT}_o \\
\sum_{io} ROUTES_{ij,o} \cdot CONNECTIVITY_{ij,o} \cdot C_o & \quad \geq \quad \overline{D}_j
\end{align*}
\]

<sup>4</sup>Variables with a hat are the output, variables with overline are user specified (horizon and demand), the remaining inputs are determined in step 2.
The model\textsuperscript{5} satisfies the following constraints:

(C1) The set of loads conveyed by the selected fleet of ships fulfill demand;

(C2) The load port $i$ can receive for loading vessel $o$, the discharge port $j$ can be served by vessel $o$, as defined in the connectivity matrix $\text{CONNECT}_{ij}$; (compatibility and feasibility)

(C3) Utilization of each vessel does not exceed its time windows of availability. The number of trips performed from load port $i$, to discharge port $j$ by vessel $o$ (taking into consideration the duration of the trip $i$ to $j$ by vessel $o$ cannot exceed the available working hours of vessel $o$, $W_{To}$) and the trips performed are sufficient to transport the volumes needed for covering the demand $D_j$;

(C4) A vessel $o$ can only be utilized for transportation if the fixed cost $FCOST_j$ is paid;

The way the three modules interact are depicted in Figure 3.

3.4. Feedback loops

Based on the output of step 3, the proposed policy is used as the new fleet configuration input for repeating the simulation dispatch plans in step 1.

The planners revise the set of feasible schedules and cost matrix for the selected vessels. Step 3 is repeated and if the solution remains unchanged, then the process terminates. Otherwise, the iterations continue using the modified data inputs until convergence to a “steady state” is reached. Thus, the proposed methodology follows a fixed point iteration approach, where consistency between fleet cost minimization and feasible scheduling is achieved by using nested modules in a three step estimation framework.

This nested approach resulted in fairly quick convergence in several business applications. For a case study in the cement industry the algorithm reached a final fleet policy in two or three iterations, while the total number of iterations never exceeded ten. Over time the fleet proposals of the dispatchers converged faster to the optimal fleet selection in step 3. The performance of the algorithm is unknown. The output of the first iteration can be considered as best bound; establishing performance metrics is left as a topic for further research.

\textsuperscript{5}The model is a variation of the standard fleet planning model:

\begin{align*}
    \min z &= \sum_{v \in V} \sum_{r \in R_v} C_{Trv} \cdot n_{vr} + \sum_{i \in N_P} C_{SPOTi} \cdot (s_i) \\
    \sum_{v \in V} \sum_{r \in R_v} B_{ivr} n_{vr} + s_i &= 1, \forall i \in N_P \\
    \sum_{r \in R_v} n_{vr} &\leq 1, \forall v \in V, r \in R_{vr}, \\
    x_{vr} &\in \{0,1\}, \forall v \in V, r \in R_{vr}, \\
    s_i &\geq 0, \forall i \in N_P \\
    \end{align*}

Where $R_v$ is the set of candidate schedules for ship $v$, indexed by $r$. $C_{Trv}$ is the sum of operating cost for sailing schedule $r$ by ship $v$ and the corresponding penalty cost, $C_{SPOTi}$ is the cost for cargo $i$ to be serviced by a spot carrier and $B_{ivr}$ is a constant that is equal to 1 if schedule $r$ for ship $v$ sails schedule $r$ and 0 otherwise. $s_i$ is a binary variable which is equal to 1 if cargo $i$ is serviced by a spot carrier and 0 otherwise. The objective function minimizes the sum of the costs of operating the fleet, constraints ensure that all cargoes are serviced and that each ship in the fleet sails at most one of its candidate schedules.
Figure 3: Step 3: Interaction of modules.
3.5. Empirical results

The methodology is well suited for selecting a fixed fleet, which supplies bulk materials (cement, grain, ore, oil) from plants to terminals, under long term performance and budgetary goals. Empirical results have shown that by addressing the fleet planning problem in an integrated framework over-fleeting is avoided, which might eventually improve unitary sea transportation costs, but to the expense of contracting a larger (suboptimal) fleet. Over-fleeting may as well be the outcome of a poor demand forecast or lack of a global cost minimization approach. An implicit assumption is that demand is known, whereas in most “real life” cases demand is the main source of uncertainty. In order to obtain a robust fleet plan different demand scenarios may be assumed. Another approach is to select the optimal fleet for a set, pre-determined demand level and contract the remaining needs dynamically in the spot market.

From a business perspective the main key performance indicators in monitoring the economic efficiency of the proposed methodology are: a) the fleet size and utilization measured by the volumes of cargo transported, divided by the capacity of the ship expressed in carrying capacity multiply with the operating period: this ratio captures the efficiency of operations in utilizing capacity through effective programming and dispatching (elimination of idle time), maximizing full shipments, minimizing slack capacity; b) the fleet chartering costs (procurement spent for ship chartering): these are influenced by the fleet size, the average ship capacity, the demand mix, the percentage of tons delivered by each ship to a discharge port.

For a set fleet, fixed costs become sunk. If the main demand assumptions are correct, no change is required in the fleeting and shipments plan throughout the relevant time period. In reality minor or major deviations occur regarding the inputs used for the set tactics and plans. Demand may overshoot the forecast, resulting in non sufficient transportation capacity for the optimal cost; major production incident will require diversions from the optimal dispatching plan, in order to meet customers’ orders. For a contracted fleet already in place, all fixed costs in step 3 are zero; the presented three step methodology may then guide fleeting adjustment decisions, based both on availabilities and on cost optimization.

4. Conclusion

Fleeting decisions are not continuous; in most cases they imply significant sunk costs. Fleeting for marine industrial supply chain operations is a strategic problem; decisions regarding fleet composition set the framework for routing and scheduling. The potential for cost savings and performance improvement by dealing with strategic, and operational fleeting decisions in an integrated framework is highly significant. Mastering the above may reveal opportunities, insights for large-scale marine industrial industrial operators and highlight customized solutions that reduce: a) costs; b) environmental offprint; and c) improve performance.

The methodology presented proposes a heuristic procedure for solving the fleet planning and scheduling problem simultaneously. The process iterates between a mixed integer problem (a modified facility location
problem for fleet planning) used as a front end for simulated feasible schedules, consuming as inputs cost estimates derived from these schedules, which incorporate the impact of constraints in the scheduling phase. Therefore the optimal fleet output is a system-wide cost minimization fleet policy for the feasible schedules simulated. Spanning all the set of possible schedules should increase the convergence in general; however, no convergence can be guaranteed.

Most ship scheduling problems are solved by static procedures, which are dynamically updated as revised inputs become available; the adoption rates of such systems and techniques is not in line with the financial stakes of these type of problems, due to the high levels of uncertainty, sophistication, technological maturity required for developing scheduling and planning decision support systems. The methodology proposed in this paper aims to facilitate the acceptance of analytics in ship scheduling and planning problems that facilitate the smooth integration of the established operational practices and heuristics of an organization with decision support tools. Hybrid approaches - like the ones presented in this paper - become increasingly important in the connected world of advanced information and communication technologies, providing “online” guidance for optimized decisions.

References


