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Classification of routing and scheduling problems in liner shipping

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Abstract

A classification scheme for routing and scheduling problems in liner shipping is developed and subsequently used to classify existing literature on the subject. Based on the classification the articles are grouped, and the main characteristics of each group and article are described. The grouping may serve as a catalyst towards developing a model or a group of models that covers the main problems within routing and scheduling in liner shipping.

Key words: Transportation, routing, scheduling, classification scheme, maritime transportation

1 Introduction

This paper presents a classification scheme for routing and scheduling problems in liner shipping and subsequently classifies existing literature on the subject according to the developed classification. The development of the classification scheme is interesting because no scheme exists which is exclusively concerned with liner shipping, and because liner shipping is growing rapidly, and the literature has yet to follow in volume (Sigurd et al., 2007). The only classification scheme concerned with maritime transportation was done by Ronen (1983), and it encompasses the three operation modes in shipping - liner, tramp and industrial shipping. Industrial shipping is characterized by cargo owners
also owning the ships. Tramp shipping resembles taxis as the ships follow the available cargo, and liner shipping resembles bus lines with a published itinerary and schedule (Christiansen et al., 2004). Since the three operation modes have different characteristics, a classification scheme developed exclusively for liner shipping will likely be different from the one developed by Ronen (1983). Furthermore, the literature related to routing and scheduling in liner shipping is largely concerned with specific applications which is why the problem formulations and solution methods are much diversified. Therefore the development of a classification scheme is important, as it may serve as a first step towards developing a general model or a group of models that covers the main problems within routing and scheduling in liner shipping.

The problem is to determine which fields should be incorporated in a classification scheme for liner shipping and to establish why they are important. In addition, articles pertaining to routing and scheduling in liner shipping must be classified according to the developed classification scheme and divided into groups in line with the characteristics in the classification scheme.

A number of taxonomies and classification schemes exist within the area of routing and scheduling. Bodin and Golden (1981), Bodin et al. (1983) and Desrochers et al. (1990) have all developed classification schemes for vehicle routing and scheduling problems. Assad (1988) also considers the routing and scheduling of the crew which is required to follow the vehicle. Based on the previously noted classifications, Ronen (1983) developed a scheme for use in connection with routing and scheduling problems in maritime transportation. Another application-specific scheme was developed later by Ronen (1988) with application to trucks.

The term liner shipping as used in this paper was first developed by Lawrence (1972) and was further refined by Ronen (1983). Routing and scheduling problems are largely tactical and/or operational in nature. If the problem also includes fleet management, it becomes more strategic in nature (Agarwal and Ergun, 2008). Within liner shipping fleet management mainly consists of determining the types and number of ships (Agarwal and Ergun, 2008). Fleet management problems will only be included in the review when they are considered in conjunction with routing and/or scheduling. Liner shipping problems
are node routing problems since the demand is situated at specific points, namely the
ports, in the network. The network is expected to be either directed or mixed (containing
both directed and undirected connections) since the matrix of sailing distances may be
asymmetric due to the nature of sea transportation. (Lane et al., 1987).

The remainder of this paper is organized as follows. In section 2, a classification
scheme is developed for routing and scheduling problems in liner shipping. In section
3, the developed classification scheme is presented in a schematic overview. In section
4, articles concerning routing and scheduling in liner shipping are classified and grouped
based on the developed classification scheme. The conclusion follows in section 5.

2 Classification scheme

The developed classification scheme is based on literature concerning classifications within
vehicle routing and scheduling and on literature treating liner shipping. The general
classification schemes used can be found in Assad (1988), Bodin and Golden (1981),
Bodin et al. (1983) and Desrochers et al. (1990). Ronen (1983) and Ronen (1988) are
classification schemes for routing and scheduling for ships and trucks respectively which
have also been used. The literature concerning liner shipping which is used the most is
Christiansen et al. (2004) and Ronen (1983). In addition, several of the articles to be
classified and grouped have been used to exemplify some of the characteristics.

2.1 Number of intersection points

This characteristic is concerned with the number of ports acting as intersection points in a
problem. Within vehicle routing this field deals with depots, and the possibilities are that
either there are one depot or multiple depots (Assad, 1988; Bodin and Golden, 1981; Bodin
et al., 1983; Desrochers et al., 1990; Ronen, 1988). These are also the possibilities in
Ronen (1983) where depots are termed origins. In general, depots have two roles namely
storage of goods and vehicle housing; in liner shipping all ports perform the first role
and the second role is irrelevant as most ships work around the clock and thus do not
need housing (Christiansen et al., 2004). An intersection point is a port where one or more routes intersect, and if the model requires one or more starting point, then these will be situated at intersection points given that intersection points exist. As in the cited classification schemes the choices are one or multiple intersection points. However, in line with the definition of liner shipping which states that a liner shipping voyage may not have an origin or destination as the voyages become closed routes (Ronen, 1983), the option of no intersection points is also a possibility. The characteristic thus becomes *Number of intersection points* with the choices *None, One* and *Multiple*.

### 2.2 Type of operation

The demand experienced in liner shipping is characterized by an origin and destination pair. However, the type of operation varies. The various classification schemes (Assad, 1988; Bodin and Golden, 1981; Bodin et al., 1983; Desrochers et al., 1990; Ronen, 1983; Ronen, 1988) have different alternatives for the type of operation such as delivery, pick-up and combinations of the two. In Ronen (1983) the alternatives emerge when answering *One* or *Multiple* to the two characteristics *The number of discharging ports per vessel voyage* and *The number of loading ports per vessel voyage*. The answer *Multiple* to both of these fields will for example indicate a pick-up and delivery problem. However, it gives no indication of whether the actions take place simultaneously or not. If they take place simultaneously, then the problem has interwoven pick-ups and deliveries otherwise pick-ups and deliveries are separated. The two types of problems differ wherefore it may be valuable to incorporate both possibilities in the classification scheme as is done in Ronen (1988). However, it can be argued that if liner shipping follows the definition given by Ronen (1983) and consequently load and discharge in each port of call, then an interwoven structure of deliveries and pick-ups should be the predominant alternative. Yet, there are articles on routing and scheduling in liner shipping which have only deliveries (Fagerholt and Lindstad, 2000) while other articles have only pick-ups (Fagerholt, 1999). Therefore the following four choices will be available for the field concerning the type of operation encountered in a problem: *Delivery, Pick-up, Pick-up and delivery separated, and Pick-up*
and delivery interwoven.

2.3 Nature of demand

The inclusion of the nature of demand as a field is supported by Assad (1988), Bodin and Golden (1981), Bodin et al. (1983), Desrochers et al. (1990), Ronen (1983) and Ronen (1988). The choices are deterministic demand, stochastic demand and demand dependent on service. The first two choices are the standards in most of the cited classification schemes where demand is either predetermined or stochastic and hence described by a statistical distribution. If the demand is uncertain, a statistical distribution is most often assumed in order to more easily incorporate the demand into a model. The possibility of demand depending on the service provided is considered by Ronen (1983), and it is valid in liner shipping as the demand experienced by the individual liner company is expected to depend on the service the company provides (Bendall and Stent, 2001; Boffey et al., 1979; Ronen, 1983; Ronen, 1988). The characteristic Nature of demand thus includes the following three choices: Deterministic, Stochastic and Demand dependent on service.

2.4 Scheduling constraints at the ports

Scheduling constraints at the ports are present in Assad (1988), Bodin and Golden (1981), Desrochers et al. (1990) and Ronen (1983) hence supporting the inclusion of a temporal aspect concerning ports in the classification scheme. Both Bodin and Golden (1981) and Ronen (1983) work with three possibilities concerning the time at which a port can be serviced. The first option is that the time to service a certain port is specified and fixed in advance, and the problem is thus a scheduling problem. The second option is that time windows exist in which a port can be serviced; this is a combined routing and scheduling problem. The last option is that there are no restrictions on when a port is to be serviced. This is a routing problem, unless a precedence relationship exists in which case it is a routing and scheduling problem (Bodin and Golden, 1981). In Desrochers et al. (1990) the choice concerning time windows is split into two where there are either one or multiple time windows. The number of time windows will not affect the nature of the problem;
therefore the choices for this characteristic in the classification scheme are *Time of service fixed in advance*, *Time windows* and *No restrictions*.

### 2.5 Number of ships

A field concerning the fleet size is included in Assad (1988), Bodin and Golden (1981), Bodin et al. (1983), Desrochers et al. (1990), Ronen (1983) and Ronen (1988), and the articles thereby support the inclusion of a similar characteristic in the scheme to be developed. Most of the classification schemes include the possibility of a fleet size of one. This is unlikely in liner shipping as according to Lawrence (1972) firms that operate ships in liner service “advertise a scheduled service between specified ports” and “employ a more extensive network of cargo solicitors and agents” which are both highly unlikely in the event that the firm only operates one ship. Assad (1988), Desrochers et al. (1990) and Ronen (1983) include the possibility that the size of the fleet is variable. A variable fleet size indicates that the problem involves fleet management aspects. The choices are therefore that either the size and composition of the fleet is fixed, or it can be changed. If the fleet is fixed, then the description of the problem will reveal the fleet size. If it can be changed, then the fleet size and composition is determined by the solution, and it is either constant or changes over the scheduling period. The problems in which the fleet is fixed are short term problems, and the problems where the fleet can change are medium to long term problems (Ronen, 1983). The characteristic *Number of ships* is included with the following three choices: *Fixed*, *Changeable - constant over scheduling period* and *Changeable - changes over scheduling period*.

### 2.6 Fleet composition

The inclusion of the field fleet composition is supported by Assad (1988), Bodin and Golden (1981), Bodin et al. (1983), Ronen (1983) and Ronen (1988) as these include the same or a similar field. Either the fleet consists of ships that are identical in all important aspects, and hence the fleet is homogenous, or the ships differ from each other on some or all important aspects, and the fleet is considered heterogeneous. What constitutes
important aspects will be defined from problem to problem; however, it is likely to include
the aspects of capacity, speed and size in terms of draught, length and width. Since
capacity is considered an important aspect and is therefore included in fleet composition,
the inclusion of a field for vehicle capacity restrictions as done by Bodin and Golden
(1981) and Bodin et al. (1983) is considered redundant. In Desrochers et al. (1990) the
possibility of having no capacity restrictions is available. This is unlikely in liner shipping
as there are few, if any, problems, where it would be possible a priori to discern that no
capacity constraints exist. Therefore the possibility of having no capacity constraints will
not be included. The characteristic Fleet composition will therefore be included with the
choices Heterogeneous and Homogenous.

2.7 Cruising speed

This characteristic is concerned with whether or not cruising speed is a decision variable,
and the inclusion is supported by Ronen (1983). Ships are not restricted on speed in the
same fashion as trucks which have to adhere to the prevalent speed limits as for example
indicated by the inclusion of the field Vehicle speed depends on type of road in Ronen
(1988). Instead ships have a maximum speed, and they can sail any speed up to this
limit. However, the cost incurred while sailing is closely related to the chosen speed as
the fuel consumption is strongly dependent on the speed (Perakis and Jeramillo, 1991).
Consequently, the possibility of adjusting the speed is an option that can heavily influence
the daily cost of a vessel (Ronen, 1983). Therefore the characteristic Cruising speed is
included in the classification scheme with the choices Yes or No.

2.8 Demand splitting

The inclusion of demand splitting as a characteristic is supported by Bodin et al. (1983)
which operates with either allowing or disallowing demand splitting. In Desrochers et al.
(1990) it is important whether the splitting is allowed a priori or a posteriori. A posteriori
splitting is only relevant when demand is stochastic. Since there are no articles in routing
and scheduling in liner shipping which have both stochastic demand and allow splitting
of demand then differentiating on the timing of splitting is likely to be of little, if any, use in liner shipping. Since differentiating on the timing of splitting is not supported by other classifications schemes either, it is not included in this scheme. In Assad (1988) the question is whether there are any rules for split deliveries, and Ronen (1988) looks at whether demand splitting is allowed between trucks or sources, which in liner shipping would be ships and ports respectively. Since demand is denoted by an origin and destination pair, and demand therefore cannot be satisfied from a different origin, demand splitting between ports is not relevant in liner shipping. However, splitting of demand between ships is relevant as this is the form that demand splitting will take in liner shipping. Thus, Ronen (1988) also supports the inclusion of this characteristic. Hence Demand splitting is included with the choices Allowed and Not allowed.

2.9 Partial satisfaction of demand

This characteristic is concerned with whether or not partial satisfaction of demand is allowed. The inclusion is supported by Bodin et al. (1983), Ronen (1983) and Ronen (1988) as these include the same or a similar field. There can be several reasons for not wishing to load certain cargoes, however, the most prevalent is likely to be that the cost of transporting the cargo is higher than the income it generates. The characteristic Partial satisfaction of demand is included with the choices Allowed and Not allowed.

2.10 Number of commodities

The inclusion of a characteristic concerned with the number of commodities considered in a problem is supported by Assad (1988), Ronen (1983) and Ronen (1988). In the first two schemes the distinction is whether there are one or multiple commodities. A reason for this distinction is that the capacity calculations often become more difficult if the number of commodities is larger than one. However, there is a shift towards a containerization of general cargo as the percentage of containerized cargo has increased from 20% at the beginning of the 1980s to 60% in 2001 (Agarwal and Ergun, 2008). In line with this the container ship fleet has increased from 1.6% of the world fleet in 1980 to 10.6% in
2003 (Christiansen et al., 2007). This shift may imply that eventually there will only be one commodity in liner shipping, namely containers. Despite this, the classification will include the distinction, and it is to be used as a warning of possible complications in the capacity calculations and with multiple compartments which are often considered when multiple commodities exist as is the case in Fagerholt and Lindstad (2000). Accordingly the characteristic *Number of commodities* will be included with the choices *One* and *Multiple*.

### 2.11 Cargo transshipment

This characteristic is concerned with whether or not transshipment of cargo is allowed. The inclusion is supported by Desrochers et al. (1990), Ronen (1983) and Ronen (1988). The last article discusses transshipment between vehicles but in shipping transshipment has to include a port as transfer point. The reason is that the transfer of cargo from one ship to another at sea is likely to cause damage to either the ships or the cargo due to the risk of collision. The possibility of transshipment is important in liner shipping as it is imperative for hub-and-spoke networks which are used increasingly by the liner operators (Baird, 2006). Consequently the field is included in the classification scheme with the choices *Yes* and *No*.

### 2.12 Number of routes

The inclusion of a characteristic treating the number of different routes that each ship is allowed to perform is supported by Assad (1988), Desrochers et al. (1990) and Ronen (1988). The last two articles mentioned include the choices one or multiple which means that either the ships are only allowed one route, or they are allowed several different routes. Since the definition for liner shipping allows for a ship to call in a port more than once per voyage (Ronen, 1983) then liner shipping can include voyages with more than one route as long as they are connected at an intersection point. The reason for requiring the voyage to be connected is the fact that liners usually operate in closed routes as per the definition (Ronen, 1983). In this context a voyage is the collection of different routes that
a ship is planned to perform during the period under consideration. The characteristic Number of routes is included with the choices One and Multiple.

2.13 Planning horizon

This field is concerned with the planning horizon, and whether or not it is defined as part of the problem description. If it is defined, then the choice is whether or not the routes must be completed within the planning horizon. The last premise is supported by Ronen (1988). The inclusion is important since the calculation of the objective function varies depending on whether all routes are finished within the given period or not. If they are not, then a rule must be established to take into account the partial routes and thereby the partial incomes and expenses that follows. The characteristic Planning horizon is included with the choices Defined - ships must finish routes in the planning horizon, Defined - ships need not finish routes in the planning horizon and Undefined.

2.14 Ships required to be empty

This characteristic is concerned with whether the ships must be empty at some point or not. The choices are that either the ships are not required to be empty at any point on a route, or they are required to be empty at least once on a route. The distinction is important as the demand for the ships to be empty in one or more ports greatly reduces the level of complexity of the capacity calculations. This is due to the fact that if the ships are not required to be empty in one or more ports, then the capacity calculations have to take into account cargo carried over from previous routes and voyages. In the articles where the ships are required to be empty the requirement is either fulfilled at the intersection point as is the case in for example Bendall and Stent (2001) and Sigurd et al. (2007) or when changing direction between outbound and inbound voyages as in Rana and Vickson (1991) where the ship is required to be empty twice on a route. The characteristic Ships required to empty is included with the choices Yes and No.
2.15 Port precedence requirement

A relationship between two ports exists when one has to be serviced before the other. This is a port precedence requirement, and it either exists or it does not. It is important as the existence of precedence helps establishing the type of problem as noted in section 2.4. The inclusion of the field is supported by Desrochers et al. (1990), Ronen (1983) and Ronen (1988). A precedence relationship can either be explicitly stated in a problem or it can be implied in the problem description. In liner shipping problems when the type of demand is pick-up and delivery interwoven, then precedence is implied if the ship has to be empty at a given port, and transshipment is not allowed. The reason is that the only possibility of transporting demand from the pick-up port (A) to the delivery port (B) under these restrictions is by loading it on a ship in A sailing towards B and reaching B without encountering a port with an empty requirement. The characteristic Port precedence requirement is included with the choices Exist and None.

2.16 Requirement for compatibility between ships and ports

This characteristic is concerned with whether or not there is one or more requirements for compatibility between ships and ports. Compatibility covers various issues - e.g. whether a ship can enter a port given the size of the ship (Ronen, 1983). With the increasing size of the liner ships this becomes more and more relevant as the largest ships can only call a limited number of ports in the world due to their size (Baird, 2006). Only by taking this into account when constructing networks and routes, will these ships provide the optimal in terms of carrying capacity and savings. Another compatibility issue is the availability of cranes. If a port is not equipped with cranes, it is paramount that the ships calling the port have cranes. The inclusion of the characteristic is supported by Assad (1988), Desrochers et al. (1990) and Ronen (1988). Requirement for compatibility between ships and ports is included in the classification scheme with the choices Exist and None.
2.17 Cost types

The taxonomies by Bodin and Golden (1981), Bodin et al. (1983), Desrochers et al. (1990), Ronen (1983) and Ronen (1988) all include a field concerning cost types; however, the content varies considerably. The most common cost types are variable or routing costs, fixed operating and capital costs and costs for unserviced demand. The last cost type arises for example when unserviced demand is expected to result in lost sales in which case the cost for unserviced demand is the cost of the lost sales. The overall division of costs will be based on the thus described tripartition. The cost types mentioned in Ronen (1983) and in the literature concerning routing and scheduling in liner shipping constitute the base for the cost types included in this taxonomy. However, the cost of unserviced demand is included despite not being present in the described literature as it is deemed to be important for future development. The cost types are then as follows: the fixed costs include the fixed cost while in operation and while in lay-up, the variable cost includes the steaming cost, the cost of entering a port, the cost of spending time in a port, the cost of cargo operation and the cost of transshipment. The cost of unserviced demand remains a single category.

2.18 Objective

The last characteristic to be included in the classification scheme is the objective. The characteristic is considered in Bodin and Golden (1981), Bodin et al. (1983), Desrochers et al. (1990), Ronen (1983) and Ronen (1988). Historically, objectives have mainly focused on either monetary issues or maximizing utility. The definition of liner shipping states that the objective of liner operation is usually to maximize profits (Ronen, 1983). In case of lacking information minimizing cost can be utilized as the objective as it requires less information (Reinhardt et al., 2007). In light of the increasing focus on environmental issues it is relevant to include an objective concerned with minimizing the environmental impact. The impact could be $CO_2$ emission or the emission of other damaging substances. Hence the choices for the characteristic Objective become Minimize cost, Maximize profit and Minimize environmental impact.
3 Schematic overview

Based on the characteristics discussed in the previous sections a schematic overview of the classification scheme for routing and scheduling problems in liner shipping has been developed. There are seventeen articles concerning routing and scheduling in liner shipping which will be classified according to the developed classification scheme. For the sake of convenience each of the articles has been assigned a number. The number will be used in the schematic overview to indicate which characteristics are applicable for the individual article. Hence the numbers opposite the choices in the schematic overview refer to the articles which contain that particular choice.

<table>
<thead>
<tr>
<th>Number</th>
<th>Article Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agarwal and Ergun (2008)</td>
</tr>
<tr>
<td>2</td>
<td>Bendall and Stent (2001)</td>
</tr>
<tr>
<td>3</td>
<td>Boffey et al. (1979)</td>
</tr>
<tr>
<td>4</td>
<td>Cho and Perakis (1996)</td>
</tr>
<tr>
<td>5</td>
<td>Fagerholt (1999)</td>
</tr>
<tr>
<td>6</td>
<td>Fagerholt (2004)</td>
</tr>
<tr>
<td>7</td>
<td>Fagerholt and Lindstad (2000)</td>
</tr>
<tr>
<td>8</td>
<td>Kydland (1969)</td>
</tr>
<tr>
<td>9</td>
<td>Lane et al. (1987)</td>
</tr>
<tr>
<td>10</td>
<td>Mourão et al. (2001)</td>
</tr>
<tr>
<td>11</td>
<td>Olson et al. (1969)</td>
</tr>
<tr>
<td>12</td>
<td>Pesenti (1995)</td>
</tr>
<tr>
<td>13</td>
<td>Rana and Vickson (1991)</td>
</tr>
<tr>
<td>14</td>
<td>Reinhardt et al. (2007)</td>
</tr>
<tr>
<td>15</td>
<td>Sambracos et al. (2004)</td>
</tr>
<tr>
<td>16</td>
<td>Shintani et al. (2007)</td>
</tr>
<tr>
<td>17</td>
<td>Sigurd et al. (2007)</td>
</tr>
</tbody>
</table>

Table 1: Numbers assigned to articles.

The list of problem characteristics is comprehensive and covers all the recurring characteristics of routing and scheduling problems in liner shipping. All problems, however, have their individual idiosyncrasies, and these are not included in the classification scheme as they are particular to a specific problem and therefore not applicable to the problems in liner shipping in general. From the references it is evident that not all the available choices are utilized by the currently stated problems in routing and scheduling in liner shipping. These choices are included nevertheless as the currently available literature on routing and scheduling in liner shipping by no means is exhaustive and therefore cannot be expected to touch upon all facets of liner shipping.
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Options</th>
<th>Articles</th>
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<td>Number of intersection points</td>
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</tr>
<tr>
<td></td>
<td>One</td>
<td>2, 5–8, 10, 12, 15–17</td>
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<td></td>
<td>Multiple</td>
<td>3, 9, 13</td>
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<tr>
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</tr>
<tr>
<td></td>
<td>Pick-up</td>
<td>5–6</td>
</tr>
<tr>
<td></td>
<td>Pick-up and delivery separated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pick-up and delivery interwoven</td>
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</tr>
<tr>
<td>Nature of demand</td>
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<td></td>
<td>Stochastic</td>
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<td></td>
<td>Dependent on service</td>
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<td>Scheduling constraints at the port</td>
<td>Time of service fixed in advance</td>
<td>1, 7, 9, 17</td>
</tr>
<tr>
<td></td>
<td>Time windows</td>
<td>2–6, 8, 11–16</td>
</tr>
<tr>
<td></td>
<td>No restrictions</td>
<td></td>
</tr>
<tr>
<td>Number of ships</td>
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<td></td>
<td>Changeable – constant over scheduling period</td>
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<tr>
<td></td>
<td>Changeable – changes over scheduling period</td>
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<tr>
<td></td>
<td>No</td>
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<td>Demand splitting</td>
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<tr>
<td></td>
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<tr>
<td>Partial satisfaction of demand</td>
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<tr>
<td></td>
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<tr>
<td>Number of commodities</td>
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<td></td>
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<td>Cargo transshipment</td>
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<td></td>
<td>Not allowed</td>
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<tr>
<td>Number of routes</td>
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<td></td>
<td>Multiple</td>
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<td>Planning horizon</td>
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<td>1–3, 5–7, 10, 13–17</td>
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<tr>
<td></td>
<td>Defined – ships need not finish routes</td>
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<td></td>
<td>Undefined</td>
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<td>Ships required to be empty</td>
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<td></td>
<td>No</td>
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<tr>
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<td>Cost types</td>
<td>Fixed costs</td>
<td>2, 4–5, 7–8, 10, 12, 16–17</td>
</tr>
<tr>
<td></td>
<td>– in operation</td>
<td>4, 11</td>
</tr>
<tr>
<td></td>
<td>– in lay-up</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Variable costs</td>
<td>1–2, 4–6, 8–11, 13–17</td>
</tr>
<tr>
<td></td>
<td>– steaming costs</td>
<td>1–2, 5–6, 8–10, 13, 15–16</td>
</tr>
<tr>
<td></td>
<td>– port entry charges</td>
<td>1, 9</td>
</tr>
<tr>
<td></td>
<td>– time spend in port</td>
<td>2, 8–9, 11, 16</td>
</tr>
<tr>
<td></td>
<td>– cargo operation</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>– transshipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cost of unserviced demand</td>
<td></td>
</tr>
<tr>
<td>Objective</td>
<td>Minimize costs</td>
<td>4–7, 9–10, 14–15, 17</td>
</tr>
<tr>
<td></td>
<td>Maximize profits</td>
<td>1–2, 4, 8, 11–13, 16</td>
</tr>
<tr>
<td></td>
<td>Minimizing environmental impact</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Schematic overview of the classification scheme and the classified articles.
4 Classification of the liner shipping literature

The objective of this section is first to divide the articles concerning routing and/or scheduling in liner shipping into groupings based on specific characteristics of the classification scheme, and second to characterize the articles according to the classification scheme developed. The three problem types scheduling, routing and fleet management can be combined in eight different ways as per Table 1. The problem type where all three aspects are absent is of no interest for our purpose and as mentioned in section 1 this article will not discuss the aspect of fleet management when not considered in conjunction with routing, scheduling or both. Therefore only six groupings will be described in the following sections. The numbers in the body of Table 1 refer to the sections in which each combination is treated.

<table>
<thead>
<tr>
<th>Scheduling</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet management</td>
<td>Fleet management</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>4.4</td>
<td>4.3</td>
</tr>
<tr>
<td>4.5</td>
<td>4.1</td>
</tr>
<tr>
<td>4.6</td>
<td>4.2</td>
</tr>
<tr>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>

Table 3: Defining the problem type.

By characterizing the problems described in the articles according to three of the characteristics in the classification scheme, it is possible to divide the articles into the problem types mentioned in Table 1. The characteristics Scheduling constraints at the ports (4) and Port precedence requirements (15) define the problem type in terms of routing and scheduling as described in section 2.4. The characteristic Number of ships (5) identifies whether or not the problem involves fleet management as described in section 2.5.
4.1 Routing problems

The basic routing problem consists of a set of ports which are to be serviced by a number of ships, and there are no restrictions on when or in which order the ports are to be serviced. The problem is to construct a feasible set of voyages while adhering to the dictates of the objective. A solution describes a voyage for each ship where the voyage is a sequence of ports which the ship has to visit along with an indication of the service to be provided at each location. As such it is a spatial problem, and there are no temporal restrictions that impact the solution (Bodin et al., 1983). Problems of this type are characterized by No restriction in characteristic (4), None in characteristics (15) and Fixed in characteristic (5).

The article by Boffey et al. (1979) describes an interactive program and a heuristic method for solving the routing problem. The interactive program uses routes introduced by management, hence only the problem described to demonstrate the heuristic method will be characterized in the following. All costs are assumed to be fixed in the short to medium term, and the objective is therefore to maximize revenue, which in this case is equivalent to maximizing profit. The demand is dependent on the service provided, and the critical service parameter is the transit time. The demand between two ports is fixed as long as the transit time remains below a stipulated critical limit. Once the transit time exceeds the limit, demand decreases with a fall-off rate which is dependent on the port pair in question.

The problem described by Fagerholt (2004) requires that each ship must sail at least one route. The problem is planned as a pick-up problem though in fact it involves interwoven pick-up and delivery. The reason for the simplification is that the empty containers which are delivered are not expected to influence the capacity constraints, and the problem has been simplified accordingly. The planning horizon is one week, and voyages consisting of multiple routes are expected to finish within this time horizon.

The article by Reinhardt et al. (2007) argues that in order for liner shipping problems to mirror the problems experienced in the industry the developed routes must be allowed to contain loops. However, when the formulation is made linear, only simple routes are
allowed. In both cases the formulation only permits one route per ship which is then repeated throughout the planning horizon. The problem considers multiple commodities because the various container types are considered as separate commodities also with regard to the capacity calculations as the ships have a separate capacity for each of the various container types. Transshipment is allowed and is associated with a cost. Since the cost varies from port to port, the solution to the problem shows the optimal ports for transshipment, the choice of which is part of designing a network.

4.2 Scheduling problems

The scheduling problem consists of deciding the timing of each individual activity. The solution is a schedule for each ship which identifies the times at which the activities at the various ports are to be carried out (Bodin et al., 1983). The problem is characterized by *Time of service fixed in advance* in characteristic (4) and *Fixed* in characteristic (5). Since the time of service is fixed, port precedence is established due to the temporal restrictions. None of the surveyed articles fall into this grouping which could indicate that this is a rare problem within liner shipping.

4.3 Routing and scheduling problems

The routing and scheduling problem is a fusion of the routing problem and the scheduling problem and encompasses aspects from both problem types. This type of problem occurs mostly as applications and is characterized by task precedence and time window constraints. A task precedence relationship forces the pick-up activity to take place before the delivery activity (Bodin et al., 1983). Consequently, the problem is characterized by *Time windows or No restrictions* in characteristic (4), however, in the last case characteristics (15) must take the value of *Exist*. Characteristic (5) must still take the value of *Fixed*.

In the article by Rana and Vickson (1991) the company has the possibility of not loading all available cargo if for example the cargo is not profitable to transport or if more profitable cargo is available in another port. Each ship is allowed one route which
must be traversed an integer number of times in the planning horizon. However, a route as defined by Rana and Vickson (1991) can contain loops, and one route containing one or more loops can also be viewed as two or more connected routes. An example would be a route 2-4-5-6-4-3-2 where each number indicates a port. The voyage starts and ends in port 2, but it can also be viewed as the two routes 2-4-3-2 and 6-4-5-6 which are connected in port 4. Hence the demand for only one route is in this case only a demand for the routes to be connected and for the string of routes for each ship to be repeated an integer number of times.

### 4.4 Fleet management, routing and scheduling problems

The fleet management, routing and scheduling problem is a combination of the described routing and scheduling problems and a requirement to establish the type and number of ships to be used by the solution (Agarwal and Ergun, 2008). This is the most complex problem of the six types described as it has the most unknown factors of all the problem types. Problems of this type have the same characteristics as the previous problem type, however, characteristic (5) must take on one of the changeable characteristics.

One of the earliest treatments of fleet management, routing and scheduling in liner shipping is by Kydland (1969). The model established by Kydland uses a large number of simulations to establish the optimal port rotation, the number of ships and the type of ships. There are several types of ships under consideration, but each simulation is done with a homogenous fleet. The model permits not loading all the cargo in a port. The cargo not loaded will then be available for the next departure, but if it is not loaded on that departure either, the cargo disappears. The model is described with stochastic demand, though it is also possible to use deterministic demand in the model. The ships are required to be empty at the intersection point; however, this restriction can be relaxed in which case the method becomes an approximation, but the degree of approximation can be good if the port with the least amount of cargo in transit is chosen as the intersection point.

Another early article was done by Olson et al. (1969). The authors developed a
computer program to solve the problem under consideration. The procedure used by the program only remembers the last region a ship visited and not the previous port hence it cannot return a ship to its starting port. Therefore there are no intersection points. The possibility of laying up a vessel at a given cost is used to control the number of available ships during the scheduling period.

In the article by Lane et al. (1987) the cargo becomes available for shipping at given times. Since there is a cost per unit of time the cargo is waiting for loading, and a cost per unit of time the ship is idle waiting for cargo, this gives rise to soft time windows. The ships must be taken from a pool of available ships, and the fleet size and types of ships to be used are part of the solution. Hence the fleet can both increase and decrease within a given range. However, once the fleet has been established, it is fixed for the planning horizon, and within this period each ship is expected to perform its assigned route, though the ships are not required to finish the routes within the period.

The problem in Fagerholt and Lindstad (2000) is a delivery problem where cargo is loaded from the intersection point which, in this case, has the role of storing the goods. There are three or four weekly calls to each location, and demand is estimated on a weekly basis which indicates that splitting of demand is necessary. The nature of demand is stochastic; however, it is transformed to a deterministic demand by setting it at 150% of the average weekly demand. Time windows exist because the depot has fixed working hours and several of the installations are closed for operation at night.

In the article by Bendall and Stent (2001) demand depends on the service provided. The number of port calls in a given port during the planning period determines the size of the demand in that port. The port precedence exists because there is a ‘natural predetermined pattern’ (Bendall and Stent, 2001) for the spokes ports coupled with the fact that all routes start and end at the point of intersection, here named the hub port. The problem is solved in two stages. In the first stage the number of voyages to be made is found by a linear model, and in stage two these voyages are schedule manually while taking into account a 24 hour non-operating period for maintenance and repair. The weeklong schedule is subsequently repeated for successive time horizon periods.

In the problem presented by Agarwal and Ergun (2008) demand is treated as a set
of commodities. The demand is identified by a demand triplet which is an origin port, a
destination port and the day of the week the demand becomes available. The last fact
paired with the cost of storing cargo establishes soft time windows. Transshipment is used
extensively, however, no cost is associated with the transshipments.

The article presented by Sigurd et al. (2007) considers the compatibility between ports
and ships. The ships have to finish the routes within the planning horizon, however, there
is no requirement that the ships commence at the intersection point as long as they wrap
around and call the ports at which they started one planning period later. This ties in
with the fact that the two week plan developed by the model is repeated over a longer
period. For some problem instances the time windows in connection with the demand for
visit separation and lead time restrictions may lead to several ports having the time of
service fixed in advance.

4.5 Fleet management and routing problems

The fleet management and routing problem is a merger between a routing problem as
described earlier and a fleet management problem. This means that besides constructing
a feasible set of routes, the solution also determines the number of ships and the types
of ships. A solution to this problem type is a decision on the number and types of ships
to be used as well as their deployment. Problems of this type are characterized by No
restriction in characteristic (4), None in characteristics (15), and characteristic (5) must
take on one of the changeable characteristics.

Pesenti (1995) presents a hierarchical decision model for a heterogeneous fleet for both
liner and tramp services. The possible routes are decided a priori by the strategic decision
makers wherefore port precedence is not relevant for this article. Because the possible
routes have already been established, the deterministic demand is given on a per route
basis. This indicates that there is little, if any, interaction between the various routes,
and consequently, transshipment and splitting of demand between services is not allowed.
The company is, however, allowed not to load all available cargo.

The article by Cho and Perakis (1996) presents a strategic routing problem with two
optimization models for the problem. The two models differ as the first model has a given fleet size, and profit is being maximized. The second model establishes the fleet size and minimizes the cost. In both models there is the possibility of laying up ships and thereby changing the number of ships available over the scheduling period. There is no requirement for the ships to finish the planned routes within the planning horizon. This is a consequence of the fact that there is no integrality constraint for the variable that denotes the number of voyages ship k has on route r during the planning horizon.

The problem presented in Fagerholt (1999) is a pure pick-up problem, and all the cargo moves from the ports to the one point of intersection. In this problem the point of intersection is where the described feeder network connects to the main network. The fleet is heterogeneous only with respect to capacity as the speed and loading/unloading capacity are assumed to be identical for the various ship types. The routes are combined to finish within the planning horizon of one week. This length ensures that by repeating the obtained routings a weekly service of all ports is achieved. The required fleet size is then chartered for the length of time that the plan is expected to be in effect.

In the article by Mourão et al. (2001) transshipment is a requirement rather than a possibility, the reason being that transshipment is the only method for getting cargo from the medium network to the feeder network. The two networks are connected in one intersection point namely the hub which is where the transshipment takes place. The ships deployed on one network cannot be used on the other network due to the demand for compatibility between ships and ports. The problem takes into account the ports’ physical and logistical conditions and consequently operates with two ship types.

The article by Sambracos et al. (2004) presents a much aggregated model and a solution that establishes optimal fleet size and routing of same. The model allows the possibility of transshipping cargo at all locations, and the solution shows that several transshipment centers are to be used. Since the model is built on the assumption that ports can accommodate any number and all types of ships then the solution provides a guideline as to where port expansions must be undertaken to support the optimal cargo transportation. The model is based on one commodity namely containers, however, the containers envisioned for use in the network are smaller than the standard sizes.
In the article by Shintani et al. (2007) there is a heavy emphasis on empty containers, and it is shown that profits increase when repositioning of empty containers is included when constructing routes. The problem description includes a requirement for weekly service which means that when setting the planning horizon, the number of ships is fixed and vice versa. In the example the time horizon is fixed at 21 days wherefore the number of ships to be used is fixed at 3 as this is the number required to make weekly calls on a 21 day roundtrip. The cruising speed is a decision variable, and the cost of proceeding at a given speed is included in the total shipping cost.

4.6 Fleet management and scheduling problems

The fleet management and scheduling problem consists of sequencing the ships’ activities in both space and time while establishing the types of ships to be used and the number of ships of each type. The solution to a fleet management and scheduling problem contains a schedule identifying the timing of activities at the various ports for each of the ships selected. This problem type is characterized by Time of service fixed in advance in characteristic (4) and one of the changeable options in characteristic (5). As in section 4.2 none of the surveyed articles fall into this grouping. The lack of articles in both groupings could indicate that the time of service is seldom if ever fixed in advance in liner shipping problems wherefore scheduling problems will rarely occur.

5 Conclusion

In this article a classification scheme for scheduling and routing problems in liner shipping has been developed. The scheme is based on existing schemes for vehicle routing problems and literature concerning liner shipping. Articles on the subject are classified according to the developed scheme and subsequently grouped according to three of the characteristics in the scheme. The grouping resulted in four groups of articles all involving routing hence none of the articles were classified as either a scheduling problem or a fleet management and scheduling problem. The classification scheme is expected to help elucidate the
characteristics of the predominantly practical problems currently in the literature and thereby create some uniformity in the literature in the long run. The scheme can then form the basis from which a general model or group of models can be developed.

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lead times.

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compound renewal demand process.

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