1 Introduction

Transportation is a service industry that enables the movement of people and/or goods from one location to another. There is a wide range of specific demands for transport, which are differentiated by time of day, day of week, month of year, journey purpose, type of cargo, importance of speed, frequency, safety and security, and so on (Ortuzar and Willumsen 2011). A transport service has to match this differentiated demand. Transportation takes a link function perspective to connect the origin and the destination arising from the transport demand. The management of transportation concerns managing a range of activities including vehicle fleet sizing, routing, scheduling, maintenance, fuel costing, communications, technology implementations, traveler and cargo handling, and carrier selection. The goals of transportation are to achieve high utilization, cost reduction, and safe and on-time transport.

According to the Council of Supply Chain Management Professionals (https://cscmp.org/supply-chain-management-definitions), logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements. Logistics includes inbound, outbound, internal, and external movements along the supply chain, which essentially takes a channel perspective. The goals of logistics are to achieve cost efficiency, service effectiveness, and customer requirements along the supply chain process, in which the latter two goals include quality factors.

As a discipline, transportation has a long history. On the other hand, logistics is relatively new and emerged as a discipline about three decades ago. It could be argued that transportation differs from logistics in two aspects: focus point and managerial function. In the first aspect, transport often takes the “individual focus” emphasizing on individual functions and pursuing its own goals or competitiveness usually from the carrier’s perspective. Logistics takes the “integrated system” viewpoint, emphasizing not only transportation but also logistics flows in the entire supply chain. Therefore, logistics often takes the supply chain’s or the customer’s perspective. Second, transportation concerns the managerial functions such as fleet management, contracting, routing, scheduling, and cargo handling, normally in a specific segment of transportation.
Logistics covers the entire transportation journey (that may involve multiple transport modes) while also considering additional managerial activities such as consolidation, storage, warehousing, packaging, repacking, repairing, re-use, and documentation. However, in the last two decades, we have seen the convergence of transport and logistics. This reflects in the overlap between the goals of transportation and the goals of logistics. Nevertheless, some transport sectors are still rather fragmented, and transport service providers may largely focus on their own operational efficiency without much consideration from the supply chain system’s perspective (e.g., in the shipping sector).

Production and operations management (POM) concerns planning, organizing, coordinating, and controlling the processes of the business operations in the creation of goods or services efficiently and effectively. POM involves managing all the resources such as people, equipment, technology, and information that are required in the creation of goods and services. POM is the central core function of every company in both manufacturing and service industries. The application of POM in transport and logistics would facilitate the achievement of these goals. In this chapter, we will discuss the impact of POM on transport and logistics.

2 Transport Modes and Features

Transportation modes are the means to achieve the mobility of people or goods. They are generally organized into five categories: road, rail, air, water, and pipeline. Each mode has its own features and may be adapted to serve specific types of demands. This section briefly discusses the features of different transport modes, which is helpful for mode selection and multimodal arrangement.

2.1 Road Transport

Road transport dominates passenger and goods transport for relatively short distance. From the road user’s viewpoint, the main advantage of road transport is accessibility and flexibility. It can access almost any location and is flexible in vehicle routing with short notice. In the business aspect, it has a relatively low entry capital cost. Special equipment is available for certain types of commodities (e.g., frozen foods or glassware). From the logistics perspective, many road haulers have broadened into or become part of logistics companies undertaking a range of activities, e.g., warehousing, repackaging, and order processing.

2.2 Rail Transport

Rail transport is more suitable for longer-distance journeys in larger countries or international land journeys (e.g., across Europe). It has advantages of reliability and fixed routes with timetables, which can facilitate the planning of business operations such as production, distribution, and inventory management. The accessibility of rail transport is rather low because many locations are not rail-connected and therefore may require road transport to finish the journey. In the business aspect, it has relatively low operating costs but high entry costs because it requires the investment of tracks, terminals, and trains. Special equipment is available, particularly for bulk cargo (e.g., bulk powder wagons, tank wagons). Rail transport has a much smaller environmental impact (such as emissions) than road transport. McKinnon (2007) estimated the carbon intensity of freight transport modes based on the UK data, and reported that the CO₂ emissions per ton-km were about 1,600 grams, 150 grams, 35 grams, 15 grams, 5 grams for by air, truck (heavy goods vehicles), water, rail, and pipeline, respectively.
2.3 Air Transport

Air transport is mainly for passengers and cargoes that are time sensitive, valuable, or perishable. The biggest advantage of the air transport mode is the fast speed in long distance, which supports just-in-time production and distribution. However, air transport is disrupted by weather conditions more often than other modes are. The accessibility of air transport is rather limited because of the restricted number of airports. In the business aspect, the entry costs (for equipment) and operating variable costs (airport terminal usage costs) are high. ERA (2014) provided statistics on the risk of fatality for a passenger travelling over a given distance using different transport modes. It reported that the fatality risk for a passenger on average (defined as the fatalities per billion km) is about 0.06, 0.13, 0.20, and 3.14 by airline, railway, coach, and car respectively. This indicates that air is the safest mode.

2.4 Water (Maritime) Transport

Maritime transport is the most effective mode to move large quantities over long distances. Maritime transport includes inland waterways, coastal shipping, and international ocean transport. Traditionally, maritime freight transport is mainly for products of low value and high density such as coal, wood, and liquid. With containerization, high-value manufactured goods have been consolidated into containers and moved by container ships. The main features of maritime transport are its capability, the smaller environmental impact (compared to road and air), and the existence of a wide range of ships available for different types of cargoes. The accessibility of maritime transport is limited to certain ports with necessary infrastructure. In the business aspect, the entry costs are relatively low for domestic water carriers but quite high for international ocean carriers.

2.5 Pipeline Transport

Pipeline transport is very effective for the limited range of products (e.g., oil, gas, water) that require a continuous flow, particularly when moving large quantities over long distances. Pipeline routes tend to link isolated areas of production to major refining and manufacturing centers (to transport oil) or to major populated areas (to transport gas). The continuous supply is the main feature of pipeline transport. The accessibility of goods via pipeline transport is highly limited. Once built, it is difficult to adjust the pipeline network in response to demands. In the business aspect, it is very expensive to install pipelines (incurring high fixed costs) but cheap to operate.

2.6 Comparison of Transport Modes

The characteristics of the above different transport modes are summarized in Table 30.1. The attributes are explained as follows:

- Transport cost per unit is related to the travel distance. Literature showed that threshold values exist for the preference of transport modes, e.g., short distance is in favor of road, medium distance for rail, and long distance for water.
- The time attribute refers to the transit time.
• The on-time reliability attribute can actually be divided into two types: absolute reliability and relative reliability. The absolute on-time reliability is defined as the absolute deviation from the schedule, whereas the relative on-time reliability is defined as the ratio of the deviation to the transit time. It is worth noting that the relative on-time reliability for water could be high due to its very long transit time, although its absolute on-time reliability may be very low.

• The accessibility attribute refers to the ability and flexibility to visit any location.

• The frequency attribute represents how often the transport service is provided and available.

• The capability attribute refers to the handling capacity.

• Goods flexibility indicates the ability of carrying different types of commodities.

• The safety attribute reflects the level of possible loss and damage.

• The emission attribute refers to the environmental impact from the transport mode.

In the freight transport, Lloyds Marine Intelligence Unit (MIU) conducted a comprehensive analysis based on the UN trade data and found that 75% of the world trade was carried by sea, and 0.3% by air in terms of volume, while 60% of the world trade was carried by sea, and 10% by air in terms of value (Mandryk 2009). The above statistics show that sea transport moves the majority of world trade, and air transport moves the goods with the highest value density. Within the sea transport industry (including tanker, dry bulk, container, and general cargo), Lloyds MIU found that about 52% of cargoes by value was carried by container ships, while only 10% of cargoes by volume was carried by container ships. Container shipping has experienced a rapid development in the last two decades.

### 3 Transport Systems and Key Performance Indicators (KPIs)

#### 3.1 Transport Systems

From the modelling perspective, transport systems may be classified into three types: taxi-type transport, industrial-type transport, and liner-type transport.

• Taxi-type transport is negotiated for each trip with specific origin and destination such as taxi on road and tramp shipping at sea.
Industrial-type transport is organized by the carrier with possible multiple collections and deliveries along the journey. The carrier may own the cargo on vehicle. Typical examples are the truck movements between distribution centers and stores, and the tanker vessel movements in the sea.

• Liner-type transport has to follow the published schedules. Examples include bus service, train service, airline service, and liner shipping services. Clearly, three types of transport systems have quite different management scopes.

3.2 KPIs

To represent the goals of transport and logistics systems, the literature often adopts four performance measures: cost, asset utilization, reliability, and responsiveness/flexibility. The first two are service providers’ internal-facing measures for efficiency, while the last two are external customer-facing measures for service effectiveness (Lai et al. 2002). The traditional key performance indicators (KPI) in transport can be categorized into two groups: operational efficiency and service effectiveness. The former emphasizes on cost reduction and asset utilization/efficiency, whilst the latter emphasizes on service differentiation and quality of service.

In the last two decades, another group of KPIs has emerged and attracted much attention, which represents the social and environmental impacts of transport. This group appears to have become more important due to the greater concerns about climate change and sustainability. The applications of POM in transport and logistics are therefore focusing on evaluating and optimizing one or multiple of the above three groups of KPIs in a specific transport system. Representative studies will be discussed in the next section.

4 POM Research in Transport and Logistics

The management decisions in transport and logistics systems can generally be divided into three levels: strategic, tactical, and operational planning (Crainic and Laporte 1997; Crainic 2000; Wieberneit 2008). At the strategic planning level, the decisions focus on the infrastructure of facility (location, layout, and capacity); the physical structure and size of resources (personnel and equipment); and the customer service types and tariff policies (contracting and pricing). Typical questions include where terminals and hubs should be built/selected, what type of fleet mix should be used, and what kind of contractual agreements should be made with other firms.

At the tactical planning level, the main decision is the transport network design, which focuses on the allocation of existing resources to meet transport service demands effectively and efficiently. In general, at this planning level, the customer demand is treated as external input data. The aim is to best match the service supply with the service demand. Fleet sizing and deployment, vehicle routing, and scheduling are among the common planning issues. In most cases, the service network has been operating and cannot be re-designed from scratch. A sub-problem is how to assign the customer demands over the existing service network.

At the operational planning level, the planners are required to deal with the dynamic environment, in which the time dimension has to be considered. Customers may make changes with short notice. Uncertainties exist in various aspects that may cause the physical operations to deviate from the plan. Disruptive events require operators to respond in real-time mode. The planners may design the service operations taking into account the dynamic and uncertain nature of the transport environment (introducing buffer time or contingency planning); on the
other hand, the planners have to be flexible and adaptive in response to disruptive events (e.g., re-routing and rescheduling vehicles).

POM methods have been applied extensively to deal with various planning issues in the transport and logistics industry. Note that it is impossible to cover all aspects of POM research in transport and logistics in this chapter. We will discuss the representative extant POM studies in a range of selected topics. These topics are selected due to their importance and representativeness in the transport and logistics industries. Nevertheless, we attempt to provide good coverage of many well studied and some newly emerging topics.

More specifically, we will select the following planning issues: service network design, fleet sizing and deployment, vehicle/inventory routing and scheduling, speed management and slow steaming, empty vehicle/container management, disruption management, crew scheduling and rostering, port/terminal management, and emission management. It should be noted that (i) some planning issues are more general than others (e.g., service network design may include fleet deployment and vehicle routing as sub-problems); (ii) some issues may partially overlap with others and sometimes be considered jointly (e.g., vehicle routing and empty vehicle management; speed management with emission management); and (iii) some issues are common in many transport sectors (e.g., service network design, vehicle routing, and scheduling), whereas others may be more specific to one transport sector (e.g., slow steaming in maritime transport).

4.1 Service Network Design

Service network design usually takes the carrier’s perspective. This is natural as the transport service provider is responsible to set up a network consisting of nodes (ports, terminals, depots) and links (connections between nodes) and deploy a fleet of vehicles (truck, train, plane, and vessel) to provide transport services. A service route can be defined as a sequence of nodes that a certain type of vehicle visits. A service network consists of a set of service routes.

The objective of service network design is to optimize the service networks by rationalizing the coverage of ports, service routes and transit time, which is a trade-off between meeting customer requirements and service operational cost. In a broad perspective, management decisions in service network design include: how many service routes should be opened, how a service route should be structured in terms of port rotation and schedule, with which frequency the service route should be used, which type of vehicles and how many should be deployed in a service route, how the demands should be assigned over the service network, and how the human resources are allocated to execute the transport services. In this view, service network design includes fleet deployment, vehicle routing, inventory routing, and crew scheduling as sub-problems, but these sub-problems may be treated in a simplified and/or aggregated level.

In a narrow perspective, service network design mainly concerns the route structure generation or selection. Woxenius (2007) summarized six generic route structures for transport network design problems:

(i) Direct link structure is exemplified by taxis and tramp shipping. It is also suitable for moving large quantities of commodities, which justifies the utilization of the vehicle.

(ii) Corridor route structure is suitable for high-density flow along an artery. The nodes in the corridor may represent big cities or ports along a river. The nodes off the corridor are served by short capillary services.

(iii) Hub-and-spoke structure is often used to connect a distribution center to a large number of stores. The hub node can also act as a cross–dock point to link any two spoke nodes.
(iv) Connected hub structure is generally applicable for large countries or international  
transportation.
(v) Static route design aims to construct a set of regular services. The sequence of nodes in the  
route and the schedule (timetables) of visits has to be determined in advance.
(vi) Dynamic route design is responding to actual demand with flexible routing between origin  
and destination nodes, under which the vehicle’s route from origin node to destination node  
varies over time.

A summary of examples of applications of the above generic route structures in passenger and  
freight transportation is given in Table 30.2. It should be pointed out there is no clear cut dis- 
tinction between these route structures, and multiple route structures could be applied to the  
same transport sector, e.g., direct links, corridor (conveyor belt) routes, connected hubs, and static  
routes are all adopted in the container shipping industry.

Table 30.2 provides useful information to simplify the service route design problems in some  
specific transport sectors or for some specific purposes. Service network design problem is a  
common problem arising from both passenger and freight transportation and in all transport  
modes, for example:

- In road transport mode, public transit network design and its approaches were discussed in  
the survey papers, Ceder and Wilson (1986), Guihaire and Hao (2008), and Farahani et al.  
(2013). The planning process can be decomposed into a sequence of five sub-problems in a  
hierarchical structure, e.g., network design, frequencies setting, timetable development, bus  
scheduling, and driver scheduling.
- In the air transport mode, airline network design problem with routing pattern selection and  
service scheduling was addressed in Lederer and Nambimadom (1998).
- In the container shipping sector, the network design problem aims to select ports and con- 
struct service routes in a way that the customer demands can be served efficiently by the  
vessel fleet, cf. recent review papers (e.g., Christiansen et al. (2007); Brouer et al. (2014); and  
Tran and Haasis (2015)).

### 4.1.1 Solution Techniques

Mathematical models for service network design mainly employ integer programming, mixed  
integer programming, non-linear programming based on three frameworks: node-arc (or link- 
based), path-based, and tree formulation (Kim and Barnhart 1999). Integer decision variables are  
often essential to select nodes, links, routes, or paths. Continuous variables may be used to re- 
present the flow volumes. Non-linearity may arise from the constraints or the objectives. Service  

<table>
<thead>
<tr>
<th>Direct Link</th>
<th>Corridor</th>
<th>Hub-and-Spoke</th>
<th>Connected Hubs</th>
<th>Static Routes</th>
<th>Dynamic Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi service</td>
<td>Intercity train service</td>
<td>Domestic airline traffic</td>
<td>Intercontinental airline traffic</td>
<td>Urban public transport systems</td>
<td>Airport limousine service</td>
</tr>
<tr>
<td>Full truckload service</td>
<td>Transport on inland waterways</td>
<td>Air transport of express cargo</td>
<td>Container liner shipping</td>
<td>Container liner shipping</td>
<td>Partial load truck service</td>
</tr>
</tbody>
</table>

Source: Based on Woxenius 2007
network design problems are often tackled in a multi-stage hierarchical procedure through decomposing the original problem into a series of sub-problems.

Due to the complexity of the underlying problem, exact optimal solutions are often difficult to obtain for realistic size of the problems. It is common to use heuristics, metaheuristics, or approximation methods to seek the sub-optimal solutions. Such methods may be classified into five groups (Guihaire and Hao 2008):

- Specific and ad-hoc heuristics (e.g., based on greedy principle or simple rules)
- Neighborhood search methods (e.g., Tabu Search)
- Evolutionary search methods (Genetic Algorithms)
- Bound-based approximation methods (e.g., Column Generation; Lagrangian Relaxation)
- Hybrid search methods that combine two or more solution methods.

In the above methods, simulation is often used to evaluate the performance of a given solution. It is worth noting that sometimes service network design problems could be greatly simplified if industrial specific characteristics could be utilized (Song and Dong 2013).

4.2 Fleet Sizing and Deployment

Fleet sizing and deployment consists of two components: supply capacity management and fleet deployment/redeployment. The former concerns determining the fleet size and mix and the capacity leasing or purchasing or laying up (idling) decisions. The latter involves determining how the fleet is to be deployed or redeployed in the service network.

Part of fleet sizing and deployment decisions may be incorporated into service network design problem (e.g., the number of vehicles deployed in a particular route is highly related to the frequency of the service). On the other hand, fleet sizing and mix may be regarded as an input and constraint to the service network design problem. In that sense, fleet sizing and mix is treated as a strategic planning issue at a higher level. The fleet sizing and deployment aims to manage the supply capacity, composition, and deployment to better satisfy customer demands. Quite often, vehicle routing is jointly considered with fleet sizing and deployment either in an integrated way or in a hierarchical way.

Hoff et al. (2010) provided a survey on fleet sizing and mix problem combined with vehicle routing. They took the industrial aspects of the fleet composition and routing and covered two main transport modes: land-based and maritime transportation. In the following, we take the maritime transport as an example to give a brief review of the existing research on fleet sizing and deployment problems. Interested readers can refer to two survey papers by Christiansen et al. (2007) and Pantuso et al. (2014) for more relevant literature on the shipping industry.

Dantzig and Fulkerson (1954) were among the first to study the fleet sizing and deployment problem. They used linear programming to formulate a problem of determining the minimum number of tanker vessels required to meet a fixed schedule of transporting Navy fuel oil. Nicholson and Pullen (1971) considered a planning problem of phasing out a fleet of existing ships and the replacement policy (by charter ships). Mourao et al. (2001) applied integer linear programming to determine the optimal number of ships to be assigned to a given hub-and-spoke system. Bendall and Stent (2005) performed real option analysis on three scenarios in a hub-and-spoke system facing uncertain demand in order to determine the best deployment scenario (which specifies the number of ships and the frequencies of calls at ports).

Fleet deployment/assignment over a given set of liner service routes including lay-up (idle) and hire decisions was first addressed in Perakis and Jaramillo (1991). Gelareh and Meng (2010)
considered fleet deployment including ship sailing speed decision for liner shipping operations. Meng and Wang (2010) developed a chance constrained programming model for the liner ship fleet deployment problem with uncertain demand. Meng and Wang (2011) studied the ship fleet deployment in a long-haul liner service route with fixed demand including the decisions of the ship sailing speed and the service frequency. Wang and Meng (2012d) extended the fleet deployment problem allowing transshipment operations. Meng et al. (2012) further extended the work in a situation with uncertain demand. A two-stage stochastic integer programming model is proposed, and the sample average approximation method is used to solve the problem.

Vessel sharing, slot exchanging, and slot purchase are quite common in the liner shipping industry. A generalization of a ship fleet deployment problem is the service capacity planning in a given shipping network. In this direction, Dong et al. (2015) considered a joint shipping service capacity planning and dynamic container routing problem with demand uncertainty. A two-stage stochastic programming model with recourse is formulated and solved using an adapted progressive hedging algorithm.

Shipping companies have to adjust their service networks in response to the change of demand patterns and/or the deployment of new ships. Adjustments of the service network may include adding new services, removing services, or modifying existing services. Whenever these adjustments take place, some vessels will be redeployed (i.e., repositioned) to a different service in order to replace another vessel. Tierney et al. (2015) addressed the ship fleet repositioning problem with the aim of maximizing profits during the ship phasing-in and phasing-out process without disrupting cargo flows and respecting the service schedules. A mathematical model is formulated and solved using a simulated annealing algorithm.

The common POM methods used in the fleet sizing and deployment issue include: linear programming, integer programming, dynamic programming, mixed integer programming, and simulation. As the fleet sizing and deployment is targeting on matching service supply with customer demand, uncertainty in demand is sometimes considered explicitly, in which chance constrained programming, stochastic programming with sample average approximation method, real option analysis has been applied.

4.3 Vehicle/Inventory Routing and Scheduling

Vehicle/inventory routing and scheduling are generally operational level decisions, although schedule (timetable) design can be regarded as a tactical decision. Due to the wide coverage and variants of the problems in this area, we classify the problems into four groups. The first group includes the classic vehicle routing problem (VRP) and its direct extensions. It aims to design the optimal delivery or collection routes from one or several depots to a number of geographically scattered customers subject to side constraints. Vehicle routing usually takes the carrier’s perspective. The second group is inventory routing problem. It integrates vehicle routing, inventory management, and delivery scheduling decisions, which essentially takes both carrier and customer’s perspectives. The third group is cargo routing problem or shipment assignment problem. It aims to determine the cargo path in a given service network. Cargo routing can take either either carrier or customer’s perspective to optimize a performance criterion. The fourth group is schedule design problem, which aims to specify the arrival and departure times of the vehicles. The studies on the above four groups are discussed briefly below.

4.3.1 Vehicle Routing Problem (VRP)

In VRP, normally each non-depot node in the service network is visited exactly once by exactly one vehicle. All vehicle routes start and end at the depot node and some side constraints are
satisfied. Common side constraints include vehicle capacity, number of non-depot nodes on any route, total time of the route, time windows of the visits, and precedence relationships.

There have been a huge number of studies published on VRP since its introduction by Dantzig and Ramser (1959). Readers can refer to the following survey papers and the references therein, e.g., Lenstra and Kan (1981); Laporte (1992); Meng et al. (2014); Lahyani et al. (2015); Ritzinger et al. (2016). VRP is highly industrially relevant and can arise from air transport, rail transport, as well as maritime transport modes. In fact, VRP is regarded as one of the success stories of POM (Hoff et al. 2010). Apart from a plethora of academic research on VRP, many software tools have been developed in the market. Exact algorithms for the VRP include direct tree search methods, dynamic programming, and integer linear programming. Well known heuristic algorithms have been developed (e.g., the Clarke and Wright algorithm). However, more often, metaheuristic methods are applied to solve NP-hard VRP problems.

4.3.2 Inventory Routing Problem

Inventory routing problem was initiated from Bell et al. (1983). They integrated inventory management of industrial gases at customer locations with vehicle scheduling and dispatching. Moin and Salhi (2007) took the supply chain management viewpoint and provided a survey on inventory routing. Recently, Coelho et al. (2014) provided a review of inventory routing and its development. They noticed that the main application area of inventory routing is in maritime logistics (e.g., ship routing and inventory management (Ronen 1993; Christiansen et al. 2004)).

In terms of solution methods to inventory routing problems, exact algorithms (e.g., branch-and-cut algorithms) have been applied in some cases. However, because the basic inventory routing problem is also NP-hard (Coelho et al. 2014), it often returns to metaheuristics, hybrid metaheuristics, or matheuristic algorithms (which combine heuristics with mathematical programming).

4.3.3 Cargo Routing Problem

The focus in this group lands on cargo routing rather than vehicle routing. When both cargo and vehicle routing are decision variables, the problem may be regarded as the first group VRP or the service network design problem. We limit this group with cargo routing and assuming the vehicle routes are fixed. When taking the carrier’s perspective, the cargo routing problem is about how to efficiently utilize the existing service supply subject to customers’ requirements. When taking the shipper’s perspective, cargo routing can be regarded as a shipper or a freight forwarder organizing trips for a set of shipments. This may involve selecting the transport modes, the carriers, and the routes in order to transport the shipments from origins to destinations efficiently.

Cargo transport is a one-way operation, whereas vehicle routing usually needs to consider the return journey. Cargo routing may involve multiple transport modes, carriers, and vehicles, while vehicle routing usually concerns a single vehicle or a fleet of vehicles operated by the same carrier. Container routing can be regarded as one example of cargo routing in a given service network. A number of studies have been published in this area in the last decade (e.g., Song et al. 2005; Agarwal and Ergun, 2008; Brouer et al. 2011). Path-based and link-based network flow models have been developed to tackle the problem.

4.3.4 Schedule Design Problem

Schedule design problem may be treated as a sub-problem in service network design. In particular, all static service network design problems involve a timetable development and optimization
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(e.g., bus service, train service, liner shipping service). In practice, transport systems are always subject to uncertainty caused by congestion and weather conditions. Therefore, schedule design should consider time uncertainty in the transport system to ensure reasonable service reliability, which implies the need of setting up the total buffer time and the assignment of buffer time among different legs of the schedule.

In the container shipping sector, Wang and Meng (2012b) developed a mixed-integer, non-linear, stochastic model for the liner ship route scheduling problem with sea contingency and uncertain port time in order to minimize the ship cost and bunker cost. Wang and Meng (2012a) considered the robust schedule design problem for a liner ship route. The objective is to achieve the optimal trade-off between buffer time allocation and schedule robustness in terms of reliability, integrity, and stability. Qi and Song (2012) designed an optimal container ship schedule in a service route with uncertain port times by minimizing an expected objective function consisting of fuel consumption and delay penalty.

4.4 Speed Management and Slow Streaming

Speed management is less relevant to air, train, and road transport modes, because these types of vehicles often operate at their designed speeds and there is not much benefit or flexibility to deviate from the designed speed. On the other hand, speed management is an important issue in maritime transport. Fuel consumption cost can account for 75% of the ship operating costs, and reducing the cruising speed by 20% can reduce daily bunker consumption by 50% (Ronen 2011).

Slow steaming refers to the practice of operating cargo ships at significantly less than their designed speeds. Since the global economic crisis in 2008, slow steaming in the container shipping industry has become a popular practice. Slower speed implies extra vessels should be deployed in a single route to maintain the service frequency (normally weekly service). Hence, it can not only reduce the ship operating cost, but also absorb spare vessels and mitigate the overcapacity issue. In addition, reducing fuel consumption implies the reduction of emissions, which is beneficial to the environment and society.

Ronen (2011) presented a cost model to analyze the trade-off between reducing ship speed and adding extra ships to a container service route by minimizing the annual operating cost of the route. Wang and Meng (2012c) optimized vessel speed on each leg of each ship route in a shipping network considering container routing. Psaraftis and Kontovas (2013) presented a comprehensive review on the models in which ship speed is one of the decision variables in maritime transportation. They classified the models according to a set of parameters, including optimization criterion, shipping market, decision maker, fuel price, freight rate, fuel consumption function, ship fleet, cargo inventory costs, port-related variables, and emissions.

Cariou (2011) discussed the sustainability of slow steaming. He stated that slow steaming could only be sustained given a bunker fuel price of at least $350 per ton for the main container trades, based on a simple cost model. However, slow steaming depends on multiple factors including ship supply, trade demand, and freight rates. This is why slow steaming is still widely adopted now although the bunker fuel price has been below $350/ton for most of the time since January 2015.

4.5 Empty Vehicle/Container Management

Trade imbalance is a common phenomenon in freight transportation, which generates a significant number of empty vehicle movements. This phenomenon arises from many transport sectors (e.g., empty truck movements on road, empty wagons and railcars on railways, empty motor carrier
movements on road, empty vessel sailing at sea (called ballast voyages), empty container movements at sea and on road/railway). Empty runs not only incur a financial burden to the carriers, but they also create congestion and emissions for the society. Therefore, efficiently managing empty vehicle/container movements is an important issue in transport and logistics. We discuss this issue in two groups: empty vehicle management and empty container management. The second group differs from the first group because containers have to be carried by trucks, trains, or vessels. In addition, empty container management has emerged as a popular and challenging topic recently.

4.5.1 Empty Vehicle Management

Empty vehicle management may be incorporated into the service network design and/or fleet deployment problem. This is because empty vehicle movements are derived from the loaded vehicle movements, and it is natural to consider them together. Dejax and Crainic (1987) reviewed the literature on empty flows and fleet management in freight transportation. A number of models have been developed (e.g., non-linear network programs (Beaujon and Turnquist 1991); multistage dynamic networks (Cheung and Powell 1996); logistics queueing networks (Powell and Carvalho 1998); and inventory control policies (Song 2005; Song and Earl 2008)).

4.5.2 Empty Container Management

Empty container management is closely associated with container fleet sizing, container purchasing, container leasing and off-leasing, and empty container repositioning, in which empty container repositioning (ECR) is the predominant component. ECR has attracted much attention in the last two decades partially due to the rapid growth of container shipping and the severe imbalance of trade demands globally and regionally. It was reported that shipping companies spent about US$110 billion per year in managing their container fleets (e.g., purchase, maintenance, repairs), of which US$16 billion (or 15%) for repositioning empty containers (Rodrigue et al. 2013). Empty containers in the transport system have a similar function to the inventory in production-inventory system as both are transported and stored in a space-time dimension to satisfy external customer demands.

In terms of the modelling techniques, ECR models in the literature may be classified into two streams (Song and Dong 2015). The first stream adopts the network flow models and often applies mathematical programming to produce a set of arc-based (or O-D based) matrices, which specify the quantity of empty containers to be moved on an arc (i.e., from one node to another node) in the network. The underlying concept is flow balancing, i.e., the container flows out of a node should be equal to the flows into the same node (Crainic et al. 1993; Brouer et al. 2011; Song and Dong 2012). The second stream adopts the inventory control models to produce decision-making rules, which are able to determine the amount of empty containers to be repositioned into/out of a node dynamically by utilizing the information of inventory levels of empty containers in the system (Dong and Song 2009; Long et al. 2012; Dang et al. 2013). Braekers et al. (2011) provided a literature review on empty container repositioning models at different planning levels (i.e., strategic, tactical, and operational levels). Song and Dong (2015) gave a survey on ECR problems from the supply chain perspective and as well as from the modelling technique perspective.

4.6 Disruption Management

Disruption management refers to dynamically recovering a predetermined operational plan when various disruptive events prevent the original plan from being executed smoothly (Yu and
Qi 2004). In the transportation industry, disruption management is usually an operational or real-time decision on adjusting transportation plans and operations in response to unusual events that may have just occurred or will occur in the near future. Common disruptive events include vehicle breakdowns, accidents, bad weather, industry actions, and severe delays. If the same type of disruptive events becomes regular, then it is possible to model their occurrence using probability distribution based on historical data. In such a case, tactical level planning (e.g., timetable design) can accommodate this type of uncertainty through robust planning and/or adding buffer time. In general, disruptive events are regarded as occasional and one-off events, which are tackled on a real-time basis.

Research on disruption management in transport industries has mainly focused on the airline sector. Clausen et al. (2010) provided a survey on airline disruption management. They defined a disruptive situation as a state during the execution of the current operation, where the deviation from the plan is sufficiently large to impose a substantial change. One challenge of disruption management is to define an appropriate objective. In fact, there are multiple objectives that should be considered. These examples include: delivering the passengers and their luggage to their destinations on-time with the booked service level; minimizing the total costs including excess crew costs, costs of compensation, hotel and accommodation to disrupted passengers and crew, and tickets on other airlines; minimizing the reputation damage (passenger dissatisfaction), and recovering the plan and schedule as soon as possible (Kohl et al. 2007). These objectives are conflicting and some are difficult to quantify. The generation of a good recovery plan is very complicated due to the rearrangement of many resources such as crews, aircraft, passengers, slots, schedules, hotels, cargoes, etc. The majority of the mathematical models and solution methods for solving the airline recovery problems are similar to those that are used for planning purposes (Clausen et al. 2010). Commonly used mathematical models include set partitioning models, set covering models, multicommodity network flow models. In practice, real-time decisions by large airlines are usually made in a sequential mode with respect to sub-problems, e.g., rescheduling the aircraft, rescheduling crews, then deal with ground problems, followed by the impacts on passengers (Clausen et al. 2010).

In maritime transport, particularly in liner shipping, a few studies have addressed disruption management recently. Brouer et al. (2013) sought the optimal recovery measure (e.g., speeding up, port omission, swapping ports of call) under a given disruptive scenario in container shipping. Li et al. (2015) presented nonlinear programming models and dynamic programming algorithms to determine the optimal operational action to catch up a delayed journey in liner shipping. Both Brouer et al. (2013) and Li et al. (2015) focus on schedule recovery after a disruptive event, which are deterministic models and do not consider future new delays. Li et al. (2016) formulated a stochastic model to adjust vessel schedules considering both regular uncertainties and disruptive events on a real-time basis.

### 4.7 Crew Scheduling and Rostering

Crew scheduling and rostering is an operational level decision, which concerns the assignment of a group of workers to performing a set of tasks. The aim is to minimize total labor costs subject to a wide variety of constraints imposed by safety regulations and labor negotiations. Crew scheduling problems arise from multiple transport sectors (e.g., freight and passenger air transport, bus and rail transit, truck and rail freight transport). Regardless of the transport sector, the common features for crew scheduling and rostering are (i) both temporal and spatial dimensions are involved (i.e., specifying the starting time and location and the finishing time and location for each task) and (ii) the tasks to be performed by crew are pre-specified in a timetable. A task may
be a flight leg in airlines, a trip between two or more consecutive segments in a train journey, or a trip between two or more consecutive stops in a bus line (Ernst et al. 2004). Crew scheduling and rostering may be treated as a sub-problem in a service network design problem (e.g., bus network design) or jointly with vehicle routing problem.

Most of the literature in this area focused on the airline sector. Crew costs represent the largest single cost factor for the airlines only second to fuel costs. Readers can be referred to survey papers such as Arabeyre et al. (1969), Barnhart et al. (2003), and Gopalakrishnan and Johnson (2005). The most popular approach to airline crew scheduling and rostering is the decomposition technique. The overall problem is laid out into two stages: (i) crew pairing and (ii) crew rostering. Crew pairing is a process of generating a number of feasible pairings/duties from the given timetable, and selecting the more appropriate one. Crew rostering is to sequence the selected pairings into rosters that will be assigned to individual crew. Recently, more effort has been committed to develop integrated models (e.g., Weide et al. 2010).

In the bus transit sector, driver schedules and rosters are constructed from given bus timetables. Different from airlines, the time scale is much smaller in which tasks are often called duties that can be performed by a crew without long rests. Wren and Rousseau (1995) presented an overview of bus driver scheduling problem and the solution methods. Multi-objective bus driver scheduling problem was addressed in Lourenco et al. (2001). There have also been some attempts to integrate crew scheduling and vehicle scheduling in a single model (e.g., Freling et al. 2003). Applications of crew scheduling and rostering in the railway sector is relatively new (Ernst et al. 2001).

It should be noted that most crew scheduling research focuses on a particular application rather than the general case. This is mainly because each application has its own characteristics and its own research challenges that are imposed by various hard and soft constraints. The safety regulations and labor negotiations vary sector by sector and country by country.

4.8 Port/Terminal Management

In most transport networks, intermediate nodes are indispensable parts. Intermediate nodes may represent depots, warehouses, distribution centers, airports, dry ports, and seaports. In particular, the seaport plays a vital interface role to connect seaborne transport and inland transport. This section provides a brief discussion on operations management issues at maritime container ports and terminals.

Two players are directly associated and responsible for port operations: the port authority and the terminal operator. The port authority normally focuses on the administration and management of the port infrastructures and the coordination and control of the activities of the different operators present in the port (Verhoeven 2010). The port authority outsources the cargo-handling activities to terminal operators who are responsible to provide handling equipment and other resources to handle ships and cargoes. There have been a large number of studies on container port/terminal productivity, which can be referred to the survey papers, Steenken et al. (2004); Stahlbock and Voss (2008); Bierwirth and Meisel (2010); Kim and Lee (2015).

From the planning-level perspective, container port/terminal management is often classified into strategic planning decisions and operational planning decisions. Strategic decisions include facility layout, berthing capacity, equipment selection, multimodal interfaces, IT-systems, and control systems. Operational decisions include berth allocation, crane assignment, stowage planning on vessel, storage and stacking in yard, equipment routing, and scheduling (Stahlbock and Voss 2008; Bierwirth and Meisel 2010).

From the container logistics perspective, maritime container terminals perform three types of functions (sub-systems): quayside operations, which focus on managing the interface with vessels
including berth allocation, container loading to/unloading from vessels; yardside operations, which focus on managing container internal transport and storage within the port area; and landside operations, which focus on managing the interface with external trucks and trains for container receipt and delivery.

Port authority and terminal operators seek to provide efficient operations in all three sub-systems in order to attract ocean carriers and gain competitive advantages. The main objective of the port operations is to achieve maximum velocity of vessel turnaround, container movements, and make the best utilization of the key resources. This may be achieved by effectively controlling and integrating the three sub-systems of port operations and turning them into an efficient operating entity. In this regard, a number of studies have been conducted to integrate multiple logistics operations at container terminals, e.g., the simultaneous optimization of berth allocation and quay crane scheduling (Meisel and Bierwirth 2013; Vacca et al. 2013); joint optimization of berth allocation and yard management (Hendriks et al. 2013; Zhen et al. 2011); and integrated vehicle dispatching and storage yard management (Wu et al. 2013).

4.9 Emission Management

Transport is the second largest greenhouse gas (GHG)–emitting sector after energy (Buhaug et al. 2009). More specifically, road, international shipping, international aviation, domestic shipping and fishing, and rail transport contribute 21.3%, 2.7%, 1.9%, 0.6%, and 0.5% of global CO$_2$ emissions, respectively (Buhaug et al. 2009). Noting that GHGs significantly contribute to global warming and climate change and pose a danger to human health and welfare, much attention has been attracted to reduce emissions from the transport sector recently. For example, the European Union (EU) has policies in place to reduce emissions from a range of transport modes such as including aviation in the EU Emissions Trading System, and CO$_2$ emissions targets for cars and vans.

Shipping was the only transport mode for which GHG emissions were not regulated. Only recently, the MEPC adopted the Energy Efficiency Design Index (EEDI) for new ships (Psaraftis and Kontovas 2013). However, there are still no compulsory regulations for the existing ships and the targeted levels of emissions from shipping. Nevertheless, the International Maritime Organization has been promoting operational measures such as ship speed reduction, enhanced weather routing, optimization of logistics chains, adjustments for arrival times, better fleet planning, and quicker loading and discharging in order to reduce emissions from ships (Buhaug et al. 2009).

A large number of studies have investigated the impact of ship speed reduction on fuel consumption, operational cost, and CO$_2$ emissions (e.g., Notteboom and Vernimmen 2009; Cariou 2011; Ronen 2011). Psaraftis and Kontovas (2013) and Wang et al. (2013) reviewed the models involving ship speed as a key decision variable to minimize the fuel consumption (equivalently minimizing CO$_2$ emissions) or to minimize the total operational cost. Christiansen et al. (2013) highlighted that more studies have been devoted to sailing speeds and environmental impact of ships in the new millennium. Mansouri et al. (2015) provided a review to examine the potential of multi-objective optimization as a decision support tool to achieve the trade-off between environmental objectives and economic objectives in maritime transport. These review papers commonly pointed out that minimization of the environmental impact is becoming more important in maritime transport, which might be achieved through optimizing ship sailing speed at operational level and/or at tactical level in relation with other decisions.

A few studies considered the CO$_2$ emission problem together with ship routing and scheduling. For example, Song and Xu (2012) analyzed the CO$_2$ emissions from two alternative Asia–Europe services interfacing with the UK and identified which is preferable in different scenarios. Kontovas (2014) emphasized the need to incorporate the environmental dimension into the ship
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routing and scheduling problem and presented several conceptual approaches. Song et al. (2015) considered a joint tactical planning problem for the number of ships, the planned maximum sailing speed, and the liner service schedule in order to simultaneously optimize the expected cost, the service reliability, and the shipping emission under uncertain port times.

There are also several studies that incorporate emission performance into port/terminal management. Golias et al. (2010) attempted to maximize berth productivity and emissions production simultaneously. Du et al. (2011) jointly optimized berth allocation and vessel sailing speeds considering the vessel emissions at sea and in mooring periods. Hu et al. (2014) presented a nonlinear multi-objective mixed-integer programming model for the berth and quay-crane allocation problem treating vessel’s arrival time as an additional decision variable. They showed that the model could improve vessels’ fuel consumption and emissions, and utilization of berths and quay cranes without sacrificing service quality.

The above discussion mainly focused on the maritime transport sector. It should be noted that there are parallel bodies of research in other transport sectors with emission considerations. For example, green vehicle routing problem represents the research stream of vehicle routing with emission considerations. For the road transport sector, interested readers can refer to the recent survey papers, Lin et al. (2014) and Demir et al. (2014).

5 Implications for Managers

The previous section demonstrates that Production and Operations Management (POM) has been widely applied in various transport sectors. The models can generally offer managerial insights or decision support tools. The former provides managers knowledge to better understand the transport systems such as how KPIs may change with respect to system parameters or control parameters; whereas the latter assists managers to make business decisions, e.g., strategic and tactical decisions based on what-if scenario analysis, operational decisions based on real-time information.

There have been many successful applications of POM models/tools in transport industries (e.g., VRP, airline). However, some transport areas/sectors are lacking or lagging behind. For example, shipping lines rarely use planning tools to manage fleet sizing, ship redeployment, schedule design, empty container repositioning, and disruption management. The implication is that managers need to commit more effort and take the initiative. For example, managers could collaborate with researchers more closely so that the discrepancies between models and real transport systems can be minimized. Moreover, many companies are reluctant to provide data to researchers and are reluctant to change the legacy systems. There is a lot to be done from a manager’s aspect.

6 Directions for Future Research

There are many research opportunities that remain or are emerging to be investigated. We preset two categories of future research opportunities: general POM modelling opportunities, and emerging ICT-driven opportunities.

6.1 General POM Modelling Opportunities

6.1.1 Objective Functions and Constraints

Existing literature often focused on a single objective in a specific aspect. More studies are required to simultaneously optimize multiple objectives. Taking the emissions as an example, there
are various ways to embed emissions considerations into POM models. First, the objective function can include a component that represents the total emissions, which essentially internalizes the external cost of emissions. Second, by treating different types of KPIs as multi-objective optimization problems, we can seek Pareto optimal frontiers. Third, some KPIs could be converted into constraints by limiting the amount of emissions at each transport leg.

Soft performance indicators such as social responsibility and ethical performance (e.g., code of ethics, conforming to regulations) have gradually become important to business managers. It would be interesting to model such soft performance indicators and incorporate them into objective functions or constraints.

### 6.1.2 Decision Integration

The decisions in a transport system are essentially inter-dependent from a system perspective. Traditionally, the strategic, tactical, and operational decisions are tackled separately. It would be desirable to integrate some of these decisions into a single model, or a coupled model. Although a great effort has been committed in this direction, more research is required. It is worth noting that many sub-problems have already been NP-hard individually (e.g., network design, fleet deployment, and vehicle routing). Therefore, integrated models tend to be more challenging from the computational complexity perspective. Nevertheless, with the development of computational power, the problems that were unaffordable to solve in the past may become tractable.

### 6.1.3 Stochastic and Dynamic Operations

Uncertainty and dynamic operations are two intrinsic characteristics of transport systems. However, the strategic and tactical problems such as service network design, fleet sizing, and deployment often assume deterministic and stable situations; e.g., Pantuso et al. (2014) stated that very few papers explicitly treat uncertainty in the field of maritime fleet size and mix problems.

### 6.1.4 Solution Techniques and Heuristic Rules

The majority of realistic mathematical models for transport systems are in the form of integer programming or mixed integer programming due to the choice decisions (either of nodes, links, or paths), which leads to NP-hard. In the literature, linear functions and continuous variables were often used as an approximation of the nonlinear and discrete variables or a simplification of system behavior. One research direction is to evaluate the quality of the solutions obtained based on such approximation or simplification. Another direction is seeking to solve to optimality and/or find tighter bounds to the optimal solutions.

Metaheuristics have been widely applied to solve transport and logistics optimization problems. Apart from well-developed metaheuristics such as Genetic Algorithms, Simulated Annealing, Scatter Search, Tabu Search, and many new metaheuristics have emerged recently that are inspired by natural systems, e.g., Ant Colony Optimization, Particle Swarm Optimization, Bee Colony Optimization, Bacterial Foraging Optimization, Artificial Immune Systems, and Biogeography-based Optimization (Boussaid et al. 2013). There are research opportunities to apply these recently proposed metaheuristics in combination/comparison with classic ones.

Industry practice based heuristic rules are worth extracting and investigating. Such rules may be not optimal, but are intuitive and often yield reasonably good results. Empirical research is needed to gather data and extract rules. Using the practical rules as a reference base, with the
help of machine learning techniques, it is possible to generate new rules that are more effective but still easy to implement. In addition, more knowledge about transport system behavior, e.g., customers’ preference and industry’s common practices, can be useful to formulate the problem more effectively.

## 6.2 Emerging ICT-Driven Opportunities

Emerging information technologies are important forces to create new research opportunities. We pointed out a few examples below.

Automation is a global trend that will have a huge impact on transport and terminal operations. Autonomous vehicles and robotics may transform the future of roads, personal transport, freight transport, and logistics. For example, container terminals are starting to implement automated equipment such as automated stacking cranes, automated rail mounted gantry cranes, and unmanned vehicle control systems.

“Internet of Things” and “Industrial Internet” have emerged in recent years. The underlying concept is to enable vehicles, travelers, equipment, facilities, and infrastructure to communicate with each other through various data streams by employing wired or wireless technologies (including smart devices). These may lead to two research directions. First, connected vehicles and travelers will be able to share data with all sorts of equipment and make better decisions on a real-time basis. Second, travelers may increasingly be able to procure mobility as a service, rather than purchase vehicles or make other long-term commitments to particular modes of travel, which will change the transport behaviors. The above research directions echo the concept of synchromodality in SteadieSeifi et al. (2014).

Big data and data mining can facilitate the management of transport and logistics. Transport industry and social media can generate huge amount of data. With the development of big data, data mining, and machine learning techniques, non-obvious travel patterns could be discovered, e.g., predicting unsafe transport operators, predicting traffic congestions and crashes, revealing traveler behaviors, and estimating real-time travel demands.

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