Chapter 1
Categorisations of Optimisation Problems in Synchromodal Logistics

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Abstract In this chapter, a view is given on optimisation of synchromodal transportation. For this, a framework is presented to distinguish four quadrants, based on local or global information available, combined with a local or global optimisation goal. We discuss how shifts can be made in this framework and how self-organisation can play a role in it. Next, a second way to distinguish between synchromodal planning problems is presented, based on the presence of uncertainty and the degree of freedom in service network design.

Introduction

In freight transportation logistics, there are various concepts. First there are multimodal and intermodal logistics. A freight network is called multimodal if the transportation of goods can be made via different modes, where a mode is a mean of transportation, such as a barge or truck. In an intermodal network, the goods are transported through a standardised unit of transportation, usually a container. In the last few years also, the concept of synchromodal transportation was introduced. Here the flexible deployment of modes, the possibility of continuous changes of the planning, and a central Logistic Service Provider (LSP), who offers integrated transport to its clients, are introduced.

The presence of such a central LSP suggests that there is a strong control of the system. However, even a big LSP only controls a small part of the total transportation system and might use parts of the transportation system that are out of his direct control. Next to this, the flexible deployment of modes in combination with the continuous changes is often placed in the direction of self-organisation. It is often assumed that it will be too complex, or complicated, for the LSP to control this system. In this chapter, we give some thoughts on the optimisation of

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F. Phillipson (ed.), *Optimisation in Synchromodal Logistics*, Lecture Notes in Operations Research, https://doi.org/10.1007/978-3-031-15655-7_1

a synchromodal transportation system and the role of the LSP in it. We will be touching the complexity of the system and the use and role of self-organisation in it. To elaborate on this, first we will introduce and use a framework that recognises four areas, based on the level of optimisation and the level of information within the logistic system. Next we look at a categorisation using the scope of the problem and the presence of uncertainty in it.

The organisation of this chapter is as follows. First, in section "Context of Synchromodal Logistics", we introduce synchromodality. Then, in section "Literature", we refer to some related chapters in the domain of modelling (complex) intermodal and synchromodal logistics, synchromodal optimisation opportunities, and self-organisation in logistics. In section "Optimisation Framework", we sketch a framework for synchromodal transportation systems based on the level of information and the level of control or optimisation. How an LSP can move its system through this framework by adding information or control is described in section "Changing Position in the Framework". In section "Complexity and Self-Organisation", we elaborate on the complexity of, and the role of self-organisation in, such systems. Next, a second way to distinguish between synchromodal planning problems is presented, based on the presence of uncertainty and the degree of freedom in service network design. We end with some conclusions.

Context of Synchromodal Logistics

Freight transportation plays an essential role in supply chains by providing the efficient movement of feedstock, goods, and finished products between producers and consumers. In the European Union (EU) particularly, freight transport accounts for almost 4.5% of the gross domestic product (GDP), while the shipping carries 90% of the EU's foreign trade [2]. However, freight transport also raises a number of issues such as pollutant emissions, noise, and congestion, which are mainly due to the road transport. A few figures illustrate this assertion. In 2014, about 49% of the total freight transportation in EU countries was done via road, 11.7% via rail, 4.3% via inland waterways, and 31.8% by sea[1] [13]. In terms of pollution, 72.9% of the greenhouse gas (GHG) emissions are due to road transport, 12.8% to maritime, and 0.5% due to railways [11]. To address both the issues of congestion and polluting emissions, a modal shift has become desirable [9]. In order to explain this concept, we will briefly review the existing transport modes.

Nowadays freight transport is mostly carried out using containers of standardised dimensions. These can be loaded and unloaded, stacked, transported efficiently over long distances, and transferred from one mode of transport to another (container ships, rail transport flatcars, and semi-trailer trucks) without being opened. The handling system is completely mechanised such that all handling is done with

[1] There is a certain amount of freight transport carried out by cargo aircrafts. However, this is not relevant for the scope of this chapter.

cranes and special forklift trucks. All containers have their own identification number and are tracked using computerised systems. These aspects make containers a preferable choice for goods transportation. The transportation chain of such containers is partitioned in three different segments [35]: *pre-haul* (first mile for the pickup process at the customer's warehouse for instance), *long-haul* (transit of containers between different ports), and *end-haul* (last mile for the delivery process at the distribution centre). In most cases, the origin or destination of containers is located in the hinterland, and therefore, the pre-haul and end-haul transportation is carried out by road. For the long-haul, however, multiple transportation modes are available such as road, rail, and waterways. In this scenario, we distinguish several types of transportation whose terminology is well-established in the literature. We distinguish between unimodal transportation (transporting load by means of only one transportation mode) and multimodal transportation (using multiple modes). We further elaborate on different types of multimodal transportation (Table 1.1). In *intermodal* freight transportation, a load is transported from origin to destination in one transportation unit without handling the goods themselves when changing modes [35]. The three-segment container transport chain previously described is an example of intermodal transport. *Co-modal* transportation, as defined in [39], is the intelligent use of two or more modes of transport by a (group of) shipper(s) in a distribution system, either on their own or in combination, in order to obtain the best benefit from each mode, in terms of overall sustainability. Synchromodal freight transportation is the next step in terms of development, based on an efficient combination of intermodal and co-modal transportation. The Platform Synchromodality provides the following definition: "Synchromodality is the optimally flexible and sustainable deployment of different modes of transport in a network under the direction of a logistics service provider, so that the customer (shipper or forwarder) is offered an integrated solution for his (inland) transport." [29]. Synchromodality emphasises the following aspects: the usage of various transport modes available in parallel to provide a flexible transport solution, the entrustment of the logistics service provider with the choice of transportation mode, and the possibility to switch in between transportation modes in real time [1].

Table 1.1 Intermodal, co-modal, and synchromodal transport [39]

Kind of transport	Multimodal transport (general term)	
Level of coordination shippers	Use of different modes in one transport from A to B	Use of different modes in a network
No operational logistics coordination between shippers: 1-to-1 link (chain) between user and provider of multimodal transport	Intermodal transport	Co-modal transport
Operational logistics coordination between shippers: many-to-many link (network) between users and providers of multimodal transport	Synchromodal transport	

In view of the existing types of transportation, the modal shift previously mentioned refers to reducing the number of containers transported by road in the long haul by dispatching them on barges or sea vessels in a smart and efficient way based on the cooperation of shippers. In other words, it is a transition from unimodal transport to either intermodal, co-modal, or synchromodal transportation, depending on the resources and the cooperation of the agents in the transportation network. The necessity of this shift has also been recognised by some port authorities [9]. In [30], the Port of Rotterdam Authority presented their goal to reduce the total number of containers transported by truck between the terminals in Rotterdam and inland destinations in North-West Europe from 55% in 2010 to 35% by 2035. For this purpose, a synchromodal network of rail and inland waterway connecting The Netherlands, Belgium, and Germany was initiated by a consortium led by the Europe Container Terminals (ECT) in Rotterdam [39]. The Extended Gate Services (EGS) network is based on the partnership between shipping lines and inland terminals [12]. The inland terminals of Amsterdam, Duisburg, Venlo, Moerdijk, and Willebroek act as virtual extensions of the Rotterdam-based deep sea terminal, in such a way that containers are trans-shipped in minimal time from the deep sea terminal in Rotterdam to the inland terminals.

Literature

In this section, we describe the main papers that give an overview of the problems in modelling (complex) intermodal and synchromodal logistics, the optimisation opportunities, the key factors needed for efficient transportation, and the first attempts on self-organisation in logistics.

Bestas and Crainic [8] describe the players in an intermodal network and the challenges that they face. They look at the shipper's perspectives on intermodal transportation, who has to decide on a certain transportation mode, and at the carrier's perspective, who has to provide an efficient and cost-effective service to the customer.

In [37], Tavasszy et al. give an introduction to synchromodality. The authors discuss the current position and evolution of intermodal transportation, the main elements of the synchromodal transport chain, and the innovations that are necessary to arrive at synchromodal transportation systems. Changes that they suggest that have to be made to the network in order to create a synchromodal system are, among others, the need for an integrated network and service design, an integrated operation and control, contracts that allow synchronised transport, a stronger collaboration, and a mind shift in planning and control. In the following sections, we will put this in a broader context.

The work by Riessen et al. [32] gives an overview of research opportunities in synchromodal container transportation in the case of the hinterland network of European Gateway Services. Their main topics are: optimisation of integral network planning, methods for real-time decision-making, and the creation of flexibility in the network planning problem.

The paper by Pfoser et al. [28] determines the critical success factors of synchromodality. They come up with a list of seven factors, which will be discussed later on in this chapter.

The papers [4–6, 14–16, 41] introduce self-organisation in the complex logistic networks, where logistics can be broader than only transportation and much of their focus is on supply networks and manufacturing. In this chapter, we combine some of the insights from their papers within in the domain of synchromodal logistics.

Optimisation Framework

If we want to optimise a synchromodal transportation system, we propose to look at the level of control in combination with the scope of the optimisation and at the information that is available to the LSP, or other decision makers, for making their decisions on modality choice or assignments. The first view is on the information aspects. Information can be available locally, where only (own) information about the direct neighbourhood is available, or globally, where information about the total system is available. The other view on synchromodal transportation systems is the degree of control and optimisation. Here also a global and local view can be taken. There is a global view when everybody in the system tries to reach, if possible given the level of control, a global optimum. It is local when every decision maker is trying to optimise his own local goal.

In a simple view, as depicted in Fig. 1.1, this can be clustered into four quadrants:

- Limited: information local and optimisation local

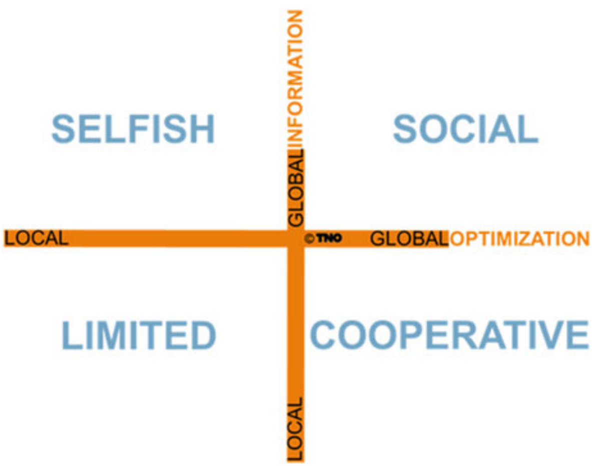

Fig. 1.1 Optimisation framework used in this book

- Selfish: information global and optimisation local
- Cooperative: information local and optimisation global
- Social: information global and optimisation global

Each of these quadrants can be realised, and most of them can be found in practice and in the literature. In the literature, not much is written about the Limited case. Reason for this is that a Limited case is not novel, and from certain perspective, this case can be seen as Social, as explained further in section "Changing Position in the Framework". An example of Selfish can be found in [38], and an example of Cooperative can be found in [20]. Examples of Social are plenty: [7, 17, 22, 23, 27, 33], and [43]. Most practical cases that are described are also Social: Case Rotterdam–Moerdijk–Tilburg, Synchromodality, Case Synchromodal Control Tower, and Case Synchromodale Cool Port control [29]. Lean and Green Synchromodal [29] can be seen as a Selfish case.

Changing Position in the Framework

Not all positions in the framework of Fig. 1.1 are as rewarding for the LSP. A shift from one quadrant to another could be interesting. First note that in [28], seven critical success factors of synchromodality are discussed:

1. Network, collaboration, and trust
2. Awareness and mental shift
3. Legal and political framework
4. Pricing/cost/service
5. ICT/ITS technologies
6. Sophisticated planning
7. Physical infrastructure

The question now is whether these factors can influence the position of the LSP in the framework, or, what changes in these factors are needed to make a shift between quadrants in the framework?

If we look at Fig. 1.1, most LSPs start in a "Limited position" from a macro view. This means, viewed from the outside, considering the whole logistic system. The LSP only uses his own information and tries to optimise his own business, not bothering (too) much about the world around him. However, the LSP might see this as a social case, as for the system that he controls, he has all the information and he has the total system under control. This was one of the reasons the Limited area is not described much in the literature; from the limited perspective of this LSP, this looks like a social environment. Think, for example, of an LSP that controls trucks, barges, and trains in his own network. In this network, the LSP acts as social. However, the used roads, railroads, ports, and other infrastructure are also used (and controlled) by other parties, making it a limited system from the macroview. When the LSP wants to shift to a Selfish or Cooperative system, he has to add some of the critical success factors to the system.

In the shift from Limited to Selfish (vertical step), there is a need for global information. This starts by using the freely available information about traffic and other resources, offered by road or port authorities. This is a step that contains no natural barriers, and an LSP is expected to make this shift, where it will improve his information position and thus, in expectation, the quality of his decisions, reaching a better solution. This step requires a good information system from the authorities, ICT/ITS connections, and the ability to use the information (automatically) in his planning process. Further information, from the logistic chain, to use infrastructure or modalities from other commercial, competing parties, gives rise to the need for trust (to share information), awareness, mental shift, and, again, good technology and planning capability.

The step from Limited to Cooperative (horizontal) is less natural. This requires collaboration, trust, a legal framework, and good technology. Again, there is an expected gain for the total system due to the cooperation, or, given incentives, reaching a system optimal solution. However, sharing these benefits is a tricky one, as it requires a mental shift to receive the willingness of being controlled. Legal agreements and a lot of trust are needed. The expected gain is motivated by Roughgarden and Tardos [34]. They show that Selfish, here meaning locally optimising, systems have their price: they prove that travel times induced by selfish agents might be the same as the total travel time incurred by optimally routing twice as much traffic and indicate, as in [36], that adding central control or incentives gives an overall improvement of the system. However, in networks with high load, the performance might not suffer too much, as can be found in [26].

The shift from Selfish to Social (horizontal) asks the same or even more trust, collaboration, and sharing as the previous step. Here again all parties have to obey (one single) authority. Here also the sophisticated planning is needed and some mechanism to share the benefits of the total optimisation.

The shift from Cooperative to Social (vertical) is again expected to be easier where there will be a natural intention to gather available information to be used in the planning. Again, the sharing of information between the commercial parties and/or within the logistic chain is harder to organise.

We can conclude that the horizontal shifts are quite hard to make, where this asks the willingness of being controlled and the trust in sharing the benefits of the shift. The vertical shifts are ambivalent. It is a natural step to gather information to use in the own planning, so gathering the information available from road and port authorities and other open data sources is expected. Going a step further and sharing information within the logistic chain and between competitors will be harder. This gives rise to two additions to Fig. 1.2, first to add subclasses between the vertical classes, where public information is used. Next, we introduce a third dimension, the total wealth, that indicates the gain to be realised by making the shifts, motivated by [34]. This is shown in Fig. 1.3. Limited is expected to realise the lowest value, and then Selfish, Cooperative and Social the highest value.

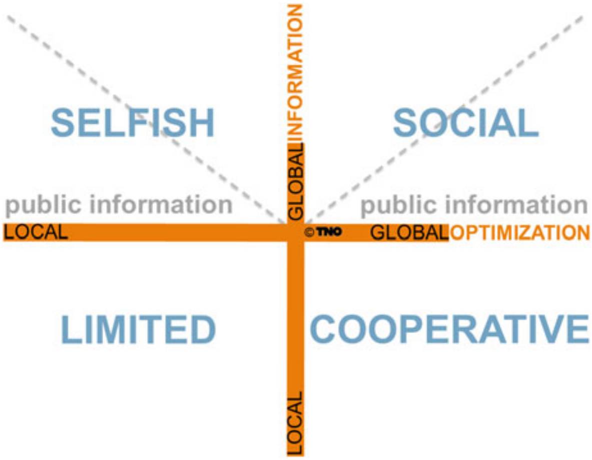

Fig. 1.2 Enhanced framework

Fig. 1.3 Adding a third dimension: objective values

Complexity and Self-Organisation

Where in the case of the Social state a sophisticated planning is needed, from a mathematical point of view, this could be the easiest state. Information is available globally; the agents are controllable and obey some global authority. The Selfish and the Cooperative states, however, have properties that bring them in the context of complex adaptive systems. A description of complex adaptive systems is found in the work by Arthur et al. [3], who identify six properties that characterise any economy: dispersed interaction, the absence of a global controller, cross-cutting hierarchical organisation, continual adaptation, perpetual novelty, and far-from-equilibrium dynamics. However, where they speak of any economy, they point out that these features apply as well to any complex adaptive system [19].

In the Selfish system, the complexity is most obvious, where there is a lack of a global controller, dispersed interaction, and continual adaption of behaviour of the individual agents on the observed state of the system. Describing the system would be a first step to identify possible incentives to steer the system, perhaps unconsciously, in the direction of the Social system.

The Cooperative state looks less complex on first sight. Here we have local controllers who can take care of some level of organisation. However, the absence of global information will cause strong adaptive reactions on decisions of others, making it less predictable as a whole.

What role can self-organisation play here? The work in [5] indicates that "Minimal data requirements" and "Adaptivity" are expected in systems that use self-organisation, what makes both the Selfish and the Cooperative state a logical application area for Self-organisation. Self-organisation is also known under other terms such as autonomous cooperation and control, self-management, and self-regulation. This is defined by Windt and Hülsmann [40] as: "decentralised decision-making in hierarchical structures, presuming interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions". There is a trend in calling the logistic system a Physical Internet [24], and the comparison is made with the, apparent, self-organisation of the Internet. Then self-organisation is thought of as the solution for logistic systems, making it a goal in itself. The containers will flow through the Physical Internet as data packets through the Internet. But is the Internet really self-organising? Actually not, the data packets do not make a decision themselves. They are controlled by the routers that have some basic rules on routing schemes. Not really adaptive also, the packets do not interact, which are managed by the sender of the packets, where a TCP protocol, Transmission Control Protocol [31], waits for an acknowledgement and sends the packet again, when it takes too much time. Or, the UDP protocol, User Datagram Protocol [31], that sends it once, assuming that the arrival of a number of packets less will not be of impact on the experienced performance of the receiver. Not really comparable to the flow of containers. The Internet can be considered self-healing in some way, however. Within the framework of the previous section, the Internet can be placed in (as expected) the cooperative part. A single controller, router on the Internet, has no global view and takes decisions based on, mostly static, routing rules. The routing rules try to realise a global optimal solution.

This means that self-organisation and decentralised decision-making do not necessarily mean having smart, selfish, entities on the lowest level. Then the selfish behaviour will lead to poor overall network performance. It can mean smart decomposition, decentralising, or distributing of decision power, but keeping it as high in the hierarchy as possible, and not using more information than strictly necessary. This kind of self-organising networks will end, in Fig. 1.1, somewhere on the border between Social and Cooperative. It is important not to see self-organisation on the lowest hierarchical level as the ultimate goal. First the general goal has to be identified. If that goal is an adaptive, scalable, or robust transportation schedule, then control on the lowest level is not the only medicine, also control on higher levels, and robust, or disruption tolerant, planning can be useful.

Uncertainty and Scope of Optimisation

Next to level of optimisation, availability of information, and possible complexity, there are two other important aspects that make a logistic problem synchromodal. These aspects are the presence of uncertainty and the scope of the optimisation.

The uncertainty can be in many parts of the logistic system, as shown in [21]. Uncertainty can be in demand, supply, or arrival of goods at the client, availability of resources and within the transportation process, think of travel times, failures in equipment, etc.

For the scope of the problem, both assignments of goods to modalities can be considered, as the operations of the vehicles (routes, departure times, etc.). The latter part is often known as service network design [10], which has a part that is not flexible at all, think of the location of (rail) roads and water ways, and more flexible parts such as timetables and routing. The latter part can also be taken into account at the (tactical) service network design phase, but especially in synchromodal logistic problems, this is often taken into account during the (more) operational planning phase.

In Fig. 1.4, these elements are combined into 4 regions of problems. In the first region, the events or orders to be assigned are not uncertain (fixed) and the infrastructure (vehicles) has fixed schedules. These are common assignment or planning problems; examples can be found in [20, 22, 23, 38]. In problem 2, uncertainty or stochasticity is added, making it a, more complicated, problem of assignment or planning under uncertainty, as shown in [18, 42]. In the third problem both the orders and the infrastructure needs to be planned. This gives a high degree of freedom, resulting in a larger problem to be solved. Examples of this approach can be found in [7, 25, 33]. The fourth problem brings uncertainty to the third problem. This problem is discussed in [27, 43].

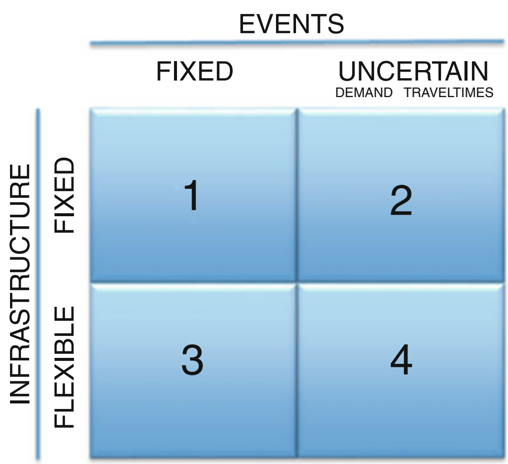

Fig. 1.4 Four types of problems

Conclusion

When optimising a synchromodal transportation system, we proposed to look at the level of control, in combination with the scope of the optimisation, and at the information that is available to the decision makers. This resulted in a framework with four main areas. We showed to expect that there is a natural drive to reach the top right area, where the total expected wealth will be maximal. However, allowing total control and sharing information will be a big hurdle to reach this state. Staying at other states, Cooperative or Selfish, some level of decentral decision-making is expected. We argued that self-organisation, meaning putting control at the lowest level, should not be the ultimate goal. Keeping the control as high as possible, smart decomposition, using the available information and robust planning, is expected to realise better results. A second way to classify problems in synchromodal logistics, we looked at uncertainty and the scope of the problem. Both ways of classifying will be used throughout this book, and we try to give an overview of various approaches to span both types of classifications.

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