AN APPLICATION OF A SYNCHROMODAL MATURITY MODEL

K.M.R. Alons-Hoen, Fontys Hogescholen

G.H.L. Somers, Fontys Hogescholen

J.H.R. van Duin, Hogeschool Rotterdam / TU Delft

Samenvatting

This article shows the results of our study to determine the general level of synchromodal maturity for shippers and logistics service providers operating in The Netherlands and Belgium. A questionnaire was used to assess the maturity of synchromodal transport for 41 companies. This research extends the literature by applying the model to a broader setting. Although 41 companies provide some good insight on the Key Performance Indicators (KPIs), generalization cannot be made on the findings. In this study most results were obtained for logistics service providers and shippers. It was observed that shippers in general are more mature in synchromodal transport, except for decision-making power. The higher score for data exchange for shippers seems to suggest that vertical collaboration is strongly supported by data exchange. Our study shows that most companies are more mature in the areas of decision-making power and transport planning. On the other hand, transport execution, pricing and type of relationships are lagging. The lagging of transport execution could be explained by absence of a frequent and dense intermodal transport network. Next to that, collaboration between different parties is critical for successful implementation of synchromodality. Comparing the scores between companies within the Netherlands and Belgium similar patterns can be observed when comparing shippers and logistics service providers. Future research will focus on further benchmarking the maturity levels of synchromodality in Europe.

1. Introduction

The transport sector is vital in today's global economy. It is continuously under pressure to transport goods more efficiently, and effectively, from origin to destination. The pressure originates from different directions. Congestion on road networks has a negative impact on the environment and makes travel times unreliable. Moreover, expected increase of oil prices, road toll, and legislation aimed at achieving greenhouse gas emission targets for 2050 (European Commission, 2011), make it economically profitable to use transport solutions that use fuel more effectively.

One trend that can be observed in making transport more effective is to increase the sizes of intercontinental container vessels. As this obviously, reduces transport costs per container on the intercontinental leg. A downside of this development is that it results in an increased peak demand in the ports in terms of unloading, custom checks, and preparing the containers from transport to the hinterland. This again results in more traffic jams close to the ports.

Moving from road transport to intermodal transport results in (slightly) decreased transport costs but leads to an increase in lead-time. Longer lead times mean more inventory in the pipeline, and this was traditionally a reason to select road transport. As road transport becomes more expensive and unreliable, due to growing congestion, intermodal transport is becoming more attractive. However, also intermodal transport is not without issues and large delays are common practice. Synchromodal transport aims to overcome these downsides by focusing on transport integrally. SteadieSeifi, Dellaert, Nuijten, Van Woensel and Raoufi (SteadieSeifi, Dellaert, Nuijten, Van Woensel, & Raoufi, 2014) describe synchromodal transport as structured, efficient, and making synchronized use of multiple modalities. This type of transport combines intermodal with road transport and uses it in an optimal way taking into account the current conditions of the network, including the actual situation around the port.

The following definition of synchromodal transport is taken from (Somers & Tissen, 2015): *'Synchromodality is the transport of maritime freight flows from port to hinterland destination or vice versa - without changing the load unit - whereby real-time changes can be made in the flexible and sustainable use of different transport modalities in a network. The logistics service provider has the control to offer optimally integrated solutions for all parties.'*

The aspects of real-time changes and flexibility are the most important changes compared to multimodal, or intermodal transport. Van Riessen, Negenborn and Dekker (Van Riessen, Negenborn, & Dekker, 2015) consider synchromodal transport as intermodal planning with the possibility of real-time switching between the modes or online intermodal planning. To ensure real-time planning it is required that real time information from many sources is combined. This information has to come from different partners in a supply chain. Therefore, a good relationship between partners is required to get the best overview of the current state of the network and plan accordingly.

The benefits of synchromodal transport for shippers result in reduced transport times, better prices, and/or improved reliability, compared to intermodal transport. Shorter transport times can also be achieved by responding adequately to disruptions to increase reliability. Real time insight into available capacity on intermodal transport will increase utilization and therefore reduce costs per shipped container for both the operational service provider and the logistics service provider.

The remainder of this article is structured as follows. The research methodology is described in Section 3. Subsequently, the results of the questionnaire are described in Section 4. Lastly, conclusions are drawn regarding the application of synchromodal transport and directions for future research are described in Section 5.

2. Background

Synchromodal transport has recently seen a large increase in number of scientific publications: over 25 in the period 2012-2018 (van Duin, Warfemius, Verschoor, de Leeuw, & Alons-Hoen, 2019) and the number is growing steadily, see for example (Dong, Boute, McKinnon, & Verelst, 2018), (Lemmens, Gijsbrechts, & Boute, 2019), (Pérez Rivera & Mes, 2019), and (Pfoser et al., 2018). In practice, however, synchromodality is implemented only on a limited scale. It is stated that the concept of synchromodal transport originated in the Netherlands. It has received increasing attention in the scientific literature in the past few years. It is now also being investigated in other geographic regions: in Austria (Ponweiser et al., 2016), in Greece (Kapetanis, Psaraftis, & Spyrou, 2016), and in Ghana (Agbo, Li, Atombo, Lodewijks, & Zheng, 2017). Implementation in practice is scarce, since there are some difficult issues that have to be resolved before implementation, especially in the area of horizontal collaboration and willingness to share data. Technological advances in the field of transport and transport modes provide new opportunities for synchromodal transport. Pfoser et al. (Pfoser et al., 2018) investigate the impact of high-performance transport modes, such as hyperloop, in synchromodal networks and conclude that it provides mutual benefits.

The first study on the acceptance and implementation of synchromodal transport based on critical success factors is the article of Pfoser, Treiblmaier, and Schauer (Pfoser, Treiblmaier, & Schauer, 2016). Another study (van Duin et al., 2019) investigated the success and fail factors of synchromodal transport applied to a case study in the Port of Rotterdam. This provided guidance on which factors were necessary for a successful implementation. In a maturity model the changes that are required for implementation are divided over five levels, each with an increasing level of maturity of the process (Lockamy III & McCormack, 2004; Paulk, Curtis, Chrissis, & Weber, 1993). The maturity model for synchromodal transport has been developed by and first described in Alons-Hoen and Somers (Alons-Hoen & Somers, 2017). It has been developed to aid companies in moving towards synchromodal transport. The maturity model is used for companies to indicate the current level they are operating on and identify areas in which improvements can be made to move towards a more mature process. Alons-Hoen, Somers and van Duin (Alons-Hoen, Somers, & van Duin, 2019) have applied the maturity model to case studies in Belgium and the Netherlands. In this study strong vertical collaboration between logistics service providers and shippers was observed, as was a-modal shipping. Horizontal collaboration was observed as a hurdle and hampered synchromodal transport, as did the corresponding data sharing. Trust issues seemed to be blocking these factors.

This article contributes to this field of literature presenting results of an exploratory case study in which the synchromodal maturity model is applied in practice, which represents the current state of synchromodality for shippers and logistics service providers and identifies focus areas for the future. By presenting case results from an application of the synchromodal maturity model in practice to a broader region and a larger group of respondents, it allows for comparison with the results of (Alons-Hoen et al., 2019) and to observe changes over time.

A maturity models consists of levels, and a set of key process areas. The combination of levels and key process areas is the full description of the model. The synchromodal maturity consists of the following five levels:

1. Ad-hoc intermodal transport
2. Structural intermodal transport
3. Synchromodal transport
4. Synchromodal transport with real-time planning and capacity
5. Extended synchromodal transport

The seven key process areas, or components, for the synchromodal maturity model are:

Transport execution: the way in which transport is executed.

Transport planning: the way in which transport is planned (planning horizon, and granularity).

Data exchange: the data requirements for correct execution of the planning.

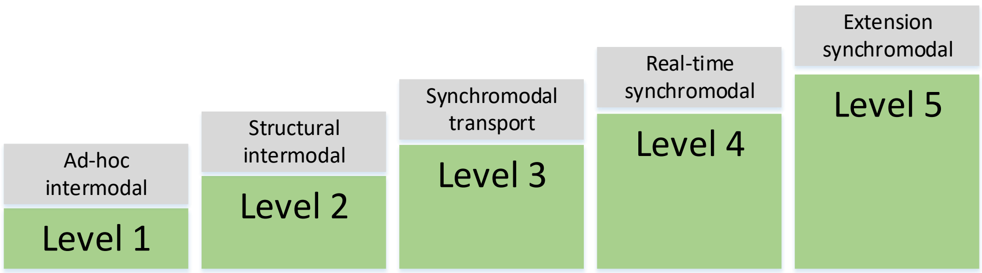
Key performance indicators: the way in which feedback is given about the performance of the operational processes.

Decision-making power: which stakeholder can decide how and when the transport is executed.

Type of relationship: degree of horizontal and vertical collaboration in the supply chain.

Pricing: how the tariffs are set and how payment takes place.

For a detailed description of the changes for each of the levels and the changes per role per level, see (Alons-Hoen et al., 2019).



Execution of transport	Truck => 80%	**Train or barge => 40%**	Train or barge => 60%	Train or barge => 80%	Train or barge =100%
Transport planning	Ad-hoc, no forecast	0-40% planned based on forecast	41-100% planned based on forecast	**Real time orders in supply chain**	**Real time orders and stock levels**
Data exchange	Per container	Forecast per customer	Forecast per customer	**Control tower to share data with more parties**	Control tower + real time stock levels
Key performance indicators	Price and time	Price and time per modality	Price, time, reliability	Price, time, reliability and utilization degree	Price, time, reliability, utilization degree and service level
Decision making power	Shipper 81-100% of orders	More than 20% a-modal booking by other party	**Orders shared in supply chain**	Real time orders in supply chain	Real time stock level in supply chain
Type of relationship	Transactional	**Limited vertical**	Intensive vertical, limited horizontal	Intensive vertical and horizontal	**Intensive vertical and horizontal + real time stock levels**
Pricing	Spot market	Alignment on tariff (tender)	**Tariff per modality and a-modal booking**	**A-modal booking and a modal pricing**	A-modal booking, a modal pricing and real time stock levels

Figure 1: Synchromodal maturity model (Alons-Hoen et al., 2019)

3. Methodology

This research is the result of a collaboration between four universities within the Netherlands and Belgium. This consortium trains researchers and lecturers to assist students with the questionnaire using train the trainer sessions.

The maturity model of Alons-Hoen et al. (2019) is further developed by the same consortium. For each of these seven key process areas one or more closed questions are created in order to define the maturity level per key process area. Based on the answers of the company, an algorithm defines the level of maturity and automatically generates a report to explain why a certain company is at a given maturity level. All answers are stored in the project's database for analysis (benchmarking) on regions, branches or company types.

The report describes the current state of intermodal and synchromodal transport of a company, including a benchmark with similar companies in the database. Moreover, advice is given on how the company can improve to a higher level of synchromodality.

Workshops are provided to students on how to apply the Maturity model, including fictional cases. The goal of these workshops is threefold: students are explained what intermodal and synchromodal transport is, they learn how to understand the maturity model and finally how to work with the online questionnaire in relation to the maturity model.

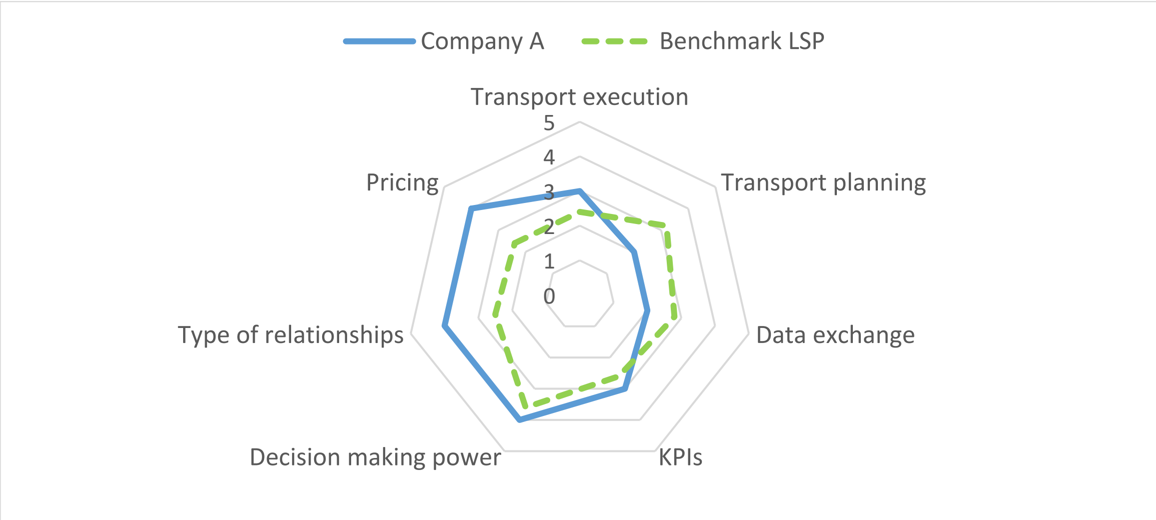


Figure 2: Example of a company benchmark

The application of the maturity model is integrated in the study programs of the universities and students receive credits for application of this model. Students are instructed which companies to approach and how to interview them using the online questionnaire. They select companies that are already familiar with intermodal transport in their own region. After the students filling in the online questionnaire using the responses of the company, students receive an automatically processed report from the research consortium, based on given answers by the company. Based on this general report, students plan a new appointment with the company to specify the advice for the specific situation and strategy of the company.

4. Analysis and discussion of results

In this section, the findings from this research are presented. In Section 4.1 the similarities and differences between the intermodal networks in Belgium and the Netherlands are described. Next, general observations and the synchromodal scores per role and component are investigated in Sections

4.2, and 4.3, respectively. Lastly, interesting relationships between two components are discussed in Section 4.4.

4.1. Freight statistics Netherlands and Belgium

The European waterway network accounts for 51,700 kilometers. The Netherlands has 5,046 kilometers of rivers and channels of which 4,800 kilometers is used for freight transport (Waterways, 2020). Belgium has a waterway network of 1,520 kilometers of which 60% has the capability to serve vessels with a loading capacity of 1,350 tons. The geographic locations of the most important rivers Rhine, Maas and Schelde make the ports Rotterdam and Antwerp important as gateways to Europe (hinterland). The railway connections (The Betuwelijn in the Netherlands and the Iron Rhine in Belgium) are also supportive in this function of the ports. The Netherlands has 3,223 kilometers railways and Belgium has 3,592 kilometers railways (de Vries, 2016).

The modal split in the Netherlands is 44% road transport, 35% coastal feeders, 18% inland shipping and railways just 2% in 2018 (Waterways, 2020). For Belgium, the data are a bit older. In the period (2002-2006) road transport accounts for 78%, inland shipping for 12% and railways for 10% (de Vries, 2016). The remainder is airfreight and pipelines.

4.2. General observations

Over the course of 2019 and 2020, 41 companies have been interviewed, in the Netherlands and Belgium, using an online structured web-based questionnaire to assess the scores for each key process area of the synchromodal maturity model. The interviewees were responsible for decision making for transport in their supply chain. Two of the interviewed companies were not located in Belgium, or the Netherlands. Out of these 41 companies, the majority are logistics service providers (LSPs) involved with continental shipping in Europe (15). This distribution over the different roles is not representative of the overall population as some roles are underrepresented. No responses were obtained for terminal operators. Care has therefore to be taken when interpreting the results. In detailed analysis per role is executed for LSPs and shippers only.

Table 1: Company role and corridor

	Continental	Intercontinental	Unknown	Total
LSP	15	3	5	23
Forwarder			1	1
Hinterland operator	1			1
Shipper/ manufacturer	7	6	2	15
Terminal operator				0
Total	24	9	8	41

The number of containers that are shipped by the forwarders, hinterland operators, and shipping lines is rather low compared to the logistics service providers and shippers in this sample, as can be seen in TABLE 2.

Table 2: Classification of TEU turnover per role (#number of companies)

	0-500	1500-3000	3000-6000	500-1500	>6000
LSP	0	0	0	1	0
Forwarder	0	0	0	0	1
Hinterland operator	1	6	3	1	10
Shipper/ manufacturer	2	3	2	1	5
Terminal operator	0	0	0	0	1
Total	3	9	5	3	17

Information was gathered regarding the use of the different modalities in the Netherlands and Belgium. Companies ranked the three modalities (road, rail, and barge) and the results are summarized in TABLE 3. Barge is mentioned more often as option 1 or 2 in the Netherlands, and rail is mentioned more often as option 1 or 2 in Belgium. These results are in line with the statistics about infrastructure in the Netherlands and Belgium, as mentioned in Section 4.1. Within the Netherlands, there are more waterways available for freight transport. On the contrary, in Belgium there are more railways available for freight transport. So, there seems be to be a clear relation between the availability of infrastructure and its use.

Table 3: Ranked usage of modalities

	Netherlands		Belgium		Other		Total	
1. Road	24	75%	4	57%	2	100%	30	73%
1. Rail	3	9%	2	29%	0	0%	5	12%
1. Barge	5	16%	1	14%	0	0%	6	15%
2. Road	5	16%	1	14%	0	0%	6	15%
2. Rail	12	38%	4	57%	1	50%	17	41%
2. Barge	15	47%	2	29%	1	50%	18	44%
3. Road	3	9%	2	29%	0	0%	5	12%
3. Rail	17	53%	1	14%	1	50%	19	46%
3. Barge	12	38%	4	57%	1	50%	17	41%
Total	32		7		2		41	

For each company the scores for the key process areas of the maturity model are determined. The resulting scores of the 41 companies for the different levels of each key process area are shown in TABLE 4. The key process areas can be divided into areas with an intermodal focus (mainly score 1 or 2) and areas with a synchromodal focus (mainly score 3-5). Transport execution belongs to the first group, and the second consists, in decreasing order, of decision-making power, transport planning, relationship, KPIs, and data exchange. For pricing the distribution is almost equal. Transport planning, KPIs, and decision making also have a significant share of level 4 and 5 observations. These results suggest that the execution of intermodal transport and pricing are lagging.

Table 4: Ranked usage of modalities

Maturity level Key process area	1	2	3	4	5	Total
Transport Execution	15	9	10	2	5	41
Transport planning	10	2	3	7	19	41
Data exchange	1	16	12	12	0	41
KPIs	11	5	8	9	8	41
Decision making power	10	1	15	3	12	41
Type of relationships	11	4	20	4	2	41
Pricing	7	15	12	5	2	41

The average scores per factor are given in TABLE 5. The first conditions are already in place: planning, decision making power, and relevant KPIs. However, the relevant horizontal collaboration seems to be behind, as well as the necessary data exchange. Overall, it can be observed that transport planning gets a high score and transport execution on average the lowest score.
It is interesting to investigate which of the 7 components of the maturity model is the best predictor of the total score of the company. The total score of the company was based on the median score of the 7 components. To this the end, the share of the companies for which a particular score on the factor matches the overall score is counted. The results are shown in TABLE 5. The relationship type has the highest score. It means that for 22 companies the score on relationship type reflects the total score of the company. It seems a necessary condition for companies to achieve a level of synchromodality.

Table 5: Component versus overall score

Component	Average score	Predicting score
Transport Execution	2.34	0.34
Transport planning	3.56	0.29
Data exchange	2.85	0.44
KPIs	2.95	0.34
Decision making power	3.15	0.39
Type of relationships	2.56	0.54
Pricing	2.51	0.46

4.3. Synchromodal scores per role

Next, the average score was calculated for each company, and then the average score for all companies in the same role. Since only one observation was obtained for forwarders, hinterland operators, and shipping lines, the corresponding scores of these companies will not be used in the analysis in this section. The average score per role and the standard deviation is calculated for the roles with more than one observation; the results are shown in TABLE 6. The numbers behind the role indicate the number of interviewed companies.

Table 6: Average maturity scores per component (and standard deviation)

Component	Logistics service provider (23)		Shipper/ Manufacturer (15)	
Transport Execution	2.26	(1.63)	2.47	(0.99)
Transport planning	3.35	(1.87)	3.87	(1.25)
Data exchange	2.70	(0.97)	3.07	(0.70)
KPIs	2.43	(1.38)	3.67	(1.50)
Decision making power	3.65	(1.30)	2.40	(1.50)
Type of relationships	2,43	(1.34)	2.87	(0.74)
Pricing	2.43	(1.12)	2.87	(0.92)
Overall	2.75	-	3.03	-

It can be observed that shippers or manufacturers have a higher average score than logistics service providers. Based on these results it can be concluded that intermodal transport is used a lot and some companies are obviously moving towards synchromodal transport.

Shippers or manufacturers have a high score on transport planning, KPIs, relationship type, and pricing. This suggests that the shippers in general have a good relationship with their logistics service provider, providing them the required data and agreeing on pricing. At level 3 reliability is added as a KPI, while this seems to be very important to companies these days due to possibly large delays in transport. It could be expected that the scores for decision making power and pricing are more in line. As level 3 involves a-modal booking and a-modal pricing. However, this is not observed in the data.

Logistics service providers get a high score on decision making power. A high level facilitates their business and is therefore to be expected. In general, it can be concluded that companies have a high score on factors that are in line with the role of the companies and what is most important to them. This provides some validity for the maturity model. It is striking that for LSPs transport execution has the lowest average score but the second highest score on variation. This suggests that there are a few exceptions that are ahead. For shippers the same holds true for decision making power.

Next to the scores per role, the scores per component per country of origin are compared; the results are presented in FIGURE 3. Companies situated in Belgium obtain a higher score on the components Transport execution, KPIs and Relationship Type. On the other hand, companies from the Netherlands score better at Transport planning and Decision-making power. These high scores on transport planning and decision-making power for companies located in the Netherlands can be explained by the fact that the majority of the companies can be classified as logistics service providers. Based on this data, the role of the company provides a better explanation for the scores, than the country.

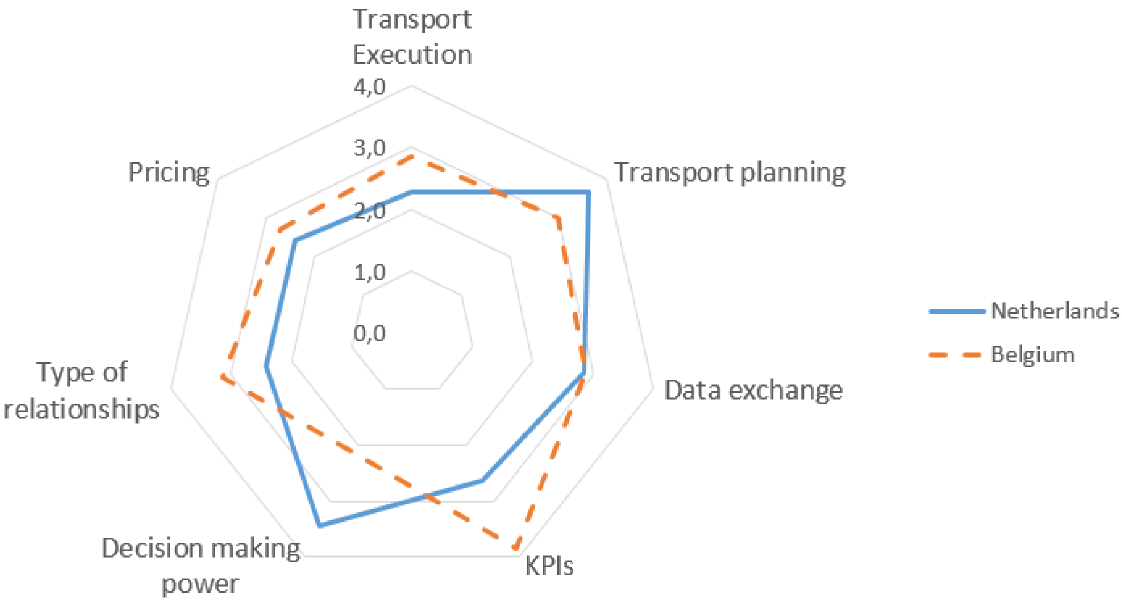


Figure 3: Average maturity scores per country of origin

4.4. Relation between synchromodal components

TABLE 7 shows the correlations between the different components of the maturity model. It is striking that there are 5 negative correlations, i.e., a higher score on one component implies a lower score on another. The expectation of the maturity model is that a higher score on one component enables a higher score on another factor. However, most of the negative and several almost 0 correlations are obtained for the transport execution factor. A possible explanation is that companies may want to use intermodal or synchromodal transport, but the usage is restricted due to insufficient or untimely capacity.

The strongest correlations are observed for data exchange and transport planning, and relationship and KPIs. A proper data exchange is required to perform a more sophisticated transport planning. In addition, companies that value reliability typically seem to have a stronger relationship with their logistics partners. Lastly, there are a few combinations of factors with an almost 0 correlation, e.g., decision making power and relationship. For a few cases, the score for decision making power outweighs the relationship score. One might think that a good relationship is a basis for stronger decision-making power, but this is not supported by the data.

Table 7: Component versus overall score

Component	Transport Execution	Transport planning	Data exchange	KPI's	Decision making power	Relationship type
Transport Execution	-0.16					
Transport planning	-0.02	0.68				
Data exchange	0.03	-0.03	0.03			
KPIs	0.06	0.29	0.37	-0.32		
Decision making power	0.12	0.05	0.16	0.51	0.02	
Relationship type	0.12	0.05	0.16	0.51	0.02	
Pricing	-0.14	0.20	0.05	0.22	0.09	0.35

For all of the factors for which a higher score is obtained than for the others there seems to be an improvement potential. Higher scores are already obtained for transport planning, decision making power, and KPIs. This shows that companies value the conditions that form the foundation for synchromodal transport but that companies can progress in data exchange, transport execution, relationship and pricing.

5. Conclusions

Our study shows that most companies are more mature in the areas of decision-making power and transport planning than other areas. This implies that companies are already capable of planning intermodal transport. Synchromodal transport occurs when logistics service providers can choose the right modality. Transport execution, pricing and type of relationships are lagging. The lagging of transport execution could be explained by absence of a frequent and dense intermodal transport network for the region under consideration. Next to that, collaboration between different parties is critical for successful implementation of synchromodality (Pfoser et al., 2016), and it was observed in this study that it needs to improve in the near future to take synchromodal transport to the next level.
In this study most results were obtained for logistics service providers and shippers. It was observed that shippers in general are more mature in synchromodal transport, except for decision-making power. Higher score for data exchange for shippers seems to suggest that vertical collaboration is strongly supported by data exchange, in line with the conclusion of (Alons-Hoen et al., 2019). Comparing the scores between companies within the Netherlands and Belgium similar patterns can be observed: companies in the Netherlands score better on transport planning and decision-making power. The concept of synchromodal transport is developed within the Netherlands and therefore the Dutch companies seem to be exploiting the benefits of this relatively new concept more.

A high correlation is observed between transport planning and data exchange, since you need to have sophisticated data exchange to perform complex transport planning. Next to that, when collaboration is stronger also more advanced KPIs are used to measure the performance and relationship between parties. Especially reliability is an important KPI since shippers outsource the choice of route, modality and trip.

It can be concluded that in order to take synchromodal transport to the next level both a denser intermodal transport network and horizontal collaboration between logistics service providers is necessary, where the latter is in theory easier to implement. Recent advances in technology, like platforms to exchange information with proper security of sensitive data, seems a promising avenue.

In the current study few observations were collected for shipping lines, hinterland operators, and terminal operators. To get a complete picture of the state of synchromodal transport a follow up study that particularly investigates the state of the synchromodal transport for the suppliers of the transport capacity is required. Our database includes results of several studies. Based on these outcomes, only limited benchmark analyses can be made for some company types. This follow-up study will enrich the benchmark, and allow for a more complete view of the current state of intermodal transport.

Within this study, companies from Belgium and the Netherlands are interviewed. However, the goods flow and accompanying container flows within Europe do not stop at the borders of these two countries. To increase the impact on the continental transport of containers within Europe this research can be broadened to other regions within Europe. Supporting this ambition further application of this model in other European countries can help progress towards sustainable container transport. The consortium of research partners has been extended with universities from the Netherlands, Belgium, Germany, Poland, Romania, and United Kingdom. This project intends to broaden the application of the model to different countries and regions in Europe. The expansion to other research areas will, at the same time, enrich our database for benchmarking and research purposes.

Acknowledgements

This research was executed as part of the project Synchro Maturity Model 3.0 funded by Connekt, KennisDC Zuid-Holland and Limburg. The authors would like to thank Rick van Well for his contribution to this research with the development of the online questionnaire tool and analysis of the data.

References

Agbo, A. A., Li, W., Atombo, C., Lodewijks, G., & Zheng, L. (2017). Feasibility study for the introduction of synchromodal freight transportation concept. *Cogent Engineering, 4*(1). doi:https://doi.org/10.1080/23311916.2017.1305649

Alons-Hoen, K. M. R., Somers, G., & van Duin, R. (2019). Moving from intermodal to synchromodal transport: a maturity model applied to a case study in Northwestern Europe. *Transportation Research Board, 19-00118*.

Alons-Hoen, K. M. R., & Somers, G. H. L. (2017). Ontwikkeling van een maturity model synchromodaal transport in het project SYN-ERGIE. *Logistiek+, 4*, 84-117.

de Vries, K. (2016). The Power of Inland Navigation. The future of freight transport and inland navigation in Europe. Retrieved from https://www.bureauvoorlichtingbinnenvaart.nl/assets/files/WaardeTransport_spreads-UK.pdf

Dong, C., Boute, R., McKinnon, A., & Verelst, M. (2018). Investigating synchromodality from a supply chain perspective. *Transportation Research Part D: Transport and Environment, 61*, 42-57.

European Commission. (2011). *Roadmap to a Single European Transport Area-Towards a competitive and resource efficient transport system*. Retrieved from Retrieved from https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en

Kapetanis, G. N., Psaraftis, H. N., & Spyrou, D. (2016). A simple synchro–modal decision support tool for the piraeus container terminal. *Transportation Research Procedia, 14*, 2860-2869. doi:https://doi.org/10.1016/j.trpro.2016.05.403

Lemmens, N., Gijsbrechts, J., & Boute, R. (2019). Synchromodality in the Physical Internet–dual sourcing and real-time switching between transport modes. *European Transport Research Review, 11*(19).

Lockamy III, A., & McCormack, K. (2004). The development of a supply chain management process maturity model using the concepts of business process orientation. *Supply Chain Management: An International Journal, 9*(4), 272-278. doi:https://doi.org/10.1108/13598540410550019

Paulk, M. C., Curtis, B., Chrissis, M. B., & Weber, C. V. (1993). Capability maturity model, version 1.1. *IEEE software, 10*(4), 18-27.

Pérez Rivera, A. E., & Mes, M. R. (2019). Integrated scheduling of drayage and long-haul operations in synchromodal transport. *Flexible Services and Manufacturing Journal, 31*(3), 763–806. doi:https://doi.org/10.1007/s10696-019-09336-9

Pfoser, S., Berger, T., Hauger, G., Berkowitsch, C., Schodl, R., Eitler, S., . . . Prandtstetter, M. (2018). *Integrating High-Performance Transport Modes into Synchromodal Transport Networks.* Paper presented at the International Conference on Dynamics in Logistics.

Pfoser, S., Treiblmaier, H., & Schauer, O. (2016). Critical success factors of synchromodality: Results from a case study and literature review. *Transportation Research Procedia, 14*, 1463-1471. doi:https://doi.org/10.1016/j.trpro.2016.05.220

Ponweiser, W., Putz, L.-M., Prandtstetter, M., Lenz, G., Pfoser, S., & Haller, A. (2016). An introduction to synchromodal networks in Austria.

Somers, G., & Tissen, K. (2015). *Synchromodaliteit Literatuuronderzoek*. KennisDC Logistiek Limburg.

SteadieSeifi, M., Dellaert, N. P., Nuijten, W., Van Woensel, T., & Raoufi, R. (2014). Multimodal freight transportation planning: A literature review. *European journal of operational research, 233*(1), 1-15. doi:https://doi.org/10.1016/j.ejor.2013.06.055

van Duin, J., Warfemius, P., Verschoor, P., de Leeuw, A., & Alons-Hoen, K. (2019). *Synchromodal transport: from theory to practice. Case study Port of Rotterdam: Identifying the success/fail factors*. Paper presented at the Transportation Research Board, Washington DC. https://trid.trb.org/view/1572478

Van Riessen, B., Negenborn, R. R., & Dekker, R. (2015). *Synchromodal container transportation: an overview of current topics and research opportunities.* Paper presented at the International Conference on Computational Logistics.

Waterways. (2020). Waterways. Retrieved from https://www.bureauvoorlichtingbinnenvaart.nl/inland-navigation-promotion/basic-knowledge/waterways visited at 29/10/2020