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Alternative transport network designs and their implications for intermodal transhipment technologies

Johan Woxenius [1*]

[1] *Division of Logistics and Transportation, Chalmers University of Technology, Göteborg, Sweden*
and
Department of Systems and Software Engineering, Blekinge Institute of Technology, Karlshamn, Sweden

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Abstract

Six principles for operation of the rail part of intermodal rail freight transport systems are described: direct link, corridor, hub-and-spoke, connected hubs, static routes, and dynamic routes. The first part is a theoretical discussion of the characteristics of the transport network designs. The theory is then applied to intermodal freight transport by analysing how each transport network design affects the need for terminal performance. The discussion includes a classification of existing transfer technologies and an analysis of how well developed technologies meet the demands. It is concluded that there is a sufficient supply of technologies, but some need to be taken further than the current blueprint phase and prove their viability in technical and economic terms.

Keywords: Corridor; Hub-and-spoke; Intermodal transport; Terminal; Transhipment technology.

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1. Introduction

Policy-makers strongly believe in intermodal road-rail freight transport (IRRFT) for solving a multitude of problems related to all-road freight transport. Promoting rail freight is thus an integrated part of transport policy in Europe (European Commission, 2001 and 2006) and Japan (Saito *et al.*, 2004), and it has prospects to make its way also into U.S. transport policy (Brown and Hatch, 2002). The stimulating measures are needed, but there is still a significant challenge for intermodal operators to compete with all-road transport, defined by Konings and Kreutzberger (2001) and Trip and Bontekoning (2002) as the need for a quality leap. Danielis *et al.* (2005) also call for significant improvements.

One area allowing for improvements is the choice of how to operate the transport network. This decision is influenced by the geography, supply of infrastructure, character of the transport demand, and, not least significantly, competition with other traffic modes. Although Cardebring *et al.* (2000) found a wide range of production

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[*] Corresponding author: Johan Woxenius (johwox@chalmers.se)

arrangements in a survey of European intermodal operators, there is evidence for claiming that IRRFT is conventionally produced.

The dominating production paradigm is night-leaps directly between large-scale transhipment terminals using gantry cranes and reach stackers (Bärthel and Woxenius, 2004). Starting with Germany in the 1980s and the Netherlands in the 1990s, European railways have gradually abandoned the wagonload production profile for direct trains (Rutten, 1995 and Wenger, 2001). According to Woxenius and Bärthel (2006), the trend of abandoning true networks for even more direct trains continues. Even CNC, with a long history of operating a hub-and-spoke system with Paris as hub, now focuses on shuttle trains (i.e., trains with a fixed number of wagons operated between two terminals) to and from ports under the new company name, Naviland (Naviland, 2006). The Swedish intermodal market was one of the last to face the transition as CargoNet changed its timetable to include only shuttle trains from January 2006 (CargoNet, 2005). Also, North America has seen a geographical concentration to fewer terminals (Slack, 1990 and Newman and Yano, 2000b).

Reasons for the operational conservatism can be sought in an inferior innovativeness by European railways (see, e.g., Loizides and Tsionas, 2002) and by the fact that freight trains are generally leaving way for passenger trains during the daytime (Racunica and Wynter, 2005). It is acknowledged, however, that it is actually truly demanding to operate complex IRRFT systems (Danielis and Marcucci, 2006). Direct trains offer simple and cost-efficient operations and a very good service on axes with large flows over long distances. The dominance of direct trains, however, implies that major parts of the freight transport market are left to all-road. If IRRFT is to play a major role in transforming the European transport system in a sustainable direction, it also has to work up the markets of relatively short distances or small flows (see, e.g., Bärthel and Woxenius, 2004, Bontekoning, 2006, and Macharis and Verbeke, 2002).

The conservative attitude of IRRFT operators is also disappointing for researchers addressing operational aspects of intermodal transport, who believe that IRRFT can compete for less-than-train flows as well as over shorter distances. There is a substantial supply of published research on alternative transport operation principles as well as wagon and transhipment technologies (for an overview, see Bontekoning *et al.*, 2003). Inventors have also made significant efforts to develop technologies facilitating more advanced traffic operations, but very few of these efforts have been commercially implemented. There are examples of both research and development initiatives that combine transport operation principles and new hardware (e.g., Bärthel and Woxenius, 2004, Bontekoning, 2006, Bontekoning and Priemus, 2004, Bukold, 1996, Kreutzberger, 1999a and b, 2004, Meinert *et al.*, 1998, Trip and Bontekoning, 2002, Woxenius, 1998a and b), but there is a tendency to treat these issues separately.

As an example, Bukold (1994 and 1996) identifies a flexibility gap between traditional production models for IRRFT. Shuttle and direct trains benefit from economies of scale but are subject to certain capacity risks, while old production models based on consolidation by marshalling single wagons or shunting wagon groups do not depend on a stable demand but are too expensive to operate. Bukold argues that new flexible corridor and hub-and-spoke production models can achieve economies of scale at much lower-capacity risk levels.

The purpose of this article is to define options for operating the rail part of an intermodal road-rail freight transport service, deduce how each option affects the transhipment terminals, and, finally, analyse whether the current supply of transhipment technologies meets these demands.

The discussion circles around six significantly different theoretical designs of transport systems: *direct link, corridor, hub-and-spoke, connected hubs, static routes,* and *dynamic routes*. The transport network designs are first presented in a general freight transport setting. The focus is then narrowed to IRRFT by defining how each network design affects the need for transhipment terminal performance. The discussion includes a categorisation of existing intermodal transfer technologies and how these fulfil the performance needs.

2. Transport network designs

From the perspective of the shipper—the ultimate user of freight transport services—and at the abstraction level of material flows, consignments are generally seen to move directly from origin to destination. In reality, however, the directness of transport services depends on the economic and practical viability of consolidation, defined by Bookbinder and Higginson (2002, p. 305) as "an active effort to more efficiently utilize transportation resources." The phenomenon is also referred to as bundling, simply defined by Macharis *et al.* (2002, p. 1) as "collection of goods to fill a transport unit." Also, mode-specific terms denote the consolidation activities, primarily in rail freight with shunting and marshalling or the terms classification, grouping, and blocking (Assad, 1980), more frequently used in the USA. The decision whether to consolidate depends on a number of parameters:

- Consignment size – the closer to the full capacity of a transport means, the more direct.
- Transport distance – the shorter, the more direct.
- Transport time demand – the more specific, the more direct.
- Product characteristics – the more specific, the more direct.
- Availability of other goods along the route – the lesser the availability, the more direct.

If consolidating flows is decided on, it is generally done in a systematic way: that is, according to a transport network design. Each design possesses inherent qualities and matches different preconditions in terms of geography, demography, supply of infrastructure and character of the transport demand. The choice of network design is also affected by when correct information about the actual demand is captured (Tjokroamidjojo *et al.*, 2006): i.e., if there is support for centralised decision-making as investigated by Newman and Yano (2000a).

Figure 1 takes the perspective of a transport system operator and presents six alternative transport network designs. A fixed example with ten nodes illustrates the different links used for a transport assignment from the origin (O) to the destination (D). The theory is based on the assumption that a sufficient supply of infrastructure enables direct links between all terminals in the network and that all terminals are capable of serving as origins and destinations as well as transfer points. The network operator can decide whether to operate the links and nodes itself or use services provided by other operators.

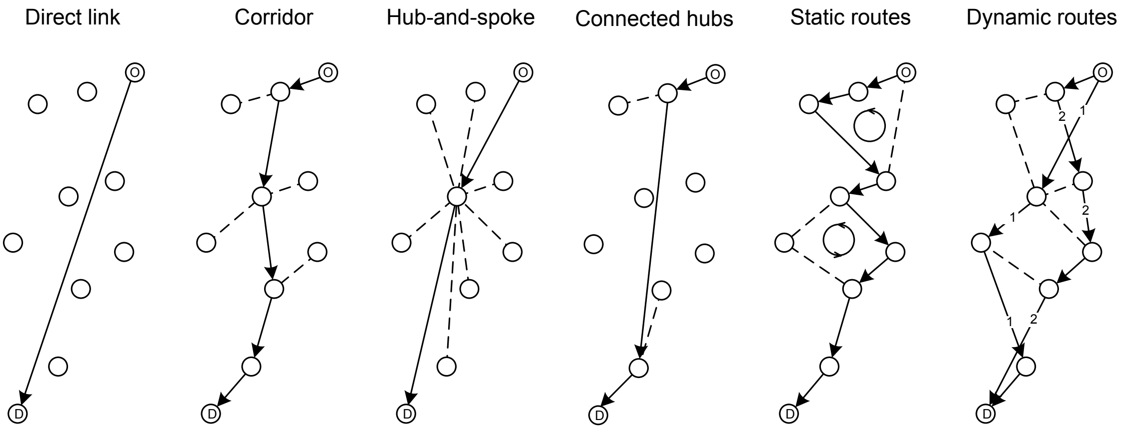

Figure 1: Six options for transport from origin (O) to destination (D) in a network of ten nodes. Dotted lines show related links in the network designs. In "Dynamic routes" two alternative routes are shown. In all other designs the routing is predefined.

In the *direct link* alternative, transport is obviously direct from O to D, and there is no coordination with transport between other O-D pairs. Also, no other nodes are involved.

The transport *corridor* is a design based on using a high-density flow along an artery and short capillary services to nodes off the corridor. The nodes are thus hierarchically ordered, here denoted corridor and satellite nodes, respectively. In this example O is a satellite node, and D is a corridor node.

In the *hub-and-spoke* layout, one node is designated the hub, and all consignments call this node for transfer, even for consignments between adjacent origins and destinations. Terminals are then either hub terminals or spoke terminals. While the operations follow simple principles, the challenge is to coordinate a large number of interdependent transport services.

The *connected hubs* design is another hierarchical layout in which local flows are collected at hubs that in turn are connected to hubs in other regions. It can thus be described as a direct link with regional consolidation. Also here terminals are either of the hub type or the spoke type.

When using the *static routes* design, the transport operator designates a number of links to use on a regular basis. In contrast to the hub-and-spoke layout, several nodes are used as transfer points along the route. Usually only a part of the load is transferred, and the rest stays on the transport means to the next node. The term exchange terminal is here used if only parts of the unit loads are exchanged; terminals with full exchange between trains are referred to as gateways. In Figure 1 O is on a one-way loop, connected by a feeder link to a two-way loop, which in turn is connected to D through another node.

The maximum flexibility is offered by the *dynamic routes* design. Links are designated depending on actual demand, and the network operator can choose many different routes between O and D. Transport services are planned by rules of thumb or optimisation methods. In an extreme form, routes can be changed during transportation.

Transport networks can be of a complex design using several basic designs. Hence, the layout principles are not mutually exclusive. The example of domestic hub-and-spoke systems in combination with other domestic systems making up a connected hubs system has already been mentioned. If the hubs themselves are significant sources and sinks, users of a direct link are then combined with users of a connected hubs design.

Hence, users and operators can perceive networks differently. A forwarder or agent might perceive most freight services as static routes, while the transport operators define their services as any of the other designs except dynamic routes.

It is also conceivable to combine direct links with a hub-and-spoke system. Liu *et al.* (2003) estimate the potential savings in total distance to be 10%, compared to operating according to one of the designs. Also, a system for very large flows can be improved by superposing the direct link, since the freight volume rarely match a discrete number of full transport means between all origins and destinations. If the surplus volume is small, it can be forwarded in a consolidation design.

3. Functional requirements on transhipment terminals

The choice of transport network design affects the level of performance that must be met by the terminals and in turn the choice of transhipment technology. The requirements on the terminals and the transhipment technology for each of the six transport principles described above are analysed in this section.

The analysis here is limited to rail transport and the dots and circles in Figure 1 represent transhipment terminals. Pre- and post-haulage by road is then performed outside the analysed system. Using this demarcation, a shipper or a forwarder with a full unit load is the system's customer. The requirements on terminals are kept more narrowly on technical performance than done by Wiegmans *et al.* (2003-2004) and the economic performance evaluation that Nijkamp *et al.* (2002) like to see, is only briefly included. If nothing else is stated, the rail services analysed are produced overnight, which, according to Trip and Kreutzberger (2002), corresponds to distances between 250 and 750 kms between 20.00 and 04.00. For the larger nations in Europe this implies domestic transport, although Woxenius *et al.* (2004) suggest technologies allowing up to 1250 kms to be covered, however using twelve night hours.

The advantages of direct trains were elaborated in the introduction, as was the need for alternative transport network designs if IRRFT is to compete for O-D pairs characterised by small volumes or short distances. A *short distance* is regarded here as shorter than the 500 kms often mentioned for Europe (Rutten, 1998, van Klink and van den Berg, 1998, and Woxenius, 1998a) and Japan (Saito, 2004) and the 500 miles (appr. 800 kms) mentioned for the USA (Gellman, 1994 and Newman and Yano, 2000b). A *small volume* refers to a volume that is less than economically viable for direct trains. This is admittedly a blunt measure, since economically viable direct trains range from a double-stack train with 100 wagons (Rodrigue, 2007) and a capacity of several hundred TEUs in the USA to a Swedish small-scale shuttle train operated with 20 wagons and a 40 TEU capacity. Nevertheless, for the rest of the article it is assumed that there is a real need for alternative network designs.

The analysis is implicitly based upon seven analytical questions about the performance and operation of the IRRFT system:

- What are the capacity and cost requirements? I.e., should the terminals be high-capacity facilities able to handle several unit loads simultaneously, or are low-cost, low-capacity terminals preferred?

- Is the reliability of the transfer function crucial? I.e. what are the consequences of a technical break-down?
- For how long are trains disposable for transhipment? I.e., can unit loads be transferred during a short stop or throughout the day?
- Can unit loads be transferred directly between road and rail vehicles, or is an intermediate storage area required?
- Must any unit load in the train be accessible, or can they be handled sequentially?
- Are there restrictions in the choice between operating with fixed train sets, shunting of groups of wagons, or marshalling of individual wagons? I.e., are rail wagons or the unit loads transferred between trains along the route?
- Is the network to be technologically open to all unit loads, or is it restricted to one or a few types?

These questions correspond to the evaluation criteria to be used in the analyses and they build the structure of the running text about each transport network principle below.

In a *direct link* design the terminals are either the origin or the destination of trains. Although all unit loads in the train are transhipped, the goods volume handled at the terminals is comparatively limited, thus reducing the capacity requirements on the terminals. The transfer time requirements depend on how long the trains are available for handling. If they stay at the terminal throughout the day, as is currently customary in Europe, this becomes a non-critical parameter. Nevertheless, due to the customers' timing preferences, the terminals are mainly busy in the early morning and the early evening. During those hours rather rapid transhipment is needed and the applied technology must be rather reliable. The same applies when the train set is used as a shuttle with a tight time table or if it is used for additional short day-leaps as presented by Bärthel and Woxenius (2004). A direct links design requires large flows to fill the trains, and the services are thus often technically open to a wide array of unit loads. This includes the heavy and somewhat awkwardly handled semi-trailers with significant effect for dimensioning of terminals and wagons. These require large and comparatively complicated terminals, and the costs must be distributed between large numbers of annual transhipments. Transhipment is often direct between trains and trucks, and the storage needs are thus moderate, but it requires direct accessibility to any unit load. The load plan is important if some customers are promised late hand-in and early pick-up of unit loads at the terminals, when those unit loads should be kept together for efficient operations.

In a system based on the *corridor* design, each train passes several terminals en route, and the transfer times must be kept at a minimum in order not to prolong the total transport time. On the other hand, only a limited number of unit loads is transferred at each terminal, and, hence, these must be economically feasible to operate on a small scale. Reliability of an individual terminal is not crucial since it only affects the unit loads to be transhipped at the terminal. The limited distance between terminals also facilitates trucking of unit loads to adjacent terminals in case of break-down. Since the rail transport service can be between any two terminals along the corridor, each unit load must be accessible for transhipment individually. Since trains are disposable at each terminal only for a limited period of time, storage space for unit loads must be provided, and road vehicles and rail wagons should be able to call terminals independently. Demands for transhipment ability of all types of unit loads might lead to conflicts with the requirement of fast transfer and low fixed costs. Hence, corridor services are preferably limited to a rather homogenous set of unit loads, often implying that semi-trailers and 40-foot containers are not accepted.

The chief characteristic of the *hub-and-spoke* design is that all unit loads pass through the hub terminal, and it must thus handle an extensive throughput. It is, therefore, of paramount importance that the hub terminal has a large capacity. It also has to be extremely reliable since the whole system is affected if the hub terminal breaks down. The design implies comparatively large detours, and for covering a large area overnight the hub terminal must offer short train stops. Hub terminals can be based on marshalling of wagons or on transhipping unit loads between trains, as is thoroughly investigated by Bontekoning (2006). They are often only designed for rail-rail transhipment, implying that they are actually not intermodal terminals. The load plan and exchange technology must offer accessibility to any unit load, and if all trains combined at the hub are not accessible simultaneously, there is a great need for intermediate storage. Semi-trailers imply no problem if wagons are marshalled but their height and weight complicate the transhipment technology significantly compared to ISO-containers and swap bodies that can be transfered horizontally. The spoke terminals face requirements similar to those of direct link terminals, but they can employ simpler and cheaper technologies if semi-trailers are excluded. The hub-and-spoke design implies long detours and time is consumed in the hub terminal, implying that time requirements are a little higher on the spoke terminals.

Since fewer trains are connected through the hubs in the *connected hubs* design than in a hub-and-spoke design, the capacity requirements are more modest. Two hub operations consume time, but the detours are less significant than for hub-and-spoke so time requirements are rather equal for the spoke terminals. If unit loads are only exchanged between a few trains, groups of wagons can be shunted at terminals, requiring that a strict load plan be followed at the spoke terminals but it facilitates a technically open system accepting a wide variety of unit load types.

In the *static routes* design the train sets traffic routes, along which exchanges between trains are performed on several occasions. The transhipment capacity required is limited, since only a few unit loads are handled at each terminal, except for the gateway terminals. The need for reliability corresponds to the number of unit loads that are handled. Static routes are often used for international transport or when time demands are modest. Short exchange times at gateway terminals are, therefore, a crucial requirement only if a short total transport time is particularly demanded. In order to make this design feasible, it is therefore necessary to restrict the accepted types of unit loads or to use a handling technology that can accommodate all types of unit loads and access them individually. The function of being a gateway terminal between network modules can be combined with that of being an origin or destination of direct link trains. Trains operated in a static route design would then use the terminals during mid-day and through the night and direct link trains during early morning and early evening.

Also, the *dynamic routes* design implies several exchanges between trains. The terminal requirements are similar to static routes, but as operations change between each transport cycle, there is a greater need for operational flexibility. Shunting is then generally difficult, since the complex combination of train services might not allow wagon groups to be formed and kept together. Nevertheless, due to the rigidity of train timetables and limited access to slack track capacity, this is currently no real option for intermodal transport. With future information systems and enhanced availability of tracks, however, dynamic timetables are foreseen for freight trains.

The requirements related to the transport network designs highly depend on the actual context, e.g., in terms of distances, the shippers' time requirements and the competing transport services. Nevertheless, an attempt at a quantitative assessment is presented in Table 1, referring to a general European situation. The scoring in this and the following tables is, admittedly, subjective in its nature, but based upon knowledge acquired during many years of research in the field.

Table 1: Requirements for the terminal function related to transport network design.

Network design	*Terminal type*	*High terminal capacity*	*Rapid transhipment*	*Low fixed terminal costs*	*Technical reliability*	*Detachability road and rail vehicles*	*Accessibility to any unit load in the train*	*Types of unit loads accepted*
Direct link	End terminal	3	3	1	3	2	2	3
Corridor	End terminal	2	3	3	3	3	2	2
	Intermediate terminal	1	4	4	2	4	5	2
Hub-and-spoke	Hub terminal	5	5	1	5	n.a.	5	2
	Spoke terminal	2	2	3	2	2	2	2
Connected hubs	Hub terminal	3	4	2	5	n.a.	2	4
	Spoke terminal	2	2	3	2	2	2	2
Static routes	Exchange terminal	2	2	3	3	n.a.	4	4
	Gateway	4	4	1	5	n.a.	4	2
Dynamic routes	Exchange terminal	3	3	3	3	n.a.	5	3

The higher the score, the higher the demand, n.a.=not applicable.

The next section is devoted to transhipment technologies and their ability to fulfil the demands of the different transport network options.

4. Supply of transhipment technologies

The rendering in this section departs from the technical features of transhipment technologies and attempts at classifying them into generic families, rather than mentioning brand names of individual technologies. The empirical base for this presentation is an extensive investigation (Woxenius, 1997 and 1998b[1]), and reference is only given here to sources not mentioned in those publications. That investigation used brochures, fax enquiries, site visits, interviews and literature to collect information about the technologies. The reports include detailed technical descriptions, pictures and information about the development projects around the technologies.

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[1] Both reports are available for free download at: www.mot.chalmers.se/staff/johwox.

Despite the large number of transhipment technologies developed over the last 40 years, intermodal terminals still look the same throughout the world. The term *conventional large-scale transhipment* is used for denoting terminals with a gantry crane overreaching railway tracks and lorry driving lanes complemented with reach-stackers, i.e., large counter-balanced trucks. Terminals are dimensioned for the semi-trailer and thus comparatively large, complicated and costly. The reach-stackers require a hardened surface, adding to investment costs. Any unit load is accessible for direct transfer between train and truck, but terminals often include a storage area. Redundant resources make the transhipment quick and reliable; the effect of a breakdown of a single transfer unit is a temporarily reduced transfer capacity of the terminals rather than total stand still. The technology is also used for train to train transhipment (Martinez *et al.*, 2004).

Marshalling and shunting yards[2] are examples of *conventional train to train transfer*, that offer large capacity and, at least for shunting, a fairly fast transfer, as investigated by Bontekoning (2006).

Several innovative technologies have been developed for increasing the capacity of train to train transhipment (Alicke, 2002; Nijkamp *et al.*, 2002; Rodrigue, 2007; Rotter, 2004). Most *new-generation large-scale transfer* technologies aim for a high degree of automation, implying significant investment costs. Some technologies reduce complexity by limiting the types of unit loads handled and by using dedicated rail wagons, while others use more incremental improvements of conventional large-scale technologies adapted for several types of unit loads.

Small-scale vertical transhipment technologies implement many of the principles used in conventional transhipment technologies, as they grip the unit loads from above and the transhipment equipment carries the full weight. The complexities range from using standard fork-lift trucks, such as those commercially operated in Japan (Saito *et al.*, 2004) and tested in Sweden (Bärthel and Woxenius, 2004), to fully automated integrated terminals, erected as a prototype in Switzerland (Tuchschmid, 2006). Some technologies limit the range of unit loads accommodated. The Japanese system is designed only for ten foot containers, which is unsuitable for transport of palletized goods (Saito *et al.*, 2004).

Small-scale horizontal transhipment means that only a small vertical lift is needed to accomplish such work as lifting a container or swap body above the container locks in order to make folding the support legs possible. The transhipment equipment itself is often not dimensioned to carry the full weight of the unit loads, and only a small force is needed to tranship them horizontally. Besides the possibility of slimmer dimensioning, the big advantage of horizontal transhipment is transhipping under the overhead contact line. However, this feature is also offered by some vertical transhipment technologies. Nevertheless, this often comes with the drawback of technical complexity, and some technologies depend on the simultaneous presence of rail and road vehicles at the terminals. The ideas of horizontal transhipment are not new – milk containers were transhipped horizontally between flat wagons and lorries in the United Kingdom already in the 1930's.

The *lorry to ground and rail wagons* group of technologies primarily facilitates transhipment of containers between a road vehicle and the ground. Some systems aim for the big market of picking up and distributing ISO-containers around ports, while

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[2] A marshalling yard uses a hill and gravity for sorting individual wagons, whereas a shunting yard forms trains from groups of wagons by use of a locomotive.

others use purpose-built containers to transport scrap iron and building site refuse. Technologies hoisting containers along a tilting frame, or levering them over the end of the lorry, have not proven to be practical for pure inland transportation of general cargo, due to insufficiently secured loads inside the unit. As a bonus, however, they generally allow for horizontal transhipment between lorries and rail wagons fitted with turntables. This technology has also been used for smaller unit loads, utilizing the maximum allowed width on rails as well as on roads. Another set of technologies fold out hydraulic jibs from the side of the road vehicle and lift the container after fastening it with a spreader or a set of chains. These pieces of equipment are usually referred to as self-loading trailers or side-loaders, and are used for transporting a container to the ground, onto another container, lorry or, as is of particular interest to this study, a rail wagon. All technologies handle ISO-containers but at least two brands are designed for also lifting swap bodies.

The principle used when a lorry lifts a swap body from the ground has inspired some rail wagon manufacturers. The results are *self-loading rail wagons,* designed for running underneath and lifting swap bodies standing on their support legs, which are first placed in a row over the tracks by lorry drivers. The rail wagons are unique, but they do not interfere with the use of any conventional system employing vertical handling. One brand is designed as independent wagons which are also suitable for conventional wagonload systems, while others are intended for use in fixed, short-coupled wagon groups or shuttle trains. The swap bodies have to be carefully sequenced according to the order in which they were unloaded, but the actual transhipment is very quick. This principle is also commercially used for moving very large special containers for paper, weighing up to 90 tons, and cassettes for steel transport.

In original *bimodal systems*, semi-trailers are permanently equipped with wheels for both road and rail use. In more recent bimodal systems, reinforced semi-trailers are fitted onto railway bogies by lorry drivers. There are no real rail wagons involved; instead, two semi-trailers are mounted directly onto opposite ends of a 2-axle bogie. The solution saves tare weight, although the reinforced semi-trailers weigh approximately one ton more than standard semi-trailers. In addition, the distance between two adjacent semi-trailers is reduced to about 30 centimetres, with positive effects on train carrying capacity and aerodynamics. The system has limited transfer capacity, and the total transfer time is long, since they are loaded sequentially. Trains cannot be shunted or marshalled, since two semi-trailers share the same bogie.

Many IRRFT designers have been inspired by the roll-on-roll-off (RoRo) principles used in short sea shipping, and have developed wagons for *RoRo-transhipment of road vehicles*. In the USA, with a very generous rail loading gauge, rolling vehicles onto a set of bridged rail wagons over a ramp has long been the dominating intermodal principle, and terminals are still often referred to as “ramps”, since a ramp at wagon height was usually the only tool needed (deBoer, 1992). Rolling highways, where full lorries are driven onto trains, were introduced in Europe in the 1960’s. The main purpose for these is to overcome a natural or legislative obstacle and is predominantly used for trans-Alpine crossings. Wagons that can swing out the loading platform for individual loading have also been presented. Common for wagons used in Europe is the complex and costly design of accommodating full lorries within the loading gauge. Semi-trailers can be transhipped independently, but ISO-containers and swap-bodies require a lorry or chassis as an interface to the wagon.

The scoring in Table 2 attempts to summarize the short presentations of the technology categories above. The difference from Table 1 is that Table 2 rates the fulfilment of the requirements rather than demands. The scoring is admittedly subjective but strongly based on the empirical work in the mentioned investigation (Woxenius, 1997 and 1998b). The rendering here must be kept rather short, thus the assessment weigh in some assumptions and facts not mentioned here. One example is that capacity for some of the technologies is easily scaled up by adding handling equipment, but the scoring in Table 2 is based on the capacity for normally fitted terminals. There is also a variety within each class of technologies and the grading reflects the general capabilities of the technologies.

Table 2: Scoring of how well each transhipment technology class fulfils the functional requirements.

Transhipment technology class	*Variant*	*High terminal capacity*	*Rapid transhipment*	*Low fixed terminal costs*	*Technical reliability*	*Detachability of road and rail vehicles*	*Accessibility to any unit load in the train*	*Types of unit loads accepted*
Gantry cranes and reach-stackers		4	4	2	4	4	4	5
Conventional train to train transfer	Shunting	5	4	4	5	n.a.	2	5
	Marshalling	4	3	3	4	n.a.	5	5
New-generation large-scale transfer		5	5	1	4	n.a.	5	3
Small-scale vertical transhipment	Direct	2	3	5	4	1	5	2
	Indirect	2	4	5	4	5	5	3
Small-scale horizontal transhipment	Direct	2	3	5	3	1	5	2
	Indirect	2	4	5	3	5	5	3
Lorry to ground and rail wagons		1	1	5	4	1	4	2
Self-loading rail wagons		3	5	4	3	5	1	1
Bimodal systems		1	1	4	3	3	1	1
RoRo-transhipment	Rolling highway	4	5	4	4	1	1	4
	Swinging platform	4	5	4	4	1	5	4

The higher the score, the higher the fulfilment of requirements n.a.=not applicable.

5. Matching the demand and supply of transhipment technologies

The scoring in Table 1 and 2 provides the basis for an analytical matching of requirements set by transport network designs according to what different technologies can offer. The matching, however, is not a mathematical exercise with an undisputable result that is valid in all contexts. Hence, this analysis is an attempt to generally evaluate if the supply of technologies allows prospective intermodal operators to choose from the current supply, or if new technologies must be developed. It is not intended as a recommendation for which technology is best suited for a certain task; the issue is simply too contextual for that.

The table in the appendix combines the grading in Table 1 and Table 2. It then appears how well each class of technology matches the demands for each transport network design and for how many criteria the technology does not fully fulfil the demands. The information in the appendix is condensed into Table 3, which show how many of the requirements that are violated for each transfer technology. Some features are not negotiable, and if they are not fulfilled, the technology is marked as disqualified. Frequency of non-fulfilment is, admittedly, a blunt measure. Nevertheless, since the scoring of technologies is highly contextual, further analysis requires specification of the case at hand, which in turn opens up for more detailed methodology. For example, Woxenius (1997 and 1998a) uses a weight-criterion analysis method to rank technologies for small-scale IRRFT and Fowkes *et al.* (1991) use a stated preference methodology for the UK market for intermodal technologies.

Table 3: Matching of functional requirement and available transfer technologies.

	Gantry cranes and reach-stackers	*Conventional train to train transfer, shunting*	*Conventional train to train transfer, marshalling*	*New-generation large-scale transfer*	*Small-scale vertical transhipment, direct*	*Small-scale vertical transhipment, indirect*	*Small-scale horizontal transhipment, direct*	*Small-scale horizontal transhipment, indirect*	*Lorry to ground and rail wagons*	*Self-loading rail wagons*	*Bimodal systems*	*RoRo-transhipment, rolling highway*	*RoRo-transhipment, swinging platform*
Direct link	0	-	-	-	-	-	-	-	-	2	4	2	1
Corridor, end terminal	1	-	-	-	-	-	-	-	2	-	-	-	-
Corridor, intermediate terminal	-	-	-	-	2	0	2	0	-	-	-	-	-
Hub-and-spoke, hub terminal	4	2	2	1	-	-	-	-	-	-	-	-	-
Hub-and-spoke, spoke terminal	1	-	-	-	1	0	1	0	-	2	-	-	-
Connected hubs, hub terminal	1	0	2	3	-	-	-	-	-	-	-	-	-
Connected hubs, spoke terminal	1	-	-	-	1	0	1	0	-	2	-	-	-
Static routes, exchange terminal	1	-	0	2	-	-	-	-	-	-	-	-	0
Static routes, gateway	1	1	2	1	-	-	-	-	-	-	-	-	-
Dynamic routes, exchange terminal	2	1	0	2	-	1	-	1	-	-	-	-	0

Numbers refer to the frequency of non-fulfilled demands; - =disqualified.

Conventional large-scale transhipment and RoRo-transhipment fulfil all demands of a *direct links* design. The latter, however, repeatedly moves costly and heavy road vehicles, and somewhat violates the basic principle of intermodality. Bimodal systems and self-loading rail wagons are primarily intended for direct links, but are limited in the unit load scope, and as such, are only suitable for specialized applications kept under one management.

Both vertical and horizontal small-scale technologies fulfil the demands set by a *corridor* design, although indirect transhipment is preferable for efficient operation. Also, lorry to ground or rail wagon techniques are conceivable, but the direct transhipment can imply certain operational handicaps. RoRo-transhipment, with swinging platforms, fulfils most demands, but shares the tare weight disadvantages with rolling highway. The end terminals can be served by the above technologies, but can also be served by conventional terminals, if the volumes of different services are added.

The hub terminal is obviously critical for a *hub-and-spoke* design. In competition for shorter distances, the new-generation large-scale technologies best match the demands, although conventional marshalling is conceivable. Spoke terminals are less critical and gantry cranes and reach-stackers are effective, but cost is a concern if there are many terminals in the system not used along with other services.

New-generation technologies can also be used for the hub terminals in a *connected hubs* design, but fewer combinations of trains allow for shunting, lower volume for conventional terminals and indirect small-scale technologies. The demand and fulfilment of spoke terminals correspond roughly to that of the hub-and-spoke design.

The exchange terminals in *static routes* are like hub terminals in connected hubs, but shunting is excluded. The gateways resemble hub terminals in the hub-and-spoke design. The analysis for *allocated routes* generally corresponds to that for static routes.

Since at least one technology fulfils all demands, or all but one demand, for each terminal function, it can be stated that there is a good match between demand and supply of terminal technologies.

6. Conclusions and implications

Some of the developed transfer technologies are purposely and consciously developed addressing certain terminal functions required for operating different transport network designs, while others are proposed by inventors on a “solves-all-problems” basis. Other developers seem to not have a clear idea about which network the technology would best fit. Still, this study shows that most proposed technical solutions can find an application, although lorry to ground or rail wagon, bimodal systems and the rolling highway are only found suitable for narrowly focused services.

The direct link, corridor, hub-and-spoke and connected hubs network operation principles are commonly applied in transport systems and exhaustively researched in scientific literature, although denoted differently by authors. The static and dynamic routes, however, are addressed less often and might attract further attention from *researchers.*

A signal to *manufacturers and inventors* is that a wide variety of transhipment technologies have already been developed. Admittedly, new and refined technologies can prosper, but they can also build on earlier efforts and experiences, rather than trying to break through untilled soil.

Most of the scoring in this study is based on what inventors and manufacturers promise in terms of technical capabilities; many technologies are never commercially tested or even become a prototype. The technical challenge of moving big boxes is insuperable; hence, inventors and manufacturers are given the benefit of the doubt that they can deliver the offered technical capabilities. The same does not apply to costs of investments and operations, since they depend highly on the number of sold systems and the context in which the technologies are implemented. Here, most manufacturers still have to prove themselves in real operation and in their ability to find a sufficient number of customers. Suspicion is not easily diverted from some inventors that the business concept is rather to attract public development funds than really working up a market. One suggestion to *agencies funding research* is to prioritize the funding of analyses investigating why the developed systems are generally not implemented before they fund further technology development.

The implication for *the transport industry* is that the relatively positive evaluation of the supply of transhipment technologies can encourage intermodal operators to develop and implement new ways of operating the rail part of their services. Although gantry cranes and reach-stackers scored very well, there are realistic alternatives. European freight rail transport is hampered by insufficient interoperability in border-crossing traffic and in some cases even domestically. Technical compatibility between intermodal systems should then focus on the exchanged resources in terms of unit loads and in some cases rail wagons. Compatibility is not crucial for the transhipment technologies that might be well-adapted to the special requirements given by the used network principle.

A message to *transport policy-makers* is that efficient operation of some of the transport network designs requires track access during daytime hours, and that the dedicated freight network, as described by the European Commission (2001) and analyzed by Reynaud and Jiang (2001), is badly needed. Since significant time and funds will be needed, giving higher priority to freight on existing tracks is an intermediate means that can be implemented without significant delay. Applying non-direct transport layouts also facilitates execution of efficient transport when direct infrastructure is lacking. Hence, there are tradeoffs between heavy initial investments, higher operational costs, environmental degradation when building infrastructures (van der Heijden, 2006), and operating transport systems. A less strict division between public and private funding might then be economically sound. For example, subsidizing more expensive low-built rail wagons would save significant costs that would be incurred by extending the UK loading gauge (The Piggyback Consortium, 1994).

Until recent years, the markets for intermodal transportation in Europe have been predominately national, resulting in short transport distances and limited market sizes. This has led to the employment of standardized systems, or systems for all types of unit loads, since a large portion of the available market has to be covered by a single system. The current trend is working towards a true intra-European transport market. This will foster specialized systems targeting only a market niche. We may foresee a period of "trial and error" for a number of new solutions before one or more technologies reach the developmental stage where they can seriously challenge the existing production paradigm of gantry cranes and reach-stackers.

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Appendix: Matching terminal types with relevant transfer technologies.

	High terminal capacity	*Rapid transhipment*	*Low fixed terminal costs*	*Technical reliability*	*Detachability road and rail vehicles*	*Accessibility to any unit load in the train*	*Types of unit loads accepted*	*Number of non-fulfilled demands*
Direct link, end terminal	*3*	*3*	*1*	*3*	*2*	*2*	*3*	
Gantry cranes and reach-stackers	4	4	2	4	4	4	5	0
RoRo-transhipment, swinging platform	4	5	4	4	1	5	4	1
Self-loading rail wagons	3	5	4	3	5	1	1	2
RoRo-transhipment, rolling highway	4	5	4	4	1	1	4	2
Bimodal systems	1	1	4	3	3	1	1	4
Corridor, end terminal	*2*	*3*	*3*	*3*	*3*	*2*	*2*	
Gantry cranes and reach-stackers	4	4	2	4	4	4	5	1
Lorry to ground and rail wagons	1	1	5	4	1	4	2	3
Corridor, intermediate terminal	*1*	*4*	*4*	*2*	*4*	*5*	*2*	
Small-scale vertical transhipment, indirect	2	4	4	4	5	5	3	0
Small-scale horizontal transhipment, indirect	2	4	4	3	5	5	3	0
Small-scale vertical transhipment, direct	2	3	5	4	1	5	2	2
Small-scale horizontal transhipment, direct	2	3	5	3	1	5	2	2
Hub-and-spoke, hub terminal	*5*	*5*	*1*	*5*	*2*	*5*	*2*	
New-generation large-scale transfer	5	5	1	4	n.a.	5	3	1
Conventional train-train transfer, marshalling	4	3	3	4	n.a.	5	5	2
Conventional train-train transfer, shunting	5	4	4	5	n.a.	2	5	2
Gantry cranes and reach-stackers	4	4	2	4	4	4	5	4
Hub-and-spoke, spoke terminal	*2*	*2*	*3*	*2*	*2*	*2*	*2*	
Small-scale vertical transhipment, indirect	2	2	5	4	5	5	3	0
Small-scale horizontal transhipment, indirect	2	2	5	3	5	5	3	0
Gantry cranes and reach-stackers	4	4	2	4	4	4	5	1
Small-scale vertical transhipment, direct	2	2	5	4	1	5	2	1
Small-scale horizontal transhipment, direct	2	2	5	3	1	5	2	1
Self-loading rail wagons	3	5	4	3	5	1	1	2
Connected hubs, hub terminal	*3*	*4*	*2*	*5*	*n.a.*	*2*	*4*	
Conventional train-train transfer, shunting	5	4	4	5	n.a.	2	5	0
Gantry cranes and reach-stackers	4	4	2	4	4	4	5	1
Conventional train-train transfer, marshalling	4	3	3	4	n.a.	5	5	2
New-generation large-scale transfer	5	5	1	4	n.a.	4	3	3

Connected hubs, spoke terminal	*2*	*2*	*3*	*2*	*2*	*2*	*2*	
Small-scale vertical transhipment, indirect	2	2	5	4	5	5	3	0
Small-scale horizontal transhipment, indirect	2	2	5	3	5	5	3	0
Gantry cranes and reach-stackers	4	4	2	4	4	4	5	1
Small-scale vertical transhipment, direct	2	2	5	4	1	5	2	1
Small-scale horizontal transhipment, direct	2	2	5	3	1	5	2	1
Self-loading rail wagons	3	5	4	3	5	1	1	2
Static routes, exchange terminal	*2*	*2*	*3*	*3*	*n.a.*	*4*	*4*	
Conventional train-train transfer, marshalling	4	3	3	4	n.a.	5	5	0
RoRo-transhipment, swinging platform	4	5	4	4	1	5	4	0
Gantry cranes and reach-stackers	4	4	2	4	4	4	5	1
New-generation large-scale transfer	5	5	1	4	n.a.	4	3	2
Static routes, gateway	*4*	*4*	*1*	*5*	*n.a.*	*4*	*2*	
Gantry cranes and reach-stackers	4	4	2	4	4	4	5	1
Conventional train-train transfer, shunting	5	4	4	5	n.a.	2	5	1
New-generation large-scale transfer	5	5	1	4	n.a.	4	3	1
Conventional train-train transfer, marshalling	4	3	3	4	n.a.	5	5	2
Dynamic routes, exchange terminal	*3*	*3*	*3*	*3*	*n.a.*	*5*	*3*	
Conventional train-train transfer, marshalling	4	3	3	4	n.a.	5	5	0
RoRo-transhipment, swinging platform	4	5	4	4	1	5	4	0
Conventional train-train transfer, shunting	5	4	4	5	n.a.	2	5	1
Small-scale vertical transhipment, indirect	2	2	5	4	5	5	3	1
Small-scale horizontal transhipment, indirect	2	2	5	3	5	5	3	1
New-generation large-scale transfer	5	5	1	4	n.a.	4	3	2
Gantry cranes and reach-stackers	4	4	2	4	4	4	5	2

Scores: The higher the score, the better the demand/fulfilment, n.a.=not applicable. Fulfilment scores below the requirements are underscored.