Product Intelligence in Intermodal Transportation: The Dynamic Routing Problem

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Abstract Intermodalism has been recognised as a promising way to efficiently reduce logistics costs and travel times of shipments in today's freight industry. Further, it has the potential to add resilience to the transportation network by providing options in the case of disruption. However, intermodalism still faces some operational challenges such as the routing of shipments in the intermodal network and the control of these shipments during their transit. In this paper we focus on the dynamic version of the routing problem in intermodal transportation, that is the control of a shipment while it moves in the transportation network. We present an approach (based on the so-called "intelligent product" notion) for efficient dynamic routing and discuss its applicability and differences with current practice.

1 Introduction

Intermodal transportation can be defined as "[...] the transportation of a person or load from its origin to its destination by a sequence of at least two transportation modes" (Crainic and Kim, 2006). The underlying idea of intermodalism is that the cooperation of different transport modes can lead to substantial advantages resulting from the combination of their individual strengths in order to build an efficient and independent transport system (Buchholz et al., 1998). As an example of an intermodal network, Figure 1 depicts a scenario where an order x has to move from place A to place B through terminals $K-T$ having a set of available routes and modes that it can use. We discuss this specific scenario later.

One of the main operational problems that intermodal operators face is the so-called intermodal routing problem (Chang, 2008), that is the selection of the best route for the transportation of a shipment given a set of options that the transportation network can offer. Furthermore, due to disruption factors in the network, an intermodal operator may need to control shipments during transportation and make decisions about alternative routes in case the initial route is no longer available. The management of *intermodal dynamic routing* involves these aforemen-

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tioned decisions and is characterised by a number of special requirements which may affect its performance.

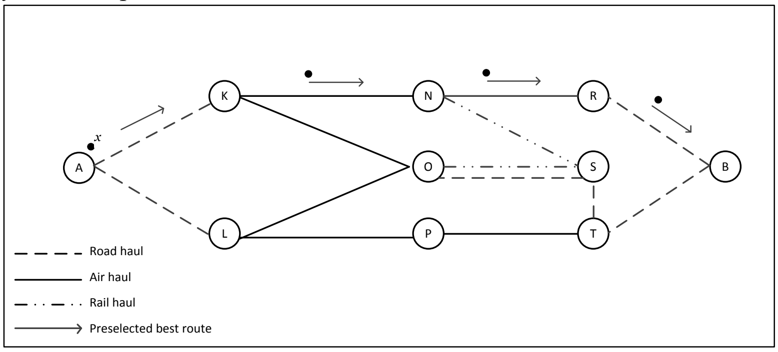

Fig. 1. An intermodal transportation network

In this paper we are particularly interested in addressing intermodal dynamic routing problems using the so-called "intelligent product" paradigm. The intelligent product notion involves control architectures where industrial operations are managed and controlled more via their moving parts (e.g. inventory, finished products) and less by centralised decision systems (McFarlane et al., 2003; Kärkkäinen et al., 2003). Such an approach has been shown to bring special benefits in terms of disruptions management and resilience in logistics environments of manufacturing processes (Pannequin et al., 2009). Moreover, it is argued that it can improve logistics and transportation operations in supply chain management again by increasing the robustness of the system (Meyer, 2011). For these reasons, we recognize potential synergies between the notion of product intelligence and intermodal dynamic routing and we discuss the potential benefits.

2 Intermodal Routing Problem

In this section we begin with describing the so-called "a-priori intermodal routing problem" which is addressed before the shipment of an order. Then we focus on the dynamic version of this problem which deals with the handling of the routes of shipments while they are in transit.

2.1 A-Priori Intermodal Routing

Intermodal routing deals with route and service choices in existing intermodal networks. Intermodal operators who are responsible for this process act as customers/users of the intermodal infrastructure and services trying to find the optimal route for a certain shipment. They buy the services offered by different modes and manage the whole process, from the collection of the product until its delivery (Macharis and Bontekoning, 2004). As an example, in the scenario depicted in Figure 1, let us assume that the pre-selected best route for order x from A to B is $A \rightarrow K \rightarrow N \rightarrow R \rightarrow B$. The nature of the a-priori intermodal routing problem makes its solution a very complex task for several reasons. One of the main factors that affect intermodal routing is time. An intermodal operator may have a different set of available options for the routing of his shipment during a period of time as scheduled lines can vary a lot. Moreover, since by definition this particular transportation problem can potentially use the whole intermodal network, different people and organisations have to coordinate even for the distribution of a single shipment. Ziliaskopoulos and Wardell (2000) and Chang (2008) summarise the important characteristics that increase the complexity of the intermodal routing problem in the multi-objective nature of the problem as different stakeholders may have different concerns, the discontinuities of the fixed schedule lines that many modes often use, the delays in switching points and the disruptions while in transit as well as the violation of the first-in-first-out policy on certain links.

2.2 Dynamic Intermodal Routing

The a-priori version of the routing problem described in the previous section deals with the process of finding the best path in an intermodal network before the dispatch of a shipment and there is a number of studies that try to solve it (Macharis and Bontekoning, 2004; Caris et al, 2008; Chang, 2008). However, in real practice, it is often the case that while an order is in transit, its a-priori defined route is blocked or disrupted and a revised route would ideally be assigned (Azadian et al., 2012). We call this the *intermodal dynamic routing problem* which is defined as the problem of identifying the best new route for an order while it is in transit and part or all of its pre-selected route is blocked or disrupted. The problem also involves all the decisions that need to be made in order for this new route to be agreed and used. From a mathematical perspective, the problem is closest to the stochastic time-dependent shortest path problems. The reader is referred to (Azadian et al., 2012) for a very thorough review on this type of problems.

Back to the example illustrated in Figure 1, let as assume that when the order x is in transit and has arrived at Terminal K, the route $K \rightarrow N$ is no longer available due to a strike in the airport located in N making the $K \rightarrow N \rightarrow R$ part of the initial route inaccessible. The alternative decisions that an intermodal operator can choose from in case of such a disruption are summarised in Table 1.

In the case of dynamic intermodal routing the identification of a new route for the order becomes even more complex than in the a-priori case, having a number of special requirements:

Table 1. Intermodal dynamic routing decisions

Decision	Description	Example
Do nothing - Wait for next available movement	Shipments will wait in a terminal until the next similar way of transportation is available	Order x can wait until the strike in Terminal N is over and aircraft can use it again
Select a different path in the transportation network	A shipment is re-planned to use a different set of terminals and modes for its transportation	Order x can move through O, S, and T or O, L, P and T in order to reach B from K
Schedule truck movement	Arrange the transportation of a shipment using a truck. Road transportation is normally more flexible as trucks can be scheduled at any time	Scheduling of a truck movement from K to N creating an alternative route for order x that did not exist before
Schedule additional aircraft/ship/train movements	Similar to scheduling truck movements. However, extra air, sea and rail transportation is normally much more difficult and costly to be scheduled than road transportation	As before

1. *Order-level information and decisions*: Since disruptions may have different effects on each shipment, different decisions may need to be made for each one based on their individual special characteristics.
2. *Lifecycle information*: Information spanning different phases of the transportation process is required in order to make the best decision about the next steps of each order. Here, the lifecycle of a shipment starts with a request for transit and finishes with its delivery.
3. *Distributed decision making*: Often, there is not a single organisation controlling the whole transportation network. Thus, it is not possible for any organisation to make all the decisions concerning all the stages of transportation of a shipment. For this reason, planning and controlling decisions have to be made and executed in a distributed environment, among different companies and geographical places.
4. *Multi-objective nature of decisions*: As discussed above, this is one of the main characteristics of routing problems. Since there is no one person/organisation planning and managing the whole transportation of a order, he cannot manage services provided by different modes based on current demand. A larger set of criteria have to be taken into account when decisions about the routing of an order are being made.
5. *Time-critical decisions*: The time that a decision is being made may affect the options that the decision maker may have, normally limiting rather than increasing their number.
6. *Time-consuming problem solving*: The high complexity of finding a new best path does not allow re-computation of solutions in real time.

3 Product Intelligence in Logistics

Many of the requirements identified in the previous section can be addressed within an intelligent product approach. For this reason, in this section we introduce the intelligent product notion, its potential benefits as well as its similarities with other concepts.

The intelligent product approach was first proposed as a building block for control architectures that could offer benefits to manufacturing, supply chain management and logistics in terms of more customised management of individual products and orders (Wong et al., 2002). Prior to this, many influences can be seen in the multi-agent based industrial control field (e.g. Bussmann & Schild, 2000) and holonic manufacturing (e.g. Van Brussel et al, 1998). These control architectures, such as the *Auto-ID driven* control architecture (McFarlane, 2002), the *Distributed, Intelligent Product Driven* control architecture (McFarlane et al., 2003), the *Inside-out* control architecture (Kärkkäinen et al., 2003) or the *Product-Instance-Centric* control architecture (Hribernik et al., 2006), suggested that industrial operations could be managed and controlled more via their moving parts and less by using centralised decision making systems oriented around the organisation and its resources. In this context, an *intelligent product* was recognised as a physical and information based representation of a product which has its own identification, can collect, retain and exchange information with its environment as well as participate in the decision making process about its next steps (Wong et al., 2002) (See Table 2 for complete definition).

Although these initial developments are well accepted in the literature, the characteristics of an intelligent product and the fundamental ideas behind it can also be found in other emerging technological topics such as *smart objects*, objects in *autonomous logistics* and the *Internet of Things*. For example, Table 2 shows the connection between the concept of product intelligence and objects autonomy comparing their definitions as well as the different levels of intelligence/autonomy of objects in these approaches showing that there might be significant synergies among the different concepts (Uckelmann et al., 2010; McFarlane, 2011). A good example of how the principles of software agents and autonomous logistics can be used for supply network management problems is analysed in (Schuldt, 2011).

The adoption of an intelligent product approach in industrial operations has been argued to bring special benefits to its users such as increased robustness in the face of change and effective management of disruptions. Apart from some qualitative statements of this argument (McFarlane et al., 2003; Morales-Kluge et al., 2011), it has also been quantitatively shown that autonomy and intelligence in products can create more robust and flexible systems. As an example, the adoption of an autonomous product-driven control architecture in a production cell is shown to improve work in process levels and lead times especially in cases where disturbance factors like perturbations take place (Pannequin et al., 2009). In another study, it is shown that dynamic routing algorithms can lead to increased levels of robustness and adaptability in production logistics (Sallez et al., 2009). In the area of vehicle routing and transportation, Meyer (2011) argues that an intelligent product approach could have significant impact in problems of supply networks based on interviews with users of a prototype that uses such an approach.

Table 2. Characteristics of Intelligent Products and Autonomous Logistics

	Intelligent Products (Wong et al., 2002; Kärkkäinen et al., 2003)	Autonomous Objects (Hülsmann & Windt, 2007; Scholz-Reiter et al., 2008)
Definitions	Possesses a unique identity	Self identification and detection system
	Communicates effectively with its environment	Communication ability ICT
	Retains or stores data about itself	
	Deploys a language to display its features etc.	Communication ability ICT
	Is capable of participating in or making decisions relevant to its own destiny	Information processing Ability to identify alternatives Evaluation system Execution
Levels of Intelligence/ Autonomy	Information handling	Identify and store static data Gather and store dynamic data
	Decision making	Process data to create new ones and solve tasks Exchange data with other objects and interact with them Intelligent information based material handling is used to initiate actions

4 Towards an Intelligent Product Approach to Intermodal Dynamic Routing

In this section we now make the connection between the intelligent product approach and the intermodal dynamic routing problem and its potential implementation is discussed.

4.1 Linking Intelligent Products with Intermodal Routing Problems

Since one the main benefits of an intelligent product approach seem to be the improved management of disruptions as we saw in the previous section, we conjecture that in the case of intermodal transportation and logistics, an intelligent product approach can have a very positive impact in the planning and managing decisions in the dynamic routing problem. Table 3 illustrates how the intermodal routing characteristics developed in a previous section map onto characteristics of an intelligent product approach. From the table we can see that an intelligent product approach might be appropriate for the solution of the intermodal dynamic routing problem:

Table 3. Linking intermodal dynamic routing and intelligent products

Intermodal dynamic routing requirements	Intelligent product characteristics				
	1. Unique identification	2. Comms with environment	3. Data gathering & storage	4. Language to display features	5. Decision making
Order-level information	*	*	*		
Lifecycle information	*	*	*		
Distributed decision making			*	*	*
Time-critical decisions			*	*	
Multi-objective decisions	*				*
Time consuming problem solving	*				*
Order-level decisions	*			*	*

At the information-handling level (characteristics 1-3), an intelligent product approach can support important serial-level information necessary for the support of fast and distributed decision making. First of all, by communicating with its environment a product or order or shipment will be capable of gathering information about its status during its whole lifecycle as well as collecting goals and objectives of different stakeholders while it is in transit. Utilising the above information can help operators identify and compare available alternatives which they could not normally find before. For example, this information can be used for the identification of alternative routes for an order ("different path in a transportation network" option), something that is not very usual in current practice.

Secondly, this information (e.g. order's current location, delay) can be accessed by organisations in different locations in order to optimise their decisions about the movement of an order. Negotiations can be more effective when all the important information is available. Moreover, even in cases when negotiation is not necessary, a single organisation can optimise its decisions when it holds information about the whole lifecycle of a shipment rather than its next step only. Finally, since each order will be uniquely identified and linked with individual data, the time required for the process of identifying the optimal route can be also reduced as all the required information will be easily accessible.

Including the decision making level as well (characteristics 4-5), an intelligent product approach can also support the decision making processes in the intermodal dynamic routing in two ways: Firstly by support communication between several operators of specialised information and secondly by enabling serial-level decisions to be made for different orders.

In the first case, customised views of appropriate information regarding a shipment's individual history and future needs can improve the final decisions about their next steps. For example, a terminal operator could reroute an order more effectively if he knew its final destination instead of just having access to the order's next station. This could reduce the time needed for the transportation of the order compared with the case where an order is put in the next available mode that operates the specific route. In the second case, orders make their own decisions about their next steps. Here, the intermodal dynamic routing problem could benefit in terms of facilitation of distributed and multi-objective decision making as the product could take into consideration several goals from multiple stakeholders and then choose the optimal solution. Orders, represented by software agents could negotiate with several stakeholders (who in turn will be represented by other software agents) and reach to an agreement without the participation of people, thus saving important working time.

4.2 Issues in Implementing an Intelligent Product Approach

As implied in an earlier section, the dynamic routing of orders in an intermodal network is not a futuristic scenario. As intermodal operators already face disruptions and other similar problems in their networks, they have found ways to overcome these difficulties. Current practice follows a rather *organisation oriented* approach where, when a new decision about a shipment's next steps has to be made, the organisation in charge of the shipment makes this decision (Christopher, 2011, chapter 7). For example, a carrier may decide to delay a shipment and expedite another one if this will maximise its benefit, irrespective of the end customer's and the logistics provider's needs. Such an approach often satisfies the needs of one organisation without taking into account the other stakeholders. Moreover, the tools that are currently in use mainly facilitate the adoption of the "next available movement" option (see Table 1) leaving aside other alternatives that could be more beneficial for the organisation in charge as well as its customers.

On the other hand, an intelligent product solution would provide a more *shipment oriented* or even *customer oriented* approach where, when a new decision about the next steps of a shipment has to be made, the shipment itself will seek for the best option. In this case, a shipment, representing a customer's/owner's needs, would negotiate with the different organisations participating in the planning and management of the shipment and reach to a decision regarding its next steps. Human travelling is a good analogy for this case. As people do, a shipment will decide which path is best for it given a set of parameters like the cost of transportation, the lead time etc. When a certain disruption happens, a shipment will seek for the available alternatives and decide what will maximise its benefit.

Since the transition from an organisation oriented approach to one which purely uses intelligent products would require fundamental changes to a number of elements of current practice (such as operational processes, data availability, technology used etc.), an intermediate approach might be used as the transitional phase between the two. In such an approach, when a new decision about a shipment's next steps has to be made, the different stakeholders will negotiate in order to come to an agreement. For example, in case a carrier needs to delay a shipment, he will negotiate about the alternative solutions for this shipment with the logistics provider and the customer before making the final decision. This *shipment oriented (but organisation based)* approach is already used by some organisations today. However, the role of the customer is not very significant and the tools in use for these negotiations can be very time consuming for all actors (Schuldt, 2011).

5 Conclusions

In this paper we have examined the way in which an intelligent product approach can be used for the improvement of the control of dynamic routing in intermodal networks. We did that by presenting a number of synergies that exist between the particular characteristics of this approach and the operational requirements of the intermodal dynamic routing problem. Among them, the identification and comparison of alternative routes as well as the negotiation between stakeholders for the decision of the final route seem to be the most important benefits that an intelligent product approach can bring to this problem.

We also discussed the different issues associated with the deployment of the intelligent product one starting from current practice and moving through a transitional phase. We summarise the main differences between these approaches:

- *Data access*: A shift from organisation-based to open access data models where information is distributed among and transferred between organisations.
- *Action space*: Broadened from considering only organisation-centric actions to a set of all available actions in the whole intermodal network.
- *Business values/priorities*: A shift from organisation-centric priorities to more customer-centric priorities where customer satisfaction plays a crucial role.

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