In-Transit Visibility

Asvin Goel
MIT-Zaragoza International Logistics Program, Zaragoza Logistics Center
Avda. Gómez Laguna 25, 50009 Zaragoza, Spain
agoel@zlc.edu.es

Technical Report

Intelligent Supply Chain Labs:
Deutsche Post World Net
DHL Exel Supply Chain
MIT Center for Transportation & Logistics
Zaragoza Logistics Center

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Contents

Contents i

Executive Summary vii

Acknowlegements ix

1 What is ITV? 1

1.1 Introduction 1

1.2 Related work 4

1.3 Visibility systems 6

1.4 Best practices 8

2 How can ITV be achieved? 13

2.1 Introduction 13

2.2 Tracking & Tracing 18

2.3 ETA update and alert mechanisms 22

3 How does ITV create value? 27

3.1 Introduction 27

3.2 Supply chain characteristics 28

3.2.1 Supply chain strategy 29

3.2.1.1 Push system 29

3.2.1.2 Pull system 30
3.2.1.3 Push-pull system 30
3.2.2 Product characteristics 31
3.2.2.1 Shelf-life 31
3.2.2.2 Sensitivity 33
3.2.2.3 Product value 34
3.2.2.4 Dangerous goods 35
3.2.3 Transport characteristics 36
3.2.3.1 Lead time variability 36
3.2.3.2 Network performance variability 37
3.2.3.3 Alternative routes 38
3.2.3.4 Multimodal transport 39
3.2.3.5 Operational accuracy 41
3.2.4 Supply characteristics 41
3.2.4.1 Variable shipping time 41
3.2.4.2 Variable shipping quantity 42
3.2.4.3 Alternative supply source 43
3.2.5 Demand characteristics 44
3.2.5.1 Demand variability 44
3.2.5.2 Lost demand 45
3.2.6 Financial characteristics 46
3.2.6.1 Cost- and performance-dependent invoicing 46
3.2.6.2 Milestone based invoicing 47
3.3 Actions 48
3.3.1 Alert customers 48
3.3.2 Optimise succeeding tasks 48
3.3.3 Incident and emergency management 49

3.3.4 Resolve threat to compliance 49
3.3.5 Resolve bottlenecks 50
3.3.6 Coordinate intermodal transport 51
3.3.7 Expedite assets in transit 51
3.3.8 Modify route of shipments in transit 52
3.3.9 Allocate in-transit inventory to customer orders 52
3.3.10 Reroute assets in transit to another destination 52
3.3.11 Use emergency orders 53
3.3.12 Revise routing decisions according to short-term forecasts 54
3.3.13 Revise reorder point according to short-term forecasts 54
3.3.14 Revise ordering time according to short-term forecasts 55
3.3.15 Revise ordering decisions according to anticipated inventory levels . . 55
3.3.16 Benchmarking 55
3.3.17 Speed up invoices 56
3.4 Values 56
3.4.1 Reduced transportation costs 56
3.4.2 Reduced inventory holding costs 57
3.4.3 Reduced depreciation costs 57
3.4.4 Reduced average lead time 57
3.4.5 Reduced lead time variability 58
3.4.6 Reduced vulnerability 58
3.4.7 Improved compliance 58
3.4.8 Improved on-time delivery performance 59
3.4.9 Reduced backorder costs 59
3.4.10 Reduced lost sales 59
3.4.11 Improved efficiency of succeeding processes 60
3.4.12 Increased speed of payment 60

3.5 Information 60
3.5.1 Asset identification code 60
3.5.2 Quantity shipped 61
3.5.3 Departure time at origin 61
3.5.4 Arrival time at destination 61
3.5.5 Current location 62
3.5.6 Status of assets 62
3.5.7 Estimated time of arrival (ETA) 63
3.5.8 Estimated status at arrival 63
3.5.9 Transportation network performance 63
3.5.10 Short-term forecast of transportation network performance 64
3.6 Case studies 64
3.6.1 Pharmaceutical cold chain 64
3.6.1.1 Situation without visibility 65
3.6.1.2 Situation with visibility 65
3.6.1.3 Summary 66
3.6.2 Consumer electronics: Digital cameras 67
3.6.2.1 Situation without visibility 68
3.6.2.2 Situation with visibility 68
3.6.2.3 Summary 71

4 How big is the value of ITV? 73
4.1 Introduction 73
4.2 Intermodal transport: Container routing 74
4.2.1 Problem considered 75
4.2.2 Decision making process 80
4.2.3 Levels of visibility 82

4.2.4 Computational experiments 83
4.3 Intermodal transport: The last leg 88
4.3.1 Problem considered 88
4.3.2 Decision making process 90
4.3.3 Levels of visibility 92
4.3.4 Computational experiments 92
4.4 Concluding remarks 95

5 Summary **97**

Bibliography **99**

Executive Summary

Technological advances such as global positioning, telematics, RFID, wireless communication, etc. allow to improve near real-time visibility over assets in transit. Despite the technological advances it appears that many global supply chains still suffer from the lack of visibility. While the costs for deploying systems providing visibility can be determined relatively easy, there is only little knowledge about the business value that can be generated with near real-time information on assets in transit. Obviously, the availability of data is not a value by itself and real-time data on assets in transit must be converted into information that can be used to generate business value.

This joint research by Deutsche Post World Net, DHL Exel Supply Chain, MIT Center for Transport & Logistics, and the Zaragoza Logistics Center, seeks to assess the value that can be generated with In-Transit Visibility. It begins with describing the concept of In-Transit Visibility and briefly surveys related work, existing visibility systems, and best practices. Achieving In-Transit Visibility in many international supply chains faces various challenges: a) assets in transit may be consolidated and deconsolidated in the supply chain b) various stakeholders in the transportation chain have different interests, business rules, process definitions, and data requirements c) capabilities to react on disruptions in the supply chain differ between the various actors involved and actors in the transportation chain usually do not have exact knowledge about the capabilities of other actors. These challenges make it difficult to identify disruptions and to appreciate their impact on the final customer. This research shows how In-Transit Visibility can be achieved and illustrates the fundamental differences between Tracking & Tracing and In-Transit Visibility.

A framework for assessing the value of In-Transit Visibility is developed in this research. This framework links visibility capabilities to actions and values and shows which visibility-enabled actions can generate which values with respect to the specific supply chain characteristics. This mapping of supply chain characteristics, actions, values, and visibility information is illustrated in case studies. Simulation tools are developed in order to quantify the value that can be generated with In-Transit Visibility. These simulation tools are described and the results of our computational experiments are presented in this report. Our experiments clearly show that In-Transit Visibility can significantly improve on-time delivery performance, reduce transportation costs, and improve supply chain performance.

Acknowlegements

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Chapter 1

What is ITV?

1.1 Introduction

When the truck driver of a German motor carrier, specialised in the road transport of air-cargo, was instructed about his next task, he accidentally started driving towards Oxford in the United Kingdom instead of Southern Germany, his designated destination. The reason for this was a simple misunderstanding which can easily occur when drivers are informed about new tasks while they are on the road (e.g. due to background noise in the vehicle). Neither dispatcher, nor driver realised that the truck was actually moving away from its destination until a couple of hours later, when the mistake was eventually discovered. With fix departure times, aircrafts cannot wait until their load arrives. Therefore, aircrafts must leave partially loaded if some of the load arrives at the airport with a delay. In such a case, not only unused capacity of the aircraft is lost, also the delayed load must wait until the next outbound aircraft with spare capacity departs. Obviously, hours of delay caused by driving in the wrong direction are a serious problem in air-cargo transport. Mistakes occur in every operation. However, not knowing that something goes wrong may even worsen the situation. If the truck was equipped with a GPS device allowing to track the vehicle at any time, the dispatcher could have realised much earlier that the driver was driving in the wrong direction. Another telephone call with the driver would have easily minimised the delay caused by the initial misunderstanding. Without visibility, however, the dispatcher had to believe that everything was going as planned. This example illustrates the importance of having visibility over assets in transit. The goal of this work is to show how visibility over assets in transit can

be used to generate value in supply chains taking into account the specific characteristics of the supply chain.

Visibility refers to the ability of having easy access to useful information. If stakeholder and actors have difficulties in obtaining required data, the lack of visibility may result in poor supply chain performance and agility. Therefore, a high level of visibility should be achieved by providing easier and faster access to more reliable and accurate data. As illustrated in figure 1.1, *In-Transit Visibility* (ITV) is one of the three subordinate components of *Total Asset Visibility*. In contrast to the other two components *In-Stock Visibility* and *In-Process Visibility*, In-Transit Visibility refers to visibility over assets which are either moving through the logistics supply chain or which are assigned to value adding tasks which are no major modifications of the assets itself, i.e. assets that are either assigned to a transportation task or some task fulfilling some minor modification such as packaging and customisation. These *assets* may include containers or ships as well as finished products or spare parts.

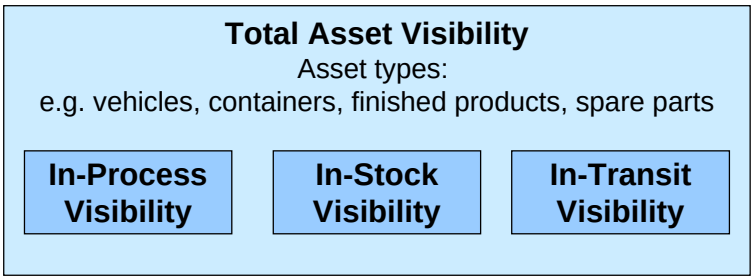

Figure 1.1: Total Asset Visibility

Depending on the capabilities of each actor in the transportation chain, In-Transit Visibility (ITV) can generate value on at least 3 levels:

- On level 1, In-Transit Visibility delivers near-real-time information on assets in transit. This information is used e.g. for short-term performance forecasts, identifying bottlenecks, benchmarking, proof of delivery, proof of compliance, invoicing, or allocating shipments in transit to customer orders.

- On level 2, information on assets in transit is compared to an updated shipment plan, allowing for e.g. updating the Estimated Time of Arrival (ETA), raising alerts, initiating mitigation actions, and optimising succeeding tasks.

- On level 3, information on assets in transit is used to influence current transportation processes, e.g. rerouting shipments, expediting delayed shipments, or coordinating intermodal transport.

According to a survey conducted by the Zaragoza Logistics Center, the main values of In-Transit Visibility expected by DHL representatives are improved on-time delivery performance, reduced inventory holding costs, and improved compliance. Furthermore, reduced transportation costs, reduced supply chain vulnerability, and reduced lead time and lead time variability are also seen as major benefits that can be generated. The respondents of our survey indicated that alerting customers, revising ordering decisions according to the short-term network performance and anticipated inventory levels, resolving bottlenecks, placing emergency orders, and improved incident and emergency management are the main value generators of In-Transit Visibility. Especially in the healthcare sector, identifying and resolving threats to compliance is regarded as a major contributor to the value of In-Transit Visibility. Most supply chains inhere some level of visibility, e.g. information updates when assets pass a checkpoint, daily status updates, or exception-based alerting. Only one of ten respondents indicated that visibility information is currently updated in real-time. Higher levels of visibility are not always seen desirable due to the costs for achieving the additional visibility. One respondent compared visibility with quality: *it pays of having a certain level of visibility, but having full visibility in real-time is not desired as the costs outweigh the benefits*. This research seeks at obtaining an understanding how In-Transit Visibility can generate value and which level of visibility is required to achieve these benefits.

The remainder of this research work is organised as follows. Section 1.2 gives an overview over literature related to supply chain visibility focusing on those works related to visibility over assets in transit. Section 1.3 briefly discusses currently existing visibility systems. Best practices of visibility use in the industry is are presented in section 1.4. Chapter 2 presents a high level framework for In-Transit Visibility. It shows how ETA updates can be provided to different actors in the transportation chains, how actors can use these updates to resolve problems and to initiate alerts when necessary. Chapter 3 shows how In-Transit Visibility can generate value for supply chains with different characteristics. Chapter 4 presents some in-depth studies quantifying the benefits of In-Transit Visibility.

1.2 Related work

In-Transit Visibility is concerned with sharing information between different actors in the supply chain. There is a line of research that focuses on determining the value of sharing downstream information with upstream partners in the supply chain. For example, Gavirneni et al. (1999) explore the value of information sharing between a retailer and a capacity-constrained supplier. By knowing the retailer's inventory position, the supplier can better utilise its limited capacity. The paper estimates the savings at the supplier due to information flow and determines when information is most beneficial. In a similar two-level supply chain with a non-capacitated supplier, Lee et al. (2000) quantify the benefits of information sharing and identify the drivers of the magnitudes of these benefits. The results indicate that the supplier can have significant savings when lead times are high. Raghunathan (2001), however, shows that the value of sharing POS data diminishes as the supplier uses more complete order history to forecast the retailer's future orders. Retailer inventory information helps the supplier to better predict the orders that will be placed by the retailer. This leads to improved performance at the supplier. Above cited research papers focus on current on-hand inventory and in-transit inventory is not considered. In-Transit Visibility could improve the capability of anticipating future inventory levels by considering inventory in the delivery pipeline. Such inventory estimates can be used to anticipate future orders.

Özer (2003) shows that inventory levels and inventory related costs can be reduced in a centralised distribution system with one warehouse serving multiple retailers if advance information on future demand is available to the inventory manager. At any given point in time, the inventory manager reviews the on-hand inventory at the warehouse, the pipeline inventory, and the orders placed by the retailers. He/she decides whether or not to place an order from the outside supplier and how to allocate the incoming batch among the retailers. As lead times are assumed to be fix, it is exactly known when pipeline inventory will arrive. In-Transit Visibility could give reliable arrival time estimates and could be used to consider pipeline inventory even when lead times are variable.

A major component of In-Transit Visibility is providing information about transportation processes to downstream partner in the supply chain. However, the literature seeking to determine the value of downstream information sharing is very scarce. Gaukler et al. (2008) quantify the benefit of In-Transit Visibility for a retailer facing uncertain replenishment lead time and uncertain demand. The authors develop a model showing how a retailer can use

information on the progress of transportation processes to efficiently place emergency orders. Zhang et al. (2006) study the value of sharing information about actual shipment quantities with the immediate downstream customers. It is shown that advance shipment notification can be used to reduce safety stock levels required if the supplier cannot always satisfy customer orders completely.

The Auto-ID Labs are a network of academic research laboratories in the field of networked RFID. Its aim is to create the Internet of Things using RFID and Wireless Sensor Networks. The goal of the Internet of Things is to globally track goods using a single numbering system called the Electronic Product Code[1]. The value of Auto-ID for transportation and the retail supply chain have been studied by Chappell et al. (2002) and Boushka et al. (2002). An item level tracking solution for multi-company supply networks has been presented by Kärkkäinen et al. (2004). In their approach, each shipment is given an identification code that reveals both the identity of the shipment, and directly tells where the tracking information should be sent.

Another line of research is based on fleet telematics solutions. Erkens and Kopfer (2001) present a communication system allowing for easily sharing information between dispatchers and drivers using mobile phones. A comprehensive discussion about how fleet telematics systems can be used to improve the efficiency of commercial vehicle operations is presented by Goel (2007). The telematics-enabled information system includes a Fleet Monitoring System allowing for automatic alerting and ETA updates. Furthermore, an interactive Dynamic Planning System optimises the current schedule using actual data obtained from the Fleet Monitoring System. The telematics-enabled information system helps to maintain punctuality, reliability, flexibility, and efficiency of commercial vehicle operations and allows for sharing actual arrival and departure times, notifications about incidents and events, and ETA updates with partners in the supply chain.

Based on several surveys conducted in 2006, Aberdeen Group presented a number of reports concerned with supply chain visibility[2]. These reports indicate that major drivers for improving supply chain visibility are concerned with visibility over assets in transit. According to Aberdeen Group (2006d), 83% of companies surveyed cite an increasing awareness of the cost and service impact of transportation on overall supply chain performance. More than three quarters say that they need to improve transportation processes because of inter-

[1] See EPCglobal

[2] See Aberdeen Group (2006a;b;c;d)

nal and customer demand for accurate delivery status and transportation costs information. 68% mention challenges arising from lead time uncertainties and desired on-time delivery performance as major driver for improving transportation processes. Accordingly, half of the companies see building up the capability to provide accurate on-line status and cost information, and connecting systems to share transportation information, as one of the most important actions for achieving transport management success. According to Aberdeen Group (2006b), basic tracking of shipments is rapidly becoming a “must have”. Companies seek operational improvement and financial value from visibility by adding the ability to alert if shipments are deviating from planned milestones and using visibility information to identifying the root causes of deviations. As reported by Aberdeen Group (2006b), many companies currently use multiple visibility systems which prevents them from gaining a single view of activity across the supply chain, and limiting the capability of obtaining consistent and timely information on order status. As a result, only a third of the companies participating in the study have alerting capabilities to let users know if actual events are deviating from plans and only slightly more are capable of updating arrival time estimates (ETA). As reported in Aberdeen Group (2006c), 59% of the survey respondents mention integration with existing systems, and 48% mention difficulty quantifying specific improvement as major obstacles towards the deployment of visibility technology.

Several research projects related to In-Transit Visibility were launched within the Sixth Framework Programme of the European Union. The BRIDGE project seeks to research, develop and implement tools to enable the deployment of EPCglobal applications in Europe. It is a 13 million Euro project that will be completed in June 2009. The CHILL-ON project seeks at developing novel technologies with focus on monitoring, managing, and tracing the entire supply chain for chilled and frozen food. It is a 15.2 million Euro project that will be completed in June 2010. Smaller projects are the CE RFID project aiming to strengthen the RFID value chain in Europe and the TRASER project seeking to develop tracking services for SME.

1.3 Visibility systems

A variety of software solutions exist today that give visibility over assets in transit. As stated by DHL representatives, DHL uses more than hundred different visibility systems and, as reported by Aberdeen Group (2006b), many other companies currently also use multiple

visibility systems which prevents them from gaining a single view of activity across the supply chain. Aberdeen Group (2006b) report the following on the systems companies use for shipment tracking: 54% use their carrier's on-line tracking system , 32% use a commercial transportation management system, 27% use a visibility solution from a third-party logistics provider, 22% use a home-grown visibility system, and 17% use a commercial supply chain visibility system.

Various systems exist that allow tracking of ships, truck, trailers, and containers[1]. Most of them operate using satellite positioning and wireless communication such as satellite communication or cellular communication networks. They regularly submit the current position, driver input, and sensor data to the dispatching office where position and status information can be used to identify deviations between actual and planned transportation processes. When vehicle ID, position, and status information can be assigned to the shipments, these systems can significantly improve visibility for single transportation legs and enable carriers to share visibility informations with partners in the supply chain.

Visibility systems for transportation chains involving multiple legs are provided by companies such as Descartes and Oracle. Sophisticated supply chain visibility solutions such as the Descartes Logistics Network Operating System (LNOS) allow for tracking and tracing on various reference numbers of various partners in the supply chain: e.g. purchase order numbers, sales order numbers, waybill numbers, shipment numbers, warehouse receipt numbers, etc.. Visibility systems can include important business documents, scanned proofs of delivery, and provide role based access control guaranteeing that each user may only see the data he/she is allowed to see. In case of events alerts can be raised and sent to predefined users. Furthermore, theses systems can be integrated into warehouse management systems and transportation management systems allowing for dynamic supply chain management and optimisation.

As can be seen, powerful tools for achieving visibility over assets in transit exist today. However, these tools only achieve their full power if they can be integrated into existing systems and systems of supply chain partners. Integration of these systems, however, is not always feasible and often very costly. Difficulties quantifying specific benefits are major obstacles towards the wide spread deployment of sophisticated and integrated visibility systems.

[1] See Andres (2004) for a survey on the fleet telematics market

1.4 Best practices

Schneider National pioneered the trucking industry by using a fleet telematics system in 1988. As reported by Cohen (1995), the company initially invested $20 million to launch its system. The outlay included $3500 worth of equipment for each of its trucks and provided 2000 personal computers connected to a central server. The fleet telematics system allows to locate trucks and to communicate with truck drivers. The improved visibility helped the company to direct drivers to the best route and to reduce deadhead miles by 25%. As communication is bidirectional, drivers can receive directions to their destinations and information about which delivery gate to use. This reduces time at the gate, allowing trucks to remain longer on the road. Each Schneider driver supervisor can manage 40 truckers, opposed to 25 before deployment of the system. Schneider also constantly monitors each truck's speed and drivers' working hours. This has helped to reduce the company reduce its accident rate by 35% and also reduces fuel costs by preventing trucks from speeding. At the end of each run, Schneider records a truck's fuel consumption, which helps the company spot mechanical problems early. Despite Schneider's benefits, decreasing costs for such systems, and technological advances, e.g. integration of CAN-bus and sensor data, many small and medium sized carriers still do not use fleet telematics systems today.

Parcel services such as those of DHL, UPS, or Federal Express allow for on-line tracking of shipments using a tracking number. These on-line shipment tracking systems provide shipment details, status information based on milestones in transportation processes, and a proof of delivery. Figure 1.2 illustrates an example of an on-line shipment tracking service.

According to Aberdeen Group (2006a), companies tracking more than 80% of their shipments are twice as likely as their peers to have an on-time delivery performance of 95% or higher. Companies that achieve the highest value from visibility technology apply statistical process control and Six Sigma analysis methods to identify recurring points of variability and delays, research their underlying causes, and take corrective actions. For example, one of the companies surveyed in Aberdeen Group (2006b) based its safety stock calculation on a high-volume lane on a lead time of five days but its visibility system revealed real lead times of only three days. As reported in Aberdeen Group (2006a), one consumer goods company found that inaccurate lead time data in its SAP system was causing some orders to be delivered five days early, while others were being delivered 20 days late. In Aberdeen Group (2006a) it is reported that P&G has been able to improve on-time delivery performance from

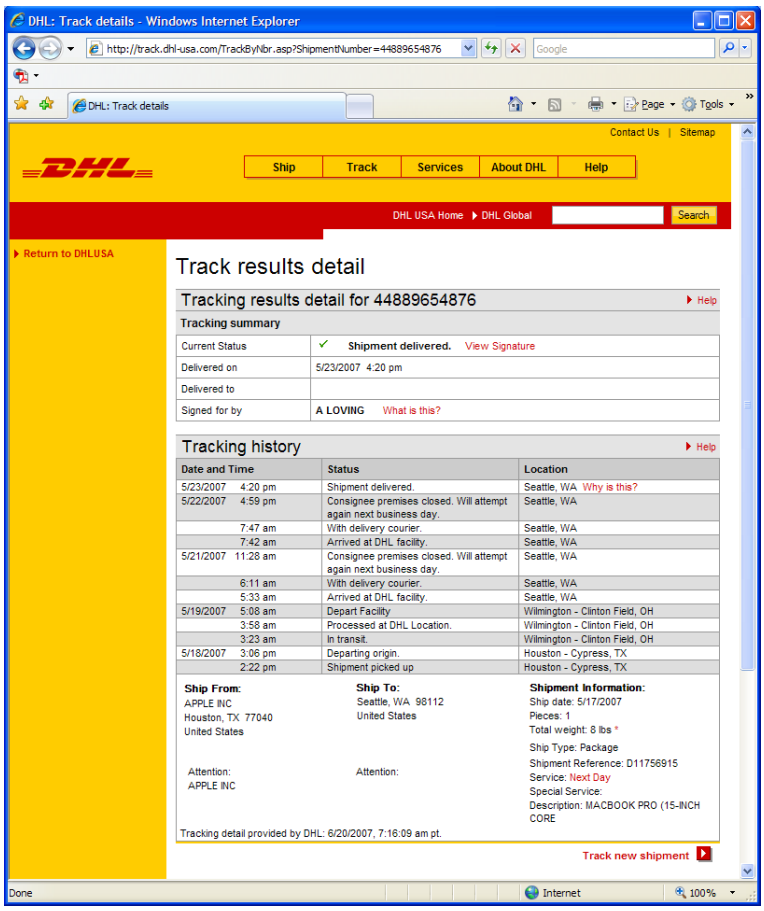

Figure 1.2: On-line shipment tracking

94% to 97% on key trade lanes after starting to track shipments from its 35 plants in the United States and Canada to its retail customers.

As reported in Aberdeen Group (2006d), the visibility system of a European pharmaceutical company, allowing to monitor several hundreds of trade lanes, has brought significant opportunities for consolidating shipments, lowering transportation spend, reducing expediting costs, and addressing potential shipping issues before they impact customer service. It is reported that the company was able to cut its inventory costs by $55 million and lowered total logistics costs by 5% through its visibility initiative.

Liz Clairborne deployed a visibility solution to monitor and manage products from the departure of the goods at one of the over 3000 suppliers through their arrival at the final destination. Visibility enabled actions, e.g. to redirect cargo to different trans-load facilities or

alternative port to avoid congestion or to expedite, have reduced import transit times by 5 to 7 days and removed 7 to 10 days of inventory due to shorter lead times[1].

Metro Group and Savi Networks launched a pilot for real-time RFID-based tracking of containers originating in Asia and bound for Metro's European distribution centre[2]. UHF Electronic Product Code (EPC) tags are applied to containers loaded with cartons of various goods to be exported, including pens and kitchen gadgets. In China, the packages are pushed through an RFID portal. After the system reads the tags, software creates an electronic packing list, which is sent electronically to MGB Metro Group Buying HK to be checked for accuracy. The packing list is then used to generate an advance shipping notice (ASN), which is sent to Metro headquarters. When the goods arrive at a Metro Group distribution centre in Unna, Germany, the system reads the tags and checks them automatically against the ASN. The pilot was deemed a success, so Metro Group decided to expand the system to additional suppliers in Asia[3].

IBM and Maersk Logistics have jointly developed a system for tracking shipping containers around the world[4]. The IBM-Maersk system uses real-time tracking devices called TRECs (Tamper-Resistant Embedded Controllers), fitted to cargo containers. The devices transmit data using a combination of wireless technologies, depending on what is available at any given time: wireless data networking technology from ZigBee or cellular phone systems or the Iridium satellite data network. Container-related data, such as physical location (derived from a GPS unit), temperature and humidity readings, and intrusion alerts, can be received instantly, sent via the wireless TREC devices and shared over a container information framework network. IBM maintains that its TREC devices will be able to communicate data at all times, allowing for visibility of vessels and their containers on the open sea. The system uses ZigBee tags[5] to transmit temperature, humidity and other types of environmental data from sensors on cases or items inside the container to the TREC device.

DHL developed RFID sensor tags allowing pharmaceutical customers to monitor the state of temperature sensitive products in transit[6]. The sensor tags consist of a long narrow piece

[1] See Aberdeen Group (2006e)

[2] See RFID Update (2006)

[3] See RFID Journal (2007b)

[4] See RFID Journal (2005)

[5] A ZigBee tag is a small RFID tag that uses the ZigBee protocol to communicate and can be integrated with various sensors to detect environmental conditions

[6] See RFID Journal (2007a)

of paper with an embedded EPC Gen 2 RFID inlay and data-storing microchip wired to a temperature sensor. Mounted on one end is the sensor, while the opposite end contains the RFID inlay and data-storing microchip. The latter is intended for storing temperature readings and other information about the product, which can be downloaded by handheld readers along the supply chain. During the pilot tests, the pharmaceutical company loads a box of products onto a pallet in its warehouse. Because of the sensor tag's long shape, the company can place the sensor side inside the box, enabling it to more accurately track temperature changes. The company can attach the tag's RFID side onto the pallet, where it is more accessible to an RFID interrogator and would be less affected by aluminium and other RF-unfriendly materials commonly found in the packaging of pharmaceutical products. The company writes information onto the sensor tag's microchip, including a description of product being shipped, its serial number, shelf life, expiration date and temperature requirements. The shelf life can be updated according to the temperature history and read in transit.

Chapter 2

How can ITV be achieved?

2.1 Introduction

In order to achieve In-Transit Visibility one must obtain relevant information about transportation processes and the status of assets moving through the supply chain. These assets not only differ by type, but also by purpose. Figure 2.1 illustrates different types of assets and their relationships. The main reason for transportation is to move items of a product from its source to its destination. Items with identical origin and destination may be bundled into shipments to save packaging and transportation costs. Standardised containers are used to ease transportation processes as they can be loaded on container ships, rail road cars, and trucks.

A problem in achieving visibility over assets in transit is that assets may be consolidated and deconsolidated in the transportation chain. As illustrated in figure 2.2, transportation processes may involve a combination of various asset types, e.g. items, shipments, containers, and vehicle. Data relevant to various assets may be difficult to associate with these assets. For example, the position of trucks may be easily obtained using positioning systems attached to some wireless communication device. Determining the position of a specific item, however, requires the knowledge about which item is in which shipment, which shipment is in which container, and which container is mounted on which vehicle. Achieving visibility over assets in transit must therefore tackle the challenge of asset hierarchies.

Another challenge in achieving visibility arises because transportation chains typically involve multiple different stakeholders. Figure 2.3 illustrates these different stakeholders and

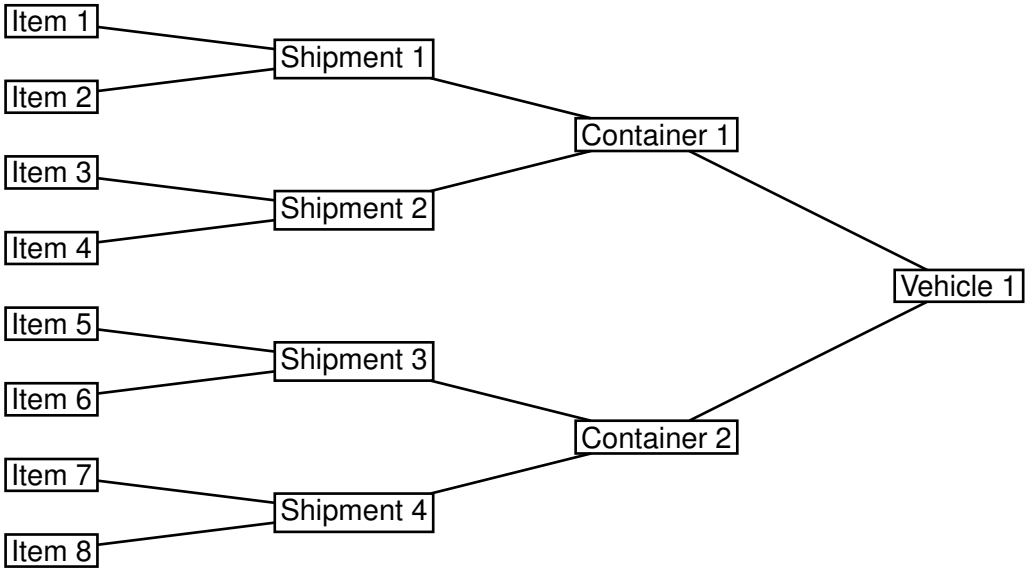

Figure 2.1: Assets moving through the transportation chain

Source: Europe Container Terminals

Figure 2.2: Palletised shipments within standardised containers mounted on a truck.

typical relationships between them. Customers require certain items which are to be transported from the source to the destination. Logistics Service Providers are responsible for organising transportation on behalf of the customer. Eventually, carriers are responsible for the actual transportation and are employed by the customer or by the Logistics Service Provider.

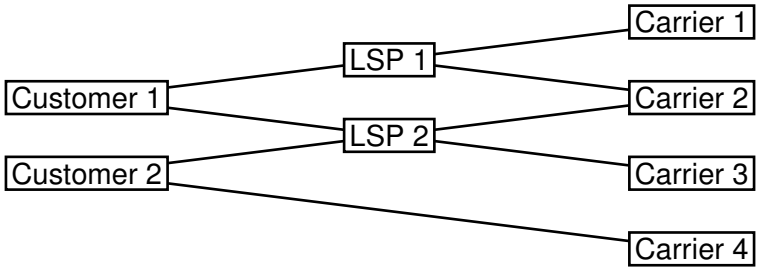

Figure 2.3: Stakeholders in a transportation chain

Each of these stakeholders has different interests, different knowledge about the transportation network, and different access to data concerning the actual progress of transportation processes.

Customers have the best knowledge about items to be transported. They are particularly interested in the timely delivery of the ordered items. As illustrated in figure 2.4, they may know a few carriers and Logistics Service Providers which may take care of the transportation of these items. However, they generally only have very high level information about the transportation network.

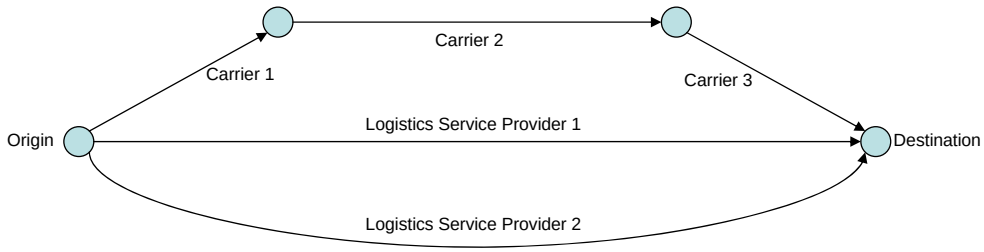

Figure 2.4: Customer's view of the transportation network

Logistics Service Providers may be responsible for consolidating various shipments with same origin and destination. After consolidation, transportation of the container is managed

by the Logistics Service Providers. As illustrated in figure 2.5, Logistics Service Providers have a more detailed view on the transportation network including transshipment terminals and different modes of transport that can be used. Once a route is chosen for a container, the Logistics Service Provider will be interested in the timely arrival of the containers at the transshipment points.

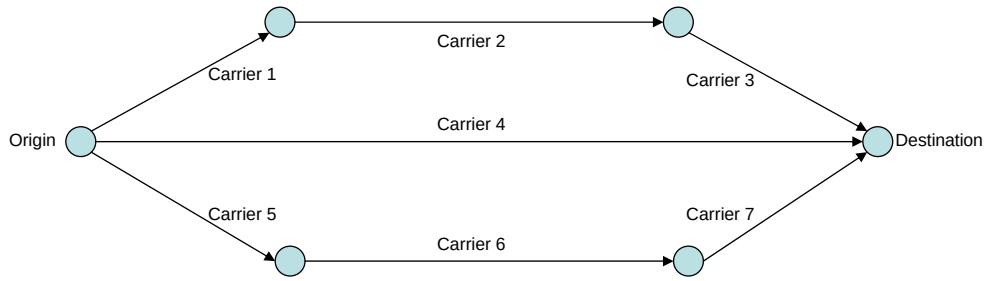

Figure 2.5: Logistics Service Provider's view of the transportation network

Carriers take care of the actual transportation processes via aircraft, truck, train, barge or vessel. They may transport multiple containers with the same vehicle and are primarily interested in timely arrival of the vehicle at the destination. As illustrated in figure 2.6, they have the most detailed knowledge about the transportation network, e.g. traffic conditions and alternative routes through the road network.

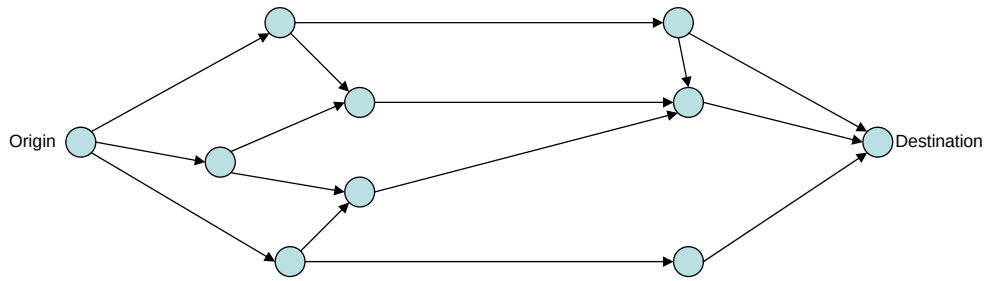

Figure 2.6: Carrier's view of the transportation network

As carriers are performing the actual transportation processes, they have the best knowledge about the progress of these processes. However, carriers only have information related to the containers and the vehicles operated, but do not have detailed information regarding shipments and items in the shipments. Logistics Service Providers have knowledge about the containers and shipments, but not necessarily about the items. Finally, customers have

knowledge about items and shipments, but not about containers or vehicles used. Of course, transportation chains may be structured differently. However, the important point in this discussion is that the various stakeholders have access to different information. In order to achieve visibility, all relevant information between the different stakeholders must be shared.

While Tracking & Tracing seeks to obtain actual data about transportation processes, In-Transit Visibility seeks to provide relevant information about assets in transit. Although some data may be relevant to carrier and/or Logistics Service Provider, the same data may not be of any relevance to the customer. For example, a delayed truck may endanger feasibility of the original transportation plan made by the Logistics Service Provider. If the carrier or Logistics Service Provider is capable of re-planning transportation processes in such a way that on-time delivery at the customer is guaranteed, information about the deviation from the original plan is not of relevance to the customer. In-Transit Visibility, therefore, also concerns the capability of each actor in the transportation chain to react on deviations from the original plan.

Some stakeholders in a transportation chain may be cooperation partners, others may be competing against each other. Information sharing mechanisms must take into account that it is often impossible to fully integrate Management Information Systems of the various stakeholders. Summarising the above, following challenges must be tackled in achieving In-Transit Visibility.

Asset hierarchies As assets may be consolidated and deconsolidated in the transportation chain, certain data will relate to consolidated assets (e.g. a box on a pallet in a truck load) and some to single items (e.g. the item within that box). A carrier typically has little knowledge and interest in the items transported. On the other hand a customer has little knowledge and interest in the vehicles used for transportation. As information may relate to various assets it is necessary to be able to map vehicles to containers, containers to shipments in the container, and shipments to the items in the shipment. Furthermore, mechanisms must be generated to ensure that visibility information is processed and passed over to the relevant stakeholders.

Stakeholders Each stakeholder has its own interests, business rules, process definitions, and data requirements. Various sources of information

may be available for the different stakeholders e.g. schedules, fleet telematics systems, manual data input, etc.. Management Information Systems of different stakeholders may come with or without standardised interfaces and are typically not fully integrated. As a result, stakeholders cannot exactly determine the requirements of other stakeholders in the transportation chain, and it is difficult to estimate the impact of disruptions on other stakeholders. As information obtained from other stakeholders may not meet all data requirements, it may be required to analyse and enrich such data in order to obtain usable information.

Capabilities Whether visibility information is relevant does not only depend on actual data concerning transportation processes, but also on the capabilities of reacting on deviations from the plan. These capabilities may differ between the various actors in a transportation chain. Actors in the transportation chain usually do not have exact knowledge about the capabilities of other actors. The impact of deviations to the final customer is therefore hard to appreciate without consulting all actors involved.

2.2 Tracking & Tracing

Tracking describes the continuous determination of position and state of shipments and vehicles, whereas tracing describes the retrospective identification of the trace of shipments and vehicles[1]. One of the challenges in Tracking & Tracing lies in the fact that information obtained about the actual progress of transportation processes may not easily be related to information stored in the corresponding Management Information Systems. Consider, for example, a vehicle equipped with telematics devices to regularly submit GPS coordinates of the current position. Management Information Systems usually only include address information of origin and destination, but no details about the exact route to be used by the vehicle. Furthermore, address information may only include street name, house number, city name, and postal code. Only when raw data such as GPS coordinates are processed

[1] See van Dorp (2002)

(using digital road maps), the relative position with respect to the planned route can be determined with a high level of accuracy. Another example is one of a customer employing a Logistics Service Provider to organise transportation. The Logistics Service Provider may inform the customer about arrival and departure times at transshipment terminals. However, if the customer is not aware of route and mode of transport, the customer may not be able to use such information to identify delays. Further challenges arise due to lags between data capture and availability of the data, as outdated data may lead to wrong assumptions on the actual state of the transportation system. Inaccuracies may also create problems, for example, inaccurate position data may make it impossible to determine whether a vehicle has already reached its destination or is only close to it.

The remainder of this section describes a generic framework allowing stakeholders to determine the current state and position of an asset in transit. In this framework, which is derived from a Fleet Monitoring System developed for motor carriers[1], it is assumed that the stakeholder obtains messages about the progress of transportation concerning a particular asset. These messages include the identifier of the asset and a timestamp. Furthermore, an estimated time of arrival (ETA) at the destination of the asset, the current position of the asset, and status information may be attached to the message.

The asset is assumed to follow a predefined path of transportation processes. This path of transportation processes may be specified on different levels of abstraction, depending on the stakeholder's knowledge. Formally this path can be described by a sequence of nodes in the transportation network and a sequence of events which are expected to occur. The execution of a transportation process represents the movement of an asset from one location (i.e. a node in the transportation network) to another. During the execution of transportation processes events may occur which trigger the submission of status information.

Each node in the planned route of the asset is associated to planned arrival and departure times. Each planned event is associated to a time window during which the occurrence of the event is expected and the status information by which the event may be identified. Some events may only occur at certain nodes in the transportation network, others may occur anywhere. Besides of events which are expected to occur, other unexpected events can also influence the progress of transportation or the state of the asset. A class diagram providing all relevant data required for Tracking & Tracing is illustrated in figure 2.7.

[1] See Goel (2007)

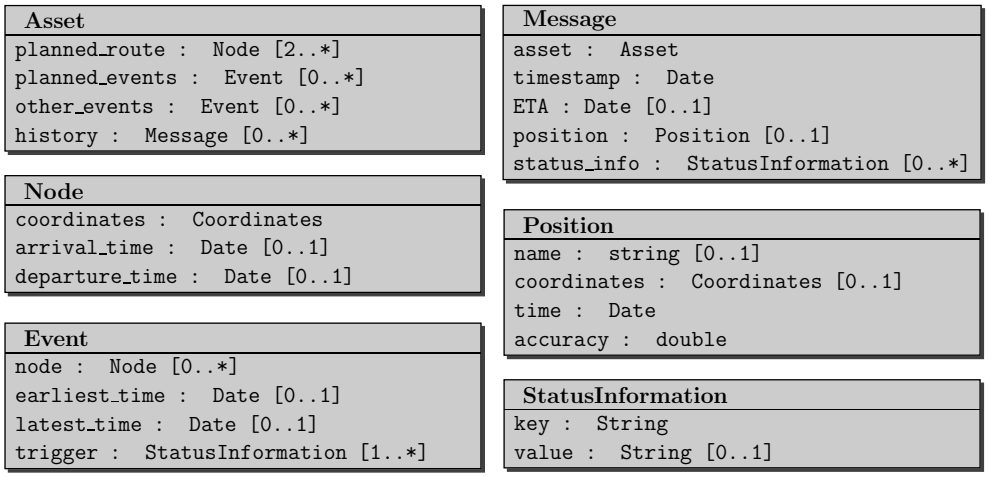

Figure 2.7: Class diagram for Tracking & Tracing

Let us assume that we are interested in tracking two shipments with identification number 101 and 102. These shipments are first loaded into a container which is then mounted on a GPS equipped truck. The truck delivers the container to a transshipment terminal from where it is forwarded by rail to the destination of the shipments. Figure 2.2 gives an example of messages that can be used to track these shipments in transit. First, a message is sent informing that shipment 101 and 102 are loaded into container 123. Then, a message is sent informing that truck 456, which has picked up container 123, has left the origin. During transportation the truck regularly sends GPS coordinates indicating the current position. At the transshipment terminal a messages indicating the arrival of the container and another message indicating the departure of train 789 are sent. When the train passes a predefined checkpoint and when the train arrives at the destination further messages are sent. With these messages and above data structure it is possible to track each item, shipment, container, and vehicle and to identify deviations from the original transportation plan. However, enough process knowledge must be available to analyse messages appropriately. For example, truck speed and working hour regulations for the truck driver are required to estimate the arrival time at the transshipment terminal; train speed and location of the checkpoint are required to estimate the arrival time at the destination.

In certain environments, monitoring the progress of transportation is trivial as message contents can be easily matched to the planned route of an asset and/or the planned events.

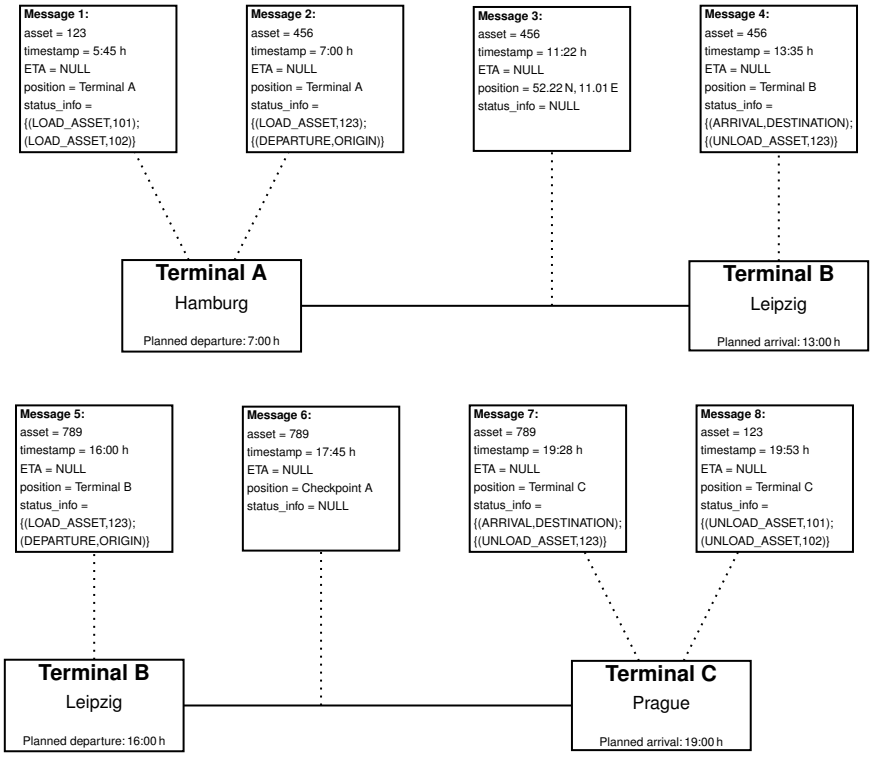

Figure 2.8: Messages

In other environments, however, this matching may be more complicated due to various reasons. The accuracy of positioning devices, for example, may make it difficult to match the position of the asset to the corresponding node in the transportation network. Furthermore, inaccurate planning data, faulty or delayed manual input, and missing information can increase the complexity of automatic analysis. Therefore, each stakeholder must make the best use of his/her process knowledge in order to monitor the progress of transportation. Fleet and container tracking systems based on positioning systems, for example may use map matching methods as described in Bernstein and Kornhauser (1996) and White et al. (2000). Sophisticated map-matching methods can deal with inaccuracies as they not only compare the current position of the asset with the planned route, but also the trace of the asset. This so-called curve-to-curve matching significantly improves the accuracy of map-matching methods. A motor carrier may also use additional status information, e.g. messages from drivers including the begin and end of breaks and rest periods. Using such

information can significantly improve arrival time estimations as regulations concerning the maximum hours of driving without break and rest periods may be considered.

Just as an incoming message can give information about possible problems, the non-appearance of an expected message may indicate that some incident occurred. For example, it may be expected that 45 minutes after begin of a break period a truck driver shall continue driving. If such a message is not received in time, the truck driver may take a longer break than expected, possibly resulting in a delayed arrival at the transshipment terminal.

A Tracking & Tracing system that is capable of analysing messages and identifying discrepancies between actual and planned transportation processes can help in identifying and resolving disruptions faster and more effectively. Human transportation managers do not need to read and analyse all incoming messages and thus, can concentrate on those messages which cannot be interpreted automatically or where unexpected incidents are identified. The drawback of such a Tracking & Tracing solution is that not every stakeholder may have enough process knowledge to be able to analyse all messages appropriately. Furthermore, it may not be practical to share all messages with every stakeholder. The following section describes how ETA update and alert mechanisms can be realised for transportation chains with various stakeholders having different knowledge of the transportation network.

2.3 ETA update and alert mechanisms

In-Transit Visibility concerns the capability of achieving relevant information over assets in transit. This not only includes the determination of the current state of the transportation system, but also information concerning the consequences of deviations from the plan. Consider a delayed truck on its way to a transshipment point. Information about the delay is certainly of relevance to the carrier, but not necessarily to the Logistics Service Provider and the final customers. The carrier may be able to reroute the truck, e.g. by using a toll road to reduce travel time (at the expense of higher costs). If, after rerouting, the truck will arrive on time, the delay is of no interest to the Logistics Service Provider and the final customers. If, however, the truck will not arrive on time, the Logistics Service Provider must be informed about the delay. The Logistics Service Provider can appreciate the impact of the delay on the final arrival at the customer. Furthermore, the Logistics Service Provider may replan transportation in order to eliminate or minimise the delay (and the impact to the client). If the resulting updated ETA at the customer is later than planned, the customer can be alerted.

Each stakeholder can monitor transportation processes using the information available to determine the state of the transportation system. Instead of just forwarding information to his clients, each actor should analyse whether deviations may have an impact on his/her clients or not. Potential impacts on the client may be eliminated by re-planning transportation according to the actual state and capabilities of the transportation system. For example, a missed train may result in a delayed arrival at the customer location of a full day (when the next train departs) if nothing is done. However, transportation processes may be re-planned such that the shipments are trucked to their final destination in order to minimise the delay. Of course, expediting shipments may involve additional costs. Depending on the relationship with his/her clients an actor may, however, be willing to cover the additional cost in order to minimise the impact of a disruption to the client.

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1. Receive message
2. Analyse message and update ETA
3. If problem is detected:
   (a) Initiate mitigation action and re-plan transportation
   (b) Update ETA
   (c) If problem cannot be resolved: alert client
4. Send message including updated ETA

Figure 2.9: ETA update and alert mechanism

Figure 2.9 illustrates such an ETA update and alert mechanism. Each actor in the transportation chain receives messages about the progress of transportation processes. These messages are analysed and arrival time estimates are updated. If a deviation results in a problem, the actor analyses whether mitigation actions can be initiated and the transportation plan must be modified accordingly. Arrival time estimates are updated considering these mitigation actions. If the problem cannot be resolved the actor alerts his/her clients. Eventually, messages are sent to the clients including the updated ETA.

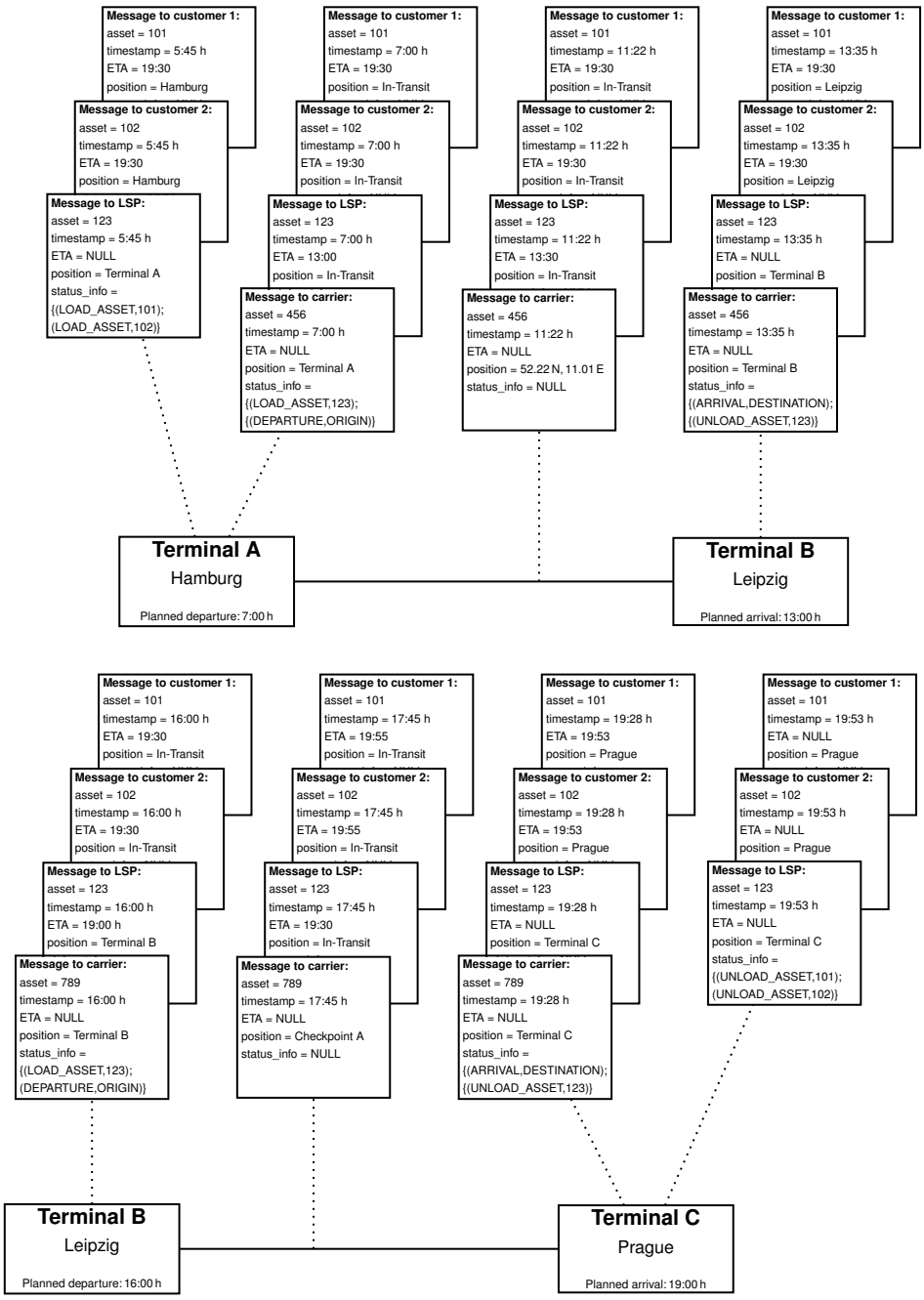

Figure 2.10: ETA update and alert mechanisms

With these ETA update mechanism, visibility in the example presented in the previous section can be achieved as illustrated in figure 2.10. Instead of forwarding messages received, carriers and LSP first analyse all messages. Based on this analysis they prepare messages to their clients containing only the information that is relevant to them. For example, the carrier who receives GPS coordinates does not forward these coordinates to his/her clients. Instead, the carrier uses his/her process knowledge to update the estimated time of arrival at the next destination. This ETA update is sent to the LSP. The LSP analyses the delay and updates the estimated time of arrival of the shipments at the final destination and sends a respective message to his/her clients. As a result, customers receive information about all delays that may have an impact on them and do not receive any information concerning insignificant delays having no impact on final arrival. As this approach only includes bilateral communication between actors and their direct clients, this approach is much easier to realise as sharing all data available. Furthermore, none of the stakeholders requires detailed knowledge about processes and capabilities of the various actors.

Chapter 3

How does ITV create value?

3.1 Introduction

Most initiatives seeking to achieve In-Transit Visibility include an investment into technology. This may include mobile devices accompanying assets in transit, fixed readers at neuralgic points in the transportation networks, and informations systems and their integration. While the costs for deploying such technology can be determined fairly easily, it is still a challenge to determine the benefits that can be generated with In-Transit Visibility.

Technology providing visibility information allows for identifying deviations between actual and planned transportation processes. Timely access to reliable information may also give opportunities of improving processes which would not be possible with a lower level of visibility. Driven by deviations and opportunities, visibility-enabled actions can be taken which eventually generate business value. Some of these actions may require some control capability, e.g. the capability of re-routing shipments in transit. As illustrated in figure 3.1, which illustrates the relationships between technology, actions, and value, these control capabilities may be provided by the same technology that is used for obtaining visibility. For example, most fleet telematics devices can be used to locate trucks and to communicate with drivers. The value generated by visibility-enabled actions justifies investments required to achieve the right level of visibility. This chapter seeks to obtain an understanding of how, subject to specific supply chain characteristics, value can be generated by specific actions and how these actions depend on the available visibility information.

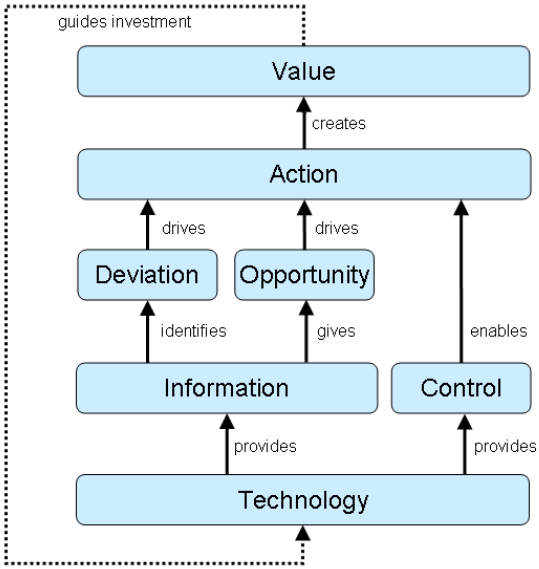

Figure 3.1: How ITV can help generating value

The remainder of this chapter is organised as follows. Section 3.2 describes several supply chain characteristics and determines which visibility-enabled actions can be taken in order to generate value according to the specific characteristics. These actions are described in section 3.3. Section 3.4 describes values that can be generated and section 3.5 gives an overview of information required to obtain better visibility. This chapter concludes with some case studies presented in section 3.6.

3.2 Supply chain characteristics

This section identifies several supply chain characteristics and the corresponding actions that can be taken in order to generate value using visibility information. First, high level characteristics of the general supply chain strategy are discussed. Then, product and transport characteristics, supply and demand characteristics, and financial characteristics are discussed.

3.2.1 Supply chain strategy

3.2.1.1 Push system

In a push system products are pushed through the channel, from the production side up to the retailer, where they are sold to the consumer. The quantity to be pushed through the channel is based on demand forecasts. In-Transit Visibility can help anticipating future inventory levels by considering inventory in the delivery pipeline. Thus, In-Transit Visibility allows to react on anticipated shortages or overages of stock. If shortages are anticipated, in-transit inventory can be expedited and additional shipments can be reordered earlier. If overages are anticipated, in-transit inventory can be rerouted to slower but less costly routes and additional shipments can be reordered later. Forecasts of future inventory levels and demands may also be used to reroute in-transit inventory to alternative retailers.

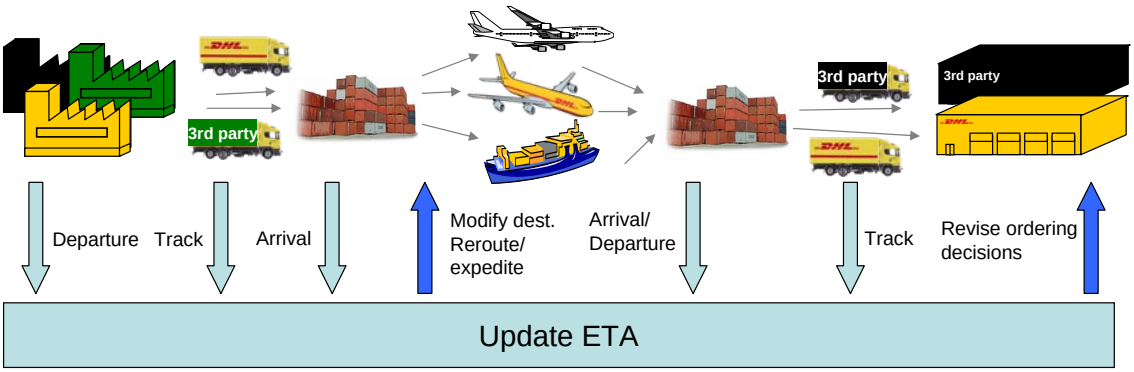

Figure 3.2: ITV in a push supply chain

Figure 3.2 illustrates how In-Transit Visibility can generate value in push supply chain.

Potential actions:

- Revise ordering decisions according to anticipated inventory levels
- Expedite assets in transit
- Modify route of shipments in transit
- Reroute assets in transit to another destination

3.2.1.2 Pull system

In a pull system, products are pulled by customer demand, i.e. production and distribution are initiated by actual customer orders, rather than forecasted demand. In-Transit Visibility allows to track shipments in transit and to detect discrepancies between actual and planned progress of transportation. Information about deviations can be used to expedite delayed shipments, reroute early shipments to slower and less costly routes, alert customers about delays. Updated arrival time estimates can be used by customers to optimise their tasks taking into account forecasted inventory levels.

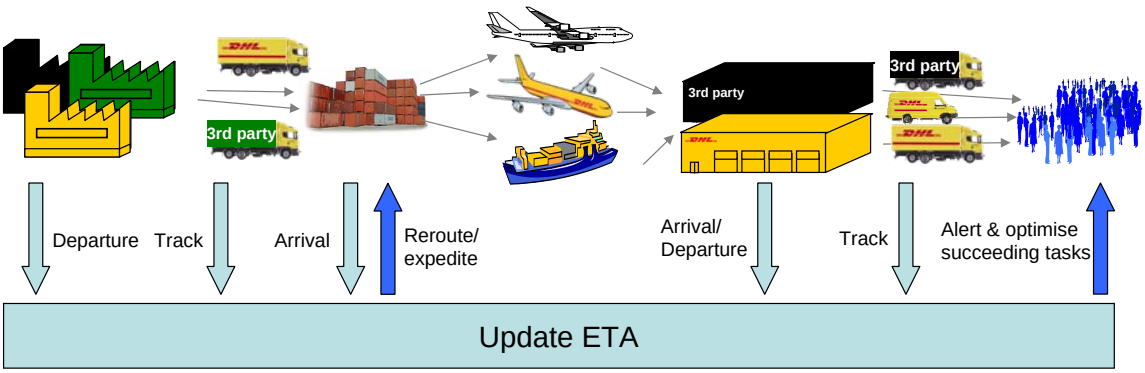

Figure 3.3: ITV in a pull supply chain

Figure 3.3 illustrates how In-Transit Visibility can generate value in pull supply chain.

Potential actions:

- Alert customers
- Optimise succeeding tasks
- Expedite assets in transit
- Modify route of shipments in transit

3.2.1.3 Push-pull system

A push-pull system is a combination of both push system and pull system, where the interface between the push-based stages and the pull-based stages is known as the push-pull boundary. In-Transit Visibility can allow for all the actions of a push and a pull system.

Furthermore, in-transit inventory can be allocated to customer orders. The corresponding shipments can be rerouted and transported to the customer location without passing through distribution centres.

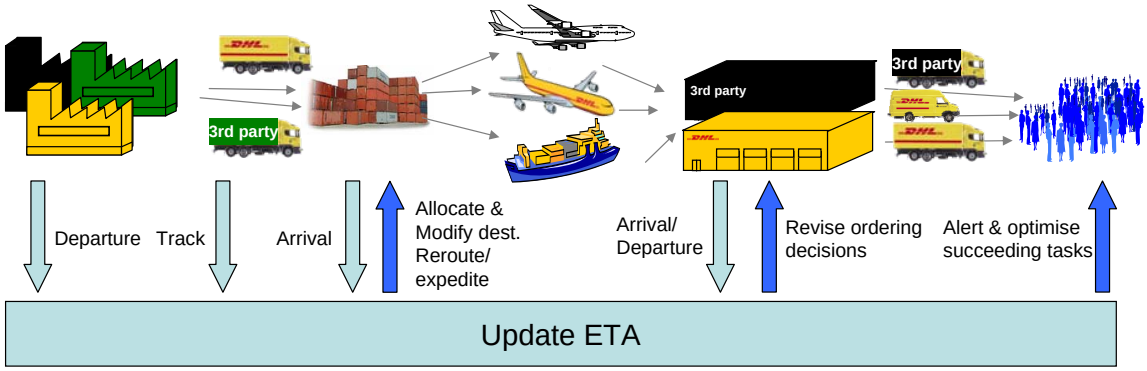

Figure 3.4: ITV in a push-pull supply chain

Figure 3.4 illustrates how In-Transit Visibility can generate value in push-pull supply chain.

Potential actions:

- Revise ordering decisions according to anticipated inventory levels
- Expedite assets in transit
- Modify route of shipments in transit
- Alert customers
- Optimise succeeding tasks
- Allocate in-transit inventory to customer orders
- Reroute assets in transit to another destination

3.2.2 Product characteristics

3.2.2.1 Shelf-life

Goods with short shelf-life may devaluate during transit. Examples of short shelf-life products are electronics such as digital cameras, or perishable goods such as food or pharmaceutical products. Excessive transit times reduce the remaining shelf-life upon arrival at the

consumer. In-Transit Visibility can be used to anticipate the remaining shelf-life and devaluation upon arrival at the destination by providing frequent updates of the estimated time of arrival. Customers can be alerted in case of delays and succeeding tasks can be optimised. If the probability of a delayed arrival is high the asset can be expedited by changing to a faster (but usually more costly) route. If the asset probably arrives very early a cheaper but slower route can be used. If the goods are likely to lose their value before arrival, emergency orders may be placed in order to fulfil purchase orders with a minimal delay. Furthermore, arrival time estimates can be used to revise subsequent ordering decisions earlier, and to reroute devaluated shipments to other destinations. Shipments can be allocated to customer orders according to their estimated remaining shelf-life upon arrival and the destination of the shipment may be modified accordingly.

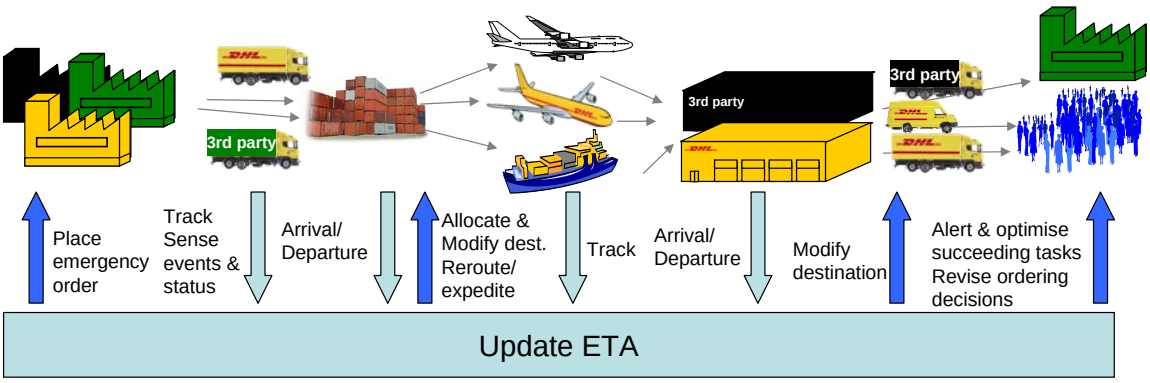

Figure 3.5: ITV in a supply chain for perishable goods

Figure 3.5 illustrates how In-Transit Visibility can generate value in a supply chain for perishable goods.

Potential actions:

- Revise ordering decisions according to anticipated inventory levels
- Allocate in-transit inventory to customer orders
- Reroute assets in transit to another destination
- Expedite assets in transit
- Modify route of shipments in transit
- Use emergency orders

- Alert customers
- Optimise succeeding tasks

3.2.2.2 Sensitivity

Goods may be sensitive to the conditions in transit, e.g. food or pharmaceutical products are often temperature sensitive, electronic equipment is shock sensitive. Sensitive goods may may loose their value in transport due to inappropriate conditions. Without In-Transit Visibility the amount of shipments arriving at the destination in perfect condition can only be determined upon arrival. However, some or all of the value of the goods may have been lost during transport.

Sensors can be used to record the conditions of transport. In-Transit Visibility can provide knowledge about whether required conditions are kept. This knowledge can be used to update the estimated quantity that will arrive in perfect condition. Threats to compliance can be identified and resolved. Customers can be alerted in case of damaged shipments and succeeding tasks can be optimised. If shipments are damaged, emergency orders may be placed in order to fulfil the purchase order with a minimal delay. Furthermore, this information can be used to revise subsequent ordering decisions earlier, and to reroute damaged shipments to other destinations. Shipments can be allocated to customer orders according to their estimated status upon arrival and the destination of the shipment may be accordingly modified.

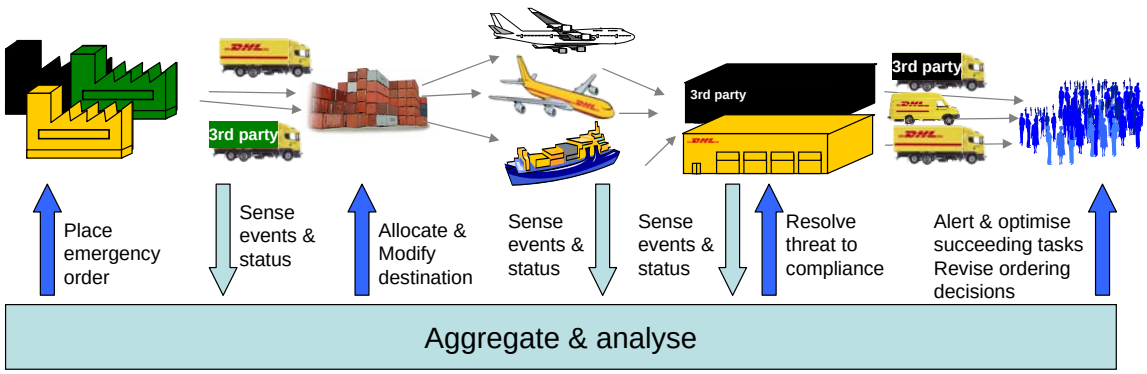

Figure 3.6: ITV in a supply chain for sensitive goods

Figure 3.6 illustrates how In-Transit Visibility can generate value in a supply chain for sensitive goods.

Potential actions:
- Revise ordering decisions according to anticipated inventory levels
- Allocate in-transit inventory to customer orders
- Reroute assets in transit to another destination
- Use emergency orders
- Resolve threat to compliance
- Alert customers
- Optimise succeeding tasks

3.2.2.3 Product value

According to Dertouzos et al. (1999), 42.5% of high-tech hardware thefts occur in transit. This accounts for fully 59.5% of the reported losses due to high-tech hardware thefts. If incidents in which the theft location is unknown are not considered, this figure rises to about 71.6%. Computers are the most frequently targeted high-tech hardware and account for 44% of incidents and for 26.8% of the losses. Only 4.2% of the incidents reported relate to theft of handheld electronic equipment such as cellular phones, however, they account for 21.3% of the losses. Considering the date of publication of the mentioned study and technological advances, it can be assumed that handheld electronic equipment is increasingly targeted today.

In-Transit Visibility allows for continuous tracking of shipment location. Sensor data can increase security by providing information such as opening of the cargo body or container. This information may be used to identify incidents and to take corrective action. These actions can help to prevent from attempted theft or to recover stolen products.

Figure 3.7 illustrates how In-Transit Visibility can generate value in a supply chain for high-value goods.

Potential actions:
- Incident and emergency management

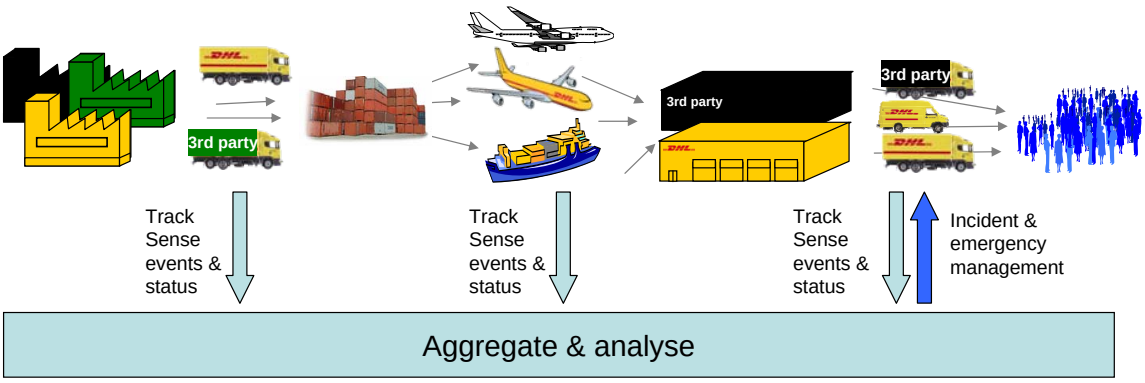

Figure 3.7: ITV in a supply chain for high-value goods

3.2.2.4 Dangerous goods

Dangerous goods are any goods that can harm people, other living organisms, property, or the environment. Responsibility and legal requirements demand that in the event of an imminent or actual release of dangerous goods, a person who has possession of the dangerous goods must make an immediate report to the appropriate provincial authority, the consignor of the dangerous goods, and possibly other persons. These reports must include data such as the the shipping name or UN number of the dangerous goods, the quantity of dangerous goods, a description of the condition of the means of containment, the location of the accidental release, etc..

In-Transit Visibility can provide sensor data and location, allowing for the identification of incidents. Incident reports can be generated immediately and appropriate measures can be initiated in co-operation with relevant external organisations, such as police, fire brigades, or medical services.

Figure 3.8 illustrates how In-Transit Visibility can generate value in a supply chain for dangerous goods.

Potential actions:

- Incident and emergency management

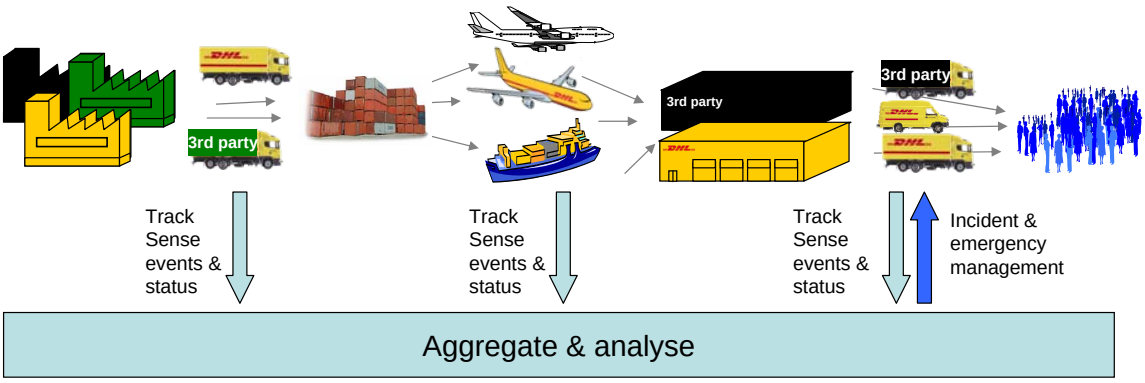

Figure 3.8: ITV in a supply chain for dangerous goods

3.2.3 Transport characteristics

3.2.3.1 Lead time variability

Lead times of assets are generally variable due to the variability in the performance of the transportation network and the variability of the performance of the asset itself. For example, temporary vehicle break-down or bad weather and traffic conditions may result in longer lead times as usual. Without In-Transit Visibility there is no knowledge about the actual progress of transportation processes, i.e. it is unknown whether an asset will probably arrive on-time or delayed and in the latter case it is also not known how big the delay will probably be.

In-Transit Visibility can provide frequent updates of the estimated time of arrival. This information can be compared with the planned progress of transportation processes in order to identify whether the asset is delayed or not. In case of delays customers can be alerted and succeeding tasks can be optimised. Furthermore, in-transit inventory can be allocated to customer orders if the remaining lead time is sufficiently small and reliable. If the probability of a delayed arrival is high, the asset may be expedited by changing to a faster (but usually more costly) route. If the asset will probably arrive very early, a cheaper but slower route may be used. If the goods are likely to arrive too late, emergency orders may be placed which will take a faster route and arrive before the delayed shipment.

Figure 3.9 illustrates how In-Transit Visibility can generate value in a supply chain with variable lead times.

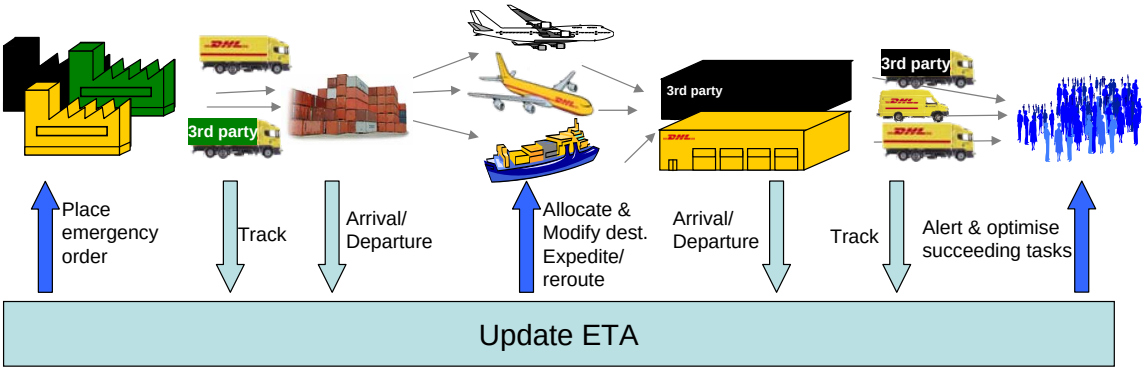

Figure 3.9: ITV in a supply chain with variable lead times

Potential actions:

- Allocate in-transit inventory to customer orders
- Reroute assets in transit to another destination
- Alert customers
- Optimise succeeding tasks
- Expedite assets in transit
- Modify route of shipments in transit

3.2.3.2 Network performance variability

The performance of almost all transportation networks depends on different factors like traffic conditions, weather conditions, available workforce, constructions or maintenance work, and temporarily higher or lower average duration of customs inspections. Some supply chains may even be influenced by political and military events. The performance of transportation networks influences transit times of all assets moving in the network. The transit times of assets using the network in the same time period are correlated. This time period may be a time of the day, some days in the week, a time in the year, or any other period of time.

Without In-Transit Visibility the only information about the performance of the transportation network is the total lead time that can be obtained by measuring the departure time at the asset's origin and the arrival time at the asset's final destination. Therefore, there is only little or no knowledge about the performance of transportation links. Only after arrival at the final

destination the performance of the transportation chain can be retrospectively analysed. At that time, however, the current performance of the transportation network may have already changed.

With In-Transit Visibility the performance of links in the transportation network can be measured at the time an asset moves through the link. The better visibility can be used to calculate average transit times and their variances for each link in the transportation network. This information can help to benchmark transportation processes and disguise unnecessary slack times. Bottlenecks can be identified and resolved and short-term forecasts of transit times can be used to revise reorder point, ordering time, and routing decisions.

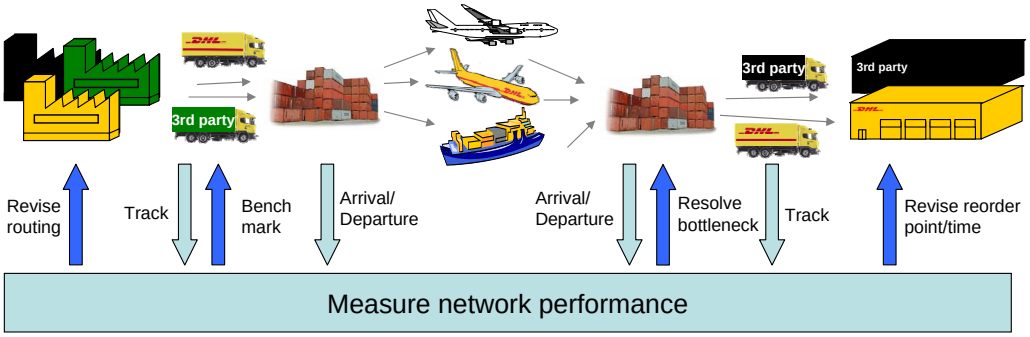

Figure 3.10: ITV in a supply chain with variable network performance

Figure 3.10 illustrates how In-Transit Visibility can generate value in a supply chain with variable network performance.

Potential actions:

- Revise routing decisions according to short-term forecasts
- Revise reorder point according to short-term forecasts
- Revise ordering time according to short-term forecasts
- Resolve bottlenecks
- Benchmarking

3.2.3.3 Alternative routes

Assets moving through the transportation network may use different routes between their origin and their final destination. These alternative routes usually have different lead times

and costs. The choice of the route is done considering the agreed arrival time, transportation costs, and the desired on-time delivery performance.

Without In-Transit Visibility there is no knowledge about the actual progress of transportation processes, i.e. it is unknown whether an asset will probably arrive on-time or delayed and in the latter case it is also not known how big the delay will probably be. Neither is it known where in the transportation network an asset is and, therefore, there is no possibility of modifying the route of the asset after departure at the origin.

In-Transit Visibility can provide frequent updates of the estimated time of arrival. This information can be used to determine whether assets will arrive on-time. If the probability of a delayed arrival is high, assets may be expedited by changing to a faster (but usually more costly) route. If the asset would probably arrive too early, cheaper but slower routes may be used.

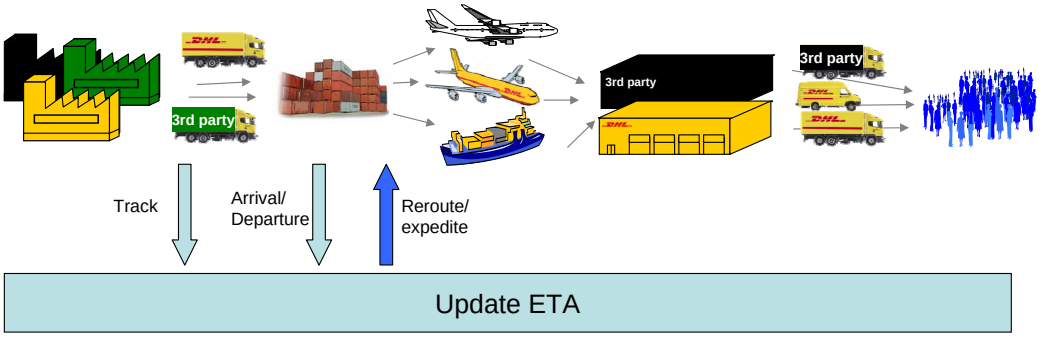

Figure 3.11: ITV in a supply chain with alternative routes

Figure 3.11 illustrates how In-Transit Visibility can generate value in a supply chain with alternative routes.

Potential actions:
- Expedite assets in transit
- Modify route of shipments in transit

3.2.3.4 Multimodal transport

In multimodal transport shipments are transshipped from one mode of transport to another. Obviously, inbound and outbound transportation at multimodal transshipment terminals must

be synchronised in order to minimise unnecessary waiting times. Therefore, outbound transportation should start as early as possible after arrival at the terminal. As arrival times of containers are uncertain, land-side transportation can often only be organised after containers are unloaded from ships and containers may have to wait until empty trucks arrive at the transshipment terminal. If reliable arrival time estimates are provided earlier, trucks can meet the container at the terminal eliminating all unnecessary waiting times and handling operations. Without In-Transit Visibility the only possibility to minimise waiting times is to hold required transportation capacity available without actually knowing when it is needed. This, of course, results in unnecessary costs for keeping idle transportation capacity available.

Mass transport vehicles such as trains, vessels, and aircrafts usually operate according to fix schedules. If containers arrive too late at a transshipment terminal they cannot be forwarded and must wait until the next outbound vehicle with spare capacity departs. In-Transit Visibility can give timely information about the progress of transportation towards a transshipment terminal. In case of a delay, shipments can be expedited in order to arrive in time.

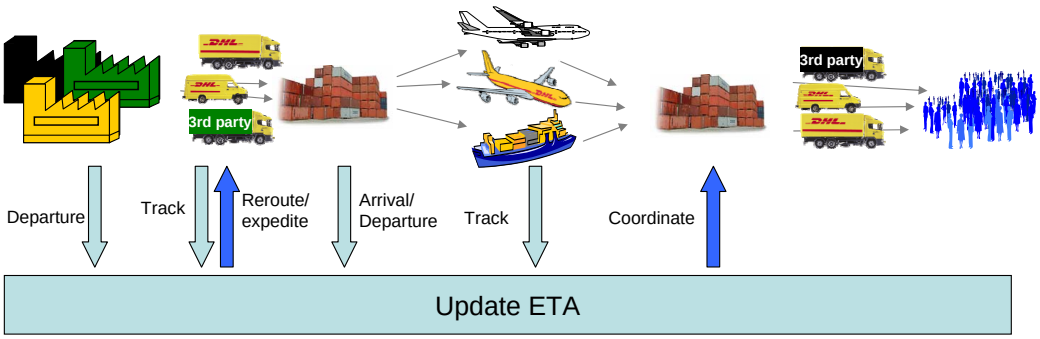

Figure 3.12: ITV in a multimodal supply chain

Figure 3.12 illustrates how In-Transit Visibility can generate value in a multimodal supply chain.

Potential actions:

- Coordinate intermodal transport
- Expedite assets in transit
- Modify route of shipments in transit

3.2.3.5 Operational accuracy

Lacking operational accuracy may result in mis-routing of shipments, (temporary) loss of shipments, or wrong handling of sensitive goods. In-Transit Visibility can help to obtain sensor data and location of shipments, allowing for the identification of operational errors. Appropriate measures can be initiated in order to minimise the impact of these errors.

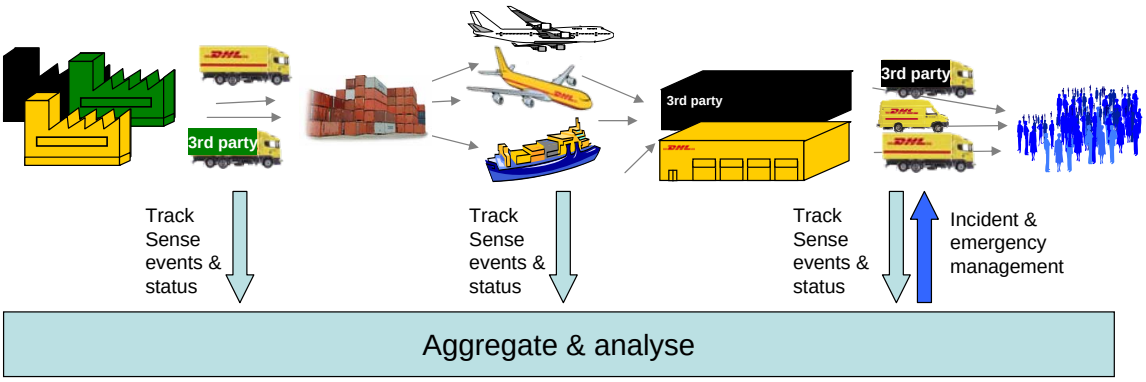

Figure 3.13: ITV in a supply chain prone to operational error

Figure 3.13 illustrates how In-Transit Visibility can generate value in a supply chain prone to operational error.

Potential actions:
- Incident and emergency management

3.2.4 Supply characteristics

3.2.4.1 Variable shipping time

Suppliers may not be able to ship the products at the time requested due to limited production capabilities, stock-outs, etc.. A delayed departure of shipments often results in a delayed arrival at the customer location, unless transit times incur some slack time. Without knowledge about shipping times, arrival times can only be estimated using historical data. In-Transit Visibility can give precise information on the shipping time. Shipments which departed with a delay may be expedited by changing to a faster (but usually more costly) route. Shipments which departed earlier than expected may be rerouted in order to save costs. If

a delayed departure will result in a late arrival at the customer location, emergency orders may be placed at an alternative supplier who may deliver in time. Alternatively, customers can be alerted and succeeding tasks can be optimised. By knowing when which shipments are shipped, In-Transit Visibility also gives opportunities for allocating in-transit inventory to customer orders.

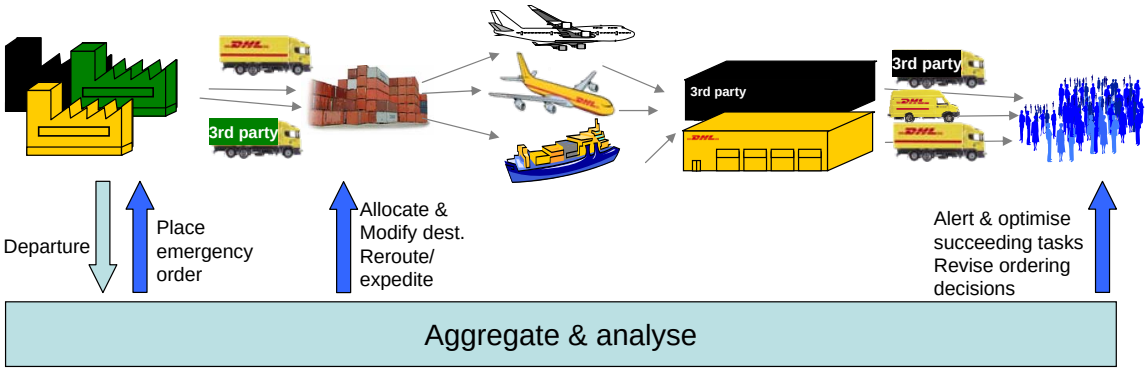

Figure 3.14: ITV in a supply chain with variable shipping times

Figure 3.14 illustrates how In-Transit Visibility can generate value in a supply chain with variable shipping times.

Potential actions:

- Alert customers
- Optimise succeeding tasks
- Expedite assets in transit
- Modify route of shipments in transit
- Allocate in-transit inventory to customer orders
- Reroute assets in transit to another destination
- Use emergency orders
- Revise ordering decisions according to anticipated inventory levels

3.2.4.2 Variable shipping quantity

Suppliers may not be able to ship the exact amount ordered due to limited production capabilities, stock-outs, etc.. This variation of shipment quantity results in an uncertainty that can

be resolved by capturing the exact quantity and type of shipments at the departure of the origin.

The knowledge of quantity and type of goods shipped can be used to anticipate inventory levels at the recipient side. Customers can be alerted and succeeding tasks may be optimised. By knowing shipment quantities, In-Transit Visibility also gives opportunities for allocating in-transit inventory to customer orders. Furthermore, ordering decisions can be revised earlier and emergency orders may be placed if less products are shipped than required.

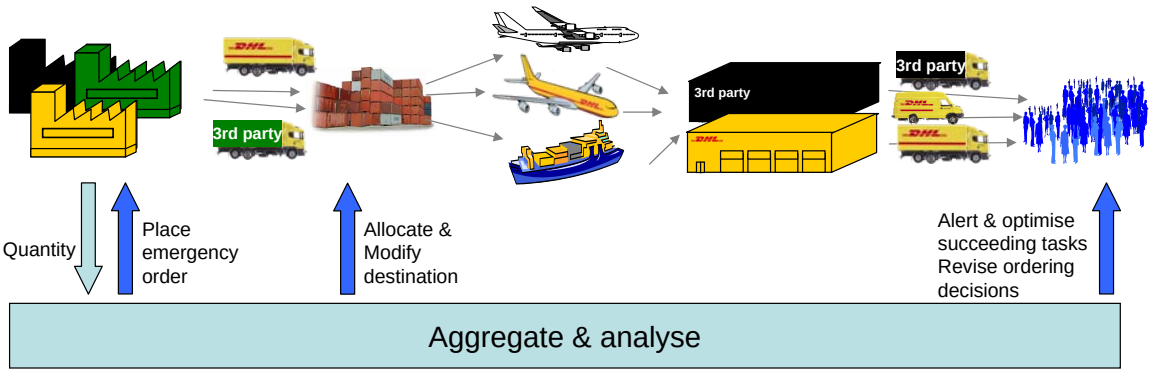

Figure 3.15: ITV in a supply chain with variable shipment quantity

Figure 3.15 illustrates how In-Transit Visibility can generate value in a supply chain with variable shipment quantity.

Potential actions:

- Alert customers
- Optimise succeeding tasks
- Allocate in-transit inventory to customer orders
- Reroute assets in transit to another destination
- Use emergency orders
- Revise ordering decisions according to anticipated inventory levels

3.2.4.3 Alternative supply source

For many products alternative suppliers exist from which the products can be ordered. These alternative suppliers usually have different lead times and costs. The choice of the suppliers

is done considering the agreed arrival time, transportation costs, and the desired on-time delivery performance. Without In-Transit Visibility there is no knowledge about the actual progress of transportation processes, i.e. it is unknown whether an asset will probably arrive on-time or delayed and in the latter case it is also not known how big the delay will probably be.

In-Transit Visibility can be used to identify deviations and disruptions of transportation processes. If the probability is high that shipments cannot be delivered as promised, emergency orders can be placed at an alternative supplier if the lead time of the alternative supplier is sufficiently small.

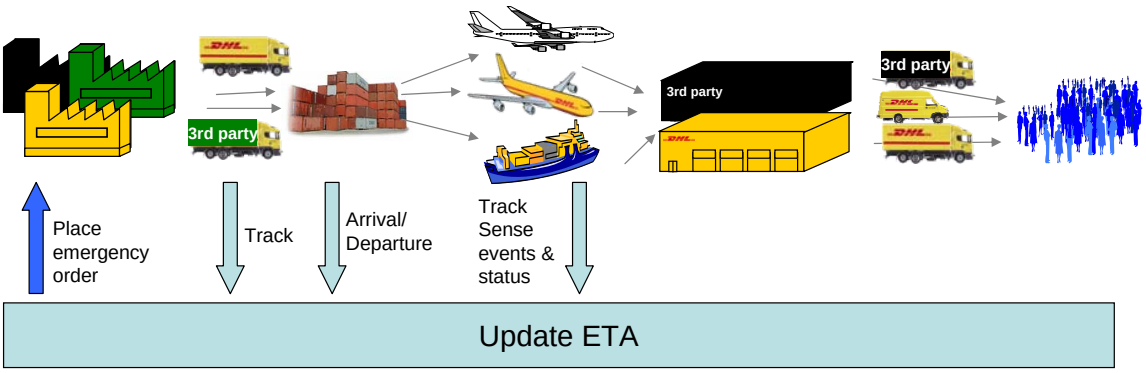

Figure 3.16: ITV in a supply chain with alternative supply sources

Figure 3.16 illustrates how In-Transit Visibility can generate value in a supply chain with alternative supply sources.

Potential actions:
- Use emergency orders

3.2.5 Demand characteristics

3.2.5.1 Demand variability

If actual demand is lower or higher than forecasted, inventory levels must be adjusted accordingly. Without In-Transit Visibility there is little knowledge about the progress of transportation processes. Therefore, there is little opportunity to modify shipment flows in order

to react on changes in demand. In-Transit Visibility can provide information that can be used to expedite in-transit inventory to fill up lessened inventory levels earlier. Furthermore, shipments moving towards a destination with excessive inventory levels may be rerouted to locations with inventory shortages. If demand is lower than expected, shipments in transit may be rerouted to slower and less costly routes while still meeting the actual demand.

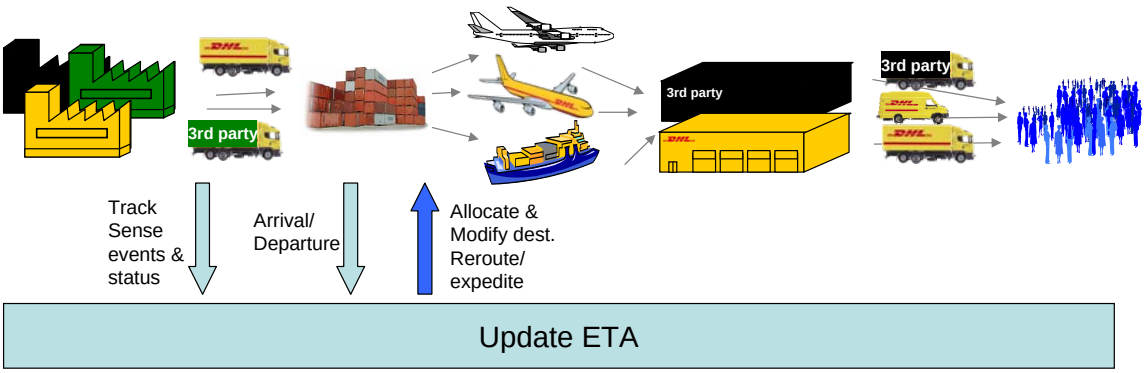

Figure 3.17: ITV in a supply chain with variable demand

Figure 3.17 illustrates how In-Transit Visibility can generate value in a supply chain with variable demand.

Potential actions:

- Expedite assets in transit
- Modify route of shipments in transit
- Allocate in-transit inventory to customer orders
- Reroute assets in transit to another destination

3.2.5.2 Lost demand

Demand may be lost if customer orders cannot be filled as demanded. Without In-Transit Visibility there is no way of identifying delays until arrival of the shipment at its destination. With In-Transit Visibility delays can be identified immediately and shipments can be expedited in order to arrive on-time. By this, inventory shortages can be prevented and less demand is lost. Furthermore, inventory shortages can be anticipated early if arrival time estimates are frequently updated. Anticipated inventory shortages can be prevented by

placing emergency orders that will arrive before the demand is lost. Arrival time estimates may also be used to estimate future inventory levels. These estimates can be used to revise subsequent ordering decisions, and to allocate in-transit inventory to destinations with urgent demand. By bypassing distribution centres and shipping directly to customer locations, handling costs, transportation costs, and lost demand can be reduced.

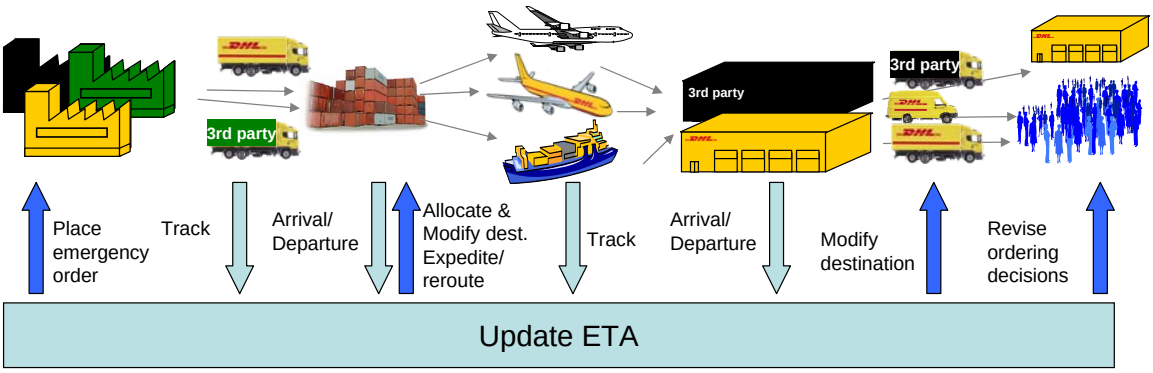

Figure 3.18: ITV in a supply chain where demand may be lost

Figure 3.18 illustrates how In-Transit Visibility can generate value in a supply chain where demand may be lost.

Potential actions:

- Revise ordering decisions according to anticipated inventory levels
- Allocate in-transit inventory to customer orders
- Reroute assets in transit to another destination
- Expedite assets in transit
- Modify route of shipments in transit
- Use emergency orders

3.2.6 Financial characteristics

3.2.6.1 Cost- and performance-dependent invoicing

The invoice amount may be dependent on actual costs and performance of transportation processes. Without In-Transit Visibility actual cost and performance related data can only be

obtained after waybills have been handed over to the accountancy. In-Transit Visibility can provide these data earlier and thus allows to speed up the generation of invoices.

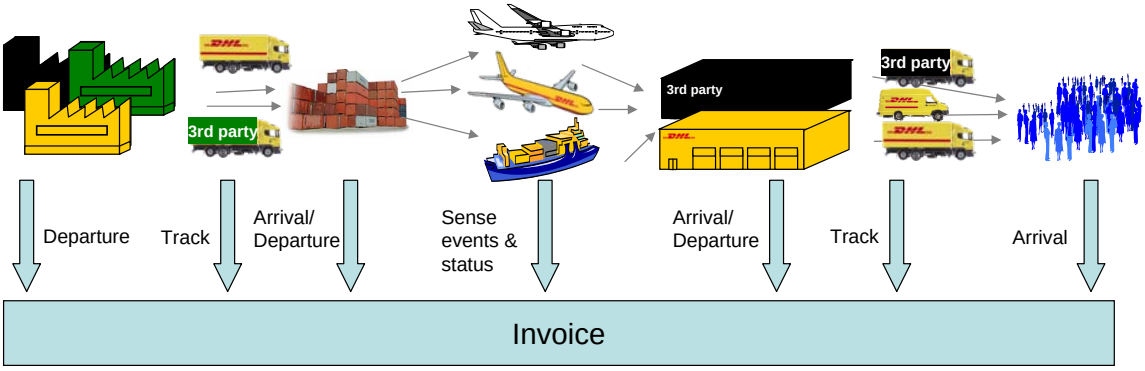

Figure 3.19: ITV for cost- and performance-dependent invoicing

Figure 3.19 illustrates how In-Transit Visibility can generate value in a supply chain where invoice amounts depend on costs and performance.

Potential actions: • Speed up invoices

3.2.6.2 Milestone based invoicing

Invoices may be prepared before the final delivery of the product. That is, an invoice may be sent after certain milestones have been completed. For example, if shipments are transported by truck and ocean vessel, a first invoice may be sent after truck transport from the supplier to the port, a second after the sea transport is completed, and the last after truck transport from the receiving port to the recipient. Without In-Transit Visibility there is no knowledge about the progress of transportation processes. The completion of milestones can only be identified after the required paperwork has been received. With In-Transit Visibility the completion of milestones can be proven instantly, resulting in earlier invoicing and earlier payment.

Figure 3.20 illustrates how In-Transit Visibility can generate value in supply chain where invoices may be prepared after completion of milestones.

Potential actions: • Speed up invoices

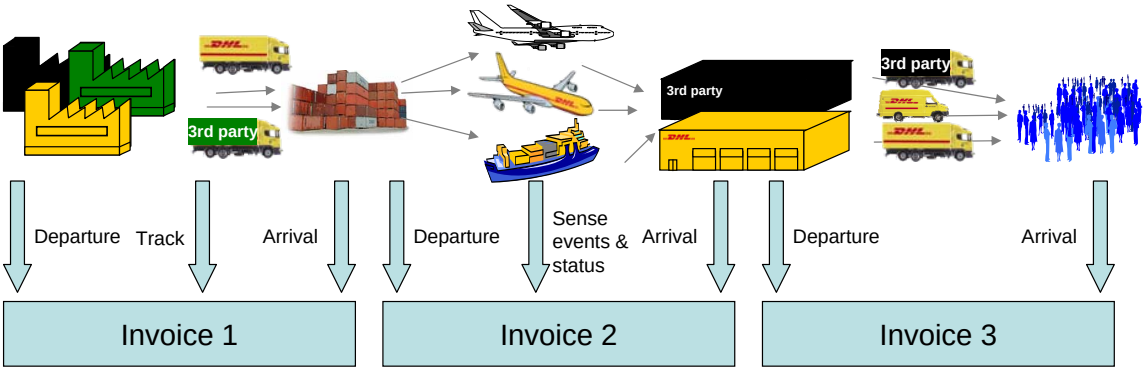

Figure 3.20: ITV for milestone based invoicing

3.3 Actions

3.3.1 Alert customers

Customers can be pro-actively alerted if discrepancies between planned and actual transportation processes occur. The value of such alerts, however, can only be determined by determining the value that can be generated by the customer. That is, only if the customer can generate some value, e.g. by optimising succeeding tasks (see 3.3.2) or by placing emergency orders (see 3.3.11), the customer will be willing to pay for the value added service.

Required information:
- Estimated time of arrival (ETA)
- Estimated status at arrival

Generated values:
- See 3.3.2 and 3.3.11

3.3.2 Optimise succeeding tasks

Tasks to be performed after completion of transportation may be executed in different sequences and at at different times. Inherent uncertainties of transportation processes result in the need for safety stock and buffer times. In-Transit Visibility can improve the knowledge

about actual transportation processes and, thus, provides the necessary data to dynamically optimising succeeding tasks taking into account arrival times of assets in transit. This increases the efficiency of these tasks and allows for reducing safety stock levels.

Required information:
- Estimated time of arrival (ETA)
- Estimated status at arrival

Generated values:
- Improved efficiency of succeeding processes
- Reduced inventory holding costs

3.3.3 Incident and emergency management

In case of incidents such as operational errors, accidents, or attempted theft, immediate measures can be taken in order to minimise the impact of the incident. In-Transit Visibility can provide location and sensor data helping to identify and analyse incidents. This allows for immediate measures reducing vulnerability of the supply chain. Depreciation costs are reduced because incidents have less impact on supply chain performance.

Required information:
- Current location
- Status of assets

Generated values:
- Reduced vulnerability
- Reduced depreciation costs

3.3.4 Resolve threat to compliance

If threats to compliance with customer or legal requirements are identified immediate countermeasures can be initiated. For example, temperature sensitive goods can be moved to cold storages when the environmental temperature is a threat to product. Perishable products may be expedited in order to comply with quality requirements upon arrival at the customer. The improved compliance translates into reduced depreciation costs.

Required information:
- Status of assets
- Current location

- Estimated status at arrival

Generated values:
- Improved compliance
- Reduced depreciation costs

3.3.5 Resolve bottlenecks

Bottlenecks occur if the throughput of certain activities is lower than the inflow. As a result shipments passing through a bottleneck have to wait before the bottleneck activity can take place. Thus, total lead time for assets passing the bottleneck (including the waiting times) are higher than necessary.

There are two ways to resolve bottlenecks: to increase the throughput and to reduce the inflow. Frequent updates of the estimated time of arrival can be used to anticipate future workload at critical points in the transportation networks. Bottlenecks can be prevented by pro-actively preparing for workload peaks, thus, increasing the throughput. If the bottleneck is predominantly used by self-controlled assets, the average lead times of assets passing the bottleneck can be minimised by reducing or coordinating the inflow of assets to this bottleneck. The inflow to bottlenecks can be reduced by rerouting some of the assets. Similarly, the assets may be sent later such that the inflow at the bottleneck is kept below or equal to its throughput capacity.

The value of resolving bottlenecks results from saved waiting times of assets and the resulting reduced lead times. The variability of lead times can be decreased as with the reduction of bottlenecks, processing times become more homogeneous. Furthermore, transportation costs can be reduced, because congestion at bottlenecks may result in unnecessary handling activities.

Required information:
- Estimated time of arrival (ETA)
- Transportation network performance

Generated values:
- Reduced average lead time
- Reduced lead time variability
- Reduced transportation costs

3.3.6 Coordinate intermodal transport

The improved knowledge of the estimated time of arrival can be used to coordinate inbound and outbound transportation at a transshipment point. With improved arrival time estimates, the average waiting time of shipments or outbound vehicles can be reduced leading to lower inventory holding costs, lower cost for having the outbound vehicle available, and reduced lead time.

Required information:
- Current location
- Estimated time of arrival (ETA)

Generated values:
- Reduced average lead time
- Reduced transportation costs

3.3.7 Expedite assets in transit

In anticipation of inventory shortages assets in transit can be expedited by modifying the route through the transportation network. For example, truck freight may be used instead of rail freight in order to meet urgent customer demand. Furthermore, assets in transit may be prioritised at handling locations in order to minimise handling times of these assets. The value of expediting shipments in transit comes from reduced inventory levels required to deal with variable lead times, an increased on-time delivery performance, reduced backorder and lost sales costs, and reduced transportation costs if expediting is less costly than placing emergency orders.

Required information:
- Current location
- Estimated time of arrival (ETA)
- Estimated status at arrival

Generated values:
- Reduced inventory holding costs
- Improved on-time delivery performance
- Reduced backorder costs
- Reduced lost sales
- Reduced transportation costs

3.3.8 Modify route of shipments in transit

Routes of assets in transit may be modified in order to save costs. For example, if inventory overages are anticipated, less costly but slower routes may be chosen for some assets in transit. Furthermore, shipments allocated to customers may be rerouted to the customer location, bypassing distribution centres and other facilities.

Required information:
- Current location
- Estimated time of arrival (ETA)
- Estimated status at arrival

Generated values:
- Reduced transportation costs

3.3.9 Allocate in-transit inventory to customer orders

The estimated remaining lead time of shipments in transit decreases gradually (but not necessarily monotonously) until the destination is reached. At some point in time the estimated remaining lead time and its variance may be bounded in a way that a certain service level can be promised to the customer. Therefore, a part of the in-transit inventory can be treated as available inventory and the inventory levels at a distribution centre or warehouse can be reduced while maintaining the same order fulfilment level.

The value from allocating in-transit inventory to customer orders comes from lower inventory levels and/or higher customer fulfilment levels.

Required information:
- Estimated time of arrival (ETA)
- Estimated status at arrival

Generated values:
- Reduced inventory holding costs
- Reduced lost sales

3.3.10 Reroute assets in transit to another destination

The destination of assets may be changed during transportation. For example, when in-transit inventory is allocated to customer orders, the final destination changes. Instead of

transporting the corresponding shipments to a distribution centre, shipments may bypass the distribution centre and be transported directly to the customer. Perishable or sensitive products may devaluate during transportation. Such shipments can be rerouted towards destinations where some salvage value can be received or where disposal of the products is possible.

The value of rerouting assets in transit to another destination comes from reduced transportation costs and lead times or from reduced transportation costs by avoiding onward transportation of perished or damaged goods. Depreciation costs are reduced due to higher salvage value of rerouted products.

Required information:
- Current location
- Estimated time of arrival (ETA)
- Estimated status at arrival

Generated values:
- Reduced transportation costs
- Reduced average lead time
- Increased speed of payment
- Reduced depreciation costs

3.3.11 Use emergency orders

In anticipation of inventory shortages, emergency orders can be placed in order to deliver required products within time (or with a minimal delay). Lead times are often negatively correlated to costs, e.g. air-freight is much faster and more costly than truck freight. As In-Transit Visibility can help to anticipate inventory shortages, emergency orders may be placed earlier. Thus, the value of In-Transit Visibility results from the potential of placing less costly emergency orders. Furthermore, earlier placement of emergency orders can result in an improved on-time delivery performance.

Required information:
- Estimated time of arrival (ETA)
- Estimated status at arrival

Generated values:
- Reduced inventory holding costs

- Reduced transportation costs
- Improved on-time delivery performance
- Reduced backorder costs
- Reduced lost sales

3.3.12 Revise routing decisions according to short-term forecasts

Due to variations in network performance, certain routes may temporarily have shorter or longer lead times than others. This information can be used to revise routing decisions. Routing decisions may be revised according to the short-term performance and costs of the links and the urgency of the shipments. The value of revised routing decisions comes from reduced transportation costs and improved on-time delivery.

Required information:
- Short-term forecast of transportation network performance

Generated values:
- Reduced transportation costs
- Improved on-time delivery performance

3.3.13 Revise reorder point according to short-term forecasts

The reorder point is the amount of inventory level at which a replenishment order should be placed. It depends on the demand and lead time distribution. Obviously, better short-term forecasts of the lead time distribution result in a more accurate determination of the reorder point. Therefore, excess inventory levels or inappropriate backorder costs or lost sales costs can be avoided.

Required information:
- Short-term forecast of transportation network performance

Generated values:
- Reduced backorder costs
- Reduced lost sales
- Reduced inventory holding costs

3.3.14 Revise ordering time according to short-term forecasts

Ordering times can be revised using short-term performance forecasts of the transportation network. With decreasing time between observation and forecast period, the accuracy of short-term performance forecasts increases. The value of In-Transit Visibility comes from better forecasts resulting in an improved on-time delivery performance.

Required information:
- Short-term forecast of transportation network performance

Generated values:
- Improved on-time delivery performance

3.3.15 Revise ordering decisions according to anticipated inventory levels

Discrepancies between planned and actual transportation processes result in discrepancies between planned and anticipated inventory levels. Earlier knowledge about these discrepancies can be used to revise ordering decisions earlier and, thus, can result in lower transportation costs, lower excess inventory levels, and reduced backorder and lost sales costs.

Required information:
- Estimated time of arrival (ETA)
- Estimated status at arrival

Generated values:
- Reduced inventory holding costs
- Reduced transportation costs
- Reduced backorder costs
- Reduced lost sales

3.3.16 Benchmarking

Without In-Transit Visibility there is only a global knowledge about the performance of transportation processes, i.e. the time difference between departure at origin and the arrival at final destination. With In-Transit Visibility the performance of single processes performed by different actors can be measured and compared. Visibility information can be used to identify unnecessary slack times or bad performance of certain processes. Actors can be penalised for bad performance and be given benefits for good performance. The value of

benchmarking result from the possibility of choosing best performing routes, carriers, etc. and from improving processes with low performance.

Required information:
- Transportation network performance

Generated values:
- Reduced transportation costs
- Improved on-time delivery performance
- Improved compliance
- Reduced depreciation costs

3.3.17 Speed up invoices

The preparation of invoices can be automatically triggered with the proof of delivery. The trace of a shipment, status information, and any kind of information on events captured in transit can be included in the invoice. The resulting value results from saved time between completion of processes and preparation of invoices. Additional information on the progress of transportation can ease the verification process by the customer. This reduces the time between handover of invoice and verification by the customer and results in earlier payment.

Required information:
- Departure time at origin
- Arrival time at destination
- Asset identification code
- Status of assets

Generated values:
- Increased speed of payment

3.4 Values

3.4.1 Reduced transportation costs

Costs associated to transportation arise from the costs for all activities performed during transportation. Transportation costs include costs for handling, and inventory holding costs related to the duration of transportation.

Minimising transportation costs often conflicts with other goals such as maximising on-time delivery performance, as higher speed and reliability of transportation usually translate into higher costs. In-Transit Visibility can enable actions which reduce transportation costs. For example, costly emergency orders may be avoided by using cheaper routes with sufficient performance, bottlenecks may be identified and resolved or avoided, intermodal transport may be coordinated, or nodes in the route may be bypassed when allocating in-transit inventory to customer orders.

3.4.2 Reduced inventory holding costs

All inventory held incurs some holding costs representing the costs associated with storage of inventory, capital tied up, and a potential devaluation. If reliability of transportation processes can be increased, less safety stock is required to deal with the inherent uncertainties in transportation. Low inventory levels are of particular importance for high-value products which tie up financial resources and products with short shelf-life which devaluate rapidly. In-Transit Visibility can help to reduce the uncertainty about current transportation processes. With lower uncertainties, less safety stock is required and inventory levels can be reduced.

3.4.3 Reduced depreciation costs

Perishable and sensitive products as well as goods with short shelf-life may lose their value during transportation. In-Transit Visibility allows to quickly react on deviations in transportation processes. Depreciation costs can be reduced by expediting shipments or allocating in-transit inventory to customers depending on the actual state of the products and customer requirements. Higher salvage value can be obtained if deterioration is identified early and appropriate actions are initiated quickly.

3.4.4 Reduced average lead time

Total lead times include time required for transportation, handling, and dwell times in which shipments are waiting for onward transportation. According to Steenken et al. (2004), dwell times of containers at large European container terminals are on average three to five days. Reducing average lead times often conflicts with other goals such as minimising transportation costs and minimising lead time variability. For example, reducing dwell times at container

terminals also reduces buffers. Without buffers, a container which arrives at a container terminal with a delay cannot be forwarded as planned. Therefore, reduced buffers may result in higher transportation costs and/or higher lead time variability. Reduced average lead times result in reduced inventory holding costs during transport. Furthermore, reduced lead times increase flexibility as ordering and routing decisions can be made later. Thus, less inventory is needed to cover lead time demand.

3.4.5 Reduced lead time variability

The variability of lead times is a major obstacle in forecasting arrival times. If lead time variability can be reduced without increasing the average lead time, safety stock levels to deal with this uncertainty can be reduced. Reduced lead time variability may also result in higher on-time performance levels.

3.4.6 Reduced vulnerability

The vulnerability of supply chains depends on the exposure to disturbances, arising from risks within the supply chain and risks external to the supply chain, as well as the ability to react on these disturbances. Thus, the vulnerability of a supply chain depends on many different factors and is difficult to measure. In-Transit Visibility can help to identify and analyse disturbances and to resolve or minimise their impacts. In particular, In-Transit Visibility can help minimising the time between the occurrence of disturbances, the identification and analysis of the disturbances, and the initiation of appropriate countermeasures.

3.4.7 Improved compliance

Non-compliance with legal or customer requirements can result in unnecessary costs, e.g. cost for disposing perished or damaged products, costs for resending perished or damaged products, or lost sales costs. Thus, high compliance rates are an important service characteristic and increase confidence in the supply chain. In-Transit Visibility can help to increase compliance rates by identifying threats to compliance and taking appropriate counter measures.

3.4.8 Improved on-time delivery performance

The on-time delivery performance reflects the proportion of assets that arrive at the time required. It is not a value in itself, however, it is often used as key performance indicator. Depending on the case it can be translated into reduced inventory, reduced backorder costs, reduced lost sales costs, or improved efficiency of succeeding processes.

3.4.9 Reduced backorder costs

Back order costs occur when a customer has to wait for his/her order to be filled. Thus, the sales are not lost, only delayed. Back orders can create additional costs for administration, delayed revenue, and loss of customer's goodwill. In-Transit Visibility can help to initiate counter measures in anticipation of potential inventory shortages. These counter measures may prevent inventory shortages or reduce the length of delays. Therefore, backorder costs can be reduced. The percentage of backlogged orders and the average length a customer has to wait until the backlogged order is filled can be determined to measure the value of In-Transit Visibility. Furthermore, some costs such as those arising for administration and delayed revenue can also be measured. However, the loss of customer's goodwill is often difficult to quantify.

3.4.10 Reduced lost sales

Lost sales cost occur when a customer order cannot be fulfilled to the customer's desires and the customer either does not place an order or withdraws a previously placed order. This may occur due to inventory shortages, unreliable lead times, intransparency of transportation processes, and inability to quickly react on customer demand. In-Transit Visibility can improve transparency, flexibility, and reliability of the supply chain and thus can help to reduce lost sales. The percentage of orders that are withdrawn by the customers can be determined to measure the value of In-Transit Visibility. However, it may be difficult to quantify lost sales costs for orders which are not placed by the customer.

3.4.11 Improved efficiency of succeeding processes

Better information about the progress of transportation processes can be used to optimise succeeding tasks. This can reduce costs and increase revenues of these tasks. However, the respective value is hard to quantify and strongly depends on the specific case.

3.4.12 Increased speed of payment

The speed of payment depends on time between (partial) completion of transportation processes and the preparation and handover of invoices, and the time between the handover of invoices, its verification, and payment. In-Transit Visibility can give an information of delivery (IOD) which can be used to trigger the preparation of invoices. Furthermore, a proof of delivery (POD) can be provided earlier, allowing for faster handover of invoices and revenue recognition. Better information about transportation processes also eases verification of invoices by customers and results in faster payment.

3.5 Information

3.5.1 Asset identification code

An asset moving through the logistics supply chain may pass several hubs. These hubs can serve as checkpoints at which an asset identification code can be captured. Given this identification code, the location of the checkpoint, and the time when the asset passed the checkpoint, it is possible to analyse the progress of transportation processes and to track the movement of an asset through the transportation chain. Checkpoints can also be moving objects such as containers or trucks and the asset's identification code may be captured during loading and unloading.

Barcodes and RFID can be used to identify assets while passing a checkpoint. Image processing such as automatic number plate recognition can be used to identify trucks and trailers passing gates. Similarly, container identification numbers can be captured using image processing systems. Commercial vehicle telematics systems can automatically submit information about a vehicle's departure at the origin via wireless communication.

3.5.2 Quantity shipped

The quantity shipped gives information about how many items of a certain type are in the delivery pipeline. If less items are in the delivery pipeline than required, additional orders must be placed to fulfil the demand. If more items are in the delivery pipeline than required, future shipment quantities may be reduced.

Barcodes and RFID can be used to identify assets while passing a checkpoint. By counting the corresponding number of items that passed the checkpoint the quantity shipped can be determined.

3.5.3 Departure time at origin

The actual departure time of assets represents the begin of transportation processes. Before departure of an asset, the route through the destination and route of the asset can be changed relatively easy. After departure of an asset, destination and route of the asset can only be changed if capabilities of influencing current transportation processes are available. As actual and planned departure time can be easily compared, deviations can easily be detected.

Barcodes and RFID can be used to identify shipments when they are loaded onto a vehicle. Image processing such as automatic number plate recognition can be used to identify trucks and trailers passing gates. Similarly, container identification numbers can be captured using image processing systems. Commercial vehicle telematics systems can automatically submit information about a vehicle's departure at the origin via wireless communication.

3.5.4 Arrival time at destination

The actual arrival time at the asset's destination represents the end of transportation processes. Succeeding tasks, e.g. the preparation of the invoice, can be triggered when the actual arrival is detected.

Barcodes and RFID can be used to identify shipments when they are unloaded from a vehicle. Image processing such as automatic number plate recognition can be used to identify trucks and trailers passing gates. Similarly, container identification numbers can be captured

using image processing systems. Commercial vehicle telematics systems can automatically submit information about a vehicle's arrival at the destination via wireless communication.

3.5.5 Current location

Telematics systems allow for locating shipments "continuously" using positioning systems and transmitting the current location to a base station for further processing. Satellite positioning systems can provide very precise positioning. However, they cannot be applied in every environment. A free line of sight to at least four satellites is required for precise positioning. Due to tunnels, urban canyons, stacked containers, and other obstacles, assets cannot always receive the signals of four satellites. Cellular communication based positioning systems cannot provide the same precision as satellite systems. However, they may be more attractive for positioning as only a cell phone is required. Due to the costs of transmitting position information, an asset's position is usually only transmitted in certain intervals. As the asset may move between two subsequent position transmissions, the accuracy of the estimated location depends on the frequency with which information is transmitted.

The current location of an asset can also be determined by tracking the asset identification code when passing through hubs. If the transit time for travelling between the hubs is very stable, checkpoint based tracking of shipments can be accurate enough to estimate the current location of a shipment at any point in time.

3.5.6 Status of assets

Sensitive shipments may have special requirements on transportation, e.g. temperature sensitive or shock sensitive products such as food, pharmaceuticals, or electronic equipment. Data concerning the conditions of transport can be captured by sensors. These sensors may identify whether the conditions of transport are within tolerable ranges. Furthermore, data for subsequent analysis may be recorded. More elaborate sensors may also aggregate and analyse the captured data in order to provide easy access to useful information. Sensors can also be used to identify unexpected events, e.g. to identify whether container doors are opened. If sensors are attached to telematics devices the information about the status of an asset can be transmitted in real time.

3.5.7 Estimated time of arrival (ETA)

If the current location of an asset is known, this information can be used to update the estimated time of arrival at the assets's destination. For this, the actual and planned progress of transportation must be compared and analysed. If deviations are detected, the feasibility of the transportation plan must be determined. For example, if planned dwell times at transshipment terminals are high enough to compensate for a delay, the transportation plan remains feasible. Otherwise, the transportation plan must be adjusted. Transportation management systems can be used to adjust the transportation plan according to the capabilities of the various actors in the transportation chain and the arrival time at the final destination of the asset can be estimated.

3.5.8 Estimated status at arrival

If the current status of an asset is known, this information can be used to update the estimated status at arrival at the assets's destination. This is particularly important for temperature sensitive products as the shelf-life often depends on the conditions in transit. The recorded temperature history can be used to calculate the remaining shelf-life of products according to the Arrhenius equation. Recorded temperature history can be read at neuralgic points in the transportation chain and analysed subsequently. Alternatively, shelf-life prediction systems can be embedded on RFID sensor tags.

3.5.9 Transportation network performance

In-Transit Visibility can provide information that can be related to the performance of single links in the transportation network, e.g. by identifying assets when they pass checkpoints or by continuously tracking assets. Similar to floating car data in traffic management, "floating shipment data" can be used to determine the current performance of the transportation network. Short-term performance measurements can also be used to identify performance patterns, i.e. periods with higher and lower performance, e.g. depending on the time of the day, the day of the week, the season, etc..

3.5.10 Short-term forecast of transportation network performance

If the current performance of the transportation network is known, short-term lead time forecasts can be calculated, e.g. by exponential smoothing. These forecasts can be used to better approximate transit times for shipments that will pass these transportation links in the short-term. The improved knowledge about the performance of the transportation network can be used to improve the capability of updating the estimated arrival time for assets in transit.

3.6 Case studies

3.6.1 Pharmaceutical cold chain

Many pharmaceutical products are temperature sensitive. According to the specific requirements cold chain products are labelled “below -5° C” (freeze), “below -15° C” (deep freeze), “2° C - 8° C”, “8° C - 15° C”, or “below 25° C”. Some products must be protected from freezing, as already a short time period below zero degrees may irreversibly deteriorate the product. The shelf-life of cold chain products may be very short and may depend on the conditions in transit. A cold chain product, e.g. labelled “2° C - 8° C”, may have a longer shelf-life if continuously stored near the lower temperature bound than if it was subject to frequent changes in the temperature or stored near the upper temperature bound. The remaining shelf-life can only be determined analysing the temperature history.

Due to legal requirements it must be proven that the conditions of transport comply with regulations throughout the entire transportation chain, i.e. the transportation from the manufacturer to the end-consumer. The most common means of providing a proof of compliance is the use of temperature recorders which keep a history of all recorded temperatures. Violations of temperature ranges can be detected using these data and the remaining shelf-life can be updated using the Arrhenius-equation. A violation of temperature ranges may for some shipments mean to destroy and resend the shipment, for others it may mean a reduced shelf-life, and again for others it may mean to continue as planned but report the violation.

Besides of temperature requirements, supply chains for pharmaceutical products also have to deal with disturbances in the transportation network and variable lead times which also may impact the remaining shelf-life on arrival at the final customer.

3.6.1.1 Situation without visibility

Simple temperature recorders cannot be read at any point in the transport chain. In particular, when third-party operators are involved, there may not be any possibility of achieving the visibility required to analyse the temperature history, and to take appropriate actions when required.

If critical temperature values cannot be detected timely, there is no possibility of pro-actively reacting before prolonged exposure to low or high temperatures damages the product. Furthermore, perished products or products with reduced shelf-life may not be identified immediately. This results in unnecessary costs for transporting products towards their original destination, although they may have to be disposed or redirected towards some other destination. Moreover, the reordering of the product will be initiated later, resulting in later delivery to the final customer. The lacking capability of pro-actively identifying deviations may result in the need to choose transportation means which have highly reliable temperature control and lead times. This increased reliability will typically translate into higher costs.

Allocations of shipments to customer orders can only be done without the knowledge of the shipment's condition or after the temperature history has been read and analysed. This results in lost opportunities for allocating shipments with different shelf-life to customer orders with different minimal shelf-life requirements.

3.6.1.2 Situation with visibility

Trucks and storage facilities can be equipped with temperature readers which are capable of transmitting the measured temperature. Information about the environment temperature may be used to pro-actively initiate countermeasures if the environment temperature is a threat to the temperature the product is exposed to. Temperature readers attached to a communication device may also be put into containers and boxes in order to directly measure the temperature the product is exposed to. If the temperature is near the tolerated limits, the information may be used to pro-actively initiate countermeasures. The capability of

immediate countermeasures can reduce the deterioration rate in transit and thus, will reduce depreciation costs.

For some pharmaceutical products, temperature ranges can be seen as soft constraints intended to guarantee a certain level of remaining shelf-life on arrival. In those cases it is not absolutely required to keep the products within the ranges at all times. The knowledge about temperature histories can be used to update the remaining shelf-life and to give estimates about the remaining shelf-life upon arrival. Transportation means and routes with a certain risk of violating desired temperature ranges or lead times may be used if temperature data can be obtained analysed and countermeasures can be initiated instantly. For example, less costly temperature preserving cargo bodies may be used if the forecasted weather conditions do not have a big impact on the estimated remaining shelf-life. If the temperature changes, countermeasures, such as moving the shipments to temperature controlled storage facilities can be initiated. The higher flexibility in choosing transport means and route can reduce overall transportation costs.

In-Transit Visibility can improve the knowledge about the progress of transportation processes. Estimated arrival times and estimated remaining shelf-life on arrival can be used to optimally allocate in-transit inventory to customer orders. The optimal allocation of in-transit inventory to customer orders can be determined by solving a bi-criterial optimisation problem, considering both the desired arrival time and the desired minimal remaining shelf-life of the products.

3.6.1.3 Summary

Supply chain characteristics:

- Push-pull system
- Shelf-life
- Sensitivity
- Lead time variability

Potential actions:

- Resolve threat to compliance
- Allocate in-transit inventory to customer orders
- Alert customers
- Use emergency orders

- Revise ordering decisions according to anticipated inventory levels
- Expedite assets in transit
- Modify route of shipments in transit
- Reroute assets in transit to another destination

Generated values:

- Reduced transportation costs
- Reduced inventory holding costs
- Improved compliance
- Improved on-time delivery performance
- Reduced depreciation costs

Required information:

- Current location
- Status of assets
- Estimated time of arrival (ETA)
- Estimated status at arrival

3.6.2 Consumer electronics: Digital cameras

This case study examines how In-Transit Visibility can generate value for a producer of consumer electronics manufacturing digital cameras in Asia and selling them in Europe. After receiving a purchase order, cameras are shipped from the manufacturer to a consolidator. The consolidator prepares shipments for transportation to Europe. After transportation from an Asian terminal to an European terminal all shipments are sent to the European Distribution Centre (EDC). From the EDC shipments are transported to Regional Distribution Centres (RDC) from which final delivery to the customers is made.

While analog film cameras used to have a life-cycle of 3-4 years, digital cameras are produced with life-cycles of only 6 months. The short life-cycles result in a high risk of stock becoming obsolete. Therefore, stores and Distribution Centres (DC) in Europe only have low levels of stock.

3.6.2.1 Situation without visibility

Without In-Transit Visibility there is no knowledge about which products are sent from the manufacturer and when they are sent. Shipments are consolidated and sent to Europe, and there is no knowledge about the flow of products until arrival at the EDC. When shipments arrive at the EDC, they are deconsolidated. At the EDC each product is allocated to a customer order or a RDC. Then, products with same destination are consolidated and outbound transport from the EDC is arranged. The flow of products and the time when decisions are made is illustrated in figure 3.21.

Without In-Transit Visibility shipments can only be allocated to customer orders after they arrive at the EDC. Because of consolidation, a large number of products arrive at the EDC at the same time. As there is no knowledge about which products arrive, there is a high risk of unbalanced workloads and bottlenecks. Consolidation opportunities for outbound transportation are lost, as there is no knowledge about which products will arrive in the near future. Poor consolidation opportunities result in lost opportunities to bypass the RDC and directly ship to customers. Unnecessary long handling and lead times occur because all shipments must pass through the EDC.

3.6.2.2 Situation with visibility

In-Transit Visibility can provide information regarding the progress of handling and transportation processes. Information about the type and quantity of products shipped can be used to allocate shipments to customer orders before they arrive at the EDC. If in-transit inventory is allocated to customer orders before the shipments arrive at the consolidator, the final destination of the shipments can be considered in order to minimise handling activities by consolidating shipments with same or similar destinations. Consolidated shipments with same final destination can be transported directly to the customer without the need to pass through EDC or RDC. The flow of products and the time when decisions are made is illustrated in figure 3.22.

Updated arrival time estimates can be used to prepare for workload peaks and to pro-actively resolve bottlenecks at the EDC. Furthermore, load consolidation and routing decision can benefit from this knowledge and coordination of in- and outbound transportation can be improved. The improved coordination and consolidation opportunities may result in reduced

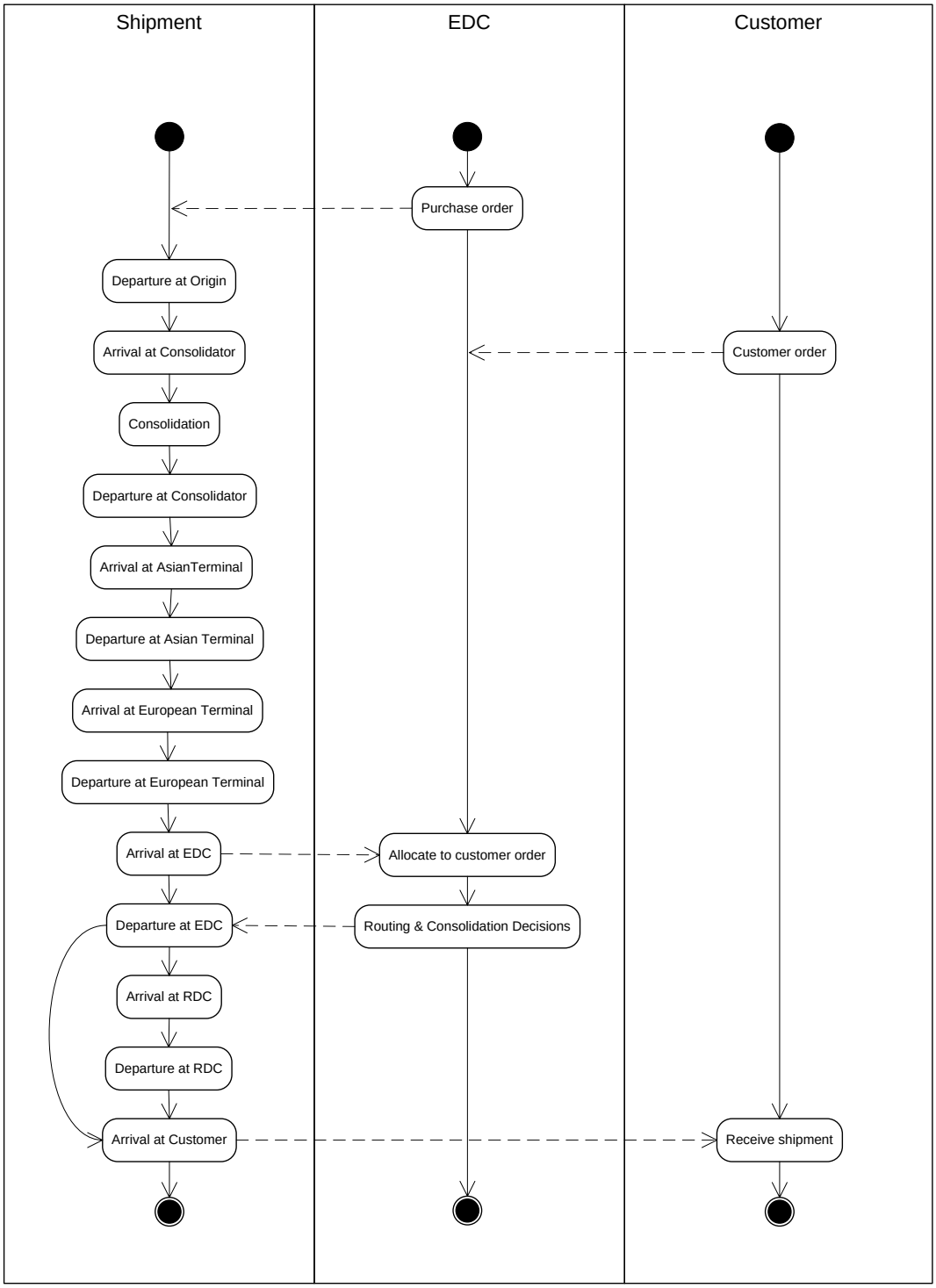

Figure 3.21: No Visibility

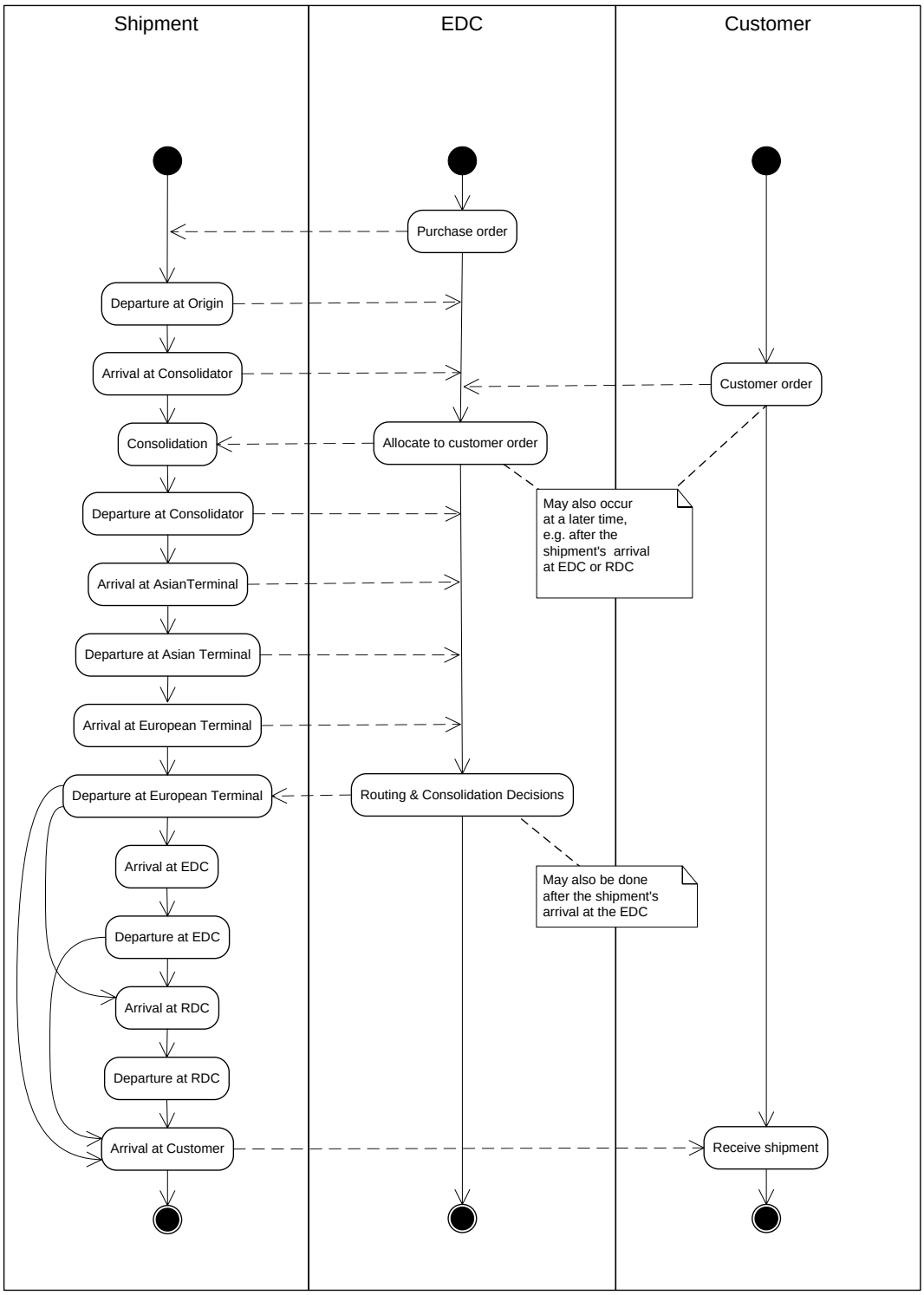

Figure 3.22: In-transit visibility

operational costs and lead times. Furthermore, the RDC may be bypassed and consolidated shipments with same final destination may be directly shipped to the customer.

3.6.2.3 Summary

Supply chain characteristics:
- Push-pull system
- Lead time variability
- Variable shipping time
- Variable shipping quantity

Potential actions:
- Resolve bottlenecks
- Allocate in-transit inventory to customer orders
- Modify route of shipments in transit
- Reroute assets in transit to another destination

Generated values:
- Reduced transportation costs
- Reduced inventory holding costs
- Reduced average lead time
- Reduced depreciation costs

Required information:
- Departure time at origin
- Quantity shipped
- Estimated time of arrival (ETA)

Chapter 4

How big is the value of ITV?

4.1 Introduction

There are three ways to assess the value of In-Transit Visibility. First, one can ask experts or practitioners to subjectively give their best estimates on the value that could be achieved. Second, one can conduct case studies of some early pilots, and infer the value from observing the results at these pilots. Third, one can start with understanding how In-Transit Visibility can enable actions changing the operating characteristics, and then deduce the benefits obtained by these visibility-enabled actions.

Cognitively, we know that increased visibility will improve forecasting, planning, inventory, and service. However, experts and practitioners have only started gaining experience with novel technologies to improve visibility and can hardly estimate how big this value can be without performing a detailed model analysis.

Deriving the benefits of different levels of visibility by conducting case studies of early pilots is problematic, because the benefits generated by early pilots depend on the base case. For example, if a company is not even aware of total transportation costs and lead times, then comparing this base case with the case in which the company applies a novel high-tech visibility solution to obtain detailed status information on transportation processes blends various effects on supply chain performance. One may improve the performance of the company by applying a low-tech visibility solution capturing total transportation costs and lead times. The value of the additional visibility obtained by the high-tech solution cannot be

easily derived, because distinctions between different effects on supply chain performance are usually not made in standard industry reports.

The third approach requires the use of analytical models that link the underlying operating characteristics to control decisions, and ultimately to performance measures. When such linkages are explicitly modelled, the impact of different levels of In-Transit Visibility can be determined.

This chapter presents two simulation studies quantifying the value of In-Transit Visibility in intermodal transport chains.

4.2 Intermodal transport: Container routing

This study seeks to quantify the value of visibility over assets moving through an intermodal transportation network. The reliability of intermodal transportation networks depends on the probability that every shipment arrives at a transshipment terminal before outbound transport begins. If a shipment arrives with a delay, the outbound vehicle may already have departed the terminal. Thus, delayed shipments may need to wait at the terminal until alternative transport can be organised. This, of course, can result into significant delays at the final destination of the shipment. In-Transit Visibility can provide the means to identify such delays, reorganise the shipment plan, and place emergency orders in order to minimise the impact of deviations on the customers.

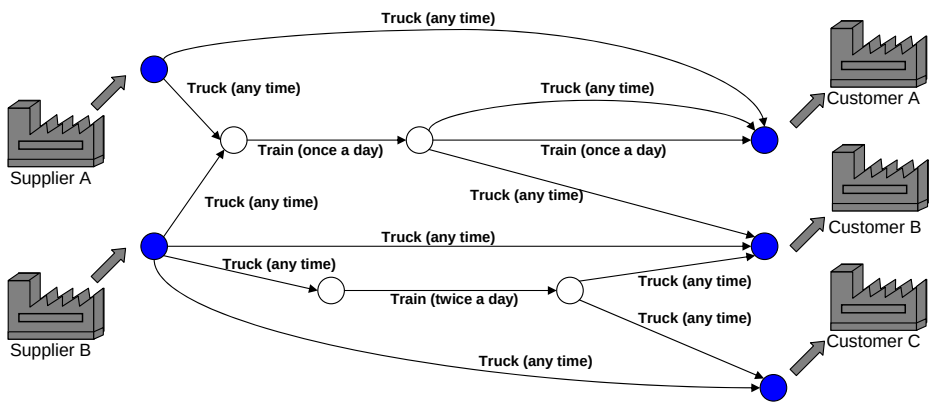

Figure 4.1: Co-modal transportation network

Figure 4.1 illustrates an example of a co-modal transportation network including rail and road transport. Each mode has its specific characteristics concerning departure times, capacity, speed, costs, and transit time variability. While trucks are available at any time of the day, trains only depart once or twice a day. Obviously, a delayed arrival at an intermodal transshipment terminal may result in a delay of a full day if the transportation plan is not changed.

This study will asses the gradual impact of In-Transit Visibility on supply chain performance by simulating the transport manager's decision making process with different levels of visibility. First, the decision making problem of the transport manager and a formal model are presented. Then, it is shown how the model is adapted in order to consider updated information on the state of the transportation system and how the transport manager solves the planning problem. Thereafter, different levels of visibility are presented. Eventually, simulation experiments are performed to determine the gradual impact of In-Transit Visibility.

4.2.1 Problem considered

Let $\mathscr{L}_{\text{supp}}$ denote a set of supplier locations, $\mathscr{L}_{\text{term}}$ a set of transshipment terminals, and $\mathscr{L}_{\text{cust}}$ a set of customer locations. Let $\mathcal{P}$ denote a set of products obtainable from the suppliers. For each product $p \in \mathcal{P}$ let $d_{l,t,p} \in \mathbb{N}_0$ denote the number of items of product p demanded by customer $l \in \mathscr{L}_{\text{cust}}$ at a point in time t. It is assumed that this demand cannot be backlogged and that stockout costs $c_{l,p}$ arise for each item of product p for which the demand at customer l is not fulfilled.

For each pair of locations $l, l' \in \mathscr{L} := \mathscr{L}_{\text{supp}} \cup \mathscr{L}_{\text{term}} \cup \mathscr{L}_{\text{cust}}$, let $\mathscr{M}_{l,l'}$ denote the set of transportation modes available to travel from l to l'. It is assumed that $\mathscr{M}_{l,l'} = \emptyset$ for each pair $l, l' \in \mathscr{L}$ with $l' \in \mathscr{L}_{\text{supp}}$ or $l \in \mathscr{L}_{\text{cust}}$. Now let us consider a pair of locations $l, l' \in \mathscr{L}$ and a transportation mode $m \in \mathscr{M}_{l,l'}$. Let $\mathcal{T}_{l,l',m}$ denote the set of departure times at l and let $\Delta_{l,l',m}$ denote the planned transit time required by mode m to travel to l'. Let $\mathcal{S}_{l,l',m}$ denote the set of shipments that may be transported by the mode of transport. Let $c_{s,l,l',m}$ denote the costs per shipment $s \in \mathcal{S}_{l,l',m}$, and let $Q_{l,l',m}$ denote the maximum number of shipments that may be transported simultaneously, i.e. the capacity of the mode. Each shipment $s \in \mathcal{S}_{l,l',m}$ contains certain quantities of different products. At the beginning of the planning period some shipments may already be in transit. These shipments arrive at a transshipment terminal or a customer location at a certain point in time within the planning period. Let $x_{s,l,t}$

denote the number of shipments of type s that arrive at a location $l \in \mathscr{L}_{\text{term}} \cup \mathscr{L}_{\text{cust}}$ at time t. Additional shipments can be generated at a supplier location at any time of the planning period.

The planning problem considered in this study is to determine shipments to be sent by the supplier and routes for these shipments in order to minimise costs, in particular, stockout and transportation costs. The routes for these shipments must comply with operational constraints imposed by departure times, transit times, compatibility, and capacity restrictions.

The following presents a formal model for the planning problem. Let $\mathcal{T} := \{t_0, t_1, \ldots, t_k\}$ denote a set of discrete points in time and let us assume that $\mathcal{T}_{l,l',m} \subseteq \mathcal{T}$ for all $l, l' \in \mathscr{L}$ and $m \in \mathscr{M}_{l,l'}$. Let

$$\mathcal{N}_{\text{supp}} := \{n_{l,t} \mid l \in \mathscr{L}_{\text{supp}}, t \in \mathcal{T}\}$$

$$\mathcal{N}_{\text{term}} := \{n_{l,t} \mid l \in \mathscr{L}_{\text{term}}, t \in \mathcal{T}\}$$

$$\mathcal{N}_{\text{cust}} := \{n_{l,t} \mid l \in \mathscr{L}_{\text{cust}}, t \in \mathcal{T}\}$$

denote sets of nodes corresponding to the supplier locations, transshipment terminals, and customer locations at certain points in time.

Let n_{dummy} be a dummy node and let

$$\mathcal{N} := \{n_{\text{dummy}}\} \cup \mathcal{N}_{\text{supp}} \cup \mathcal{N}_{\text{term}} \cup \mathcal{N}_{\text{cust}}$$

denote the set of nodes in a time-expanded network. The arcs in the time-expanded network are generated as illustrated in figure 4.2.

For each pair of locations $l, l' \in \mathscr{L}$, each transport mode $m \in \mathscr{M}_{l,l'}$ and each departure time $t \in \mathcal{T}_{l,l',m}$ let us generate an arc from node $n_{l,t}$ to node $n_{l',t'}$ where $t' := \min\{\tau \in \mathcal{T} \mid t + \Delta_{l,l',m} \leq \tau\}$. Let $\mathcal{A}_{\text{transport}}$ denote the set of these transportation arcs. For all locations $l \in \mathscr{L}_{\text{term}} \cup \mathscr{L}_{\text{cust}}$ and each $i \in \{0, 1, \ldots, k-1\}$ let us generate an arc from node n_{l,t_i} to node $n_{l,t_{i+1}}$. Let $\mathcal{A}_{\text{wait}}$ denote the set of these arcs representing the transition from one time period to another.

For all nodes $n \in \mathcal{N}_{\text{supp}}$ let us generate an arc from node n_{dummy} to n. Let $\mathcal{A}_{\text{supply}}$ denote the set of these arcs representing shipments sent by the supplier. For all nodes $n \in \mathcal{N}_{\text{cust}}$ let us generate an arc from n to node n_{dummy}. Let $\mathcal{A}_{\text{demand}}$ denote the set of these arcs representing customer demand. For all nodes $n \in \mathcal{N}_{\text{cust}}$ let us generate an arc from node n_{dummy} to n. Let $\mathcal{A}_{\text{stockout}}$ denote the set of these arcs representing unfulfilled customer

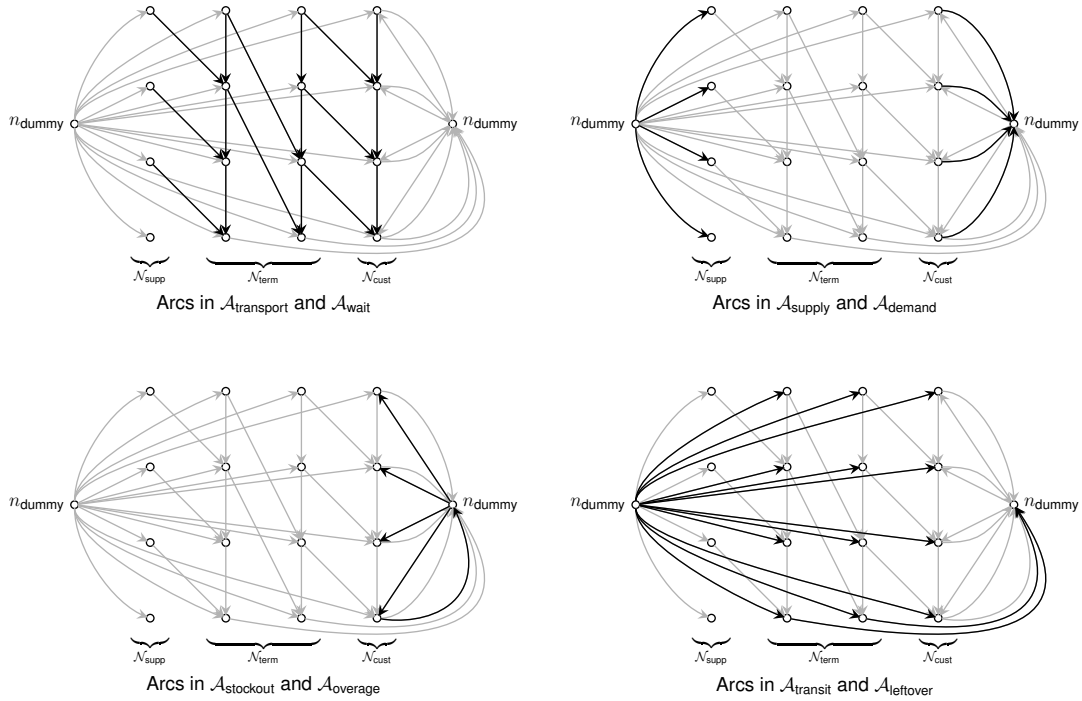

Figure 4.2: The time-expanded network

demand. For all locations $l \in \mathscr{L}_{\text{term}}$ let us generate an arc from node n_{l,t_k} to node n_{dummy}. Let $\mathcal{A}_{\text{leftover}}$ denote the set of these arcs representing shipments which are in the delivery pipeline at the end of the planning horizon. For all locations $l \in \mathscr{L}_{\text{cust}}$ let us generate an arc from node n_{l,t_k} to node n_{dummy}. Let $\mathcal{A}_{\text{overage}}$ denote the set of these arcs representing overage inventory at the customer at the end of the planning horizon.

We also generate arcs from node n_{dummy} to each node $n \in \mathcal{N}_{\text{term}} \cup \mathcal{N}_{\text{cust}}$ in order to consider shipments in transit which arrive at a transshipment terminal or customer location at some point in time within the planning period. Let $\mathcal{A}_{\text{transit}}$ denote the set of these arcs.

The set of all arcs in the time-expanded network $(\mathcal{N}, \mathcal{A})$ is

$$\mathcal{A} := \mathcal{A}_{\text{transport}} \cup \mathcal{A}_{\text{wait}} \cup \mathcal{A}_{\text{supply}} \cup \mathcal{A}_{\text{demand}} \cup \mathcal{A}_{\text{stockout}} \cup \mathcal{A}_{\text{leftover}} \cup \mathcal{A}_{\text{overage}} \cup \mathcal{A}_{\text{transit}}.$$

For each node $n \in \mathcal{N}$ let $\mathcal{A}_n^+$ denote the set of arcs entering the node and let $\mathcal{A}_n^-$ denote the set of arcs leaving the node.

Let $\mathcal{S}_{\text{item}}$ denote the set of all possible shipments containing exactly one item of one product. Let

$$\mathcal{S} := \mathcal{S}_{\text{item}} \cup \bigcup_{\substack{l,l' \in \mathscr{L} \\ m \in \mathscr{M}_{l,l'}}} \mathcal{S}_{l,l',m}$$

and let $q_s \in \mathbb{N}_0^{|\mathcal{P}|}$ represent the amount of items contained by a shipment of type $s \in \mathcal{S}$. For each arc $a \in \mathcal{A}$ let $\mathcal{S}_a \subseteq \mathcal{S}$ denote the set of shipments that may use the arc. For each arc $a \in \mathcal{A}_{\text{transport}}$ let $\mathcal{S}_a := \mathcal{S}_{l,l',m}$ where l and l' denote the corresponding supplier location, transshipment terminal, or customer location and m denotes the corresponding mode of transport. For each arc $a \in \mathcal{A}_{\text{wait}} \cup \mathcal{A}_{\text{supply}} \cup \mathcal{A}_{\text{leftover}} \cup \mathcal{A}_{\text{transit}}$ let $\mathcal{S}_a := \mathcal{S}$. For each arc $a \in \mathcal{A}_{\text{demand}} \cup \mathcal{A}_{\text{overage}} \cup \mathcal{A}_{\text{stockout}}$ let $\mathcal{S}_a := \mathcal{S}_{\text{item}}$.

For each arc $a \in \mathcal{A}$ and each $s \in \mathcal{S}_a$ let $c_{s,a}$ represent the costs for using the arc. For each arc $a \in \mathcal{A}_{\text{transport}}$ and each $s \in \mathcal{S}_a$ let $c_{s,a} := c_{s,l,l',m}$ where l and l' represent the corresponding supplier location, transshipment terminal, or customer location and m represents the corresponding mode of transport. For each arc $a \in \mathcal{A}_{\text{stockout}}$ and each $s \in \mathcal{S}_{\text{item}}$ let $c_{s,a} := c_{l,p}$ where l represents the corresponding customer location and p represents the product in shipment s. For all other arcs $a \in \mathcal{A} \setminus \left(\mathcal{A}_{\text{transport}} \cup \mathcal{A}_{\text{stockout}}\right)$ and all shipments $s \in \mathcal{S}_a$ let $c_{s,a} := 0$.

For each arc $a \in \mathcal{A}_{\text{transport}}$ let $Q_a := Q_{l,l',m}$ be the maximum number of shipments that may use the arc where l and l' denote the corresponding supplier location, transshipment terminal, or customer location and m denotes the corresponding mode of transport. For all arcs $a \in \mathcal{A}_{\text{demand}}$ and each $s \in \mathcal{S}_{\text{item}}$ let $\chi_{s,a} := d_{l,t,p}$ where l and t correspond to the customer location and time associated to arc a and p corresponds to the product associated to shipment s. For all arcs $a \in \mathcal{A}_{\text{transit}}$ and all shipments $s \in \mathcal{S}$ let $\chi_{s,a} := x_{s,l,t}$ where l and t correspond to the location and time associated to arc a. For each $(s,a) \in \mathcal{S} \times \mathcal{A}$ let $x_{s,a}$ denote the non-negative integer variable representing the number of shipments of type s traversing arc a.

The planning problem can now formally be described as follows.

(1) $$\text{minimise} \sum_{s \in \mathcal{S}} \sum_{a \in \mathcal{A}} c_{s,a} x_{s,a}$$

subject to

(2) $$\text{for all } n \in \mathcal{N} : \sum_{s \in \mathcal{S}} \sum_{a \in \mathcal{A}_n^+} x_{s,a} \cdot q_s = \sum_{s \in \mathcal{S}} \sum_{a \in \mathcal{A}_n^-} x_{s,a} \cdot q_s$$

(3) $$\text{for all } s \in \mathcal{S}, n \in \mathcal{N}_{\text{term}} : \sum_{a \in \mathcal{A}_n^+} x_{s,a} = \sum_{a \in \mathcal{A}_n^-} x_{s,a}$$

(4) $$\text{for all } a \in \mathcal{A}_{\text{transport}} : \sum_{s \in \mathcal{S}} x_{s,a} \leq Q_a$$

(5) $$\text{for all } a \in \mathcal{A} : x_{s,a} = 0 \text{ for all } s \in \mathcal{S} \setminus \mathcal{S}_a$$

(6) $$\text{for all } s \in \mathcal{S}, a \in \mathcal{A}_{\text{demand}} \cup \mathcal{A}_{\text{transit}} : x_{s,a} = \chi_{s,a}$$

(7) $$\text{for all } s \in \mathcal{S}, a \in \mathcal{A} \setminus \left(\mathcal{A}_{\text{demand}} \cup \mathcal{A}_{\text{transit}}\right) : x_{s,a} \in \mathbb{N}_0$$

The objective function (1) is to minimise the sum of transportation and stockout costs. Equation (2) imposes that at each node the sum of products arriving equals the sum of products leaving the node. Equation (3) imposes that each shipment arriving at a node corresponding to a transshipment terminal also departs from that node. Constraint (4) represents capacity constraints on transportation arcs. Constraint (5) represents shipment/arc compatibility constraints. Eventually, (6) assigns fix values to some of the decision variables and (7) constrains the domain.

Note that if each product can only be transported by one type of shipment and demand can be represented as a multiple of the shipments' contents, above problem can be interpreted as a multi-commodity network flow problem, see Ahuja et al. (1993). Up to now we have not considered variability of transit times. How to deal with variability of transit times will be discussed in the next section.

4.2.2 Decision making process

In this study it is assumed that there are two decision makers in the transportation system: (a) the transport manager and (b) the terminal operator. The transport manager's responsibility is to plan transportation of shipments in order to minimise costs. The terminal operator's responsibility is to deal with unforeseen deviations from the plan. That is, if deviations between actual and planned transportation processes occur and the transportation manager does not adjust the plan accordingly, the terminal operator must locally decide on the flow of shipments whenever outbound transportation cannot be performed as planned.

It is assumed that each terminal operator is instantly informed by the transport manager when the transportation plan is modified. Consequently, each terminal operator knows how many shipments of a certain type shall be transported by each mode. Furthermore, each terminal operator knows when vehicles arrive and depart from the terminal and in which sequence shipments arrive at the terminal. It is assumed that terminal operators cannot appreciate the consequences of modifying the mode of transport. Therefore, it is assumed that terminal operators perform transshipment operations in a way that each shipment is transported by the mode of transport originally planned. Furthermore, terminal operators decide according to a First-In-First-Out strategy, i.e., shipments are assigned to outbound vehicles in the sequence in which they arrive until all shipments are forwarded or the capacity of the outbound vehicle is exhausted.

Without In-Transit Visibility the transport manager solves the model described in the previous section once, and each terminal operator takes care that every shipment is forwarded as planned. If the transport manager is informed about the progress of transportation processes, he/she can use this information to update the transportation plan according to the perceived state of the transportation system.

Whenever updated information about the progress of transportation processes becomes available to the transport manager, he/she updates origin and/or destination of each arc in $\mathcal{A}_{\text{transport}}$ and $\mathcal{A}_{\text{transit}}$. Considering these changes all shipment flows are updated, taking into account the First-In-First-Out strategy of terminal operators and constraints (2) to (7). The updated plan reveals the impact of deviations between planned and actual transportation processes. Furthermore, it provides the starting point for plan adaptation by the transport manager. After updating the plan as described above, the transport manager re-solves the planning problem by doing the following:

Initialisation: For all arcs $a \in \{\tilde{a} \in \mathcal{A} \mid \tilde{a} \text{ corresponds to the future}\}$ and all shipments $s \in \mathcal{S}$ set $x_{s,a} := 0$.

Satisfy demand: Repeat the following while there is a node $n \in \mathcal{N}_{\text{cust}}$ with

$$\sum_{s \in \mathcal{S}} \sum_{a \in \mathcal{A}_n^+} x_{s,a} \cdot q_s \neq \sum_{s \in \mathcal{S}} \sum_{a \in \mathcal{A}_n^-} x_{s,a} \cdot q_s.$$

1. Let n be the node corresponding to the earliest point in time at which above condition holds. Set

$$\delta := \sum_{s \in \mathcal{S}} \sum_{a \in \mathcal{A}_n^+} x_{s,a} \cdot q_s - \sum_{s \in \mathcal{S}} \sum_{a \in \mathcal{A}_n^-} x_{s,a} \cdot q_s.$$

2. If there is a product $p \in \mathcal{P}$ with $\delta_p < 0$, do the following:
   (a) Find the cheapest *suitable* route from a node $\tilde{n} \in \{n_{\text{dummy}}\} \cup \mathcal{N}_{\text{term}}$ to n.
   (b) If $\tilde{n} \in \mathcal{N}_{\text{term}}$, choose a shipment $s \in \bigcap_{a \text{ in route}} \mathcal{S}_a$ with

$$\sum_{a \in \mathcal{A}_{\tilde{n}}^+} x_{s,a} > \sum_{a \in \mathcal{A}_{\tilde{n}}^-} x_{s,a}$$

   which contains product p. Increase $x_{s,a}$ by one for all arcs a belonging to the route.
   (c) If $\tilde{n} = n_{\text{dummy}}$, generate a (new) shipment $s \in \bigcap_{a \text{ in route}} \mathcal{S}_a$ which contains product p. Increase $x_{s,a}$ by one for all arcs a belonging to the route.
3. Otherwise, choose a product $p \in \mathcal{P}$ with $\delta_p > 0$ and do the following:
   (a) Generate a new shipment $s \in \mathcal{S}_{\text{item}}$ which contains exactly one unit of product p.
   (b) Choose the arc $a \in \mathcal{A}_{\text{wait}} \cup \mathcal{A}_{\text{overage}}$ which starts at n and increase $x_{s,a}$ by one.

Balance flows: Repeat the following while there is a node $n \in \mathcal{N}_{\text{term}}$ and a shipment $s \in \mathcal{S}$ with

$$\sum_{a \in \mathcal{A}_n^+} x_{s,a} > \sum_{a \in \mathcal{A}_n^-} x_{s,a}.$$

1. Choose the arc $a \in \mathcal{A}_{\text{wait}} \cup \mathcal{A}_{\text{leftover}}$ which starts at n and increase $x_{s,a}$ by one.

This solution approach first seeks to satisfy customer demand by routing shipments in transit to the customer, or by ordering new shipments from the supplier. It starts with determining the first customer node with an inbalance. If the customer receives less items of a product than required, a shipment containing the product must be routed to the customer. Only those routes are *suitable* for which there exists a shipment $s \in \mathcal{S}$ that can be routed to the customer to (partially) satisfy the demand of product p. This shipment may either be a shipment in transit which becomes available at some node $\tilde{n} \in \mathcal{N}_{\text{term}}$ (i.e. $\sum_{a \in \mathcal{A}^+_{\tilde{n}}} x_{s,a} > \sum_{a \in \mathcal{A}^-_{\tilde{n}}} x_{s,a}$), a shipment to be sent from a supplier, or a virtual shipment representing a stockout. Idle capacity must be available for all arcs a in a suitable route and shipment/arc compatibility constraints must be satisfied. If the customer receives more items of a product than required, excess inventory at a customer node is subsequently carried over to the next time period. After in- and outflow at each customer node is balanced, excess inventory in the delivery pipeline is subsequently carried over to the next time period.

4.2.3 Levels of visibility

The effectiveness of the decision making process described above depends on the gap between reality and the actual state of the transportation system. The earlier the transport manager is notified about deviations, the smaller the gap between reality and model representation used for planning. Therefore, shipment flows are more likely to be performed as planned. If the transport manager has little knowledge about the state of the transportation system, decisions made by the transport manager may be based on outdated data. This results in discrepancies of planned and actual shipment flows and, thus, to unnecessary costs and/or unsatisfied customer demand.

In this study we consider four different levels of visibility:

Level 0 - No visibility In Level 0 the transport manager does not receive any information about delayed departures and arrivals. Therefore, any delay may result in a stockout as no mitigation actions can be planned.

Level 1 - Daily snapshot In Level 1 the transport manager receives a daily update containing information about delays of all departures and arrivals scheduled on the previous day.

Level 2 - Departure/Arrival In Level 2 the transport manager requests and receives delay information at each scheduled time of departure or arrival at a node.

Level 3 - Checkpoint In Level 3 the transport manager requests and receives delay information at the scheduled time of arrival at each checkpoint en-route including the scheduled time of departure or arrival at a node.

In the following, the transport manager's decision making process with respect to these different levels of visibility is simulated. The resulting supply chain performance is then compared according to the level of visibility.

4.2.4 Computational experiments

This section presents computational experiments conducted in order to quantify the gradual benefits of increasing the level of visibility. For this, a supply chain for the automotive industry is studied. As a result of lean management and just-in-time practices, many automotive manufacturers have drastically reduced inventory levels. Low inventory levels necessitate punctual and reliable transportation, because any mismatch between supply and demand can result in significant disruptions of manufacturing processes. In the worst case, inventory shortages can result in stopping the production line. As costs for stopping the production line are enormous, transport managers may decide to ship missing items per air freight, even if the cost of transportation is within no relationship to the price of the items, sometimes only worth a few cents.

Figure 4.4 illustrates the rail services used to replenish different plants from a major supplier of parts and components. Every day two trains depart from the supplier. Each of these trains has a capacity of 20 swap bodies, i.e. standardised containers that can be transported by train or heavy truck. After arrival at the first terminal, responsibility for transportation is transferred from the first rail operator to the second rail operator. Shunting operations are required to compose the daily outbound train with capacity of 40 swap bodies. After arrival

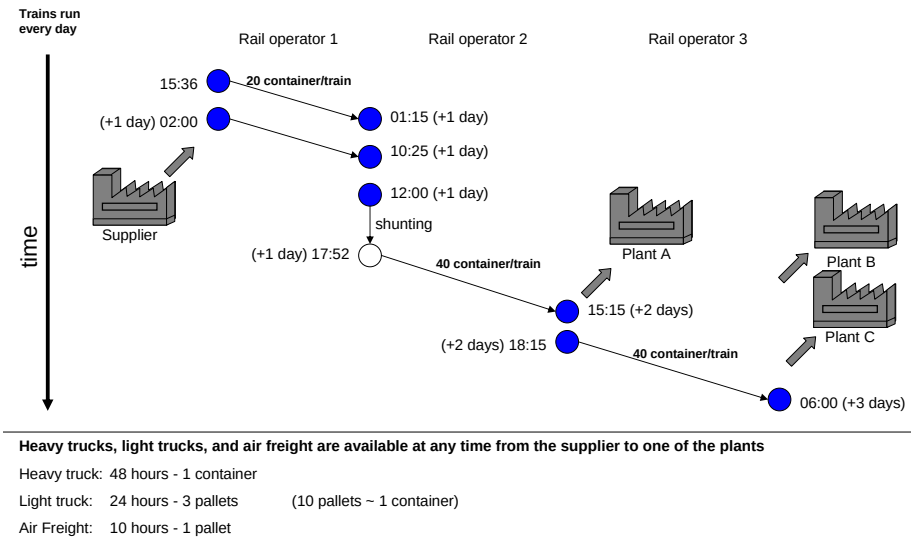

Figure 4.3: Rail services

at the second terminal, responsibility for transportation is transferred from the second rail operator to the third rail operator. Furthermore, some of the swap bodies may be unloaded and transported to plant A near the second terminal. All other swap bodies are transported to plant B or C.

As a substitute for rail transport, heavy trucks can carry a single swap body from the supplier to one of the plants. Furthermore, light trucks and air freight may be used if transport by heavy truck is not fast enough. While swap bodies used for transport by rail and heavy truck are assumed to hold 10 pallets, it is assumed that light trucks can only transport 3 pallets at a time and the unit load of air freight is one pallet. Due to different speed limits and regulations concerning drivers' working hours, light trucks have higher average speed than heavy trucks. The fastest but most expensive mode of transport is air freight.

Figure 4.4 illustrates a situation in which In-Transit Visibility can generate value. A delay of shunting operations at the first terminal results in a delayed arrival at the second terminal. Swap bodies for plant B or C cannot be forwarded as planned and arrive at the third terminal with a delay of a full day. If the transport manager receives early information about the delay, he/she can place emergency orders from the supplier in order to prevent stockouts at either of the plants. Of course, the costs of these emergency orders depend on the time available between placing the emergency order and when the products are required.

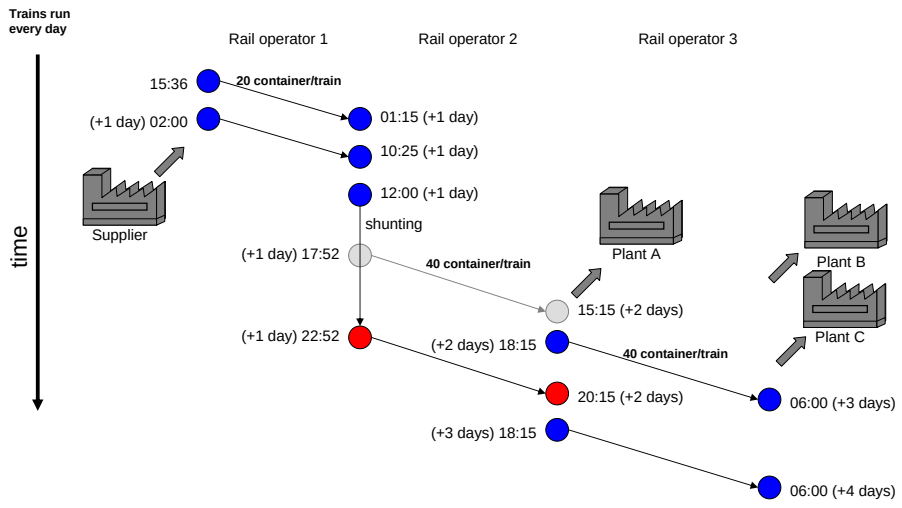

Figure 4.4: Rail services with delayed shunting operations

For our computational experiments we assume an accumulated daily demand just above the capacity of the rail services. That is, those shipments which cannot be transported by rail are transported by heavy truck. It is assumed that the daily demand is evenly distributed between 6:00 h and 22:00 h. The probability of a significant delay resulting in a missed connection at a terminal is assumed to be 1% or 5%. Furthermore, it is assumed that shipments are not re-allocated to another plant while they are in transit. One thousand simulation runs, each simulating a planning period of 14 days, are performed for each level of visibility. Table 4.1 shows the on-time delivery performance, i.e. the percentage of all items which are delivered on time with respect to the total number of items required.

Delay probability	1%	5%
Level 0	97.75	93.97
Level 1	99.27	97.09
Level 2	99.75	98.90
Level 3	99.92	99.62

Table 4.1: On-time delivery performance

It can be seen that on-time delivery performance can be significantly increased with an increase in the level of visibility. Of course, improving on-time delivery performance does

not come for free. In order to react on deviations between planned and actual transportation processes, emergency orders must be placed. These emergency orders incur an increase in transportation costs as fast and costly modes of transport must be used in order to prevent stockouts.

Figures 4.5 and 4.6 illustrate the modal split of all items sent. In Level 0, the transport manager does not receive any information about delays. Therefore, no emergency orders can be placed in order to prevent stockouts. This, of course, results in low on-time delivery performance. On-time delivery performance is significantly improved when moving to Level 1. In Level 1, stockouts are primarily prevented by using light trucks and air freight. That is, the fastest and most costly modes must be used as information is only updated on a daily basis. In Level 2, information about delays is known earlier. This further improves on-time delivery performance. Because information is available earlier, cost efficient heavy trucks may be used for emergency orders and less light trucks and air freight are required to provide the higher service level. Level 3 further increases the service level. In our test case, this comes at the expense of more frequent use of light trucks. Moving from Level 1 to Level 2 or Level 3 not only improves on-time delivery performance, but also reduces the number of shipments sent by air freight by around 80%. Thuis, usage of the by far most costly mode of transport is significantly reduced.

An interesting aspect is, that a high level of visibility can also allow for reducing buffer times in transportation chains. Obviously, a reduction of buffer time creates a higher risk of missed connections. However, as can be seen in table 4.1, the on-time delivery performance can be improved (Level 1 $\rightarrow$ Level 3) even if the probability of missed connections is increased (1% $\rightarrow$ 5%). This, however, results in higher transportation costs as more costly modes of transport must be used to maintain a high on-time delivery performance.

It must be noted that the simulation is myopic and the transport manager assumes that future processes take place as planned. In Level 0, the transport manager does not receive any information about delays. If shipments cannot be forwarded as planned, they must wait at the terminal until the next day. As the transport manager keeps on pushing shipments into the transportation chain, the terminal becomes a bottleneck because the capacity of the outbound train is exhausted by waiting shipments. An important issue is that the excess inventory at the terminal acts as a safety buffer for the next delay. In all other levels, the transport manager reduces the inflow to bottlenecks whenever he/she receives information

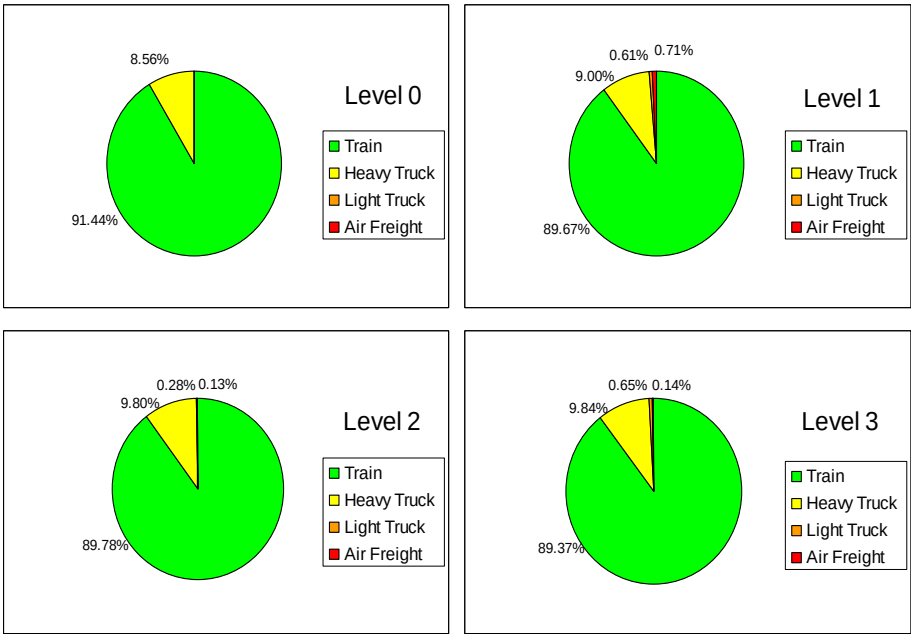

Figure 4.5: Modal split with 1% probability of significant delay

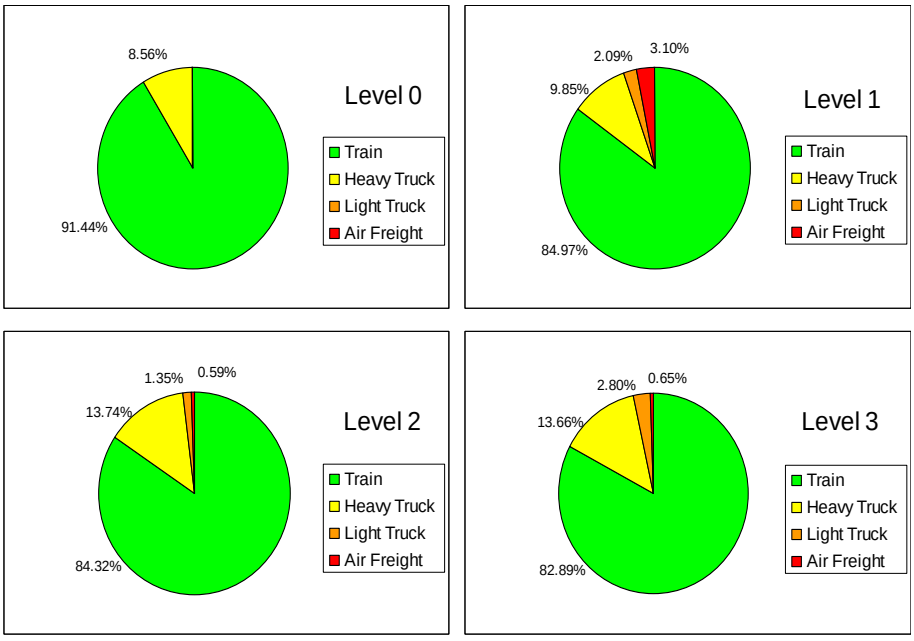

Figure 4.6: Modal split with 5% probability of significant delay

about delays. This reduces the average waiting time of shipments, but also reduces the safety buffer.

4.3 Intermodal transport: The last leg

Arrival times of containers at transshipment terminal may vary for many reasons. Due to this uncertainty in arrival times, land-side transportation can often only be organised after containers are unloaded from ships. This, however, creates a high level of dynamism for motor carriers as land-side transportation shall typically start as soon as possible. This level of dynamism can be actively controlled using In-Transit Visibility. For example, IBM and Maersk Logistics have jointly developed a system for tracking shipping containers around the world (RFID Journal (2005)). The real-time tracking devices use a combination of wireless technologies to submit container-related data such as the physical location. If such container tracking devices are used, the arrival time of containers at terminals can be estimated with high accuracy. This allows for organising land-side transportation before the container is unloaded. Consequently, the level of dynamism the motor carrier has to deal with is reduced. Decreasing the level of dynamism comes at the cost for investments for achieving In-Transit Visibility. In order to justify such investments, one needs to understand how the level of dynamism impacts the performance of motor carrier operations. The goal of this study is to assess the impact of dynamism on motor carrier performance. First, the problem considered in this study is described. Thereafter, the decision making process and different levels of visibility are described. Eventually, the simulation conducted is described and discussed.

4.3.1 Problem considered

The Pickup and Delivery Problem with Profits

In this study we will consider a generalisation of the Pickup and Delivery Problem with Time Windows (PDPTW). The PDPTW is the problem of finding a set of tours, for a fleet of vehicles, in order to serve a set of transportation requests at minimal costs. In the case of full truckloads each transportation request is specified by the origin and destination of the load, and time intervals during which origin and destination must be visited. Each vehicle has a given start location, and an end location, and can serve at most one transportation

request at a time. In other words, the Pickup and Delivery Problem with Time Windows deals with the construction of tours in order to visit all pickup and delivery locations and satisfy precedence, pairing, and time window constraints. Precedence constraints deal with the restriction that each pickup location has to be visited prior to visiting the corresponding delivery location. Pairing constraints restrict the set of admissible tours such that one vehicle has to do both the pickup and the delivery of the load of one transportation request. Time window constraints restrict the time during which pickup and delivery locations may be visited.

In the Pickup and Delivery Problem with Profits (PDPP) it is not necessary to serve all transportation requests. Each transportation request is associated a revenue which only can be collected if the transportation request is served. The goal of the PDPP is to maximise profits, i.e. the difference between all collected revenues and the costs for operating the tours. The PDPP is a combined load acceptance and routing problem which generalises the PDPTW and the Travelling Salesman Problem with Profits studied by Feillet et al. (2005). Furthermore, the PDPP is a special case of the General Vehicle Routing Problem introduced by Goel and Gruhn (2007).

Drivers' Working Hours

Drivers' working hours in the European Union are regulated by EC regulation 561/2006 which entered into force in April 2007. According to the new regulation driving periods, breaks, and rest periods for a single manned vehicle must be scheduled as follows:

- After a driving period (i.e. the accumulated driving time between subsequent breaks and rest periods) of four and a half hours a driver shall take an uninterrupted break of not less than 45 minutes, unless he takes a rest period.
- The daily driving time (i.e. the accumulated driving time between the end of one daily or weekly rest period and the beginning of the following daily or weekly rest period) shall not exceed 9 hours. A regular daily rest period is any period of rest of at least 11 hours.

Further regulations apply, e.g. for drivers engaged in multi-manning, the maximum weekly working time, the accumulated driving time during any two consecutive weeks, and the duration of weekly rest periods. However, they will not be considered in this study for simplicity.

Figure 4.7 illustrates an example of the schedule of a drivers' working day. As we can see, drivers' working hour regulations have a high impact on total travel times, i.e. the time required to travel from one location to another including driving periods, breaks, and rest periods. In this study we will assume that vehicle tours must comply with above regulations. For a more comprehensive discussion of EC regulation 561/2006 and approaches for considering drivers' working hours in vehicle routing the reader is referred to Goel (2008).

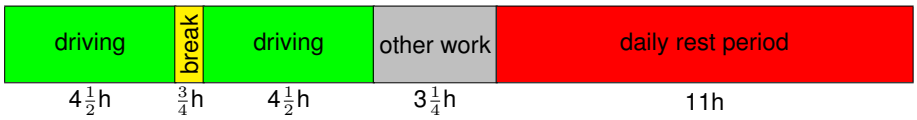

Figure 4.7: Driving periods, breaks, and rest periods

Dynamics

In this study it is assumed that the only external source of dynamism is the arrival of new transportation requests. More precisely, we assume that in the beginning of the planning period a certain percentage of all transportation requests is known and new transportation requests arrive dynamically. Furthermore, it is assumed that vehicles move with constant speed and that drivers take their breaks and rest periods as planned by the decision maker, i.e. at any point in time the decision maker has full knowledge about position and state of all vehicles.

4.3.2 Decision making process

This section describes the decision making process used to dynamically update vehicle tours. Whenever new transportation requests become known the decision maker seeks to insert the new request into tours using the insertion heuristic described in Goel and Gruhn (2007). Each iteration of this method can be divided into the following three phases:

1. **Determine incremental costs of insertion:** For each unscheduled transportation request and each vehicle, determine the incremental costs of inserting the transportation request into the tour of the vehicle.

2. **Propose insertion:** For each unscheduled transportation request, propose insertion to the tour with lowest incremental costs.
3. **Accept proposal:** Among all proposals received for a tour, determine the most profitable transportation request, i.e., the transportation with the biggest (positive) difference between revenue and incremental costs.

The insertion method continues until no further profitable transportation request can be found.

Thereafter, a Large Neighbourhood Search is performed to dynamically optimise the schedule considering all transportation requests known. The Large Neighbourhood Search algorithm can be described as follows:

0. **Initialisation:** Find an initial solution; choose a stopping condition
1. **Repeat** the following until the stopping condition is met:
   (a) **Remove:** Choose a number k and randomly remove k transportation requests from their tours
   (b) **Re-insert:** Generate a new solution by applying an insertion method
   (c) **Move or not:** If the new solution is feasible and better than the current solution, replace the current solution by the new solution

We assume that drivers are continuously instructed about new tasks via mobile communication devices. That is, drivers are either busy fulfilling their current tasks or idle waiting for a new task. It is assumed that drivers immediately start travelling towards the next destination when they are informed about a new task. Furthermore, it is assumed that once a driver has started travelling towards the next destination he/she cannot be diverted until the destination is reached. Under these assumptions it is easy to see that drivers should not be informed too early, as this would reduce the possibilities for dynamically reoptimising tours considering new transportation requests. On the other hand, drivers should neither be informed too late, as this would result in unproductive waiting times. Therefore, we assume that drivers are informed according to a *Minimum-Wait Least-Commitment* strategy. That is, if a travel time of Δ is required to reach the next destination and the time window at the destination opens at time t, the driver will be informed at time $t - \Delta$ or the earliest time thereafter. With this strategy we do not commit to travel to the next destination unnecessarily early. Furthermore, this strategy minimises the unproductive waiting time of the vehicle.

4.3.3 Levels of visibility

Opportunities to generate efficient vehicle tours depend on the time between when transportation requests are known and when transportation shall begin. That is, the earlier the carrier knows which transportation request to serve, the better he/she can combine transportation requests in order to minimise empty mileage and unnecessary costs. Typically some transportation requests are known well in advance and some become known dynamically. The time difference between arrival of a new transportation request and the time the corresponding time window opens shall be referred to as *advance notification time*. In this study we compare scenarios which distinguish themselves by the percentage of transportation requests which are known well in advance and by the advance notification times for dynamically arriving transportation requests.

4.3.4 Computational experiments

This section presents computational experiments conducted in order to quantify how motor carrier performance depends on the percentage of transportation requests which are known well in advance and advance notification times for dynamically arriving transportation requests. In all simulation experiments tours for 100 vehicles are generated considering 500 transportation request. Pickup and delivery locations of transportation requests are distributed as illustrated in figure 4.8 in which the frequency of a location being either pickup or delivery location of a transportation request is indicated by the size of the circle. Most of the transportation requests incur a pickup or delivery in the region between Paris, Düsseldorf, and Frankfurt. Some transportation requests, however, have very remote pickup or delivery locations, for example Florence, Dublin, Gothenburg, and Helsinki. Time windows at pickup and delivery locations are set to either 2 or 12 hours. The begin of the time window for the pickup location of each order is equally distributed within the 5 days of our planning horizon. Travel distances are based on the direct distances, however are multiplied by 1.3 in order to consider deviation occurring in road transport. Travel costs are proportional to the travel distance. The revenue of the transportation requests is set to double the costs of transporting the shipments. That is, the shippers are not only willing to pay for the transport itself, but also for the return trip to the start location. Each vehicle travels at a speed of 75 km/h and regulations concerning drivers' working hours as described above must be complied with.

Figure 4.8: Distribution of pickup and delivery locations

In the beginning of our simulation, tours are generated from scratch using the insertion method described above. Afterwards, the Large Neighbourhood algorithm is used to optimise the solution. The resulting solution after one hour of computation time is used as initial solution for the simulation experiments. In each time period new transportation requests become known dynamically. In our simulations the Large Neighbourhood Search algorithm was only allowed 60 seconds of computing time per timestep (representing one hour in our simulation scenario). All decisions made may be revised at any time unless the driver is already informed about the respective task. With the beginning of a new timestep the start location of every vehicle is updated in order to consider the execution of drivers' tasks.

Figures 4.9 and 4.10 illustrate the results of our computational experiments with different percentages of transportation requests known in advance and different advance notification times. The results clearly show that in our setup the percentage of transportation requests known well in advance has a significant impact on the profitability if advance notification times are small. Below 10 hours of advance notification times profitability is fairly stable. When advance notification times are increased from below 10 hours to above 12 hours, profitability can be significantly improved. Furthermore, advance notification times of more than a day may be reduced to 12 hours with only moderate reduction of profitability. An

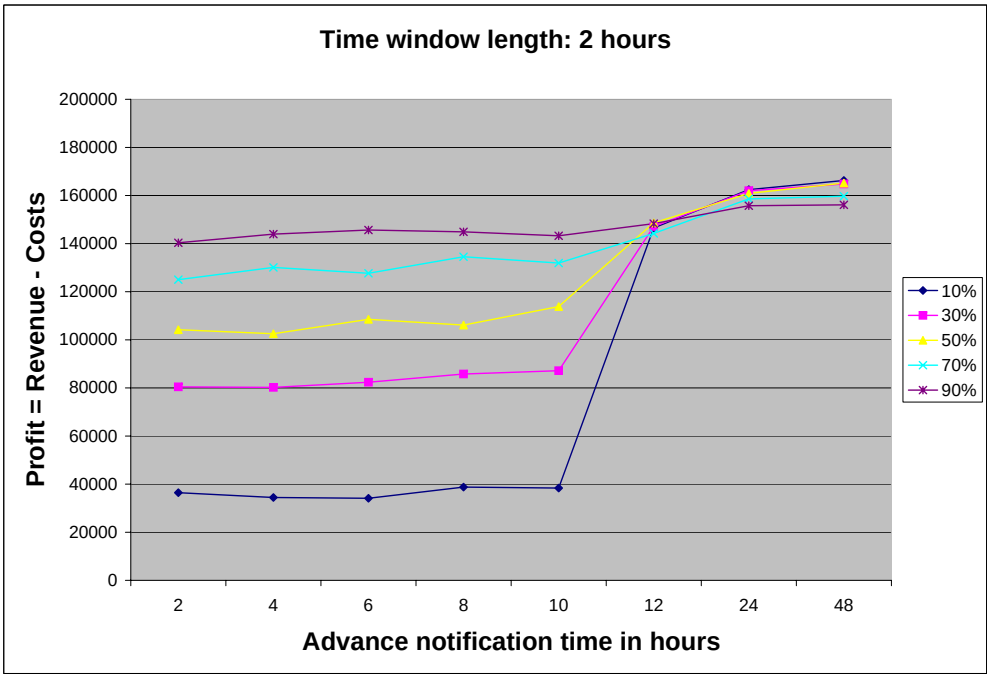

Figure 4.9: Results of computational experiments with small time windows

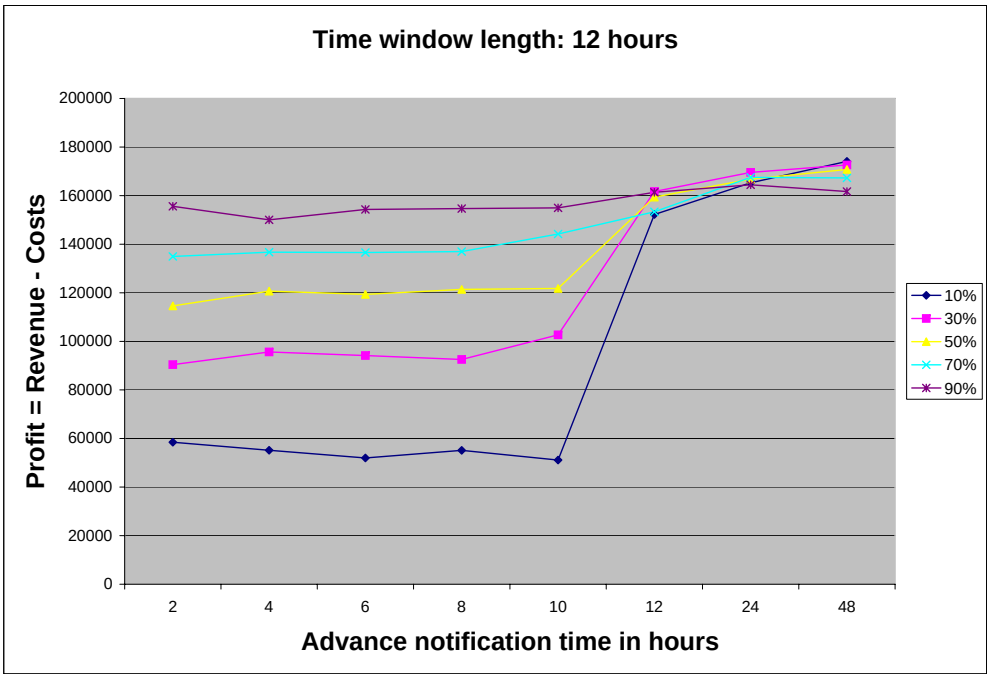

Figure 4.10: Results of computational experiments with large time windows

interesting observation is that the sharp increase in profitability occurs when advance notification times approximately match the duration of a daily rest period of 11 hours. As similar simulation experiments conducted for problems without drivers' working hours do not show this sharp increase, it appears that drivers' working hour regulations are a crucial factor in dynamic vehicle routing.

Another interesting phenomenon contradicts our intuition. One would expect that a higher percentage of transportation requests known well in advance would always result in higher profitability. However, our results show that best results are obtained when only 10% of transportation requests are known in advance and advance notification times are 48 hours. Of all experiments with advance notification times of 48 hours the worst results are obtained when 90% of transportation requests are known in advance. One explanation for this phenomenon is that with an increase in problem size the search space grows exponentially. In a small search space a larger percentage of the search space can be explored by the heuristic, resulting in a higher probability of finding high quality solutions. In other words, finding a needle in a small haystack is much easier than finding one of a few needles in a haystack of ten times the size.

4.4 Concluding remarks

This chapter presents quantitative studies demonstrating the value of In-Transit Visibility for intermodal transport chains. The first study presents a transportation model combining shipment and route choice and shows how In-Transit Visibility can be used to dynamically update the transportation plan in order to minimise stockout and transportation costs. By simulating the transport manager's decision making process with different levels of visibility, the gradual benefits of In-Transit Visibility are quantified. Computational experiments show that on-time delivery performance can be significantly improved by increasing the level of visibility from daily updates to near-real time visibility. The second study assesses the value of advance information about transportation demands by simulating the motor carrier's decision making process. It is shown that profitability can be significantly improved if advance notification times are increased from below 10 hours to above 12 hours.

Chapter 5

Summary

This report assesses the value that can be generated with In-Transit Visibility. It surveys related work and best practices and shows how In-Transit Visibility can be achieved in international supply chains involving various actors and stakeholders, each with different capabilities and interests. By classifying supply chain characteristics and potential visibility-enabled actions, this report shows how different benefits can be generated depending on the visibility information available. In-depth studies quantifying the value of In-Transit Visibility for intermodal transport chains are presented and computational experiments are conducted showing that In-Transit Visibility can significantly improve on-time delivery performance, reduce transportation costs, and increase performance of actors in the transport chain. The results of these simulation studies allow comparing the benefits with the costs for achieving the required level of visibility. By this, the right level of visibility for a specific supply chain can be determined.

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