A comprehensive analysis of an intelligent platform for supply chain management

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Report CW 509, February 2008

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A comprehensive analysis of an intelligent platform for supply chain management

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Chapter 1

Context and Business Analysis

In this chapter, an in-depth analysis is made of the supply chain's structure, its involved players and its associated business processes. In the first section, the general functioning of the supply chain, its involved stakeholders, and the role they play within the supply chain is explained. The section further describes how they benefit from automating (parts of) their supply chains. In the second section, typical business processes, active within the supply chain, are analyzed, including some existing technological solutions for achieving some automation of the supply chain. Finally, a new solution, based on the use of wireless sensor networks for automating supply chain management, has been proposed. The functional and relevant requirements for such an *intelligent* system or platform are then explored and they serve as a first move towards a software analysis and architecture of such a platform which will be described in Chapter 2.

1.1 Introduction to the intelligent supply chain

Applying logistic concepts within the boundaries of a single enterprise isn't sufficient enough anymore. It's essential to have a vision on the total supply chain, starting from suppliers of raw materials, along manufacturers and distribution centers, towards end-customers [11]. Within this logistic chain, enterprises often lose the link with each other and the end-consumer, since their activities and information systems are not optimally tuned to each other. To integrate all these different links in the logistic chain with each other and to better tune them to the output market, efficient supply chain management is crucial. It is responsible for better control of the flow of goods and assets along the entire chain and a more fluent information exchange the various parties is necessary.

Supply chain management is a cross-functional inter-enterprise system that uses information technology to help support and manage the links between some of a company's key business processes and those of its suppliers, customers, and business partners. The goal of supply chain management is to create a fast, efficient, and low-cost network of business relationships to get a company's products from concept to market. A primary driver of competitive advantage for an enterprise lies in building a supply chain that is fast responsive, flexible and especially customer-oriented.

Many companies today are making supply chain management a top strategic objective and major e-business application development initiative. Fundamentally, supply chain management helps a company get the right products to the right place at the right time, in the proper quantity and at an acceptable cost. The goal of supply chain management is to achieve a better control of product flow and assets, a just-on-time planning of transport, precise inventory management, and enhancing collaboration with customers, suppliers, distributors and other partners. To achieve this goal, many companies today are turning to Internet technologies to Web-enable their supply chain processes, decision making, and information flows between their partners. However, critical to receiving feedback on the status of every link in the supply chain is real-time visibility into the location and movement of products across the trading network and inside the storage environment.

Today, automation of the supply chain is mainly limited to bar code scanning, which requires manual intervention and line-of-sight visibility between the scanner and the goods. In this case, parties like logistics providers and manufacturers, spend numerous hours on performing manual inventory management, which therefore leads to inefficiencies into the already complex chain. However, many of these inefficiencies can be resolved when real-time visibility is created when identification through RFID[1] or sensor technology is provided throughout the entire supply chain. These technologies may definitely have a large impact on the efficiency of the entire supply chain, since enterprises may use this automatically collected information into their existing IT-infrastructure in order to better automate and streamline their business operations with each other. With the integration of this new dimension of information, enterprises can better manage the links between their suppliers and customers. This could mean that, for instance, providing subsequent parties in the supply chain with information regarding the flow of goods in advance, those parties may better plan their operations in advance, and coordinate them whenever the goods arrive.

1.2 Goods, assets and transportation means

One of the key elements in the supply chain are *goods*. Goods consist of raw or processed materials that generally need to be transported from one stakeholder to another. Goods are passive entities, they cannot directly influence the decisions taken in the supply chain themselves.

Every good has some properties associated with it, which may be called assets. An *asset* is a property of interest of the good which is relevant for the handling stakeholders. Examples of a good's assets are the physical factors like temperature or humidity of the good, the good's current location and destination, the real value, priority, type or owner of the good. It can also be the current handling logistics provider and current handling personnel. As showed, assets can provide valuable information about the goods' current status and therefore they should be automatically monitored throughout the entire supply chain. An asset can possibly impose constraints on the handling and transportation of the good. The constraint can for instance indicate that the good should be kept cold or should be handled with care.

Goods can be shipped in containers, in crates, in boxes, on pallets or they can just be bulk goods. The type of packing can also be mixed, i.e. a crate that's packed in a box and placed on a pallet that is possibly shipped in a container. Obviously, there are other combinations of packings possible.

[1]RFID, Radio-Frequency IDentification

1.2.1 Categories of goods

The following categories of goods can be identified:

1. *Human consumable goods*: Goods that are suited for human consumption and therefore they possibly have to be cooled. Each of these goods has a decline date that varies for each good individually. This could possibly mean that consumption goods need a fast and specialized transportation. Examples of consumption goods are milk, meat, grain, fruit and vegetables, bottled soft-drinks and even medicines.

2. *Non-food goods or ordinary consumption goods*: These are goods that are not intended for human consumption. Their handling is dependent on their type. Examples of non-food goods are steel, cotton, wood, electronics,...

3. *Dangerous and hazardous goods*: Goods that need to be handled with care and/or transported through specialized stakeholders. Examples of such goods are chemical products such as chlorine, petrol, oil,...

1.2.2 Categories of assets

The following categories of assets can be identified:

1. *Physical assets*: The good's assets that can be associated with the physical condition or state of the good. Physical assets include temperature, humidity, acceleration and velocity, location.

2. *Timing assets*: All the constraints related to timing and duration. For instance, a truck loaded with trees is generally less urgent than a truck loaded with steel rolls that are needed to continue the production in a automobile factory. Other examples of goods that can have specific timing assets are, e.g. medicines or any other medical supplies.

3. *Good-specific assets*: All, besides the physical, asset properties of good itself or those that can be associated with it or with any user. The good's destination, its owner or current handling provider, the possible value assets like the good's real worth and its material assets. For instance, it must be necessary for a transport loaded with chemical products that it can be located and that the physical assets of the chemicals can be monitored at real-time, while for a transport loaded with grain it's less important to provide real-time information about the condition of the good and the location of the transport.

1.2.3 Transportation means

There are different means possible to transport goods from one point or stakeholder to another. Goods can be transported by truck, by ship, by train or by airplane. The transportation of the good from a supplier to a consumer can also be a combination of those different means which all have a different entity responsible for transport. Each mean obviously involves different types of handling and can carry specific types of goods or packings. A truck can only be loaded with a single container, while a ship can carry hundreds of them. A container can contain valuable or dangerous products which require careful handling, or it may contain human consumable goods, which need a constant cooling during the container's trip.

1.3 Different players along the supply chain

This section makes an analysis of the different involved stakeholders and actors in the supply chain. Section 1.3.1 describes the stakeholders which are parties with a specific responsibility within the supply chain. Section 1.3.2 discusses actors, which are users who belong to a certain stakeholder and interact with enterprise systems. They use these system to accomplish their various tasks. Finally, Section 1.3.3 discusses the different roles a stakeholder can possess. A role describes the additional needed system functionality a stakeholder needs in certain circumstances.

1.3.1 Stakeholders

In the classical representation of the supply chain, one can identify the following stakeholders and their relationships with each other. These are illustrated in Figure 1.1 which represents the natural flow of goods and information along the chain.

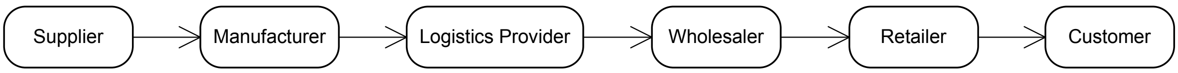

Figure 1.1: The classical supply chain representation.

Figure 1.1 illustrates the usual flow of a good along the typical supply chain as discussed in the literature [11]. The supplier provides (raw) materials to a manufacturer, which then constructs a good composed from the supplied (raw) material parts. The manufacturer then makes use of the services offered by a logistics provider to transport the goods to the wholesaler. The wholesaler is then responsible for the good's distribution to retailers in its wide environment. Retailers then distribute the goods in their local neighborhood to various end-customers.

This supply chain representation has some limitations, since different combinations of links between two stakeholders are possible. Based on the type of the good and its associated assets, the good can have a different path along the supply chain. For instance, vegetables supplied by a vegetables grower, do not have to be processed by a manufacturer, but they come directly from the vegetables supplier who delivers them to an auction or distributor. Various retailers can purchase these vegetables at the auction and distribute them themselves to end-customers, without using logistics providers. Besides these six classical stakeholders, there are also (additional) external parties active in the supply chain. One of those external parties is, for instance, the government which could enforce current legislations, involving the good's handling along the supply chain or promote the use of certain transportation means or packings. In other words, the government practices influence on the flow of the goods and the stakeholders' operations. Therefore they also require information from the various regular stakeholders. The same holds true for various other external parties such as for instance a stakeholder's contracted security company. This company could require information where e.g. valuable goods are stored on the storage site, or which user from a contracted logistics provider can come and pick up a specific good and when that user is allowed to pick it up.

These observations result in a modified and more realistic representation of the classical supply chain, which is illustrated in Figure 1.2. The solid lines in the figure represent the logical flow of the goods as well as the information exchange between two parties, while the dotted lines only represent the information exchange between an external party and a supply chain's stakeholder. This representation has the logistics provider as the central stakeholder, since it's offered services are needed by almost every other enterprise.

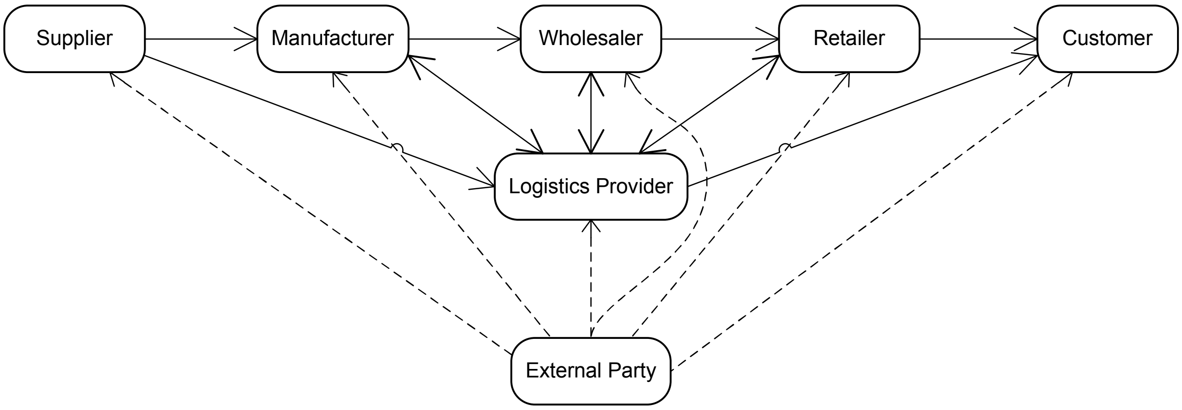

Figure 1.2: A generally more realistic representation of the supply chain's stakeholders and the good flow between each other.

Mainly all stakeholders, except for the (end-)customer, consist of enterprises, that all differ in size and structure. There exist large enterprises that could span multiple nations, but there also exist a significant amount of SMEs[2] in today's supply chain. Similar to the conceptual relations between stakeholders, enterprises have agreements with each other, and thus they possess the need to exchange information in order to coordinate each other's activities. These agreements between stakeholders in general are very time dynamic and can be instantaneously instantiated.

The following stakeholders are part of the supply chain as illustrated in Figure 1.2:

1. **Supplier**: The supplier is a stakeholder who supplies goods to other stakeholders. Suppliers can supply (raw) materials or partly finished goods to stakeholders further along the supply chain. Examples of suppliers are, for instance, vegetables growers or steel mills.

2. **Manufacturer**: A manufacturer is a supply chain's stakeholder who basically transforms raw materials or intermediate goods into finished goods. The manufactured goods are then ready for transportation to an intermediate destination such as a warehouse or storage depot. Besides executing manufacturing processes, manufacturers can also manufacture goods for other manufacturers and hence they act as intermediate suppliers for each other. Examples of such intermediate suppliers are window factory that supplies an automobile factory with car windows. This specific type of relationship is identified as a role, and is discussed in Section 1.3.3.

3. **Logistics Provider**: Logistics providers are responsible for the transportation of goods between two stakeholders and the assurance of the good's assets. The logistics provider owns transportation means such as trucks, ships or airplanes and storage infrastructure such as depots and sites. Logistics providers distribute goods from a supplying stakeholder to a destination stakeholder by using transport units and possibly intermediate

[2]SME, *Small and Medium Enterprise*

logistic hubs. These hubs handle the incoming goods and provide storage until they are transported further. In order to plan the next part of the transportation route, logistics providers require different kinds of asset information about the goods, like their destination and type, and information about the available resources like transportation units or drivers. Since the logistics providers' market is a very competitive one, a logistics provider should, in order to gain competitive advantage, try to offer additional services to its customers. An example of such a value gaining service is real-time localization and asset tracking of the transported goods. In order to improve these services, logistics providers are interested in the tracing of the good at the smallest transportable unit such as a container, pallet or crate or even at the good level, in combination with real-time monitoring of the good's asset.

4. **Wholesaler**: The wholesaler is a stakeholder who provides intermediate storage for the goods before any further distribution of them. The wholesaler receives its goods mainly through logistics providers and distributes its goods mainly to retailers, although possibly ordinary end customers can buy and fetch their goods at the wholesaler. Wholesalers are interested in the tracing of goods at product or crate level, since inventory management and asset monitoring are very important activities for them.

5. **Retailer**: The retailer is a small-scaled wholesaler who is responsible for the distribution of goods in its local neighborhood. Retailers receive their goods from wholesalers or logistics providers, and deliver them to end-customers. Retailers are just as wholesalers generally interested in the tracing of the good at the product or crate level, since inventory management and asset monitoring are both important activities for them.

6. **Customer**: The customer is the endpoint or addressee for a good along the supply chain. A customer consumes goods which were delivered through the chain by a logistics provider, a wholesaler or a retailer. Customers can impose demands on the various stakeholders responsible for transportation, storage and manufacturing of goods across the chain. These demands can be a fast shipment, at the lowest costs, with respect to quality handling and origin assurance, real-time good tracking and asset information through (real-time) monitoring of the good.

7. **External Party**: An external party is a stakeholder located outside the supply chain, but who can influence the goods' handling along the chain. The government and security companies (contractors) are, for example, external parties who require an exchange of information between them and the other stakeholder.

   The government authorities could, for instance, signal road problems, road conditions, traffic information and weather updates to logistics providers, in order to provide them with the necessary information for shipment, air and road transport. Security companies are mostly responsible for securing of the good's storage site.

   The following types of external parties exists in the supply chain:

   (a) *Government*: Government authorities define legislations and enforce them. They could for instance define which type of goods and/or packings are subsidized and which ones are taxed, which roads are priced at which hours, which transportation means are encouraged or which custom duties are applied to a particular good. They are also interested in the various products and goods stocked or transported through their country or administrative region. Besides their legislative duties, the government also have informative duties, like signaling road problems, weather conditions, and traffic information to logistics providers or other stakeholders.

(b) *Harbor or airport company*: The harbor or airport company runs the daily activities in the harbor or airport. The employed personnel loads and unloads containers and goods on ships or airplanes. Therefore, these employees need information considering the handling of each good or container coming from a logistics provider. This information reflects, for instance, the container's contents in order to load the right container on the right ship or cargo on an airplane.

(c) *Security company*: An external contracted security company which is responsible for securing a particular storage site. These companies might thus be interested in, for instance, information concerning the location of valuable goods and containers on the storage site.

1.3.2 Actors

Since most supply chain's stakeholders consist of various enterprises, actors are generally employed by them. An actor is a user who interacts with other users and the active processes running on the enterprise's systems or resources. Basically, an actor retrieves, stores or acts on information coming from the supply chain's enterprise business processes. Possible examples of actors involved in the domain of supply chain logistics are:

- *Factory worker*: An employee employed by a manufacturer. This person could perform the assembling of different goods into one product, which then needs to be transported.

- *Loading employee*: The personnel responsible for loading the goods into a truck, train, ship or plane.

- *Driver*: A person employed by a logistics provider and responsible for the transport of goods.

- *Government agent*: The government employs several agents like e.g. customs agents and employees of the national food agency.

  Customs agents are responsible for checking the contents of transportation units or storage infrastructure like for instance containers and depots. They are interested in the asset information concerning the type, quantity, origin and destination of the transported good. Customs agents possibly are concerned with checking of the non-violation of the goods' assets during transport. Basically, customs agents want to retrieve all available information concerning a stakeholder's goods to check if they do not violate current legislations. For instance, customs agents check if the owner or transporter paid sufficient customs duties in order to transport or have produced the good.

  Agents employed by the government's food agency are assumed to check if stakeholders in the logistics domain do not violate current legislations concerning human-consumable products. Fruit and vegetables logistics providers for instance must guarantee that their products have been continuously stored below seven degrees.

- *Security officers*: Security officers are employees of a stakeholder's contracted security company.

- *Harbor worker, harbor officer, airport worker, airport officer*: These persons are actors, employed in external party companies.

- *Home user*: The home user is an instance of the customer stakeholder. A home user could be interested in the status of his purchased goods, considering their assets and different locations during their transport over several stakeholders along the chain. According to agreements between stakeholders, the user could require a certain quality of service (e.g. access to various data) or a non-repudiation of origin (e.g. from certain parts in the purchased good).

1.3.3 Roles

In the previous sections it became clear that, during their daily activities, stakeholders can sometimes act as suppliers or customers for each other. The current supply chain representation requires therefore the introduction of another concept, namely *roles*. A stakeholder can possess some roles that describe the additional behavior, responsibilities and actions the stakeholder can take. They are needed since, as described earlier, stakeholders can act as intermediate suppliers or customers for each other. This can, for instance, be illustrated in the following example of the transport of a postal packet, where the initial supplier is not a supplier of raw materials, but rather an ordinary end-customer that acts as a supplier for a logistics provider. Therefore, the functionality of the supplier should be expressed as a role an actor or stakeholder can possess.

The following roles can be identified in the domain of supply chain logistics:

- *Source supplier*: The source supplier of a good is the initial supplying stakeholder.

- *Intermediate supplier*: A stakeholder acting as an intermediate supplier for a contracted stakeholder. This means that the stakeholder delivers its goods to the next succeeding stakeholder in the chain.

- *Intermediate consumer*: A stakeholder acting as an intermediate consumer for a good. After receiving the good, the intermediate consumer can make decisions to take the right actions, based on the good's provided information or the enterprise's planning process.

- *End-customer*: The final consumer of the good, he or she is the end-addressee.

Figure 1.3 illustrates by means of a scenario the usage of the roles along the supply chain. An ordinary customer sees through a marketing campaign a particular car which he or she decides to purchase. The customer places an order at the brand's local automobile retailer, who submits the order to the brand's automobile manufacturer. The manufacturer plans the assembling of the car, but the actual assembling of the car requires car windows supplied by a contracted window supplier. The figure shows the supply chain starting form a supplying car window manufacturer, who delivers car windows through the services offered by a contracted logistics provider, to the contracted automobile manufacturer.

In Figure 1.4, the changing of a stakeholder's roles is illustrated. The car window supplier acts as an intermediate supplier for the automobile manufacturer, who then acts as an intermediate consumer.

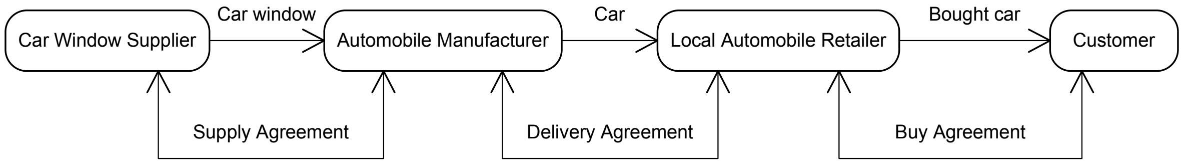

Figure 1.3: Flow of a good through the supply chain, starting from a car window supplier, through a automobile manufacturer and local automobile retailer, and finally to a customer.

After assembling of the car by the manufacturer, the good is changed into a new car, which is then transported from the manufacturer to a local automotive retailer. Once the car arrives at this retailer, the customer should pay the remaining amount of money to the local retailer. After this payment, the car is finally transported to the customer or picked up by the customer, which is now the new owner.

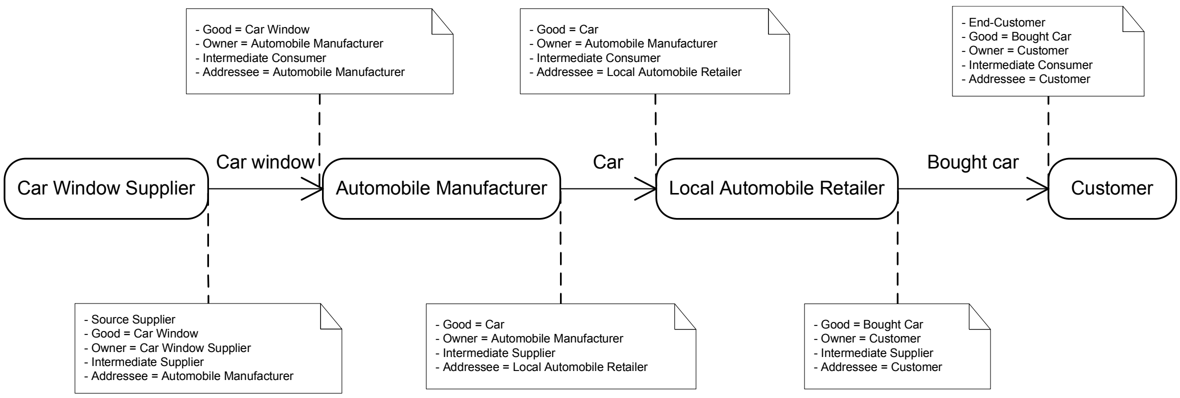

Figure 1.4: The changing of a stakeholder's roles along the supply chain.

1.4 Different business processes of the supply chain

To create optimal business value, the business processes of the different supply chain's stakeholders should be automated, coupled and streamlined to each other. This coupling of business processes involves a transparent and flexible information exchange between the processes of one stakeholder, between the processes belonging to different stakeholders or between processes from a stakeholder and the processes of an external party. In this section, the typical supply chain business processes for an enterprise are identified and described.

1.4.1 Business process categories

As illustrated in Table 1.1, the supply chain's stakeholders business processes are structured around three main categories. The first category is structured around '*Operations*', which involves the management of factory operations, such as the registration of incoming and outgoing goods, production and packaging of them, and the monitoring of the goods' assets. Their management mainly takes place at a lower level, typically a stakeholder's local division, like a factory of warehouse. The second category of business processes is structured around '*Business Activities*'. This category includes all the stakeholder's processes responsible for

Operations:	**Business Activities:**	**Sales & Finance:**
Inbound Registration	Planning	Marketing
Outbound Registration	Asset Management:	After Sales Support
Producing	• Inventory Management	Billing
Monitoring	• Tracking	Selling
Packaging	• Tracing	Customer Management
Cross-cutting: Authentication, Authorization, and Logging		

Table 1.1: Business processes and categories of the supply chain's stakeholders

planning, scheduling and management of the various enterprise resources, assets and transportation units. This management can be performed at a stakeholder's local division or at a higher company-wide level. Finally, the last category of business processes is structured around is '*Sales and Finance*', which involves all processes related to customer management, marketing, sales and finance.

The following business processes can be categorized as related to '***Operations***':

1. *Inbound and outbound logistics*: The in- and outbound logistics process registers all incoming and outgoing goods of an enterprise. This process is very time consuming when manual intervention is needed. The in- and outbound processes are coupled with the inventory management processes, since new goods enter while others leave the enterprise.

2. *Producing and packaging*: The producing process involves all actions involved in the production of a raw material or the assembling of them into an intermediate good. As with the inbound and outbound logistics process, the production process is has a large influence on the inventory management process, since it produces new goods from supplies.

   The packaging process packs all produced goods inside dedicated packings. These packings can be enhanced with intelligent devices.

3. *Monitoring*: The monitoring process records all asset information coming from intelligent devices attached to goods.

The following business processes are part of the '***Business Activities***' category of business processes:

1. Planning: Planning is a very wide business process. The planning process can be divided into different types and levels of planning, dependent on the type of stakeholder.

   (a) *Resource planning*: Manufacturers have to plan the current and future usage of their resources. It mainly involves scheduling of the available machinery and employees in factories.

   (b) *Logistics planning*: The typical planning process done by a logistics provider. The logistics provider's planning process is responsible for issuing transportation schedules to allocate goods to an appropriate transport at the right time.

The logistics planning process is heavily coupled with the resource planning process, since it must be possible for any involved stakeholder to plan the scheduling of its resources ahead whenever a transport will arrive. A logistics provider must also be able to plan the coordination between its different hubs. Whenever a transport departs from a hub towards another hub, the destination hub should be notified that this particular transport loaded with a particular type of goods and assets is coming its way within a certain amount of time. The destination hub should then be taking the necessary actions, which can depend on the incoming goods' assets. The same holds true for a manufacturer that ordered a shipment of supplies, transported by a logistics provider.

(c) *User planning*: User planning is related to employee management. The process tries to determine the optimal setting of employees to fulfill a particular task at a specific moment in time, or it can also plan tasks for employees. As with logistics and resource planning, the user planning process is coupled with the other kinds of planning processes.

(d) *Forecasting demand*: A stakeholder must have the possibility to easily forecast its demand and resource planning. The forecasting can be performed if the previous stakeholder in the chain supplies its succeeding stakeholder with the necessary information. The same holds true in the cases where a stakeholder informs a proceeding stakeholder that it's ready to process new incoming goods. In the case of logistics, a manufacturer should inform the logistics provider that there are some goods almost ready to be transported. The logistics provider can then schedule and eventually dispatch a truck to the manufacturer at the right moment.

2. Asset Management contains a set of processes, involving the management and retrieval of asset information. For the domain of supply chain management, this asset management can generally be divided into three parts:

   (a) *Tracking and Tracing*: Tracking and tracing of goods and assets is a process that creates real-time visibility in the supply chain. The stakeholders associated with a particular good can gather real-time information about the location or condition of the good in the supply chain or inside the enterprise. The manufacturer is typically interested where a particular crate with supplies is placed in its storage house, while the end-customer is interested where his newly bought product currently located along the supply chain road or under what condition it is transported. He or she can, for instance, have ordered a new computer, that will be assembled by a computer manufacturer and shipped by a global logistics company. The customer then wishes to see in what stage of the assembly process the computer is and where it's currently located.

   (b) *Asset monitoring*: The monitoring of assets provides additional information to stakeholders. Besides location information, the customer is typically interested in the current status of it's good. For instance, in the context of food transportation, it should be possible to retrieve the current conditions like temperature, light, and humidity of the good.

   (c) *Inventory management*: Inventory management is an important processes for every enterprise involved in the storing, selling and/or manufacturing of goods. With an automated and precise inventory management, the enterprise can easily cut costs and gain competitive advantage over others by monitoring the inventory autonomously and ordering additional supplies automatically.

The following business processes can be categorized as related to '***Sales and Finance***':

1. *Customer management*: The customer management processes all information concerning customers. One practical example of the customer management process is that the customer must be provided access, if allowed, to asset information of its purchased goods which are currently handled by the enterprise. Another viewpoint of the customer management process, is that enterprises, to be agile enough, should really know their customers to produce the optimal amount of business value. This process of knowing and managing customers is crucial for the enterprise. All other processes like marketing are depend on the customer management process.

2. *Marketing*: Marketing involves promoting products and enterprise services for specific target groups of customers. Besides traditional product promotion, an enterprise using intelligent supply chain logistics, may also offer and promote these asset management services to its customers.

3. *Selling*: The selling process is the process where the purchased goods are handed over to the other party (together with billing). After selling a good, it should not not be possible for a proceeding party to retrieve information from a succeeding party due to privacy legislations, unless otherwise stated. Another practice of the supply chain is that an succeeding party desires information about the history of the handling of the newly acquired goods.

4. *Billing*: Billing is very important for each company since it's a revenue making process. Customers should pay selling stakeholders and logistics providers, manufacturers should pay suppliers, while logistics providers must make it possible to allow customers to pay them. The billing process must be integrated with a logging process, since the billing process provides valuable information for the company's accountants and management staff.

5. *After sales support*: The after sales support process provides support for customers after their purchasing of the goods.

Finally, the following business processes can be categorized as rather '***cross-cutting***', since they are needed by various enterprise activities throughout the supply chain.

1. Logging: To know where each good currently is, and to prove by real-time logging that the good's assets are not violated according to the SLAs between two entities is very important. This information should be logged on various levels.

2. Authentication: Define which user is allowed to get in contact with the good. Define what information (assets) a user is able to retrieve from the goods. This process is normally described in a corporate security policy.

3. Authorization: Defines the actions an authorized user is allowed to perform.

As the focus of this report is building a communication platform for supply chain management, by adding real-time visibility and asset monitoring through innovative technology, the processes situated in the operations and business activities categories are naturally more technical than the one residing in the user management category. Therefore they impose the biggest challenges in building such an system.

1.4.2 Business context and value chains

Business context

The context of a general stakeholder's enterprise in the supply chain is illustrated in Figure 1.5. This business context view [7] illustrates the exchange of economic resources as cash, goods, asset information, and labor between economic entities. Customers purchase goods and asset information from stakeholders, which is an exchange of the good or information for cash. Stakeholder's enterprises pay employees to acquire labor from them. Finally, stakeholders purchase goods and information from suppliers, which is an exchange of goods or information for cash.

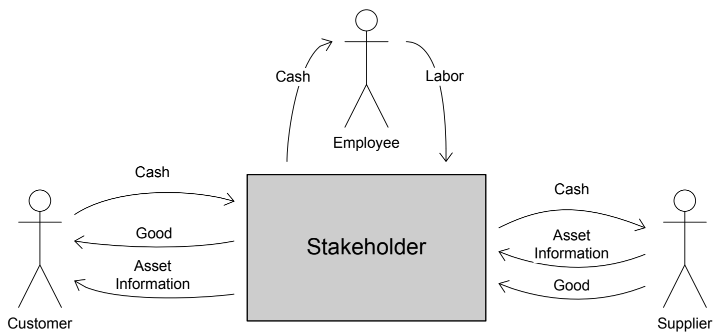

Figure 1.5: Business context of the supply chain's stakeholders

Value chain analysis of each stakeholder

A value chain analysis of an enterprise captures the enterprise's business activities and links them to each other to form a value chain network. Performing this value chain analysis of each stakeholder is a step towards the provision and coupling of the various business processes, that should both be supported by the communication platform [12, 7]. Initially, the value chain of each individual stakeholder will be given in this section, whereas the value chain network between all stakeholders in the supply chain will be given later on.

Supplier: Figure 1.6 represents the value chain of a supplier. Its main business processes are *planning*, *asset management* through asset monitoring, *production* and *packaging* of raw materials, *employee management* through labor acquisition, and *sales*. The supplier's customers can purchase the produced (raw) materials and asset information of these materials during production. The need for and value of this information depends heavily on the type of goods. For example, electricity companies purchasing carbon from suppliers are not as interested in the production conditions of the carbon, as stakeholders in the food industry are.

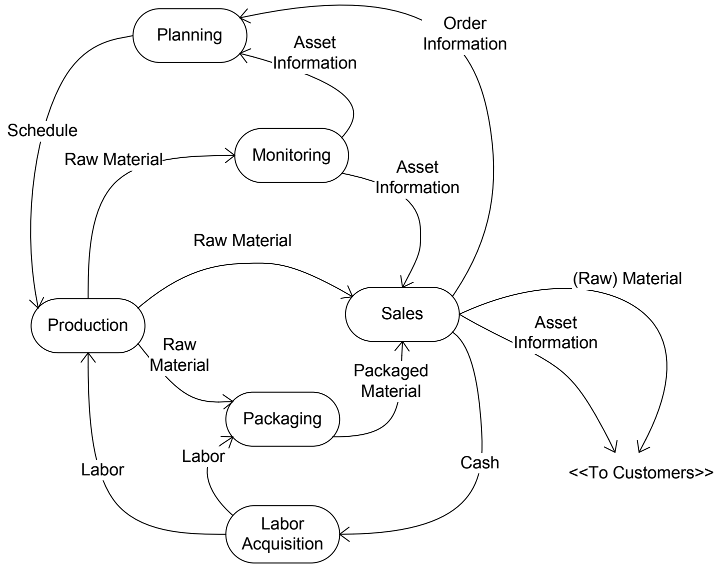

Figure 1.6: Value chain of a supplier

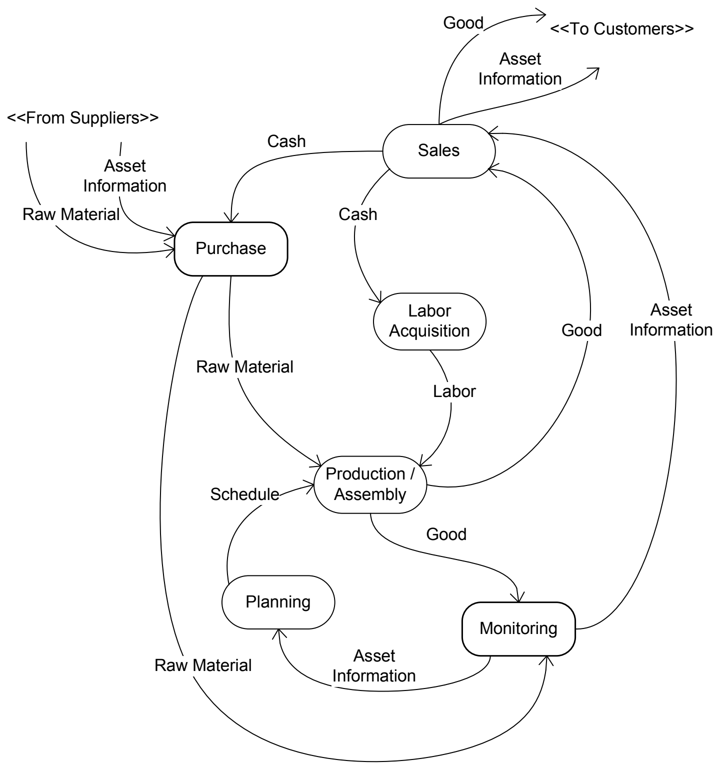

Figure 1.7: Value chain of the manufacturer

Manufacturer: The manufacturer's value chain is illustrated in Figure 1.7. Its main business processes are *planning*, *asset management* through asset monitoring, *purchase* of raw materials from suppliers, *production* or *assembling* of these raw materials, *employee management* through labor acquisition, and *sales*. Manufacturers acquire raw materials from suppliers. As their customers can be other manufacturers, wholesalers or retailers, they then transform the acquired raw materials into (intermediate) goods or finished products. Besides the selling of manufactured goods, manufacturers can also require various asset information for their daily activities or supply (or sell) it to their customers.

Logistics provider: Figure 1.8 represents the value chain of a logistics provider. Its main business processes are *transport planning*, *asset management* through asset monitoring, the *transport* of the goods itself, *employee management* through labor acquisition, and *selling* its transportation services. The transportation services offered by logistic providers can in general be traded for cash by all stakeholders, which is also illustrated in Figure 1.2 in Section 1.3.1.

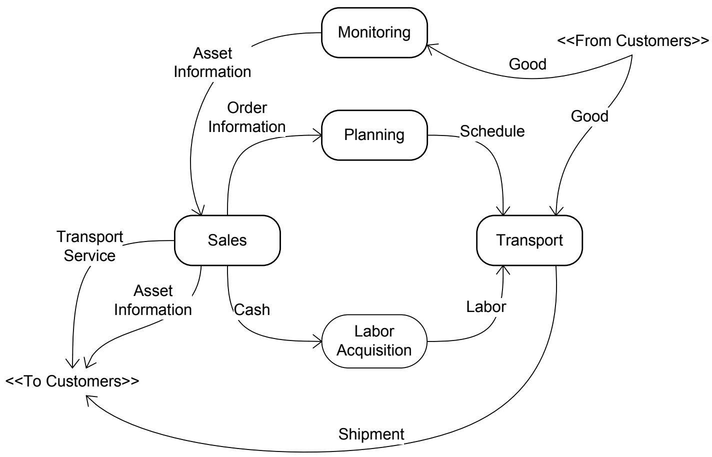

Figure 1.8: Value chain of the logistics provider

Wholesaler: The wholesaler's value chain is illustrated in Figure 1.9. Its main business processes are *acquisition* of products through shipments, *selling* products, and *asset management* through product monitoring. Wholesalers receive their products through contracted logistics providers, from whom they can demand asset information concerning their orders' shipments.

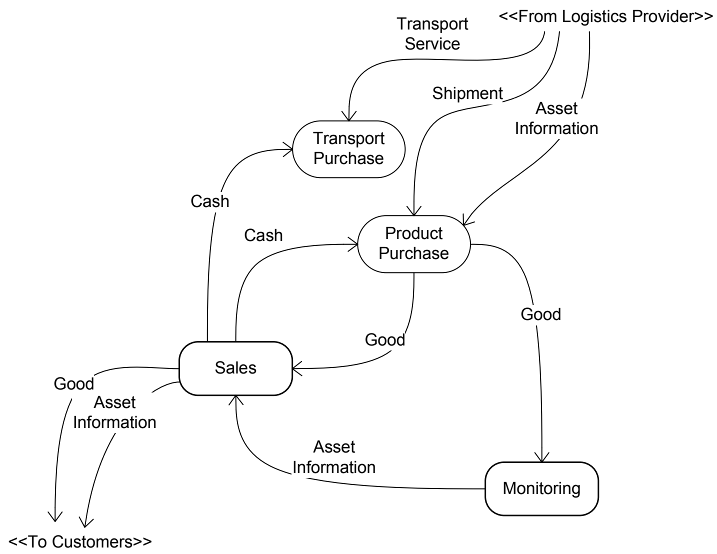

Figure 1.9: Value chain of the wholesaler

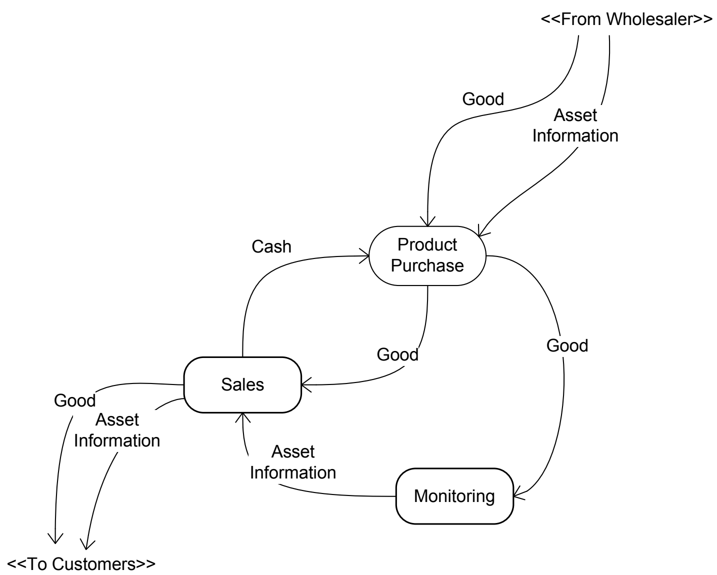

Figure 1.10: Value chain of the retailer

Retailer: Finally, Figure 1.10 represents the retailer's business processes. These include *acquiring* and *selling* products, and *asset management* through product monitoring. Retailers acquire their products mainly from wholesalers by using own means or through the services offered by logistic providers. As the latter is similar as the requested transportation service from wholesalers to logistics providers, it is not taken into account in Figure 1.10.

Although, all supply chain stakeholder's primary business processes [12, 11] are illustrated in the above figures, each of these stakeholder also has secondary business processes like human resource management, research and development, and management of enterprise infrastructure. All figures do not illustrate the marketing process of a stakeholder explicitly, as this process generally falls under the main category of sales.

Value chain network of the entire supply chain

The value chain network of the entire supply chain is represented in Figure 1.11. It shows the coupling of each stakeholder's value chain into one common network.

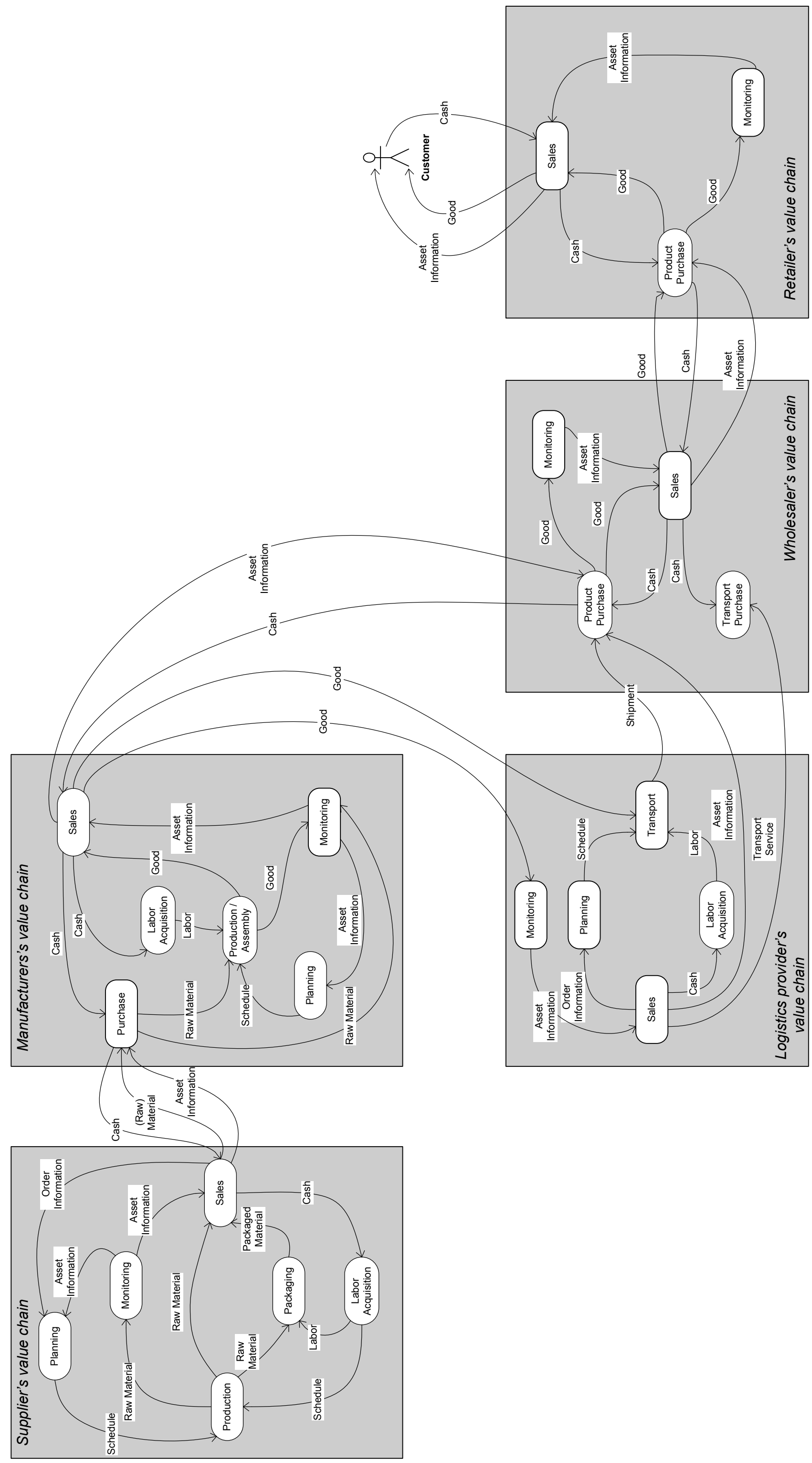

Figure 1.11: The value chain network of the supply chain

1.5 Solutions for automated supply chain management

Why does the supply chain need an automated solution with intelligent packings? The main answer to this question is twofold: (i) to reduce logistic and operational costs for the enterprise, and (ii) to achieve a better relation with the business partners and customers by offering visibility along the chain and thus achieving quality standards and trust. These two are critical success factors which are needed for an enterprise in order to achieve competitive advantage.

As explained in Section 1.1, supply chain management through intelligent packings offer the possibility to achieve real-time visibility to the goods and products throughout the chain. It's thus possible to detect inferior or track and trace the different goods throughout the supply chain. Fraud and theft detection is made more easy and effective through the automatic monitoring of the product and the immediate reporting to the responsible persons. Intelligent packings offer opportunities for all stakeholders, in order to improve their daily operations. These packings allow the capturing of information throughout the entire logistic chain. Based on that information, any stakeholder can monitor its assets of interest and dynamically adapt its decisions according to the perceived data.

However, automating the supply chain introduces difficulties and problems. Ethical problems such as the consumer's privacy are an important issue, but they are not handled in this report. Problems of a more technical nature are explained in the following paragraphs.

Standardization may serve as a representative example of a problem in the applicability of these intelligent packings. Communication through one standard allows different players to transparently share information with each other and to synchronize each other's business processes. However, in a realistic business context, standardization is not always possible. Therefore, translations between different standards need to happen.

Infrastructure is a second important factor. Each stakeholder has to invest in some infrastructure. This means that one supplier is able to provide information about the quality of origin through its infrastructure, while some stakeholders further along the good's flow chain do not possess the required infrastructure to assure the quality of transport and origin. This may lead to some serious product differentiations and competitive advantages of certain parties in the market. These high-tech enabled stakeholders may together form a network of enterprises with certain quality labels, regarding their capabilities of automatic good's monitoring.

Security is another important issue. It might not be possible for an outsider to retrieve or tamper with information about the goods inside a packing. In order to prevent this espionage or possibly more worse consequences such as the theft of valuable goods, or fraud with goods concerning, for instance, the quality of origin, the intelligent packings must provide some security mechanism.

1.5.1 Classical solution: Bar codes

In the classical solution goods are provided with external identifiers such as serial number plates, instruction labels, shipping and packaging labels, company logos, decals, fleet wraps, bar code labels, and other forms of product identification labels. Bar code labels on each good can provide a more automated solution, but they still require a manual intervention of the good's handling staff to be processed.

1.5.2 Current innovations: RFID-tags

Eventually the bar codes of the goods can be extended or replaced with RFID-tags, which are sometimes in the logistics context called Smart Labels [6]. Those ‘Smart Labels’ allow the retention of bar code label information in popular formats while adding RFID. They combine together the human-readable text of the identifier and the electronic data for the RFID. In this case, the supply chain processes can be automated by using automatic scanners at the entrance of storage depots or logistic hubs. RFID can be divided into two categories, namely passive RFID-tags and active RFID-tags. Passive tags are not battery powered and gain energy by the electric field of a nearby scanner. Active tags are (battery) powered and can therefore broadcast their identification in a very limited range. Also, RFID-tags are generally not equipped with sensors, which makes them only useful for offering identification information.

This RFID-based solution seems very promising, but it still has many drawbacks because the management of the goods is not fully automated yet. Some of the main drawbacks are:

- When using a non-electronic external identifier marked on the good, everything must be kept up-to-date manually in the system. In the case of bar codes, there must be a straight line of sight to the reader, if this is not the case, a manual intervention is needed.
- Inventory and information management can be automated by using (active) RFID, however this solution is dependent on the limited communication range of the RFID-tags or scanners.
- Asset or event monitoring is very difficult or not possible. This is especially true for events that require an immediate attention from a user, like the unauthorized opening of a container door, or other types of events that are not registered in the IT-system, such as the movement of the good to another location.
- The confidentiality of the data contained in the RFID-tag or marked by the external identifier is not guaranteed to be safe. One major challenge in securing RFID tags is the shortage of computational resources within the tag [10, 9].

1.5.3 Wireless sensor and actuator networks

Wireless sensor and actuator networks [5] can be used to collect or offer data to interested and authorized users. This can all be done in real-time, thus achieving real-time visibility and asset monitoring of goods along the supply chain.

Besides offering enhanced real-time visibility through sensing of the environment, one of the main advantages of using of wireless sensor networks in the supply chain is that they are able to perform mesh networking. This means that they do not suffer from a limited communication range as RFID-tags do suffer from. A second advantage is that sensor nodes have some processing and storage capabilities, and thus, when compared to RFID-tags, one can put more application ‘intelligence’ inside them. The node’s storage capabilities in combination with mesh networking offer a solution for the limited communication and computation capabilities of RFID-tags. The opportunity to provide more intelligence inside the supply chain itself, provides the advantage that one can react faster and anticipate to certain events. This means, for instance, that in a cooled container the temperature can be continuously monitored and compared to a given threshold. When the temperature exceeds the threshold, the sensor node can decide to turn on the cooler and eventually inform the responsible persons. Other scenarios include localization where the nodes locate themselves without any external intervention, and asset recording where the nodes record all events and asset information. Extending the supply chain with these intelligent sensor nodes allows one to anticipate on the dynamism of the chain.

However, there exist drawbacks in the use of wireless sensor networks for supply chain management. Although since the nodes do have some computational resources, they remain limited, similar as their energy supplies. It may also not possible to integrate them seamlessly into the supply chain as expected, since numerous hardware designs and protocols are yet available for sensor nodes. As a consequence, this results in sensor networks which consist of highly heterogeneous devices which therefore makes a full seamless integration into the supply chain a complicated process. Also, given the amount of transported goods, the sensor network approach will rapidly evolve towards a ultra large-scale infrastructure, which requires easy and efficient management.

Finally, one should not be blind for the current RFID-solutions for supply chain management [14, 13], but extending this solution with intelligent sensor nodes is currently a more realistic solution, then relying on only sensor networks for supply chain management.

1.5.4 Towards an intelligent communication platform

Current supply chain logistics may thus benefit from using a heterogeneous combination of RFID-tags and wireless sensor and actuator nodes, both placed at goods and/or infrastructure. However, given this extremely heterogeneous and largely extended combination of different devices and technology, one may require some standardization of the underlying communication platform. Secondly, given the huge range of possible applications that may benefit from the use of these networked devices, there must be some kind of uniform, easy to use platform that offers basic support for life cycle management of its installed applications. This platform should be deployed in an end-to-end fashion on the tiny sensors, some more general purpose infrastructure like RFID-scanners, intermediate nodes for data processing, and on enterprise back-end infrastructure like application servers and end-user devices. More details about such an end-to-end communication platform are described in the next section.

1.6 An end-to-end communication platform for supply chain management

The application domain for building a communication platform for supply chain management support is faced with a lot of different requirements and challenges. Due to the natural complexity of the supply chain, with many different stakeholders, enterprises and actors, a generic solution must be sought that extends the classical solutions with real-time visibility and asset monitoring. The all-in-one solution is the placement of smart devices on the goods which monitor their assets. This approach achieves more real-time visibility and asset monitoring inside the supply chain.

Basically, the communication platform for supply chain management will be enhanced with real-time information coming from goods to support their activities. This information should be integrated in the various business processes from the associated stakeholders. It must also be possible for stakeholders to retrieve additional information from the system concerning a particular good, wherever the good could be located physically.

This section describes the requirements for building such an end-to-end communication platform for supply chain management. This platform will be deployed in a two-dimensional end-to-end fashion: (a) on various infrastructure like sensors attached to goods, user devices, and back-end systems, and (b) between all involved stakeholders (suppliers, manufacturers, logistics providers, . . .). Figure 1.12 illustrates both end-to-end aspects. There is a horizontal end-to-end aspect, where stakeholders exchange information with each other. This is needed to better streamline their business processes to each other.

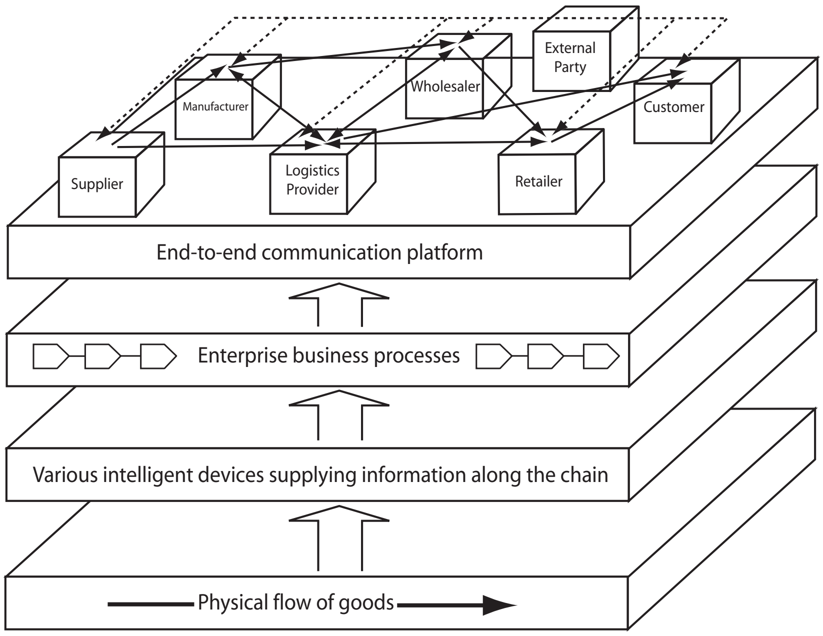

Figure 1.12: The communication platform for supply chain management

1.6.1 General requirements and challenges

Since enterprises in the logistics domain all vary in size, location, corporate policy and total budget, each enterprise will rely on an different heterogeneous combination of devices and networks. This infrastructure may thus contain different RFID-tags and readers, wireless sensor nodes attached to products, wired and wireless gateways, general purpose nodes for site security or monitoring conditions, and back-end systems like powerful application servers and user consoles, running the enterprise's key business processes.
Due to these variations in infrastructure, various challenges arise. The entire platform can be treated as a complex distributed software system, composed of different individual systems. Figure 1.13 illustrates a representative example of the platform equipped with different services and consisting of geographically dispersed systems and stakeholders. In this figure, an inventory management application for a logistics enterprise, e.g. relies on a heterogeneous combination of devices and networks: (1) a fixed network of powerful enterprise resource planning servers in the back-end, (2) wireless gateways such as WiFi-hotspots distributed

over multiple warehouses, trucks, and trailers, and (3) many thousands of various kinds of programmable sensor nodes attached to products or containers for collecting data on temperature, humidity, or location. Different users, including the logistics' enterprise employees and home-users, can then retrieve these values in order to get a full trace of their products during transport.

Two main challenges complicate the development, use, and management of these sensor applications. These challenges include (a) the heterogeneity of the environment, and (b) the dynamism of the operational environment.

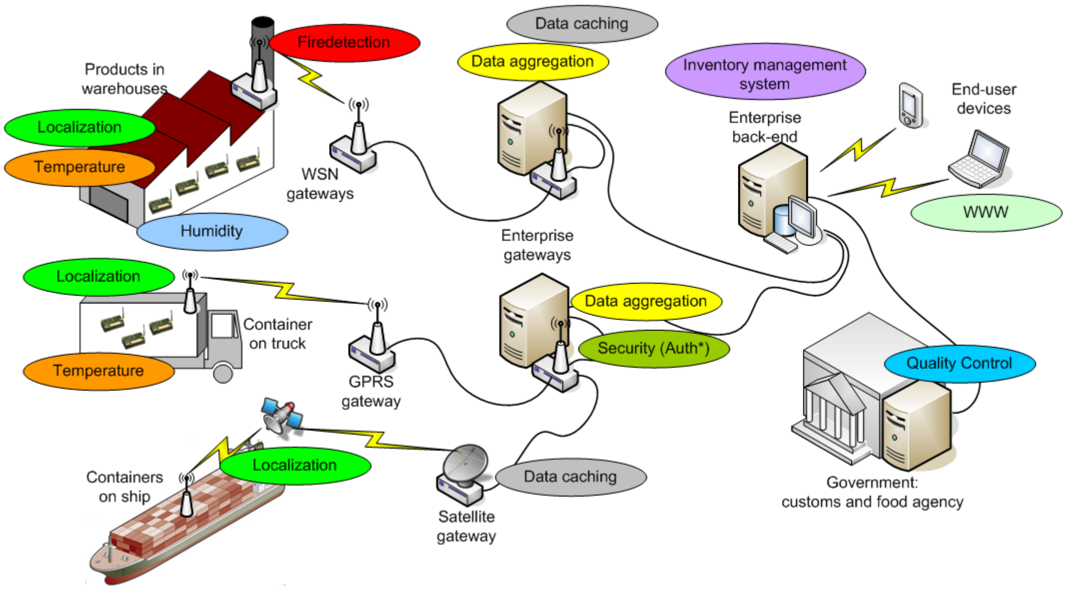

Figure 1.13: The communication platform for supply chain management running different collaborating applications.

Heterogeneity is a complex key challenge to deal with when building distributed software systems, especially in the context of sensor networks as it mainly complicates uniform management. Heterogeneity exists at multiple levels: (i) resource and network heterogeneity, (ii) heterogeneity in posed requirements, and (iii) platform heterogeneity. From a software perspective, modularization is an excellent approach to deal with these different kinds of heterogeneity, as it allows one to customize the software being installed on the different infrastructural components and under different application scenarios.

In the context of supply chain logistics, resource heterogeneity is very common as there are many different types of devices involved, ranging from simple wireless sensor nodes, gateway nodes, employees' PDAs towards powerful application servers. Heterogeneity in network types is also common since sensor nodes communicate with each other using low bandwidth radio communication (ZigBee), while PDAs and gateways or access points may use WiFi, and application servers in general use high-speed network connections. Requirements can be heterogeneous as well, as they may be related to quality-of-service (QoS) or quality-of-data (QoD), security, performance, etc. Finally, besides sensor networks, other kinds of distributed systems, such as P2P networks or grid infrastructures for data processing, may as well be involved in the context of distributed industrial applications, resulting in a wide heterogeneity in computing platforms.

Dynamism The operational environment of large-scale distributed systems is subject to changes in time. To deal with this dynamism, distributed applications should be developed using reusable components. This approach allows one to easily replace individual components. Together with this component-oriented approach and by implementing coordination mechanisms, one can achieve consistent system and platform-wide adaptations.

In realistic distributed applications, dynamic changes happen due to, for instance, the changing of end-users' requirements, network or device failures. This dynamism may have influence on the installed applications and services. Not only existing functionality can therefore alter or be removed, also new functionality could be required to be installed. This adaptation of functionality and behavior of distributed sensor applications is not without any risk. First, one must take care that existing applications can be broken if an installed component is modified, disabled or completely removed. Second, safe distributed reconfigurations are difficult to achieve in sensor networks mainly through resource limitations, unreliable communication, and the huge amount of involved devices.

1.6.2 Specific process requirements and challenges

Besides the physical distribution of the goods from one stakeholder to another, the platform should provide significant support to couple and streamline the relevant business processes of each involved stakeholder to each other. As illustrated in Figure 1.12, this perspective is represented in the horizontal end-to-end dimension.

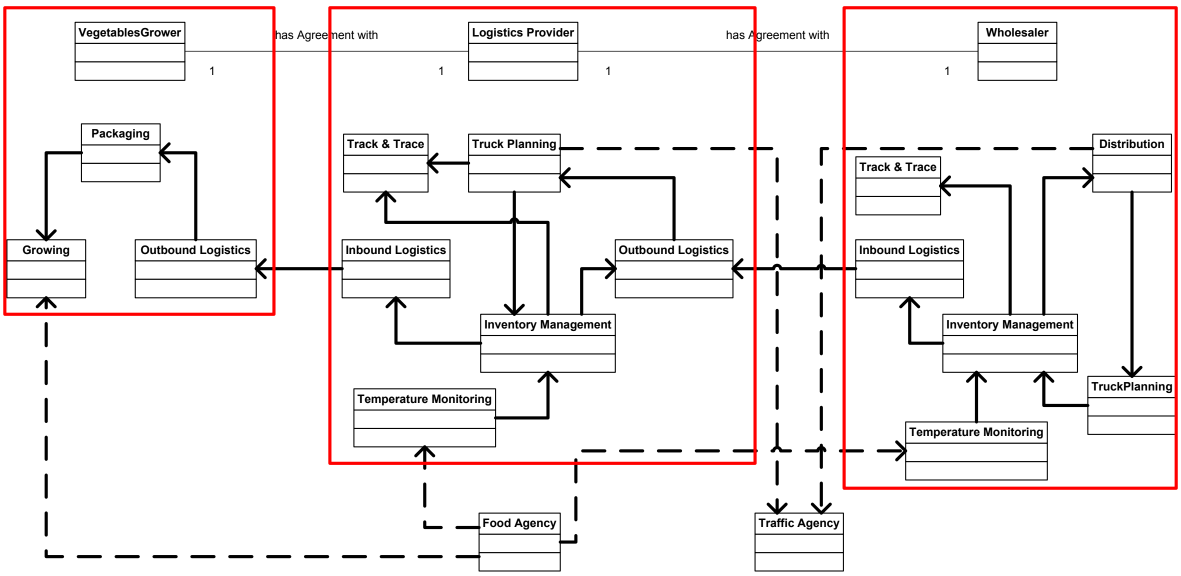

Figure 1.14: High level overview of business process dependencies

In order to execute its task, a business process has information requirements and dependencies w.r.t. other business processes. These processes could possibly be inter-enterprise and thus inter-enterprise information exchange is very crucial. This exchange of information requires the translation of possibly different data formats from each stakeholder, but it requires also that the APIs of both involved processes are mapped to each other. Besides this translation, the platform is also responsible to ensure that high-level service agreements between two parties are checked and enforced. However, the coupling is not limited to stationary coupling of processes. The logistics domain is very price-sensitive, therefore stakeholders often differentiate their prices and offered services. The platform should therefore provide support for dynamic coupling of business processes..

Figure 1.14 represents the network of business processes, with three individual stakeholders. Each stakeholder's activities are bounded to the red rectangles. In this example case, a vegetables supplier delivers its products through a logistics provider to a wholesaler. The suppliers' business activities are mainly manual labor, like the growing and packaging of the vegetables. They could also be the registering of its products going through outbound logistics. The figure also illustrates the dynamic coupling of processes, where, for instance, the wholesaler could decide, based on a price comparison, to switch between different logistic providers. However, this wholesaler still desires certain information concerning the conditions of transport of its purchased goods. The wholesaler should therefore only have to indicate to change the dependencies of some of its processes, while the data transformation then can happen automatically.

1.6.3 Non-functional requirements

The following requirements are the non-functional requirements for a communication platform to automate supply chain management:

Scalability

Realistic distributed sensor applications typically consist of a huge amount of devices, crossing system administration and enterprise boundaries. As a result of this large-scale deployment, manual management of all devices is considered infeasible as it is cost-inefficient and often error-prone. High-level policy interpretation and distributed coordination mechanisms can provide a solution to perform safe and efficient automated management.

The system should be scalable in at least two dimensions. Every good in the supply chain could be equipped by a sensor node or a tag, this means that the system should be scalable for usage with huge amounts of goods. Secondly, the system should be scalable to various entities and parties along the supply chain. This means that possibly multiple parties can join and leave the chain and that they all require an information exchange between each other.

Since many logistics companies may ship millions of tons of goods annually, this has implications on the distributed system which must be scalable enough to handle these amounts of goods. Since scalability is strongly coupled with management, one must therefore assure that the overall system behavior is stable and remains manageable. Manual management is often error-prone and cost-inefficient. Therefore, an automated management solution, based on policy interpretation and distributed coordination mechanisms, may provide the network administrator a uniform approach to manage all devices and installed applications in a safe and coordinated manner.

Adaptability

The system should be adaptable to various customer needs, goods and assets. Since SLAs are very important between two enterprises, they must also be considered. This could possibly involve an adaptation of the software running on their systems. Since the supply chain consists of numerous goods, all attached with programmable nodes, this adaptation process could be very labor intensive and costly. The system should be therefore able to adapt or reconfigure itself under varying circumstances.

Interoperability

As the supply chain handles goods coming from different stakeholders, one must assure that all involved devices are inter operable with each other. The same holds true for the software installed on all devices. This software may require communication paradigms such as RPC, tuple space abstractions, or specialized routing algorithms. Requiring all paradigms to be installed on all involved devices beforehand is simply impossible (as the intelligent goods can come from different stakeholders). Therefore, it must be possible to install the needed communication paradigms on the fly or translate different paradigms into each other, whenever an application requires it.

Usability: precision

The system should always return the most precise and up-to-date information in order to generate the maximal business value. The required precision could be stated in various agreements between different parties.

Usability: Delay

The end-to-end delay is important for such applications. The amount of delay for a lookup is a good indicator for the offered Quality of Service. The reducing of this amount by using intermediate caching solutions seems very feasible for a complex network of entities and relationships like the supply chain.

Reliability: Failure resistant

The system should be protected against failures, since they could possibly impose problems in the coordination of the business processes active in the supply chain. There could be the policy that the system should timestamp all its captured information and thus information that's newer than a given threshold is still considered relevant and valid.

Security and privacy

Security of the communication platform is important in industrial deployments. It is undesired that unauthenticated and/or unauthorized users retrieve data or alter the platform's configuration by installing or removing services. Therefore, the platform and its data must be secured to prevent misuse of it.

1.6.4 Domain model of the platform

The domain model of the supply chain, illustrated in 1.15, describes in a more elaborated manner the problem domain. It includes the concepts of goods, assets, asset monitoring devices such as RFID-tags and sensor nodes. The figure illustrates the three parts of the model: an infrastructural part, a communication part, and a enterprise part.

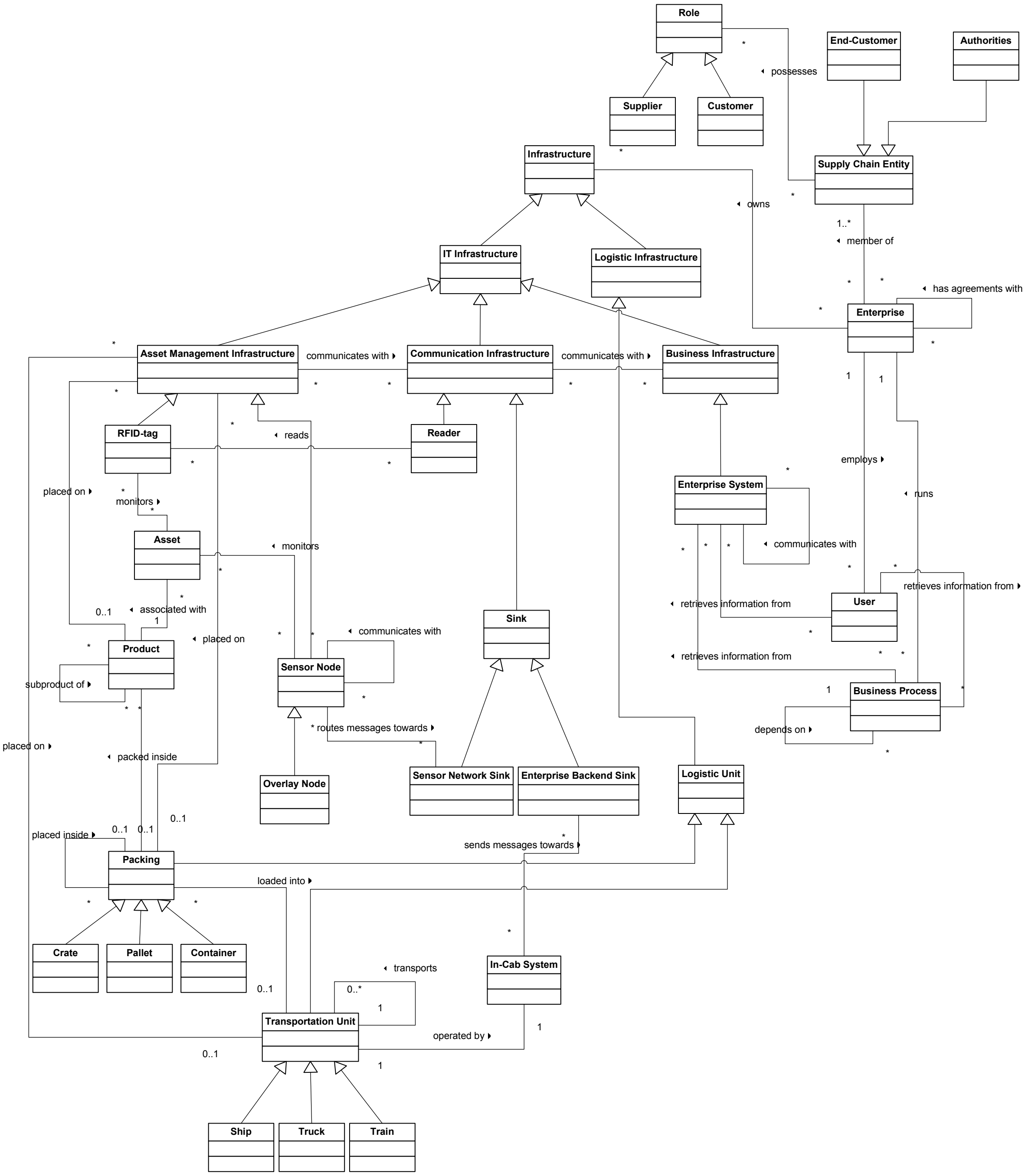

Figure 1.15: The problem domain of intelligent supply chain logistics

The infrastructural part of the communication platform at each stakeholder can be divided into at least three parts. The first part includes the cheap low level devices, responsible for the goods' asset monitoring and registration. These devices communicate with a more sophisticated part, namely all communication infrastructure. The communication infrastructure includes all devices responsible for data aggregation coming from the asset monitoring devices. The third part includes all business infrastructure where the enterprise's business processes reside on.

1.7 Supported scenarios of multimodal transportation

This section describes some basic scenarios of multimodal transportation that are supported by the platform. These scenarios can be used as basic cases to illustrate the requirements and operation for the underlying communication platform, and eventually to test and validate the architecture of the entire supply chain management system.

1.7.1 Life cycle of a good

The life cycle of the good, illustrated in Figure 1.16, starts with the producing of the good from various raw materials. It is often wanted, especially in the food industry, that one can trace the origin of the food. This could mean that one places smart devices (e.g. sensor nodes) on each good part or crate at the supplier. During the processing and transport of the goods, one is often interested in the good's history and quality assets. For instance, how can a fruit and vegetables logistics provider assure its customers that the transported goods were always cooled below a certain temperature or that the goods were always handled with care, i.e. no shocks during transport or transported by the best logistics providers.

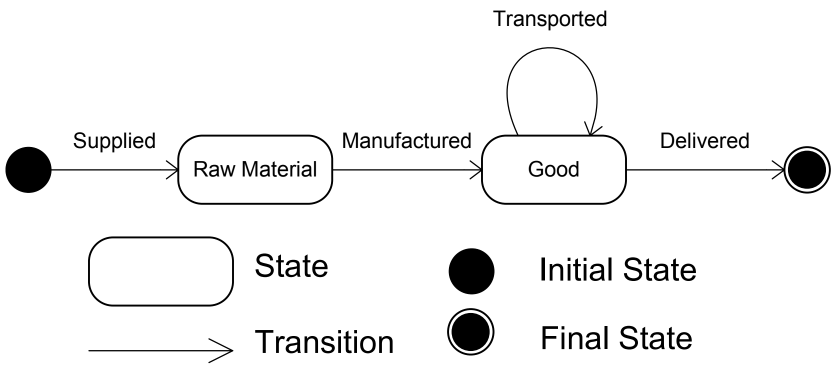

Figure 1.16: The life cycle of a good.

Key issues throughout the life cycle of the good are the following:

1. *Information representation:* How does one represent the information stored in the tag or sensor node attached on the good.
2. *Information access:* Which player is allowed access to the information stored on the tag, sensor node or in the enterprise systems.
3. *Information retrieval:* How will the information stored in the supply chain system be retrieved.

4. *Security (authentication/authorization):* How to enforce the (corporate) security policies along the supply chain.

5. *Asset monitoring:* What needs to be monitored throughout the chain? At what granularity and quality does it need to be monitored? How accurate should the stored information be (e.g. real-time information retrieval)? Should it be possible to retrieve real-time information or more cached information, or is a hybrid solution also possible?

6. *Information responsibility:* (i) Who is responsible for already stored and sensed information. (ii) Where will that information be stored? Will it be inside the network on the storage sites or will it be completely in the enterprises back-end? Or is a hybrid solution possible?

1.7.2 Production of goods

The key stakeholder in this scenario is the *manufacturer*, who is responsible for transforming raw materials into products. The manufacturer receives its raw supplies from one or possibly more suppliers, places these supplies inside the stock and eventually constructs new goods from these supplies.

The delivery of supplies from a supplier to manufacturer can possibly be done by an external logistics provider, contracted with the supplier and/or manufacturer, the supplier can deliver the goods himself or the manufacturer can own and exploit his transportation units to pick these himself.

In the first case, the external manufacturer must be informed that another shipment of raw materials/goods will shortly arrive at the factory. This implies that they must agree on a common data representation and communication protocol. In the second case, a common company-wide standard for information representation and retrieval is suitable. This standard is integrated in the corporate policy. Another issue is that in some cases the origin of the supplied goods must be verifiable and be kept in the system. An end-customer or the government can, for instance, be interested in these data.

1.7.3 Storing of goods

There will typical be different stakeholders and actors involved in the storage of the goods on a storage site or depot. The government or external security companies are especially interested in the goods stored on their territory or depot, and thus it must be possible to transfer this information to them.

Some goods possess assets that indicate how the good should be handled. For instance, certain goods need to be handled with special care or under certain conditions, e.g. dangerous goods or goods suitable for human consumption. This information must be kept inside the system, and these assets must be continuously monitored. The handling stakeholder thus requires real-time information coming from the intelligent devices. He may explicitly demand this information or the devices may automatically supply this information to the stakeholder.

1.7.4 Transportation of goods

There are different combinations of transportation possible: for instance, goods packed in crates on pallets and shipped in containers. Each container is loaded on a truck which is transported by a train or ship. Each involved stakeholder wants the same or possibly different information, and not all information can be given to the other parties, possibly due to privacy reasons and corporate security policies.

Since sensing and communication by the sensor nodes are the greatest energy consumers, this information should be retrieved only few times, or depending on the agreement between stakeholders more frequently. The location where this information will be stored is also important. The information could be stored on the sensor nodes closely to the good or perhaps logged in a database. Storing information closely to the good could mean that the information could be stored on a pallet level, on the container level, on the transportation unit's system.

Since the good's owner is interested in the location and assets of his/her goods, the owner should contact the responsible entity. If the ship itself takes care of the communication with the mainland, the good's owner should contact the shipping company or he/she should contact its logistics provider. The first case where the owner should personally contact the shipping company seems unrealistic, thus the second case where the logistics provider relays the asset information query is more feasible. Whenever the ship arrives at a harbor and the truck leaves the ship, the truck then is responsible for the communication with the owning logistics provider and end-customer. This indicates that it must be possible to relay the communication between different entities.

1.7.5 Retailing of goods

Currently, as discussions with experts in the field of supply chain logistics indicate, retailers are not a demanding party for intelligent packings. They see those packings as an extra costs that will be payed by the end-customer. However, retailers can benefit from providing goods with intelligent devices. Especially when selling goods suitable for human consumption, the prove of origin and asset quality of goods are very important factors, also for retailers. For instance, small retailers often do not have a large turnover, which may therefore result in goods that become out-dated. This could be fined by the authorities or ordinary customers can sue the retailer. Whenever the retailer chooses for an automated inventory management system, with goods which are kept inside the database and removed whenever a customer purchases them, the retailer can more easily keep track of those out-dated goods in its store.

1.7.6 Delivery of goods

In this scenario, it should generally not be possible for a former stakeholder to further retrieve data from the delivered goods to the succeeding entity. The retrieval of this data might be in violation with the privacy legislations. There exists a real life case (Metro Group, Germany [2]) scenario, where the RFID-tags are made unusable (unreadable), once the customer leaves a warehouse.

1.8 Glossary

Actor. *Actors* are the users that interact with the system. They want to use the system to accomplish a certain goal. The scenario leading to such a goal is described in a *use case*.

Asset. An asset is a property of interest of the good which is relevant for the handling stakeholders. Examples of a good's assets are the physical factors like temperature or humidity of the good, the good's current location and destination, the real value, priority, type or owner of the good.

Logistic hub. A *logistic hub* is solid infrastructure, such as a building, warehouse, or storage site, that accepts incoming goods, possibly performs some processing on them, and dispatches them, according to a well-defined transportation scheme, towards another logistic hub.

Logistic unit. A *logistic unit* is a movable, e.g. a crate, pallet, container, or a mobile entity, e.g. a cart, truck, ship, train, that can be equipped with a programmable wireless node.

RFID. An RFID tag is an object that can be applied to or incorporated into a product, animal, or person for the purpose of identification using radiowaves. Some tags can be read from several meters away and beyond the line of sight of the reader [3].

Role. A *stakeholder* can possess some roles that describe the additional behavior, responsibilities and actions the stakeholder can take.

Stakeholder. A *stakeholder* represents an entity like an enterprise that is involved in the intelligent platform. This entity has a number of functional expectations of the platform to accomplish its business goals. A *stakeholder* consists of a number of *actors*.

Supply chain management. Supply chain management is a cross-functional inter-enterprise system that uses infor- mation technology to help support and manage the links between some of a company's key business processes and those of its suppliers, customers, and business partners.

Wireless sensor network. Recent advances in micro-electro-mechanical systems (MEMS) technology, wireless communications, and digital electronics have enabled the development of low-cost, low-power, multi functional sensor nodes that are small in size and communicate untethered in short distances. These tiny sensor nodes, which consist of sensing, data processing, and communicating components, leverage the idea of sensor networks based on collaborative effort of a large number of nodes [5].

Chapter 2

Software analysis

This chapter presents the software analysis for a middleware platform, supporting distributed sensor applications, mainly in the context of supply chain logistics. First, the different stakeholders, involved in the development, management and usage of the software platform are categorized into four groups. Secondly, the different functional and non-functional requirements that arise in the development and management of these distributed applications are described. Thirdly, a domain analysis and context view is given for each of these these involved stakeholders. Finally, a concluding glossary, reflecting on the used terminology and described concepts, is included.

2.1 Stakeholders

This section divides the involved stakeholders into four categories. First, there exist technology providers who provide the core technology and system software for the underlying middleware platform. This middleware platform should provide the necessary support for the requirements of a second category of stakeholders, namely the end-user's category. These end-users are interested in the information and functionality, offered by the distributed sensor applications running on top of this middleware platform. Thirdly, platform providers are responsible for the platform's proper installation, configuration and functioning. Finally, integrators are responsible for the writing of application-specific plug-ins and their coupling into one or more end-to-end distributed applications residing on the middleware platform.

2.1.1 Technology providers and specialists

Technology providers are the category of stakeholders who deliver high-tech hardware and out of the box implementations of core algorithms to construct the communication platform. Their delivered technology involves, for instance, highly energy-efficient programmable sensing devices, RFID-tags, RFID-scanners, wireless access points, application servers or portable notebook devices. They may, as technology specialists, also provide highly complex, but optimized, domain-specific services such as an efficient implementation of a wireless mesh routing algorithm, accurate localization, or security primitives to allow, for instance, encrypted communication between sensor devices.

2.1.2 End-users

In the context of supply chain logistics, end-users belong to the identified business players from Section 1.3. They include suppliers, manufacturers, logistics providers, wholesalers, retailers, end-customers, or related enterprises or organizations. These users may be interested in the functionality and information offered by the communication platform for several reasons. For instance, this information may result in a better coordination of their daily business activities, like the establishment of a better visibility on stock quantities or inefficiencies in production processes, thus increasing revenues and decreasing costs. These benefits are not only limited to operational benefits, they can also be of a strategic nature, where the customer is given visibility into the functioning of the enterprise and the status or quality of its purchased products. This customer-oriented approach and the establishment of a better customer trust relation, as described in Section 1.1, may help the enterprise to gain an important competitive advantage over others.

2.1.3 Platform providers

Platform providers provide the core software components of the middleware platform, its APIs, its configuration, and possibly some basic services that enable business application developers to optimally exploit the capabilities of the underlying programmable networked devices. These core components form a subsystem of the platform that should support the interconnection of all involved hardware platforms and should provide advanced management support for each of these architectures. This management support enables network managers to achieve certain quality requirements, like availability or security, by introducing, for instance, intermediate data caching or advanced security services inside the infrastructure.

2.1.4 Integrators

Integrators develop complete end-to-end applications by means of implementing application-specific services and combining the functionality that is offered by basic services. Integrators require a set of APIs, given by platform providers, to be able to deploy their complete applications on the underlying middleware platform.

2.2 Functional requirements

The functional requirements for the intelligent platform for supply chain logistics can be divided into two parts. The first part contains the requirements one expects from the middleware platform itself, namely the *platform requirements.* The second part is related to the *application functionality* one may expect from representative distributed sensor applications for supply chain logistics, using the intelligent platform.

2.2.1 Platform requirements

Platform requirements represent the functionality one may expect from the middleware platform. These requirements are related to the following three categories stakeholders, who are involved in the platform's development and management, or in its corresponding application or service development and deployment. These stakeholders are the (i) technology specialists, (ii) platform providers, and (iii) integrators.

Deployment support. Deployment support involves support for life-cycle management of the installed functionality. This life-cycle management is crucial for the platform, since it involves the installation of new and additional functionality, its configuration, replacement, and removal. Software developers may as well be given an API to use (some) of this life-cycle management support, as possibly required by their application.

Configuration support: Configuration support involves the tuning of the platform to meet certain qualities. Since the platform may serve several concurrent applications, qualities should be adjustable for each application.

Uniform resource access. Software developers need an easy and uniform (standardized) access to the different available hardware components, such as the radio or available sensor and actuators, of the underlying device platform. Information about the availability of these resources must be retrievable, while undefined resource access must be caught preventively by the platform. This uniform resource access allows developers to program their applications in a well-defined and platform-independent manner.

2.2.2 Application-specific requirements for supply chain logistics

Concrete end-user requirements are generally translated by integrators into complete end-to-end applications, which are then distributed on a variety of devices ranging from small resource-constrained programmable sensor nodes placed on goods, possibly on some fixed infrastructure in warehouses, and towards high-end application servers or portable end-user devices. These integrators should analyze the end-user's requirements and translate them into a composition of suitable software components. This composition involves the writing of new application-specific services, or the using and combining of basic services, offered by technology specialists, or more advanced services, offered by platform providers or third party software providers. Further, integrators must also be able to guarantee certain quality requirements as e.g. Quality of Information (accuracy and freshness of data), or scalability metrics (the maximum number of nodes in the environment) the end-user's application requires. In the context of the intelligent supply chain management platform, many examples of these complex end-to-end applications depend on similar quality metrics and functionality or information offered by many of these application-specific plug-ins or services.

Many applications for supply chain logistics depend on services that offer information like the *location* of the programmable node and the *environmental conditions* of the product attached to the node. In intelligent supply chain logistics, the following applications may thus serve as representative examples:

(a) An *inventory management application* monitoring the current quantities and location of each individual item inside a warehouse. This application requires a localization and identification service running on the programmable node attached to each involved item. The application, containing the intelligent about inventory management, may be deployed on the enterprise back-end application server, while operators and factory workers may have graphical front-end for this application, displaying the current location and quantities of each product in the warehouse.

(b) A *transport planning system* using the actual location of trucks and containers to calculate a suitable transportation plan. This application requires an identification and localization service deployed on each logistic unit such as a containers or trucks. An additional condition monitoring service running on the containers can also provide valuable information about the current conditions of the transported product, and can possibly influence the planning of the route and subsequent handling of the cargo at an intermediate logistic hub.

(c) An *asset and building management application* using information about the type of the stored goods in a warehouse. This application involves diverse monitoring services installed on several infrastructural components. This sensor data can then processed and interpreted by a central building management system and displayed to a responsible actor. Based on the processing outcome, such a system can, for instance, control the building's airco application, detect intruders and signal inappropriate placed goods in the warehouse to the responsible operator.

2.2.3 Concrete use cases

First, the *platform-specific* use cases are given, then the *application-specific* use cases for supply chain logistics are given.

Platform-specific use cases:

Use case 01: Install new functionality
See Use case 01 in A.1.1

Use case 02: Remove existing functionality
See Use case 02 in A.1.2

Use case 03: Alter existing functionality
See Use case 03 in A.1.3

Use case 04: Configure platform
See Use case 04 in A.1.4

Application-specific use cases for supply chain logistics:

Use case 05: Manage inventory
See Use case 05 in A.2.1

Use case 06: Plan transport
See Use case 06 in A.2.2

Use case 07: Manage assets and buildings
See Use case 07 in A.2.3

2.2.4 Use case diagram

The use case diagram shows the relationship between the system's stakeholders, its use cases and their inter-relation. This use case diagram is illustrated in Figure 2.1, and includes both the four platform-related use cases, as well as the three use cases for representative end-to-end supply chain applications, as described in Section 2.2.2.

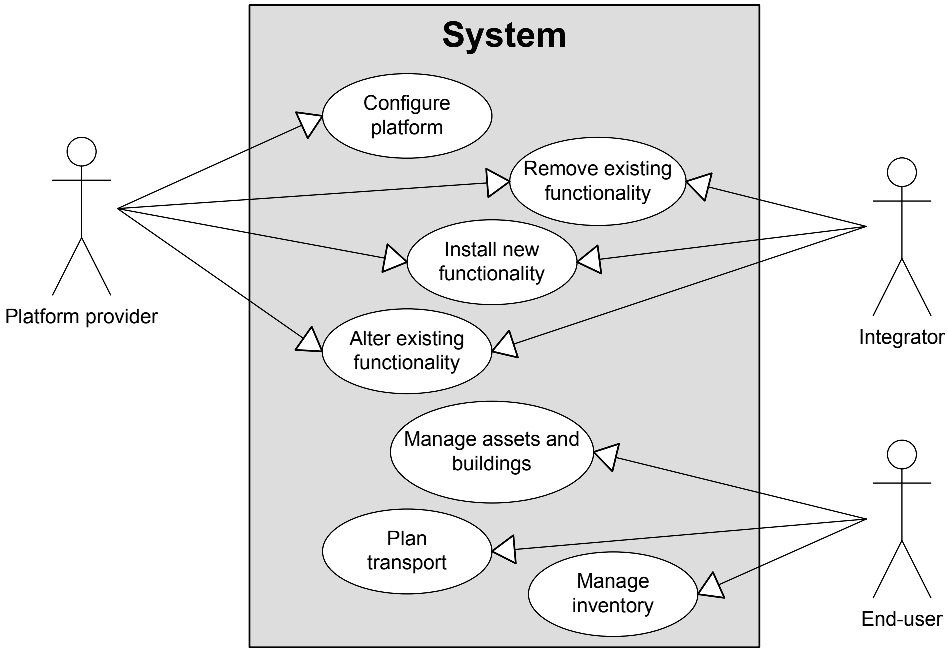

Figure 2.1: Representative use case diagram for intelligent supply chain logistics

2.3 Non-functional requirements

Non-functional requirements are often crosscutting aspects that influence the functioning and behaviour of the platform. These aspects can roughly be divided into two categories. On the one hand, aspects like modifiability, hardware and software interoperability or heterogeneity are related to development qualities. On the other hand, aspects like availability (e.g. network, resource or data availability), scalability, or security are related to operational and managerial qualities. This section describes all these non-functional requirements that need to be handled when developing a platform for distributed sensor applications.

2.3.1 Modifiability

As the communication platform may prove to stakeholders its advantages or operational benefits over time, one may get interested in deploying additional applications and integrating them with their daily processes. The platform must therefore provide support for adaptivity in the long term. Existing applications may also be changed or replaced by newer ones. However, the life cycle management of software components may not influence the functioning of other unrelated components. This means that, for instance, the removal of a component on a programmable node may not cause a restart of the entire node. The following figure illustrates the quality scenario for modifiability.

2.3.2 Heterogeneity

Diversity in requirements, environment and infrastructural components, for instance, domain-specific applications, mobile settings, or inter-node differences, are very common in distributed sensor applications. To deal with these various kinds of heterogeneity, the common middleware

Source:	End-user, integrator, platform provider, technology specialist
Stimulus:	Wishes to add, delete, or modify functionality. One may as well wish to tune certain quality metrics.
Artifact:	Changes can be made to the following components of the intelligent platform: • The end-user application components developed by integrator stakeholders. • Generic services developed by integrators, platform providers, or technology specialists, residing on programmable nodes. • The core middleware platform itself and its involved components.
Environment:	At runtime, compile time, build time, or design time
Response:	The platform allows one to change, by giving appropriate API access: 1. Application-specific functionality and behaviour. 2. Service-specific functionality and behaviour. 3. Platform-specific functionality behaviour.
Response Measure:	This separation of applications, generic services, and platform-specific functionality allows one to decrease the dependencies between the three subsystems and increase the flexibility of performing changes

Modifiability quality scenario

platform must be able to provide support for different component configurations, suitable for the corresponding operational scenario and its requirements. By providing a number of generic core components, acting as basic building blocks, one can support the application developer, resp. network manager, in developing his distributed application, resp. practising his management task. These basic blocks should be writting a platform-specific language, and provide generic functionality, through a set of uniform APIs, to their users. The following figures illustrates the quality scenario for heterogeneity.

2.3.3 Availability

Assuring qualities metrics about the availability of data and network resources is crucial for application scenarios such as supply chain logistics. Many activities of possibly different stakeholders depend on the proper functioning of hardware and software components. This availability of the entire distributed application is associated with system failure and its associated consequences. A failure occurs when the system no longer delivers a service that is consistent with its specification, this failure is observable by the system's stakeholders.

However, in these realistic scenarios, where many cheap programmable nodes may be involved, assuring one hundred percent availability is difficult. The nodes may be subject to failures, or the application may suffer from data delays or losses. Therefore to assure any quality metrics about availability, one must be able to anticipate to, or at least detect possible flaws, to take the appropriate actions. The following figure illustrates the quality scenario for availability.

Availability can be further divided into two types:

Source:	Integrator, platform provider
Stimulus:	The *integrator* wishes a generic base, consisting of a number of software components, to develop his applications on. The *platform provider* wishes to be offered some basic functionality in order to tune the platform to meet certain quality attributes.
Artifact:	The overal system can be constructed from a number of generic components, customizable to a heterogeneous environment.
Environment:	At runtime, compile time, build time, or design time
Response:	The platform allows one to: • Reuse functionality from generic components. • Tune the behaviour of the platform.
Response Measure:	By offering components, offering generic functionality, one can support heterogeneous scenarios. These components should however be written in a platform-specific programming language.

Heterogeneity quality scenario

Network availability: The network management requirement is very broad. It includes time synchronization, data aggregation and caching points, routing issues and fault recovery. One must be able to deal with dynamic conditions and the large scale of deployment.

Data availability: Aggregation of results at fixed points in the communication platform influences the life and traffic on the platform. In combination with caching, one can create persistence.

2.3.4 Interoperability

The assurance of interoperability between different services and service compositions is very important in distributed sensor applications. Different infrastructure and installed functionality must be able to cooperate together to meet the stakeholders' requirements.

To assure interoperability between different devices and software components running on them, one must provide components that are responsible to translate data from one format into another. Standardization is also very important to describe the types of sensors and their data. Several standards like [8, 4] currently exist for sensor systems.

2.3.5 Scalability

In a realistic environment, the system will be deployed on a large scale. This scale of deployment may have implications on latencies, management and quality of data. Therefore, one must be able to configure the platform to deal with these kinds of requirements by, for instance, providing load balancing, or caching and aggregation points in the network. The following figure illustrates the quality scenario of scalability.

Source:	Internal to the system caused by node or communication failures, noise,...
Stimulus:	A fault of one of the following classes occurs: • crash: a component repeatedly fails to respond to an input. • timing: a component responds but the response is late. • response: a component responds with an incorrect value.
Artifact:	The following resources should be available, but can be subject to failures: • Communication channels: wired and wireless. • Infrastructural components, especially resource-constrained programmable sensor nodes.
Environment:	At runtime during normal operation, or at degraded mode (i.e. the system runs on a fall back scenario)
Response:	The middleware platform should behave in the following manner: 1. Notify appropriate stakeholders like the network manager. 2. Record critical events and data, match it against quality metrics. 3. In case of significant faults: notify appropriate stakeholders like the network manager. 4. In case of slight faults: automatically take the appropriate actions as specified in configuration files. 5. Disable components that can cause any further faults or failures, according to certain policies. 6. Continue to operate. When operating in degraded mode, the platform will be configured as indicated by specific policies. All unnecessary functionality will for instance be switched off. Platform providers should act in the following manner: 1. Detect the cause of failure 2. Maximize availability by, for instance, deploy additional caching components or adjust the configuration of involved devices.
Response Measure:	Availability time should be maximized, while repair time should be minimized.

Availability quality scenario

Source:	End-user, integrator, platform provider, technology specialist
Stimulus:	The number devices and amount of gathered data is too large. This leads to difficulties in handling the incoming data (processing, storing) or difficulties to manage all devices.
Artifact:	The entire platform: sensor devices, communication devices, enterprise back-end devices
Environment:	At runtime, compile time, build time, or design time
Response:	The platform allows one to change: 1. The system can be at runtime equipped with services dedicated to ensure scalability. These services are, for instance, load balancing, data caching, data aggregation, duty cycling. 2. The entire system can be managed by a dedicated API. Some parts of this management can be automated. In this case, the system autonomously gathers metrics, matches them against thresholds and determines the appropriate actions to be taken.
Response Measure:	Throughput and delays exceed certain thresholds. The amount of devices exceeds a certain threshold. The number of users, concurrently using the system, exceeds a certain threshold. The platform can dynamically be extended with services dedicated to ensure scalability.

Scalability quality scenario

2.3.6 Security

The platform may be used by several competitive stakeholders. Therefore, one must be able to shield data from two competitors or share data between contracted stakeholders. Also, only authorized parties may alter the functionality installed on each infrastructural component. The communication platform must therefore incorporate support for this non-trivial security requirement.

Different adversary parties, malicious devices or faulty software components may exist in the environment where the distributed sensor application execute. Adding support for security to detect suspicious behavior of application components and users and allowing to take the necessary actions must therefore be incorporated.

Many different stakeholders may possibly install software components on the devices to satisfy their various functional requirements. However, the installation of one faulty application component may disrupt the execution of another proper software component. Similarly, as the domain of supply chain logistics is very competitive, one may place malicious devices in the environment, possibly snooping or disrupting crucial information. To deal with these unwanted inferences of software components or devices, one must take the appropriate security actions. This may, for instance, involve the usage of secure communication between devices. The latter may result in, for instance, the detection, isolation and removal of the individual faulty application component, and the signaling to the responsible network manager. The following figure illustrates the quality scenario for security.

Source:	Individual or a system that is correctly or incorrectly identified, or of unknown identity. One is internal/external, authorized/non-authorized with access to limited resources or vast resources.
Stimulus:	Tries to display data, alter or delete data, access system services, consume system resources, reduce availability to system services.
Artifact:	System services, data within system
Environment:	At runtime, compile time, build time, or design time
Response:	Authenticates user, hides identity of the user, blocks access to data and/or services, allows access to data and/or services, grants or withdraws permission to access data and/or services, records access/modifications or attempts to access/modify data/services by identity, stores data in an unreadable format, recognizes an unexplainable high demand for services, and informs a user or another system, and restricts availability of services.
Response Measure:	Time/effort/resources required to circumvent security measures with probability of success, probability of detecting attack, probability of identifying individual responsible for attack or access/modification or data and/or services, percentage of services still available under denial-of-services attack, restore data/services, extend to which data/services damaged and/or legitimate access denied

Security quality scenario

2.4 Domain analysis

This section gives an elaborated domain analysis of each category of involved stakeholders and their activities. First, the end-users will be analyzed, then the integrators, followed by the platform providers, and concluded by the technology specialists.

2.4.1 End-users

The supplier

A supplier is a supply chain stakeholder who has only the processing of raw materials and outbound logistics involved. Therefore, suppliers generally do not possess the need for inbound logistic processes to function properly. The supplier is generally only interested in visibility and inventory management of its goods. In the context of the intelligent platform for supply chain logistics, this management may be (partially) automated by attaching programmable nodes to goods or logistic infrastructure.

Suppliers, using the intelligent supply chain management platform, may provide various kinds of services to their customers. Each agreement between a customer and the supplier to use a particular service is settled in a contract that describes the privileges, rights, and outcome of the service agreement of both parties. Based on these contracts, the customer may, for instance, access order-specific data (e.g. the order status) from the supplier's system. Of course, there may exist differentiation in service level agreements between a supplier and each of its customers.

As suppliers are the source of the supply chain, they are mostly held responsible for the quality of the produced good. A supplier therefore needs to guarantee that a product's quality satisfies the agreed contracts between itself and its customers, customs, or the government in general. Any form of quality control mechanism or automation through these intelligent goods may therefore be very important for the supplying enterprise. Through this quality control mechanism, suppliers can establish a very important trust relation with their customers, and possibly gain a quality certificate by the authorities. However, suppliers must be able to prove this quality of origin, processing, handling, and transport of products. This may as well be automated by such an intelligent platform. Therefore, suppliers must on the one hand allow their customers or an external party to retrieve data from their systems, while on the other hand, they ought to publish data towards other stakeholders.

Key requirements in summary: achieving visibility, inventory management, some kind of non-repudiation of quality indication, customer and quality management, general production planning, and outbound logistics.

Domain model: The supplier's domain model is illustrated in Figure 2.2. Suppliers are generally not interested in individual programmable sensor nodes. They only see the end application and its benefits to their value chain.

Important domain model concepts: The following concepts relevant for the supplier's domain model:

Service: Suppliers may offer several *services* to their customers. These services can range from fast handling of goods, towards the offering of additional information about a customer's order.

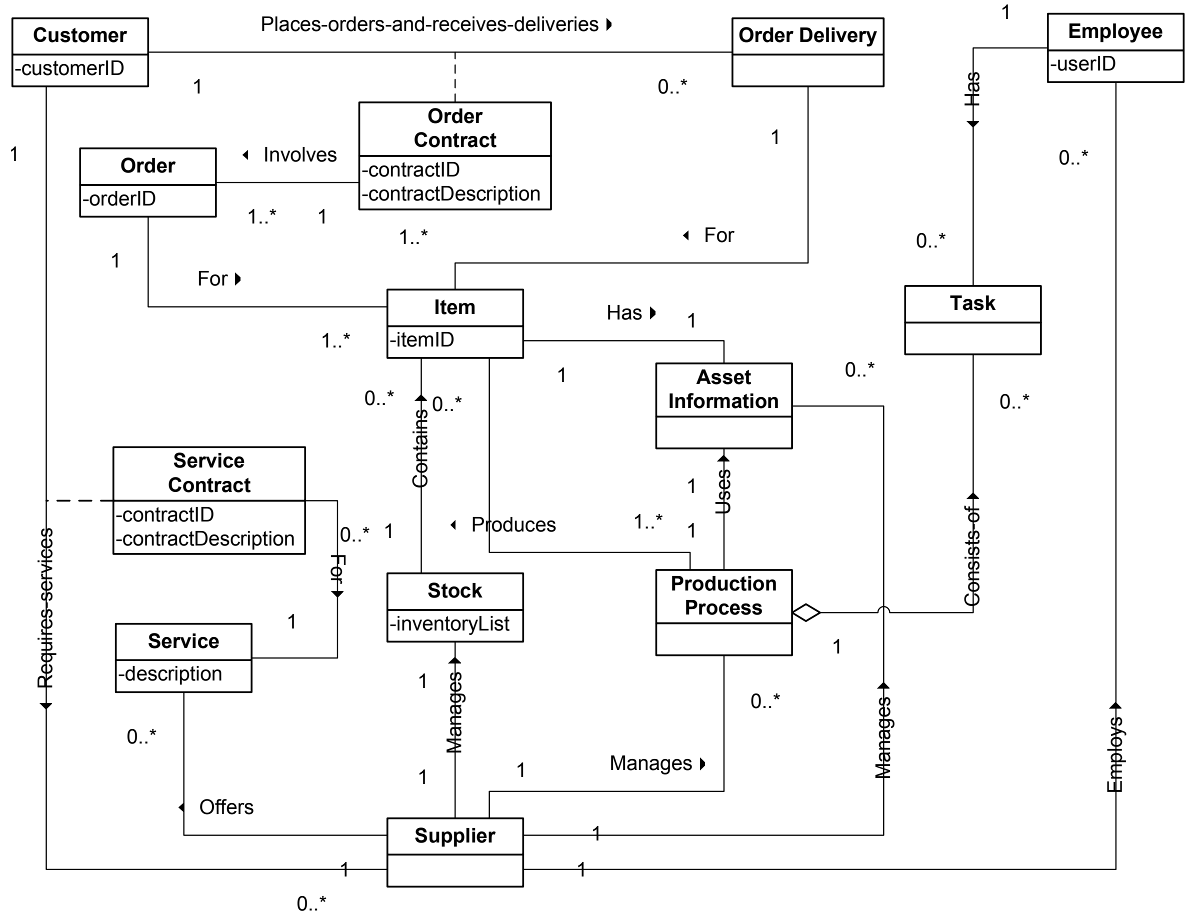

Figure 2.2: Domain model for the supplier

Service Contract: A *service contract* between a customer and a supplying stakeholder specifies obligations, privileges and rights of the agreement between both parties.

Order, Order Contract, and Order Delivery: Customers place an *order* for one or more items produced by a supplier. An *order contract* specifies the important details including the rights and obligations of both parties. In some moment in time, these orders will then delivered to the customer. This order *delivery* event will be recorded by the supplier and involves a changing of ownership of the ordered item.

Production process: The *production process* of a supplier can benefit from the information offered by the intelligent platform. This information can possibly ease planning of the production process and reduce costs.

Item The supplier's production process produces *items* which are placed inside the stock. Each item can have some assets associated with it, of which their asset information might be retrieved by the manufacturer.

The manufacturer

The manufacturer's activities are similar to those of suppliers. They assemble or transform raw materials into finished products or intermediate goods. They depend on material delivery from suppliers, and of course on the market demand.

Manufacturers have inbound and outbound logistic processes running as they depend on suppliers and consumers. Many manufacturers are typically interested in market prices and forecasting market demand through performing an intensive study of the (world) market for their product domain. Because manufacturers operate factory floors, they want support from the platform for their resource and factory scheduling processes. Manufacturers are also interested in accurate stock management, which is of course strongly coupled with inbound and outbound logistics.

Other requirements are strongly coupled with the manufacturer's business processes as given in Section 1.4.2. For example, employees must be able to fetch their daily tasks from the company's application server. To perform its task more easily, an employee should be able to receive feedback directly from the intelligent goods instead than from the manufacturers back-end systems. This may involve active communication between the actor and the goods (again reflecting certain challenges regarding to security or interoperability)

Key requirements in summary: inbound and outbound logistics, visibility, inventory management, non-repudiation of quality indication or quality control, customer management, and planning in general.

Domain model: The manufacturer's domain model is illustrated in Figure 2.3. The most important concepts in this domain model are the following:

Important domain model concepts: The following concepts are important for the manufacturer's domain model:

- **Manufacturer** The *manufacturer* employs employees and has customers and suppliers. Manufacturers might offer services which can be sold to customers.
- **Customer** The manufacturer's *customers* place on the one hand product orders at the manufacturer, while on the other hand they might request (additional) services from the manufacturer. These services are specified by a contract between the manufacturer and the customer. This contract can state certain service level agreements which the manufacturer should offer to the other party.
- **Production Process** Each manufacturer manages a production process for its manufactured products. The management relation means that the production process requires an adequate scheduling.
- **Stock** The *stock* plays a central role in the manufacturer's activities. It contains the quantities of available items, as well as possibly some additional information concerning their location and environmental conditions. All business processes that depend on this stock, may benefit from the use of asset information coming from intelligent items.

The logistics provider

Logistics providers are needed in the supply chain to deliver products from one stakeholder to another stakeholder. They therefore have to offer services for both parties. Logistics providers

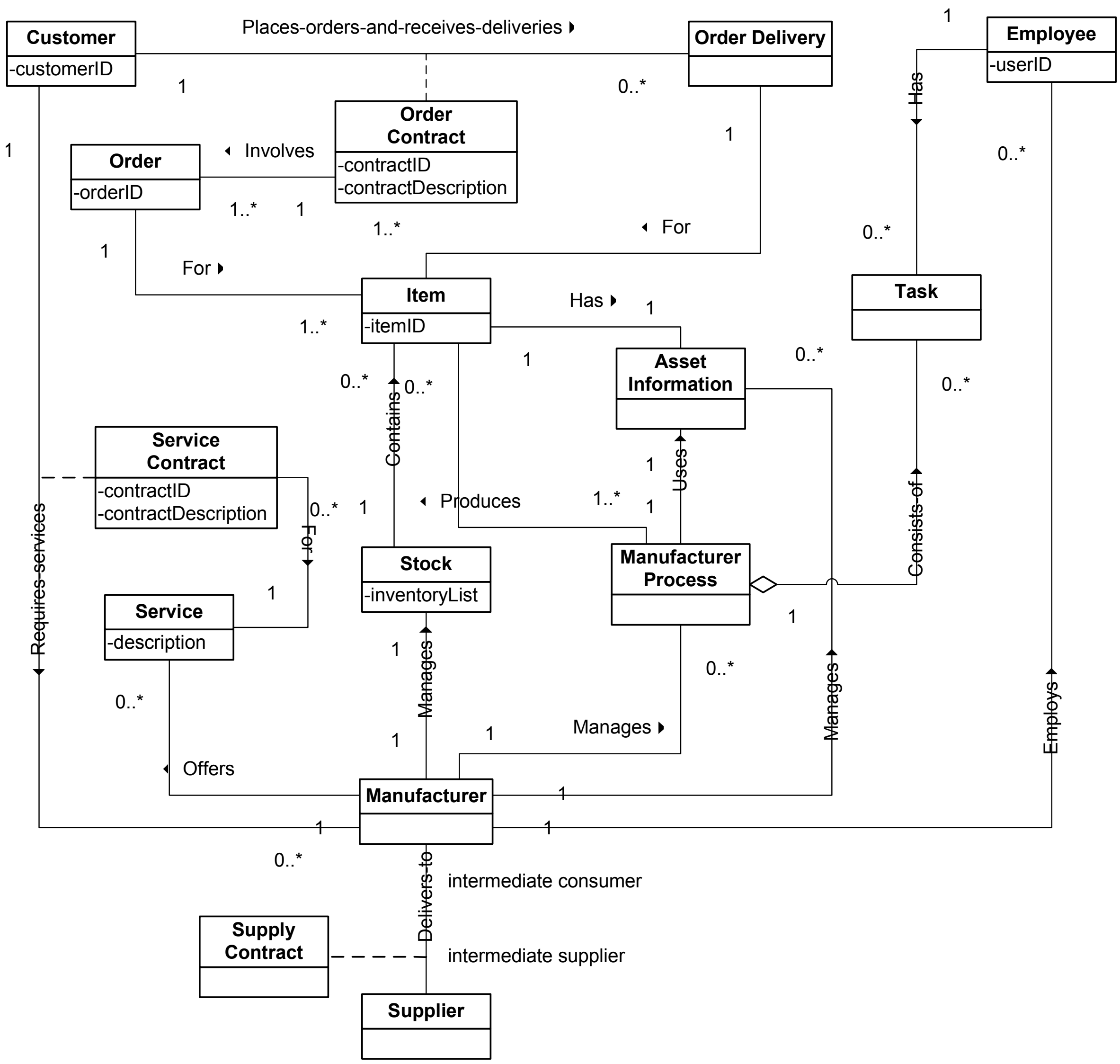

Figure 2.3: Domain model for the manufacturer

are subject to many legislations, which could require a spreading of transportation means, regulate transport and driving times.

Logistics providers are essential players in the supply chain. A provider is active between many succeeding chains by handling their transportation. Logistics providers are mostly faced with planning issues. This planning requirement involves, for instance, finding a suitable truck or route. The provider has possibly different logistics units, such as various trucks, but also possibly ships, train-wagons or airplanes. Most logistics providers use their own methodology of handling and packing their goods. Some of them have containers, boxes, crates or pallets. These packings are often of great value, and therefore a logistics supplier wants to keep track of them.

Since a logistics provider is highly dependent of the incoming transportation orders, customer management is also a crucial process. Offering discounts and exclusive contracts for big enterprises and shipments,

The non-repudiation of quality of the transportation of the good is also very important for customer relationship management. If the provider can prove that the transported goods are handled with care as stated in the agreements between the two parties, the customer will definitely want to reuse the services of the provider for other possibly larger or more valuable shipments.

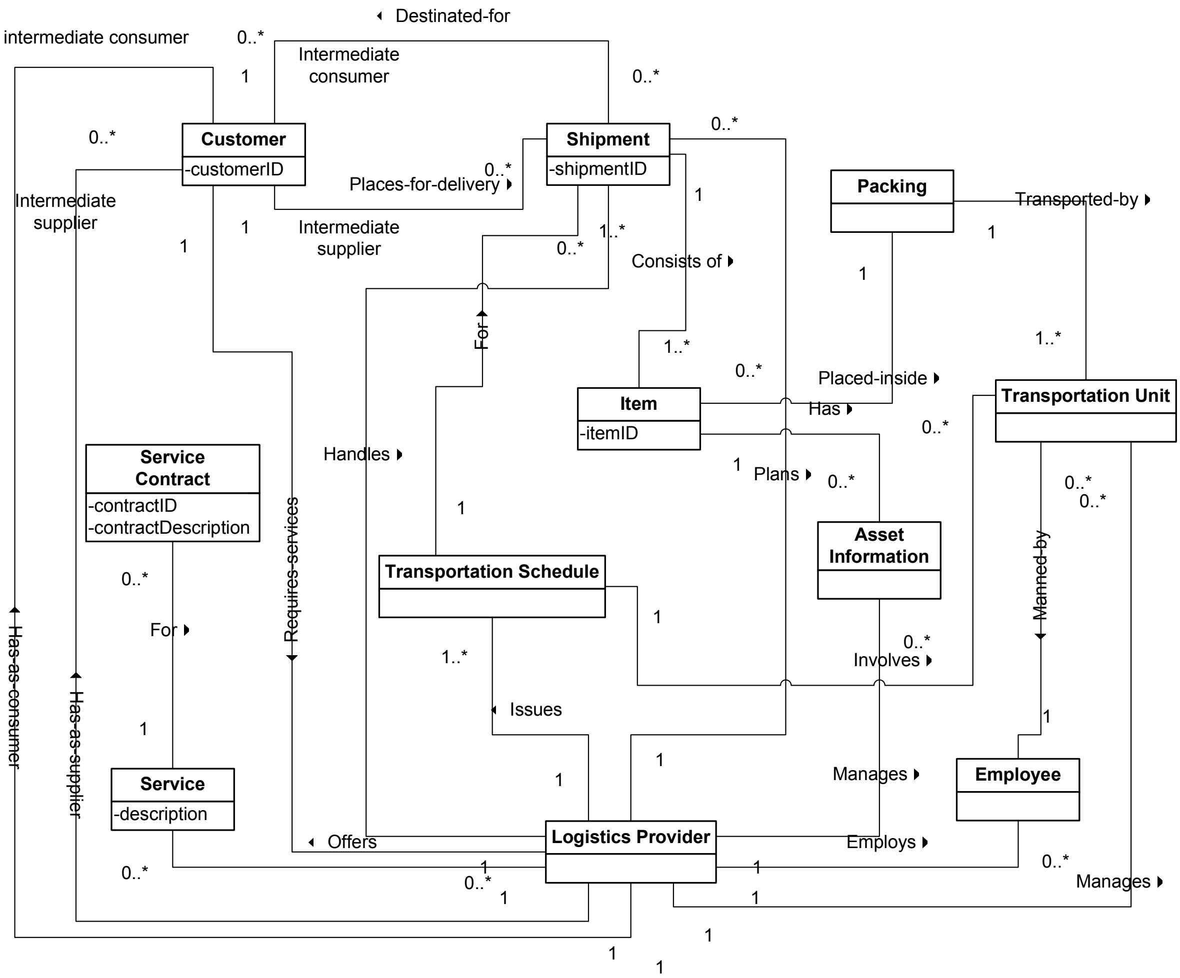

Figure 2.4: Domain model for the logistics provider

Key requirements in summary: inbound and outbound logistics, visibility, resource planning, inventory management, non-repudiation of quality indication and customer management.

Domain model: The logistics provider's domain model is illustrated in Figure 2.4. The most important concepts in this domain model are the following:

Important domain model concepts: The following concepts are important for the logistics provider's domain model:

Logistics Provider The *logistics provider* manages employees (drivers, loaders) and different transportation units (trucks, ships, airplanes, trains and wagons). Logistics providers can offer services to their customers, for example the offering of real-time visibility or conditioned transport.

Shipment A *shipment* is a transport of goods from one supplying stakeholder to another consuming stakeholder. The shipment consists of different items with assets. These assets possibly need to be monitored during transport.

Transportation Schedule Each shipment needs to be planned by the logistics provider. The planning searches for suitable transportation means and employees. The planning process then issues a *transportation schedule* describes the route, the needed employees (drivers, loaders,. . .) and the time tables.

The wholesaler

A wholesaler's enterprise is responsible for the distribution of goods to retailers or to other enterprise divisions. The wholesaler could do an appeal to a logistics provider, our it could own an entire logistics division itself. In the former case, the wholesaler's requirements are only loaded with visibility, inventory and stock management. In the latter case the wholesaler's requirements are loaded with the same requirements for planning as a logistics provider. Since wholesalers could sell different kinds of products, they require all kinds of asset monitoring and non-repudiation of quality, which is very important for wholesalers' customers. All sorts of marketing campaigns and special discounts for regular customers come in play since a wholesaler is very active in the distribution and consumer part of the supply chain. Wholesalers form the bridge between the producing and consuming part of the supply chain.

Key requirements in summary: inbound logistics, visibility, inventory management, customer management, marketing, non-repudiation of quality, forecasting demand, outbound logistics.

Domain model: The wholesaler's domain model is illustrated in Figure 2.5.

Important domain model concepts: The following concepts are relevant for the wholesaler's domain model:

Wholesaler Wholesalers sell products from manufacturers and/or suppliers to retailers or end-customers (depending on the industry domain). Whenever the stock level of a certain product runs low, the wholesaler places supply orders at the product-specific supplier.

Supply order A supply order is an order for a certain product, with a certain quantity of the product, at a supplying stakeholder.

Supply Contract Each wholesaler has contracted parties that supply goods to the wholesaler's enterprise. The contract is between a wholesaler and supplying stakeholder, such as a supplier of raw materials or a manufacturer (depending on the industry domain). The contract has a clause that indicates which logistics provider is used for the delivery of the supplied goods. This contract might be very time dynamic, as wholesalers are very close to the customers and thus very sensitive to price changes. Wholesalers generally seek the best, with respect to a given

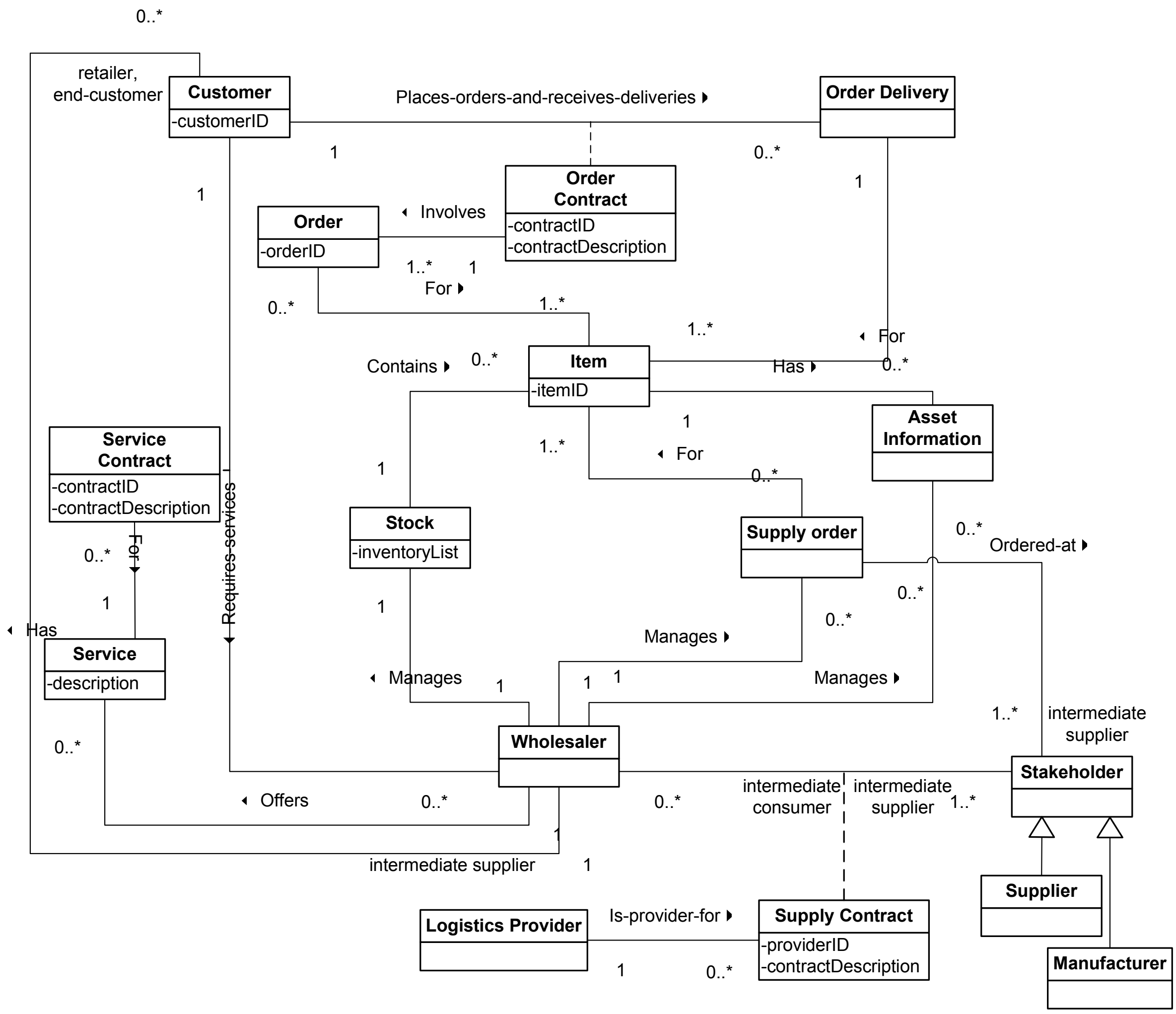

Figure 2.5: Domain model for the wholesaler

price/quality trade off, logistics providers for the delivery of their various products.

The retailer

A retailer is a small wholesaler. Retailers distribute the goods in their local neighborhood. They are faced with mostly the same requirements as wholesalers, however the scale of these requirements is smaller than those of wholesalers.

Key requirements in summary: inbound and outbound logistics, visibility, inventory management, customer management, marketing, non-repudiation of quality.

Domain model: The domain model for the retailer is given in Figure 2.6. The model is mainly similar to the domain model of the wholesaler. The only difference between both models is that retailers order their supplies at wholesalers (depending on the industry domain).

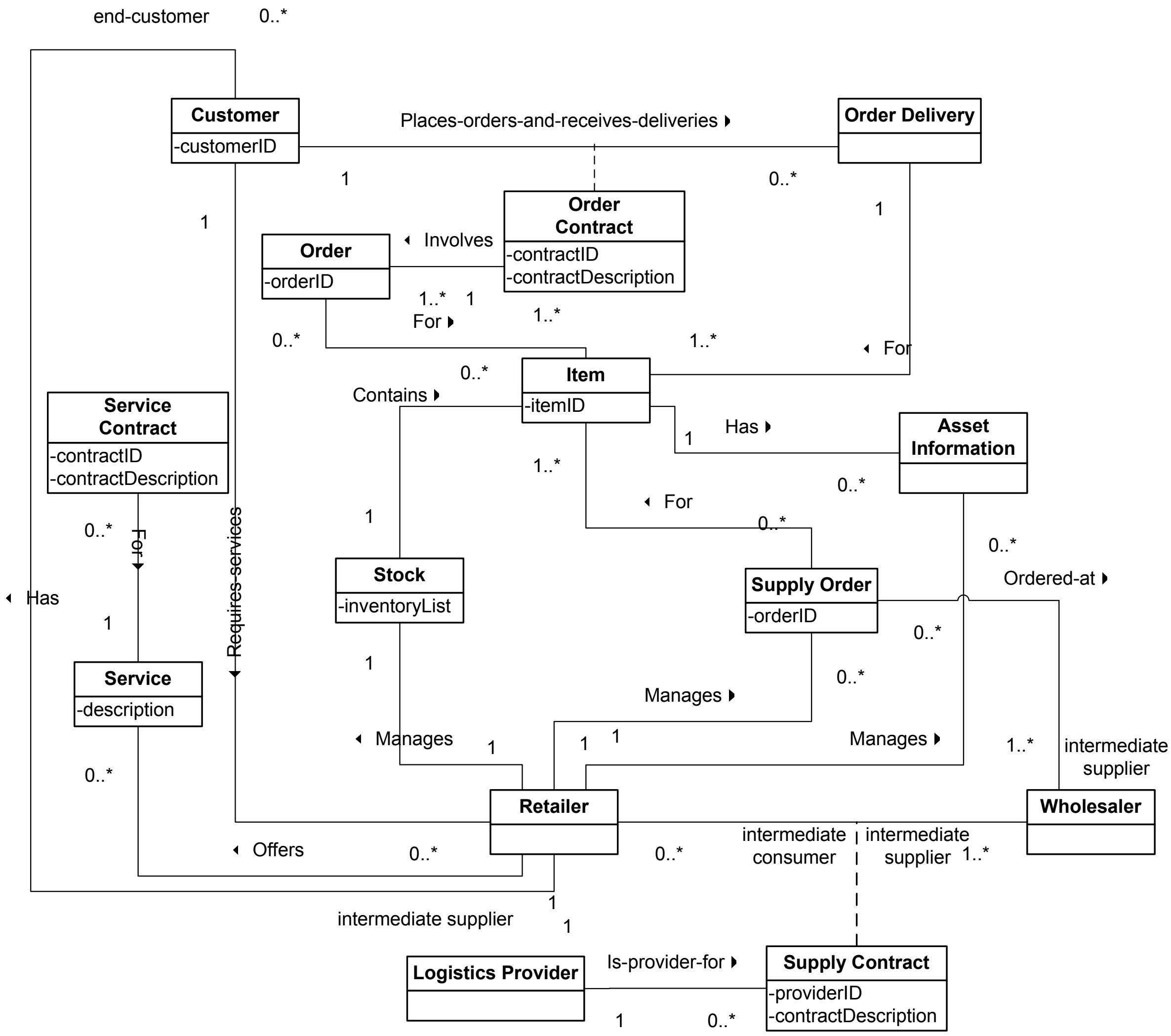

Figure 2.6: Domain model for the retailer

Important domain model concepts: The most relevant domain concepts for retailers apply also for manufacturers, therefore they are not listed anymore.

2.4.2 Integrators

Integrators often come into contact with the end-users. Therefore, they need to know their customer's domain and activities. Integrators form the bridge between the platform providers and the end-users as they integrate the end-user's applications on the platform

2.5 Context viewpoint

The context view of the intelligent platform for supply chain management is given in Figure 2.7. The view captures all interface interactions between the platform and its involved stakeholders. Table 2.1 describes each stakeholder and a short description of its interactions with the intelligent SCM platform.

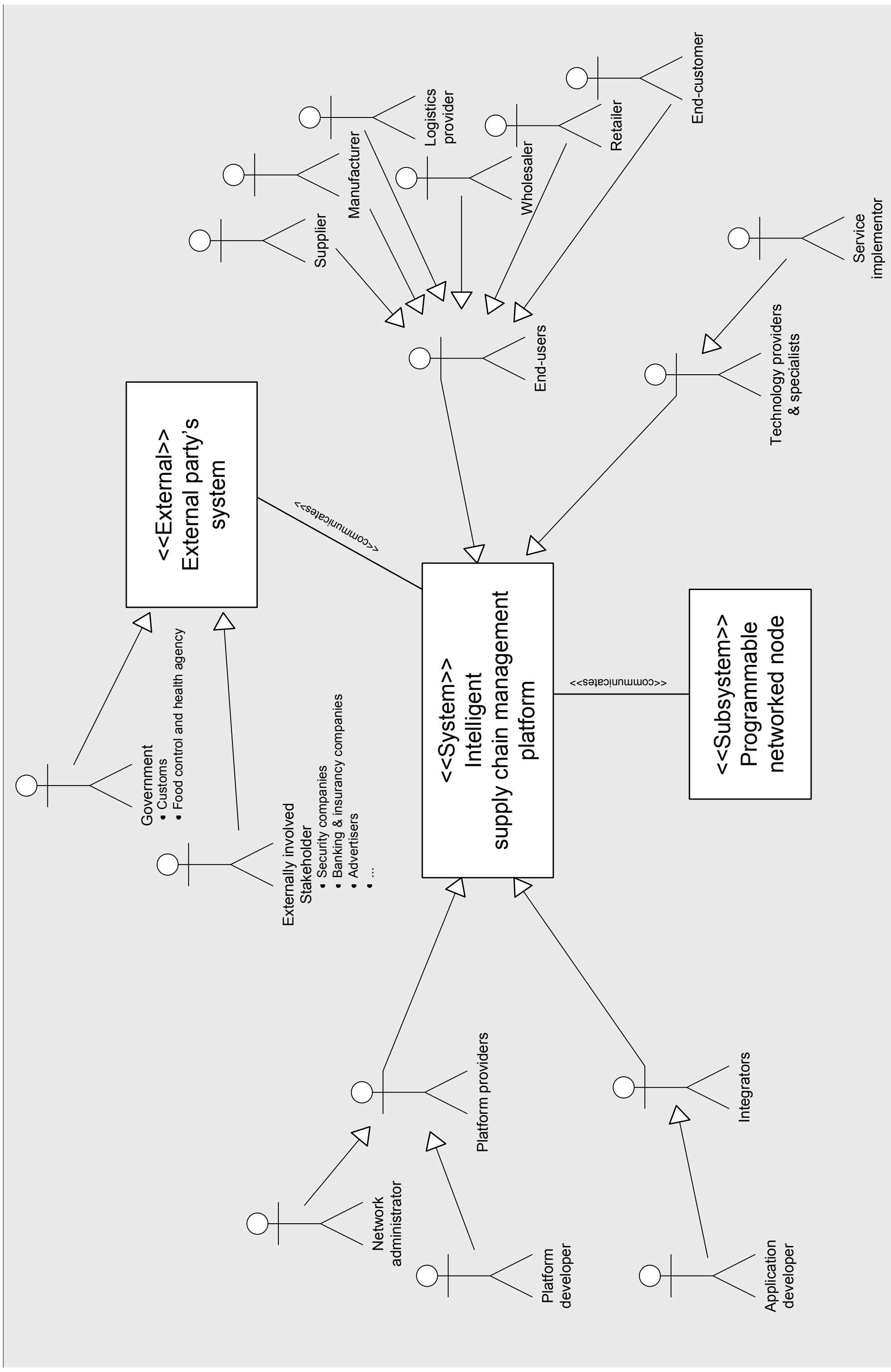

Figure 2.7: Intelligent SCM Platform Context View

Actor	Actor description	Interface description
End-user	Several stakeholder can be identified as end-users. They include the following types of stakeholders: • Supplier • Manufacturer • Logistics provider • Wholesaler • Retailer • End-customer	End-users expect information and functionality from the intelligent SCM platform. The expected information and functionality, however, is stakeholder-specific and might change through time
Technology provider & specialist	Technology providers and specialists deliver hardware for the platform, while specialists like service implementors develop specific platform and technology-specific functionality.	Implement functionality closely related to the used technology (e.g. localization algorithm, dependent on the used ranging transceivers).
Platform provider	Platform providers develop and maintain the communication platform. They include network administrators and platform software developers	They are mainly responsible deploying new functionality as well as managing the entire infrastructure and its already installed software
Integrator	Integrators are application developers who develop complete applications by composing them from several distributed services residing in the infrastructure.	They combine functionality and information from different services to form a whole.
External stakeholder	While activities of external stakeholders are in general not as closely related to the supply chain as activities from end-users, their activities might depend on information from the SCM platform. Examples of external stakeholders, besides the government, are related to the domain of: • Banking and insurance • Physical security services • Advertisement and marketing	External stakeholders have their own systems, tuned to their activities. However, to support these activities, they may require information and functionality from the SCM platform. Therefore, as each external party has its own sector-specific system, information between the intelligent SCM platform and each external legacy system should go through a well defined protocol.

Table 2.1: Stakeholder and interface description for the Context view

2.6 Glossary

Generic service. A *generic service* is a common service, reusable for different applications from possibly different stakeholders. Examples of these generic services may include a localization service that may deliver location data to an asset management application or a transport planning application.

Quality Scenario. *Quality scenarios* describe the non-functional requirements, e.g. modifiability or security, of a system. They describe different situations which can happen in or on the system and define the expected behaviour of the system. The functional requirements are described in *use cases*.

Use case. *Use cases* describe the functional requirements of a system. A use case is a scenario describing one sequence of actions started by an *actor* or *stakeholder* to reach a certain goal. The non-functional requirements are described in *quality scenarios*.

Appendix A

Use cases

A.1 Platform-specific use cases

A.1.1 Use case 01: Install new functionality

Primary actor: Platform provider, Integrator
Stakeholders:

- Platform provider: wants to manage his network.
- Integrator: wants to install additional functionality.
- End-user: has a concrete requirement for this functionality.

Importance: Primary.
Preconditions: The user is authenticated and authorized.
Postconditions:

- The functionality is installed.

Main Success Scenario:

1. The user chooses to install new functionality on the platform.
2. The user provides the software components that will be installed.
3. The user selects a subset of nodes that are used to deploy the new software components on.
4. The platform distributes this component to all relevant programmable nodes.
5. The platform installs the software components on each of the involved nodes.

Alternative Flows:

A.1.2 Use case 02: Remove existing functionality

Primary actor: Platform provider, Integrator
Stakeholders:

- Platform provider: wants to manage his network.

- Integrator: wants to remove unnecessary functionality.

Importance: Primary.
Preconditions: The user is authenticated and authorized.
Postconditions:

- The functionality is removed.

Main Success Scenario:

1. The user chooses to remove certain functionality from the platform.
2. The user chooses the software components that will be removed.
3. The user selects the nodes where the removal will happen.
4. The platform determines the feasibility of this removal.
5. The platform removes the selected software components on the selected nodes.

Alternative Flows:

4a. The platform determines that the removal is conflicting with other components residing on the local node or other dependent nodes.

4a.1. The platform notifies the user.

A.1.3 Use case 03: Alter existing functionality

Primary actor: Platform provider, Integrator
Stakeholders:

- Platform provider: wants to manage his network.
- Integrator: wants to install additional functionality.
- End-user: has a concrete requirement for this functionality.

Importance: Primary.
Preconditions: The user is authenticated and authorized.
Postconditions:

- The platform's functionality is altered.

Main Success Scenario:

1. The user chooses to install new functionality on the platform.
Include Use case 01: Install new functionality

Alternative Flows:

1. The user chooses to remove functionality on the platform.
Include Use case 02: Remove existing functionality

A.1.4 Use case 04: Configure platform

Primary actor: Platform provider
Stakeholders:

- Platform provider: wants to configure the platform to (better) meet certain qualities.
- Integrator: wants that his application is independent of the configuration by the platform provider.
- End-user: has quality requirements that should be enforced on the platform.

Importance: Primary.
Preconditions: None.
Postconditions:

- The platform is configured to meet the required qualities.

Main Success Scenario:

1. The platform provider chooses to configure the platform.
2. The platform provider configures the necessary components.
3. The platform provider chooses the set of nodes running the components to be configured.
4. The platform enforces this configuration on all involved components.

Alternative Flows:

A.2 Application-specific use cases

A.2.1 Use case 05: Manage inventory

Primary actor: End-user
Stakeholders:

- End-user: wished to manage and monitor its inventory.

Importance: Primary.
Preconditions: None.
Postconditions:

- The system displayed the current state of the inventory.

Main Success Scenario:

1. The end-user wishes to retrieve the actual conditions of his warehouse's inventory.
2. The application retrieves the state and location of all individual items inside the selected warehouse.
3. The application processes the retrieved data and displays the current state of the inventory.

Alternative Flows:

A.2.2 Use case 06: Plan transport

Primary actor: End-user
Stakeholders:

- End-user: Wishes to plan its transportation means. He is interested in the most optimal route to the destination.

Importance: Primary.
Preconditions: None.
Postconditions:

- The transport planning application has determined the desired route.

Main Success Scenario:

1. The end-user selects to plan a route, based on a starting point, destination, and cargo.
2. The system retrieves the most actual data concerning the current state and location of the available transportation means (containers, trucks, ...)
3. The system calculates the most optimal transportation route.

Alternative Flows:

A.2.3 Use case 07: Manage assets and buildings

Primary actor: End-user, Integrator
Stakeholders:

- Integrator: Develops, configures and installs the asset management application on the platform.
- End-user: Wants to use an asset management application to manage its goods and building infrastructure.

Importance: Primary.
Preconditions: None.
Postconditions:

- The asset management application is installed on the platform and ready to be used.

Main Success Scenario:

1. The integrator deploys the asset management application on the platform. The application consists of several cooperating components (services). These services are individually deployed on the platform.
2. The asset management application is deployed on the platform and is ready to be used.

Alternative Flows:

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