

Future Logistics - Challenges, Requirements and Solutions for Logistics Networks

Martin Roth, Axel Klarmann, Bogdan Franczyk

Abstract—The importance of logistics has changed enormously in the last few decades. While logistics was formerly one of the core functions of most companies, logistics or at least parts of their functions are nowadays outsourced to external logistic service providers in terms of contracts. As a result of this shift new business models like the fourth party logistics provider emerged, which designs, plans and monitors the resulting logistics networks. This new business model and topics such as Synchronomodality or Big Data impose new requirements on the underlying IT, which cannot be met with conventional concepts and approaches.

In this paper, the challenges of logistics network monitoring are outlined by using a scenario. The most common layers in a logical multilayered architecture for an information system are used to point out the arising challenges for IT. In addition, first appropriate solution approaches are introduced.

Keywords—Complex Event Processing, Fourth Party Logistics Service Provider, Logistics monitoring, Synchronomodality.

I. INTRODUCTION

NOWADAYS, companies are faced with increasing competitive pressure, unpredictable market changes and dynamically changing regulations. These challenges must be handled in an appropriate manner to fulfill processes faster, better and more flexible. Therefore, companies outsource their internal activities to external providers to reduce costs, increase profits or to focus on its core business [1].

This evolution also occurs in the logistics service sector. Enterprises are outsourcing their logistics department as well as the related services like warehouse management, transportation or material handling and so forth. Additionally, the closely connected IT functions like logistics information systems are also outsourced. The resulting networks, consisting of various logistics service providers (LSP), have a very collaborative, complex and dynamic character. These logistics networks have to be planned, coordinated and monitored. With this, ambitious business models like the fourth party logistics providers evolved. Hence, a 4PLP is defined as an independent, singularly accountable, non-asset based integrator of a client's supply and demand chains [2] by integrating upstream (e.g. suppliers) and downstream (e.g. distributors) actors of the supply chain [3].

M. Roth is with the Information Systems Institute, University of Leipzig, Germany (e-mail: roth@wifa.uni-leipzig.de).

A. Klarmann is with the Information Systems Institute, University of Leipzig, Germany (e-mail: klarmann@wifa.uni-leipzig.de).

Prof. Dr. B. Franczyk is Professor at the Information Systems Institute, University of Leipzig, Germany and with the Institute for Business Informatics, Wrocław University of Economics, Poland (e-mail: franczyk@wifa.uni-leipzig).

Another approach to optimize logistics and, therefore, to alleviate the effects of the present challenges is modality. The first shift was from single modality to multimodality. That implies that multiple modes of transport, for example rail and sea, are used to get goods from the origin to the destination. The next evolution is synchronomodal logistics. Synchronomodality also deals with switching between different forms of transport, but within a strategy of a more timely, efficient and environmentally friendly distribution. Another difference is that synchronomodal logistics minimize buffer times, support bundling and allow quick changes between the different modes of transportation. Therefore, the whole transport process is more flexible, whereby the costs can be reduced, the quality can be increased and a good sustainability in the worldwide competition can be achieved [4].

The above mentioned shifts cause a rising complexity in transactions, in logistics and in the supporting IT systems. But not only outsourcing or shifts between transport modalities increases the complexity for IT. With the greater use of automatic identification and data capture technologies (AIDC) such as RFID or wireless sensor networks as well as social networks the amount, velocity, variety and value of data has changed dramatically. This evolution is called Big Data and also takes place within the logistics sector. Big Data is discussed widely and is seen as one of the most challenging aspects in IT today [5].

In this paper a new solution approach is introduced, whereby the focus is on monitoring the evolving logistics networks. Monitoring logistics networks is challenging because of its collaborative, complex and dynamic nature as well as the interaction between IT and business is very pronounced at this stage.

This contribution is organized as followed. Section II describes the above mentioned business model in more detail by means of a typical workflow. Afterwards the resulting business challenges for the 4PL with focus on monitoring process executions are introduced. A scenario is used to exemplify those challenges. In Section IV the technical requirements to face the business challenges are outlined which are the foundations for the solution approaches (Section V). Section VI presents the related work and discusses their use for this application area. Finally, the paper ends with a conclusion and future work of the approach.

II. THE 4PL BUSINESS MODEL

To emphasize the characteristics of the 4PL business model, a typical workflow and a scenario is outlined in this section.

The following presented 4PL service lifecycle consists of

the phases: *analysis, design, implementation, operation and retirement* [6]. A company, further called customer, utilizes the 4PL to transport goods from Osaka to Leipzig. This outsourced logistics service must be contractually secured. A contract records the agreed upon obligations and responsibilities of contractual parties in terms of business process conditions. These conditions are often expressed as goals which must be reached by each party [7]. The goals can be extracted from the customer needs or from law and are known as Service Level Objectives (SLOs) [8].

Therefore, both parties draw up a contract with some SLOs, which define measurable indicators like delivery quality, delivery reliability and delivery flexibility. The 4PL has to ensure the compliance to these during the whole service execution towards the customer. Relating to the defined SLOs, the 4PL choose the suitable LSPs from a pool. Those companies can collaboratively accomplish the contract between the 4PL and the customer. The capabilities of each LSP are described in preliminary stages. After selecting appropriate LSPs and drawing up contracts with them the *analysis* phase ends.

During the *design* phase the 4PL models a suitable logistics network regarding to the previously agreed conditions. This model is illustrated in a formalized way in form of a process model like Business Process Model and Notation (BPMN). Due to the fact that the process model only covers the static structure of processes, a simulation is used to investigate the dynamic behavior of the modeled processes. At this point the 4PL knows how to orchestrate and execute the logistics services offered by the appropriate LSPs to accomplish the whole operation towards the customer.

In the *implementation* phase the integration of the LSP and the alignment of the existing logistics systems as well as the IT support are done. Therefore, the data sources and sinks are defined as well as the composition of a monitoring system. By using the monitoring system, the 4PL is able to estimate if the service execution of each LSP was successful or not.

During the *operation* phase the 4PL monitors the service

execution realized by each LSP. The gathered data is stored for a long-term analysis of each logistics network.

At the end of the service lifecycle the contract expires and the service terminates. The process execution is analyzed and possible lacks will be eradicated (*retirement*).

Fig. 1 illustrates a possible logistics network with the agreed contract conditions, material flow and common data sources in logistics like RFID or barcode. For the sake of convenience the only integral part of the contract is time. Further parts could cover sensor measurements such as temperature, shocks, humidity and so on. The overall delivery time between Osaka and Leipzig is 48 hours, whereby the LSP-specific delivery time is 12 hours (LSP1), 24 hours (LSP2) and 12 hours (LSP3). The responsibilities of each LSP are represented as squares.

After pointing out a typical workflow and a scenario, the next section addresses the business challenges focused on the monitoring phase of the resulting networks (*operation*). Other challenges like the LSP selection or organizational impacts are out of scope.

III. BUSINESS PROBLEMS

This section covers the arising challenges of the 4PL business model and Synchronmodality at the business level. The following enumeration shows the prime challenges:

BI: All outsourced services are contractually secured. If e.g. the delivery of the good is delayed, the 4PL has to pay the contractual penalty to the customer. To secure the robustness and sustainability of the managed logistics network, the 4PL has to pass by the penalty to the guilty member. Otherwise the LSPs who fulfilled the SLOs successfully also have to pay or the 4PL has to calculate possible monetary penalties into the offer. Both approaches will lead to a non-competitive logistics network, in which no LSP participates or no customer wants to outsource services to. Therefore, a mechanism is needed to identify the LSP who is responsible for the breach of a contract.

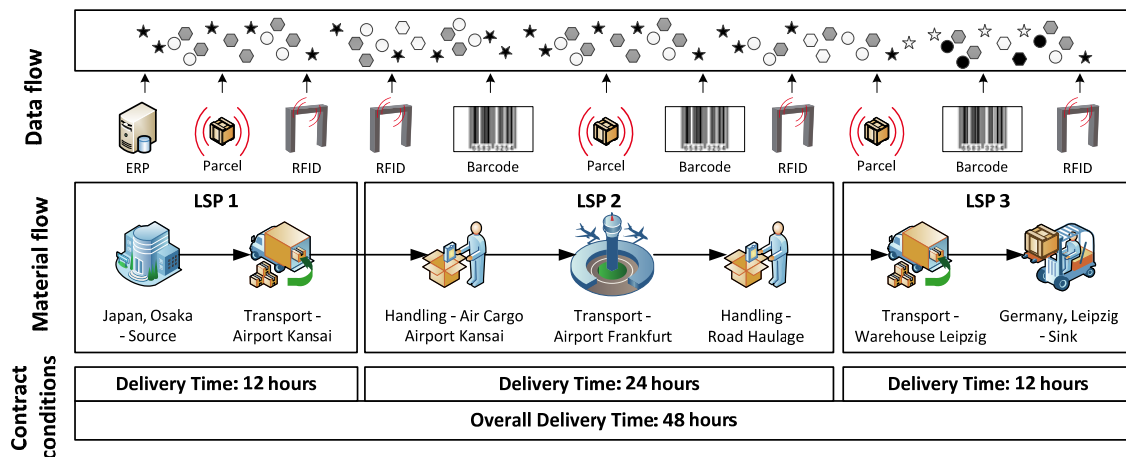


Fig. 1 A logistics network

B2: To ensure the competitiveness of a logistics network, a proactive mechanism would be a further development to prevent breaches of contract. If e.g. the transportation service of LSP2 is delayed, the whole process execution is vulnerable, because LSP3 only possesses trucks and their use is too time-intensive to compensate the delay. Hence, a method to recognize these circumstances in an anticipatory manner is needed.

B3: Nowadays, efficient logistics such as Green Logistics is becoming increasingly important. Thus, it is obvious that e.g. shipping space must be used efficiently. The transportation of already damaged goods is not practical. Thus, a monitoring mechanism is needed, which observes and analyzes the transport conditions during the process execution and informs the 4PL about exceeding.

B4: The structure of logistics networks is characterized by many points of change. This leads to a rising risk of misloadings (e.g. wrong barcode scanned). This is a special issue of sensitive goods like perishable goods, but also important for ordinary goods. Moreover, the 4PL has less influence on the IT of the involved LSPs and has to rely on the information gathered by the LSP. This information can be manipulated and the latency until the data is at the 4PL is too high. To face this challenge the monitoring structure of goods must be modified.

B5: To realize innovative concepts like synchromodal logistics it is necessary, that decisions can be made during the process execution and not only during the design phase. Therefore, it is essential, that the required data is as fast as possible available to support decision makers and/or systems. That means that a failure is proactively identified and compensating measures can be initiated as soon as possible (see B2) or that the next transport medium in a logistics network can be chosen as late as possible (Synchromodality). This leads to a very dynamic binding of LSPs. Hence, the solution approach has to support real-time capabilities to linking them.

B6: The dynamically changing regulations also complicate the long-term planning. Existing logistics systems are not flexible and adaptive enough to integrate new or change present processes and systems rapidly. Furthermore, there are a lot of external data sources available, which also should be integrated to gain more information about circumstances which could affect the process execution. Therefore, the integration of new systems and external services must be realized in a short period of time.

Looking from an IT perspective to these challenges it is necessary to provide data visibility, accuracy and transparency at the highest possible level. Hence, the main objectives of logistics must also be applied for the used data. Not only the right goods, but also the right data regarding directly or indirectly to the good must be delivered at the right point of time, to the right place, with the right quality and quantity and to the right costs (6Rs, [9]).

IV. TECHNICAL REQUIREMENTS

This chapter associates the business problems with the resulting challenges for facing them from the IT perspective. Therefore, the common multilayered architecture for information systems is used to classify the IT challenges.

There is a multitude of different technologies, which can be accompanied the process execution or can be used to measure the transport conditions (see Fig. 1). Monitoring systems utilize these technologies to gather data and are, therefore, able to draw conclusions from the ongoing process execution. Such systems are multilayered and their basic structure can be seen in Fig. 2.

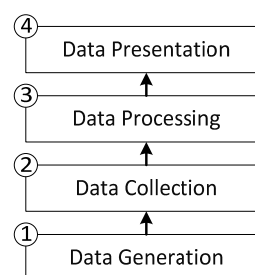


Fig. 2 Common multilayered architecture for information systems

Data are generated (1) from a source, collected by a system (2), then processed (3) and finally used (4) e.g. for visualizations. In the following, the IT challenges are considered from bottom (1) to top (4).

(1) *Data Generation:* One of the major challenges in the 4PL business model and concepts like Synchromodality is the data generation. Today's monitoring solutions are usually used to track the vehicle where the goods supposed to be. Manual errors, more than one barcode label on a good or missing labels lead to misloadings (see B4). Moreover, tracking information is generated with RFID or barcodes, which are usually used stationary. Hence, tracking information is generated at interfaces like goods receipt or issue and provides not the needed data quality. Indeed, it is possible to equip means of transportation with IT like RFID readers in the shipping space, but in the 4PL business model it is not expedient to equip the trucks of the LSPs with expensive technologies. To achieve a maximum of transport efficiency, the transport as well as the storage conditions must be monitored (see B3). Therefore, goods must be equipped with IT, so that they are capable to interact with the environment autonomously, e.g. sending the position of the good to the 4PL. As a result, the tracking structure needed is at the item-level not at vehicle tracking (see B5). Due to the fact that there are usually many goods in the shipping space the communication between the IT-enabled goods as well as with the environment must be investigated.

(2) *Data Collection:* The velocity, value, variety and volume of data dramatically changes during the last years. The so called Big Data can also be found in the logistics sector. Regarding to (1), the amount of data is still rising and all those low-level data must be collected by suitable methods. Moreover the integration of various systems must be done in

shortest time to provide dynamically arising engagements or the synchromodal shift (see B5). Another important aspect is the needed time to take appropriate actions. The data must be gathered in real-time and push them into the next layers to gain the data visibility and transparency as needed (see B5). To enable concepts like Synchromodality or the dynamically binding of LSPs, external systems must be integrated easily (see B6) considering their characteristics. Therefore, the underlying IT must support concepts like loose coupling.

(3) *Data Processing*: To overcome the challenges constituted by Big Data a suitable approach to process the collected data is needed. As a result of the increasing amount of data, the solution approach has to transform low-level data in meaningful information, so that the processed data possess the maximum value for the company. To tackle the challenges of the rising volume of data, the approach must be scalable and should provide an intelligent mechanism to reduce the amount of data. Furthermore, cloud service such as weather or traffic information systems must be integrated and processed to support proactive actions (see B2). Another important aspect is that the IT provides versatile opportunities to perform a dynamical target-performance comparison. Thereby, it is possible to identify delays during the process execution (see B1). To achieve an automated comparison, the SLOs must be formalized and turned into an appropriate data format which can be processed by different tools. To facilitate new concepts and to be able to make decision during the process execution, data must be as fast as possible available. Thus, the processing of the data must be done in a real-time manner (see B5).

(4) *Data Presentation*: The last layer takes care about the presentation of the collected and processed data. Thereby, an user-oriented visualization of the data must be supported to provide the maximum of the data value for enterprises. For example, a manager is only interested in KPIs like delivery quality, whereas an engineer wants to get an overview of technical details. Moreover, the data must be visualized at any device (e.g. PC, tablet, smartphone) with no loss of information density. Furthermore, the processed data, e.g. a delay is identified, must be displayed in real-time (see B5). Depending on the integrated services, a mechanism must exist which support the decision maker with compensating measures in real-time (see B2).

V. SOLUTION APPROACHES

After identifying the technical requirements to tackle the business problems, initial technical solution approaches are outlined on an abstract level without going into detail of a particular tool or technique.

(1) *Data Generation*: To facilitate the shift from vehicle to goods-tracking, first prototypes were made with GSM and GPS modules, which allow the detection of the current position of a good (GPS) and the autonomous communication with the environment (GSM) (see B4). Depending on the service level objectives, sensors are integrated to measure the delivery quality like temperature (see B3) in real-time. According to first investigation results, it must be possible that goods can interact with each other. Therefore, a low energy

Bluetooth module is installed at every wireless sensor node, whereby one node in the shipping space is the master and the others are slaves. So the slaves sent their measurements via Bluetooth to the master. Afterwards, the master sent the measurements of every slave as well as the coordinates of the master to the 4PL monitoring system. By doing so, not every sensor node needs a SIM card and redundant data can be cleaned or the GSM module can be deactivated until there is no Bluetooth connection to the master. The gathered data is pushed into an event cloud, which is the interface between the data generation and data collection layer.

(2) *Data Collection*: Logistics networks can be seen as widely distributed IT-systems. To automate business logic as distributed systems, design paradigms are used to build computer software. A popular paradigm is service orientation, which is often used in new, modular software. In service orientation every operation capabilities is separated into services, which is solving an independent concern. This design paradigm has its strength if calls are synchronous, the workflow is sequential or transactions are used. Regarding to B5 and B6, service-orientation is not suitable, because data cannot be handled in real-time and the dynamic nature of logistics network is neglected. Therefore, service-orientation must be extended by event-driven capabilities. By doing so, the current state of a process execution can be detected by place temporal and causal events into relationship. Furthermore the designed system is loosely coupled, which means, that each part has little or no knowledge about the other parts of a system. Thus, it is easy to integrate IT-Systems from new LSP or external services like traffic information systems into the 4PL platform.

(3) *Data Processing*: In logistics, new technologies like AIDC are widely used (see Fig. 1). These technologies produce a large amount of data with different structures, which are not easy to handle. Complex event processing (CEP) is designed to deal with the increasing velocity, value, variety and volume of data in real-time. CEP is defined as a set of tools and techniques for analyzing and controlling the complex series of interrelated events. Thereby, the events are processed as they happen, thus continuously and in a timely manner [10]. An event is the central aspect of CEP and is defined as “anything that happens, or is contemplated as happening (change of state)” [11], e.g. a RFID-enabled good is recognized by a RFID reader. If an event summarizes, represents, or denotes a set of other events, it is a so called complex event, e.g. a good left the issuing area [11]. With the use of CEP the 4PL gain situational awareness because a high variety of data sources – internal and external (e.g. traffic systems) - can be processed rapidly (see B2). Moreover, CEP can handle the rising velocity of data while processing them in real-time, which will lead to a better availability and visibility of data. Using e.g. RFID leads directly to the challenge that a flood of data is generated, whereby companies are only interested in high information value. Therefore, it is necessary that a dispatcher does not receive messages like “good_1 was read at reader_1 at 12:45 UTC”. According to that, CEP provides filtering mechanism so that all redundant messages

will be percolated which will reduce the volume of data. The result is that only one message is pushed to the dispatcher. It can be stated, that the message “good_A was read at reader_A at 12:45 UTC” does not possess a high information value. CEP offers the opportunity to aggregate data to obtain a higher information value. By using these mechanisms it is possible to aggregate technical data (e.g. RFID reads) to business processes, whereby the message is transformed to “good_A for Mr. Smith left the warehouse at gate 23. The delivery is delayed for 45 minutes”. This message is used to evaluate the performance of LSPs and to investigate their compliance regarding to the defined SLOs. With CEP, the 4PL can relate events to key performance indicators (KPIs) such as delivery quality. To identify delays, the SLOs must be described in a machine-readable form (see B1). These SLOs describe the target state of the process execution, whereby the IT (see (1) data generation) is the reflection of the actual state. With the integration of different external cloud services like traffic information system, it is possible to foresee if the overall contract can be fulfilled by given circumstances. If the flight from Japan to Germany is delayed (see Fig. 3) for 4 hours, the overall contract cannot be fulfilled. By using CEP, it is possible to detect such circumstances early on, so that the 4PL has enough time to take compensating actions. In the example, it is conceivable that LSP 3 is substituted with LSP 4, because the new LSP uses faster trucks and so can compensate the delay from LSP 2. Thus, the overall contract can be fulfilled.

Fig. 3 shows the use of CEP by means of the previously introduced scenario. Though, the explanation is at an abstract level with no reference to a specific tool. If the event_1 from the ERP system is pushed into the CEP-engine, a ticker starts (1). If the RFID_Event_1 is received as well as the ERP_Event_1 and the ticker is less than 12 hours, the delivery carried out from LSP1 is successful (2). If the ticker is more than 12 hours, an event “Delivery_delayed” will be generated. The responsibility of the delivery is now at LSP2. After LSP2 loads the goods and generated the RFID_Event_2, the flight plan will be checked. In this example, the flight is delayed. Therefore, the Deliver_will_be_delayed_Event is generated (3) and the 4PL has enough time to take compensating actions.

Due to the fact that the goods are equipped with IT, it is possible to check the local influences on the process execution. If the Geo_Event_2 is received and the distance is more than 500 meters and the traffic is low and the weather is fine (both information are pushed from external services), it can be assumed, that the delivery will be on time (4). At the end of the overall process execution, the last RFID_Event is pushed to the CEP-engine. If the ticker is less than 48 hours, the event Overall_Delivery_successful is generated.

In addition, CEP provides pattern detection and machine learning capabilities. To gain a more accurate forecast, it is necessary to investigate historical data about process executions and correlate them with real-time data. By doing so, trends and patterns can be identify. The following example is just a very simple one: If LSP1 needs ten times 8 hours to fulfill the contract, it can be said, that LSP1 needs about 8 hours for the eleventh execution.

(4) *Data Presentation:* After the data is generated, collected and processed, the presentation of these data is the last step. Due to the reason that a 4PL has to manage many logistics networks with many process executions the visualization of the data must be clearly arranged. The 4PL has only to be informed if the process execution does not or will not fulfill the defined SLOs. This is also known as “management by exception”. Therefore, an easily understandable signaling is used to present the data e.g. in form of a traffic light. If one process execution does not or will not match with the defined SLOs, the light goes red. The 4PL has the opportunity to drill down e.g. the event “Delivery delayed” to identify the reason. Furthermore, alternatives to compensate different events can be shown to the 4PL. Besides the data presentation on classical PCs, information also have to be clearly arranged on mobile devices such as smartphones or tablets. For this reason, the dashboard must also be implemented as apps or with the use of responsive web design. Sites using this kind of design provide an optimal viewing experience, which means that the site is easy to read and navigate. Depending on the solution of the devices, the dashboard-site will be rearranged, which leads to an optimal view on the current state.

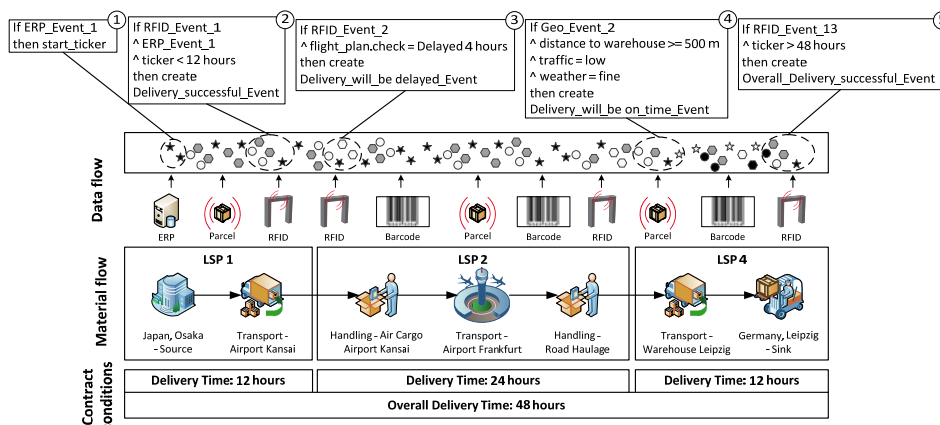


Fig. 3 Usage of CEP within a logistics network

VI. RELATED WORK

To monitor the transport conditions some products are already available. DHL offers two versions of the SmartSensor¹, which are also attached to the goods. If the RFID version is used, the conditions can only be read at certain stationary points within the transportation by using RFID-Reader. The resulting data visibility and transparency is not adequate regarding to the new requirements. The GSM version communicates autonomously with the underlying IT-platform. Due to the fact that localization can only be made on the basis of GSM and there is no opportunity that the sensor can interact with each other, this product is also not suitable.

Another sensor system is called DropTag². This sensor is also attached to the good and offers opportunities to keep track of dropped and damaged parcels. This system uses Bluetooth to interact with the surrounding systems, e.g. smartphones. The DropTag only support sensors to identify shocks, which is not enough to monitor the most transport conditions and, like the SmartSensor RFID, the data visibility and transparency is not sufficient.

CEP is a relative young discipline, whereby the most important concepts and tools already exist. Technical problems like scalability are mostly solved, but functional issues are not treated sufficiently [12]. The overall approach and the use within the logistics area, especially for the 4PL business model, are not covered in current research. Yao et al. analyze the use of CEP in hospitals using RFID. They introduce a framework and provide a possible solution to improve patient safety. Some parts of the approach can be partly adopted, but the framework is too abstract and not suitable for the presented application area [13]. Wang et al. introduced a framework for bridging the gap between physical and real world with the use of RFID and CEP [14]. This framework provides comprehensive support of RFID applications, but only covers a small part of the overall approach outlined in this paper. In [15], Zang and Fan describe how event processing can fit in enterprise information systems. Thereby, they argue that with the evolvement of software architecture into SOA and the adoption of RFID, event processing can be an important player in enterprise information systems. The rules and the architecture used are not suitable for logistics. The project ADiWa³ uses the Internet of Things to bridge the gap between the real and the virtual world. The data processing is also done with methods and concepts of CEP, but the main focus is on the use of RFID and the application area is an industrial park. This does not reflect the new requirements given by the 4PL business model or Synchronomodality.

VII. CONCLUSION AND FURTHER WORK

In this paper, concept and models are introduced, which influence the logistics sector and the underlying IT dramatically. Due to the 4PL business model, concepts like

Synchronomodality and Big Data, new business challenges emerge which have a big impact on IT. Thus, the resulting business challenges are identified and described, with focus on monitoring the process execution. With respect to those six challenges, requirements for the underlying IT are defined and solution approaches are outlined.

In this paper, the authors only give an overview, because a detailed consideration is too complex for one publication. Therefore, the subject of further work is to take a closer look on every outlined solution approach. The solutions are already prototypically implemented and first investigations have shown that the overall approach is powerful enough to provide the needed data visibility, accuracy and transparency for the new business models and concepts. To achieve this, CEP is used, which allows logistics companies to identify and anticipate exceptions and possibilities represented by events.

ACKNOWLEDGMENT

The work presented in this paper was funded by the German Federal Ministry of Education and Research under the project LogiLeit (BMBF 03IPT504A).

REFERENCES

- [1] Lockwood-Lee, J., Forey, G., Lockwood, J.: Globalization, Communication and the Workplace: Talking Across the World. Continuum International Publishing Group (2010)
- [2] Win, A.: The value a 4PL provider can contribute to an organisation. International Journal of Physical Distribution & Logistics Management 38, 674-684 (2008)
- [3] Schmitt, A., Weber, P.D.J.: 4PL-Providing als strategische Option für Kontraktlogistikdienstleister: Eine konzeptionell-empirische Betrachtung. Deutscher Universitätsverlag (2006)
- [4] Eveline van Stijn, D.H., Yao-Hua Tan, Bram Klievink, Sietse Overbeek, Frank Heijmann, Markus Pikart, Tom Butterly: THE DATA PIPELINE Global Trade Facilitation Conference 2011, (2011)
- [5] Bughin, J., Chui, M., Manyika, J.: Clouds, big data, and smart assets: Ten tech-enabled business trends to watch. McKinsey Quarterly 56, 75-86 (2010)
- [6] Roth, M., Donath, S.: Applying Complex Event Processing towards Monitoring of Multi-party Contracts and Services for Logistics – A Discussion. In: Daniel, F., Barkaoui, K., Dustdar, S. (eds.) Business Process Management Workshops, vol. 99, pp. 458-463. Springer-Verlag, Berlin Heidelberg (2012)
- [7] Weigand, H., Xu, L.: Contracts in E-Commerce. In: Meersman, R., Aberer, K., Dillon, T. (eds.) Semantic Issues in E-Commerce Systems, vol. 111, pp. 3-17. Springer US (2003)
- [8] Luo, Z.: Service Science and Logistics Informatics: Innovative Perspectives. IGI Global (2010)
- [9] Gudehus, T., Kotzab, H.: Comprehensive Logistics. Springer-Verlag, Berlin Heidelberg (2009)
- [10] Luckham, D.C.: The power of events: an introduction to complex event processing in distributed enterprise systems. Addison-Wesley, Boston (2002)
- [11] Luckham, D., Schulte, R.: EPTS Event Processing Glossary v2.0. Event Processing Technical Society (2011)
- [12] Bruns, R., Dunkel, J.: Event-Driven Architecture: Softwarearchitektur für ereignisgesteuerte Geschäftsprozesse, Springer-Verlag, Berlin Heidelberg (2010)
- [13] Yao, W., Chu, C.H., Li, Z.: Leveraging complex event processing for smart hospitals using RFID. J Netw Comput Appl 34, 799-810 (2011)
- [14] Wang, F., Liu, S., Liu, P., Bai, Y.: Bridging physical and virtual worlds: complex event processing for RFID data streams. Advances in Database Technology-EDBT 2006 588-607 (2006)
- [15] Zang, C., Fan, Y.: Complex event processing in enterprise information systems based on RFID. Enterprise Information Systems 1, 3-23 (2007)

¹ <http://smartsensor-temperature.dhl-innovation.com/>

² <http://www.cambridgeconsultants.com/news/pr/release/116/en>

³ <http://www.adiwa.net>