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Investigating into the Prevalence of Complex Event Processing and Predictive Analytics in the Transportation and Logistics Sector: Initial Findings From Scientific Literature

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INVESTIGATING INTO THE PREVALENCE OF COMPLEX EVENT PROCESSING AND PREDICTIVE ANALYTICS IN THE TRANSPORTATION AND LOGISTICS SECTOR: INITIAL FINDINGS FROM SCIENTIFIC LITERATURE

Completed Research

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Abstract

As ever new sensor solutions are invading people's everyday lives and business processes, the use of the signals and events provided by the devices poses a challenge. Innovative ways of handling the large amount of data promise an effective and efficient means to overcome that challenge. With the help of complex event processing and predictive techniques, added value can be created. While complex event processing is able to process the multitude of signals coming from the sensors in a continuous manner, predictive analytics addresses the likelihood of a certain future state or behavior by detecting patterns from the signal database and predicting the future according to the detections.

As to the transportation and logistics domain, processing the signal stream and predicting the future promises a big impact on the operations because the transportation and logistics sector is known as a very complex one. The complexity of the sector is linked with the many stakeholders taking part in a variety of operations and the partly high level of automation often being accompanied by manual processes. Hence, predictions help to prepare better for upcoming situations and challenges and, thus, to save resources and cost. The present paper is to investigate the prevalence of complex event processing and predictive analytics in logistics and transportation cases in the research literature in order to motivate a subsequent systematic literature view as the next step in the research endeavor.

Keywords: Logistics, Complex Event Processing, Predictive Monitoring, Predictive Analytics, Transportation.

1 Introduction

With the ever growing diffusion of sensors and other small technical devices yielding signals and responses, a data treasure is being created which many companies already have their eyes on recovering. Not only do enterprises from the sector of information and communication technologies envision huge potential coming with the new data, but also companies producing and shipping goods expect valuable insight and decision-making support from the new data resources (Davenport 2014, Mayer-Schönberger 2013).

In order to do so, however, intelligent ways of processing the data need to be applied. Methods of complex event processing (CEP), predictive data monitoring and analytics and proactive techniques, respectively, appear to be suitable for the purpose.

With the help of real-time processing of the incoming signals and events, monitoring processes and swiftly reacting to certain situations can be enabled. By using the collected data in order to understand the historic developments and to draw conclusions for the (nearer and further) future is another option to utilize the data. In its ultimate extent, the data can be used for forecasting the future and, in case of expected situations or undesired events, appropriate counter-measures initiated accordingly.

The present paper presents the results of an investigation of the current scientific status quo of complex event processing and predictive analytics in the transportation and logistics sector. Moreover, it introduces those application areas and use cases in which the technologies have already been realized (or are currently being done so).

For that purpose, the present paper introduces the terms event processing and CEP, predictive and proactive monitoring and analytics as well as a differentiation between some of the confusing terms. In addition, a preliminary literature study of roughly five dozen papers has been conducted in order to categorize the different publications into the different areas of transport, logistics and supply chain management. Eventually, an understanding of the current prevalence and significance of the above-mentioned technologies in the transportation and logistics domain and the distribution of the existing use cases across the different areas within the domain can be gained from the overview of scientific literature.

The above-mentioned work is part of a broader research endeavor which deals with the benefit potential of the technologies in the areas of logistics, transportation and supply chain management. Consequently, the work presented in this paper are considered to be the initial step of the overall research and to be followed by a systematic literature review and the subsequent identification, confirmation and extension of benefit categories for decision-makers in the domain. Eventually, a profound benefit prediction and the compilation of essential preconditions for a wide acceptance of the technologies throughout the domain represent the ultimate goals of the research work.

2 Background study

In this part, the different technologies are introduced and explained. After introducing the technologies of event processing and complex event processing, the subsequent sub-chapters deal with the technologies of predictive analytics and predictive monitoring. The sub-chapter also focuses on the coherences between CEP and monitoring and the differentiation between predictive monitoring and predictive analytics. Thereafter, proactive monitoring and analytics are explained.

2.1 Complex Event Processing

Prior to the definition and explanation of the concept of complex event processing, the greatly related terms of "event" and "event processing" need to be presented as these two terms are referred to in all the definitions in one way or another.

For these reason, it is important also make an introduction to "event" and "event processing": Luckham (2002) declares that "an event is an object that represents or records an activity that happens, or is thought of as happening". The definition is being used and referred to by himself and other authors thereafter (Dunkel et al 2000, Edwards et al 2010, Etzion 2011, Kuo et al 2013, Luckham 2002, Luckham 2008a, Luckham 2008b, Luckham 2011, Luckham & Schulte 2008, Moxey et al 2010). On the other hand, the change of a system state is the main definition for Dunkel et al (2000). Concepts of the respective business domain describe these changes and constitute the basic events (Dunkel et al 2000). When it comes to certain business environments, an event could be anything remarkable that occurs in a business process. For instance, it can be a problem, an opportunity, a threshold reached or a deviation (Michelson 2006).

A good definition for event processing is a computation that performs operations on events, incorporating also actions such as reading, creating, transforming and deleting events (Luckham & Roy 2008). In a deep analysis also proposed by Luckham, the basic idea behind event processing comes with the behavior of a system. It can be a model developed by a computer program with a "simulation language". Then, the program creates events that mimic the interaction between components of a system (Luckham 2008c).

Following this, complex event processing is a concept related to generate actions to system, people and device. These actions are triggered according to predefined patterns of events, which can be hierarchized according to its importance. In other words, "CEP is about getting better information, in real time" (Adi 2007). Another definition also based in events claim that these actions are triggered of a complex range of different events in different times and contexts, and not only by a single event (Adi 2007).

CEP consists of get information through the principles of processing clouds of event. Furthermore, technologies are needed to implement those principles (Luckham 2008c).

It could be also defined as a concept for methods, techniques and tools in order to process events in real-time continuously and promptly, which means in the course of the events happening. It derives from complex events and must be seen as a combination of several single events (Eckert & Bry 2009).

According to Dunkel et al (2000), CEP is "an event processing model to cope with a huge number of events. […] The main idea of CEP is that events are not independent from each other, but exhibit interdependencies and correlations. Therefore, event processing has to consider multiple events occurred over a longer historical period tying to match an event pattern that is meaningful for a certain application domain" (Dunkel et al 2000). An important concept for the definition is Information Systems (ISs). Real-world activities can be described as events in the lowest layers of IS. These events follow certain patterns and form a complex relationship between them. CEP comes to enable the awareness of target real-world activities by tracking these patterns and IS (Terroso-Saenz et al 2012).

2.2 Predictive Analytics and Monitoring

The subsequent sections contain definitions of 'predictive analytics' and 'predictive monitoring', respectively, and clarify the difference between the two.

2.2.1 Predictive analytics

The term 'predictive analytics' belongs to the area of business analytics and basically uses information, data or understanding that happened in the past in order to predict the future with the help of data mining techniques (Ranadivé 2006, Siegel 2013). The idea is about identifying relationships between the existent data in the past, finding patterns in the collected data and then showing some trends in the future. It applies not only for real-time that impacts operational process but also in batch. One example for the first case is real-time identifications of suspicious transactions while the second case could be target new customers in a website (Lustig et al 2010).

According to an IBM study, the main question behind predictive analytics is "What could happen?" It will give necessary insights to provide answers related to the historical data. Thereby, predictive analytics enables the anticipation of scenarios. It is possible to look into the future rather than just react to what has already happened. It does not base on single data only, but on trends and correlations to identify patterns. Many organizations use predictive analytics for all kinds of decision for example business actions and operations (IBM 2013).

Delen & Demirkan (2013) add another question besides "What could happen?" in order to define predictive analytics: "Why will it happen?" which explains the reasons for some trends or possible facts in the future (Delen & Demirkan 2013). When it comes to Supply Chain Management, Waller & Fawcett (2013), declare that "it uses both quantitative as qualitative methods to improve supply chain design and competitiveness" (Waller & Fawcett 2013). Finally, predictive analytics is considered as a toll using statistical techniques, data mining and machine learning. The main goal is to "make predictions about unknown future events" (Lechevalier et al 2014).

2.2.2 Predictive monitoring

The meaning of predictive monitoring is about anticipation, management and mitigation of critical events, potential alterations and unexpected circumstances (Di Nitto et al 2008; Salfner et al 2010). Basically, the term contains the aspect of monitoring real-time developments and to make forecasts about the (mainly short-term) future.

Monitoring is essential to detect occurrence of events, enabling the identification of the real cause(s) of an unexpected event, e.g. a process failure (Obeid 2010). Looking at the definition of CEP, this idea is totally related to that concept. Monitoring is also an important part of event processing conceptual architecture. It will be important for "administrative purposes, notify failures in the event infrastructure, and gather and display statistics about the event flow" (Edwards 2010). According to Yao et al 2011, "CEP rules […] can provide sufficient support for processing RFID and other sensor data, such semantic data filtering and real-time monitoring" (Yao et al 2011). As a conclusion, it is needed that event processing and service orientation are integrated into each other in order to achieve an effective monitoring (Buchmann et al 2011).

When it comes to event-based diagnostics, there is a clear necessity for more powerful monitoring. Then, it will be done with Complex Event Processing, which provides capabilities to a distributed system. Thus, we are able to improve the monitoring and diagnostics at the network level (Luckham & Frasca 1998). Especially, because even CEP is partly understood as a new technology used in order to detect business condition by means of monitoring of a flow of events and recognizing patterns in real-time (Lundberg 2007).

Important predecessors and facilitators of CEP and, thus, extremely related to monitoring are Business Activity Monitoring (BAM) and Active Databases which enabled alert notification and triggers based on reactive rules and still are essential to helping people understand (in general terms) what is CEP about (Luckham 2008d). Sometimes, CEP and BAM are even considered to be quite complementary. According to this view, an amalgamation of "real-time data absorption and analysis capabilities with strong presentation facilities to interface with the decision-makers" is realized with the integration of both concepts (Wootton & Fritz 2008).

In the most general form of CEP, the concept of an event pattern is very important because once the events can be standardized, it enables the prediction of upcoming events (Luckham 2008a). By combining of event processing with data analytics techniques and embedding real-time analytics in order to predict events in the short term, predictive monitoring is achieved (Moxey et al 2010).

As has been explained in the last sub-chapter, predictive business is an approach that enables the anticipation of costumer needs, avoidance of potential problems and creation of opportunities (Lundberg 2007). Feldman et al have leveraged initial proposals to extend CEP with predictive capabilities and developed a concrete combination of a predictive model with probabilistic rules that fires alerts based on predictions (Feldman et al 2013; Metzger et al 2015).

2.3 Proactive Monitoring and Analytics

After explaining the link between the common terms ‘proactive analytics’ and ‘prescriptive analytics’, the terms ‘proactive analytics’ and ‘proactive monitoring’ are defined and distinguished from each other.

2.3.1 Differentiation between proactive and prescriptive analytics

In some circumstances, the term “proactive analytics” is replaced with ‘prescriptive analytics’ and used synonymously.

For a better clarification, the definitions of the dictionary can be used as first step. While the attribute ‘proactive’ is defined as “action and result-oriented behavior” (BusinessDictionary.com) in opposite to the reactive one that waits for events to happen and then tries to react to them. Proactive behavior aims at identification and exploitation of opportunities and in taking preemptory action against potential problems and threats (BusinessDictionary.com). Prescriptive, on the contrary, differentiates from proactive because it takes into consideration not only actions before an event takes place, but also deals with rules and instructions to deal with these actions. The exactly definition is: “giving exact rules, directions, or instructions about how you should do something” (Merriam-Webster Dictionary).

According to Peter Coffee (2015), the difference between these two concepts is the question behind them: While the statement for prescriptive is “this is how to do it”, for proactive the sentence is “this is how to make sure it won’t blow up”. Despite the small differences between these two concepts, they will be treated synonymously throughout this paper.

2.3.2 Proactive analytics

Proactive analytics can be considered as the extension to predictive analytics, as it is possible to take advantage from the knowledge about the (most likely) course of the actions and to plan measures accordingly (Puyet 2013). According to Davies (2014), the “optimization of complex problems with many dependencies, predictive modeling, regression analysis and other advanced methods for proactive decision making” (Davies 2014) belong to proactive analytics.

In contrast to predictive analytics, prescriptive analytics not only predicts the events that will happen, but also enables and supports decision-making and, consequently, aims to lead to the best response, given the limited resources of an enterprise. It is made using mathematical algorithms keeping in view a system of potential decisions and the interaction between those decisions (Lustig et al 2010, Wu & Coggeshall 2012). The question that drives prescriptive analytics is “What should we do?” using simulation and optimization. It will provide a set of possible and suggesting action alternatives based on predictive Analytics. It is possible also answer why these actions are recommended and show a reliable path to an optimal solution (IBM 2013). Prescriptive Analytics is realized by a bridge between pure analysis and actual optimization in order to generate specific action recommendations in order to achieve a goal (Groeger et al 2014). As part of earlier research, the authors have incorporated aspects of prescriptive analytics into the development of Future-Internet-based supply chain control towers which were supposed to detect undesired events in the short-term future and to suggest most effective counter-measures (Alias et al 2014). Another approach towards prescriptive analytics, which shows the relationship between predictive and prescriptive analytics once more, is to identify two phases: After predicting the future at first, this future is then carefully shaped (Basu 2013).

2.3.3 Proactive monitoring

Analogous to what has been presented for predictive monitoring earlier, there is a combination of classic monitoring of data streams and proactive analytics.

Proactive monitoring has been referred to as “cognitive,” or “knowledge-driven” monitoring, to reflect its top-down nature” (Mumaw et al 2000). According to Trad and Kalpic (2004), “proactive monitoring implies several factors: automation, detection of problems before they become critical, and reception of reports and alarms by someone who understands their significance” (Trad & Kalpic 2004).

Furthermore, “proactive monitoring is characterized by defining a monitoring strategy before engaging in monitoring” (Mumaw et al 2000). Proactive monitoring can be sub-divided into three categories: deviation detection, problem prediction, and compensatory action. By following this analytical approach, it is possible to understand the relationship between proactive monitoring and prediction, as you scan the incoming signals for anomalies, then predict upcoming events, such as deviations and problems, and eventually take adequate counter-action (Smallman & Cook 2013).

3 Overview of scientific literature

The major purpose of the research work described in the present paper was to investigate the prevalence of complex event processing and predictive analytics in logistics and transportation cases in scientific literature and, thereby, to determine the current status quo of complex event processing and predictive analytics in the transportation and logistics sector. Apparently, the question reveals a research gap which has not been closed sufficiently in current scientific literature. Similar literature studies have been conducted with other technologies and their prevalence in the transport and logistics sector earlier. For instance, Frehe et al (2014) have conducted a neatly organized literature study in order to examine the role of big data in the logistics sector. Fosso Wamba et al (2015) sketch the business value of big data in various industries. Also, Waller and Fawcett have looked into the potential of data science, predictive analytics and big data in the logistics domain (Waller & Fawcett 2013a; Waller & Fawcett 2013b).

3.1 Literature base and analysis method

In order to create an overview of pertinent scientific literature, the authors have collected a total of 207 publications which exhibit a more or less strong link to the technologies of CEP, or predictive or proactive analytics/monitoring, respectively. The compilation has been performed with EBSCO, Elsevier's Scopus, ScienceDirect, IEEE Xplore, and Google Scholar, using search terms like ‘transport’, ‘logistics’ and ‘supply chain management’ in combination with the terms of the technologies explained in the preceding chapter.

However, not all of them present solutions or solution approaches with a more or less clear relation to transport and logistics operations, which are either directly derived from the logistics domain or observed among logistics-related processes in the value-creating (e.g. manufacturing) sectors. The residual publications rather focused on technical details or successful implementation examples in different sectors and environments.

For the further consideration, only those publications that do feature a strong or sufficient relation to the transportation and logistics domain have been included into the literature base. In order to determine the papers with a link to the pertaining domain, that relation has been refined into the attributes ‘strongly linked’, ‘sufficiently linked’ and ‘weakly or not linked’, dropping the latter from further consideration. In the end, 58 different publications have formed the basis for a detailed analysis of the current state of the above-mentioned technologies in logistics environments. (The publications used for the overview have been marked with an asterisk in the References chapter.)

Basically, the works have been published between 1998 and 2015 and authored by researchers working in many different countries, mainly the United States of America, Israel and Germany.

The papers have been worked through in order to identify the precise technology applied and the specific application environment into which the technology has been introduced. For that, an assignment of each publication to the technology categories it belongs to and to the application area within a newly created logistics classification has been executed. By doing so, the authors were capable of safeguarding a sufficient level of detail when preparing the results. Some papers were eligible to be assigned to more than one category, which again leads to the fact that the total sum of the publications in a logistics category is not necessarily equal to the sum of the individual technology subtotals.

3.2 Logistics process classification

In order to assign the publications to the different application areas in an effective manner, a new logistics classification had to be created. While existing classifications, such as the process classification in the Supply Chain Operations Reference (SCOR) model, fail to provide a satisfactory level of granularity with respect to the application areas of CEP, or predictive or proactive analytics/monitoring, respectively, traditional categorization oftentimes does not cover all areas of logistics processes (within the logistics domain and outside of it) adequately (Blanchard 2004, Langford 2007, Vahrenkamp 2005).

Hence, the new classification encompasses the logistics domain category, the value-creating sector category and a general category of supply chain management. In the logistics domain category, processes of transport, transshipment and storage processes are differentiated from each other. Within the transport processes, processes are distinguished from one another according to the transport mode and type. In the category of value-creating sector, all application examples with respect to logistics processes in a series of industries have been subsumed. The third category comprises solutions for logistics in general, mainly referring to supply chain management concepts with more than one or two stakeholders involved.

3.3 Results and findings

Within the three technological areas, there is considerable difference in prevalence. Figure 1 shows that CEP is implemented in more application areas than the other areas. Whereas CEP is integrated in 37 application examples mentioned in the examined publications, predictive technologies are used in 30 applications and proactive approaches applied in 14 cases. One explanation is the longer history of CEP in opposition to the other two technologies. Another one may lie in its benefits and advantages in logistics and transportation processes. It is to be highlighted that CEP and predictive technologies nearly go head to head which indicates the huge potential in the domain promised by predictive technologies that still need to be untapped.

In view of the three major categories of the new logistics classification, a similar picture can be seen in Figure 2: While the logistics domain has 42 publications dealing with different application areas and examples, the value-creation sector merely exhibits 22 papers, with production areas dominating over examples from the services industry. The supply chain management category counts 17 relevant publications.

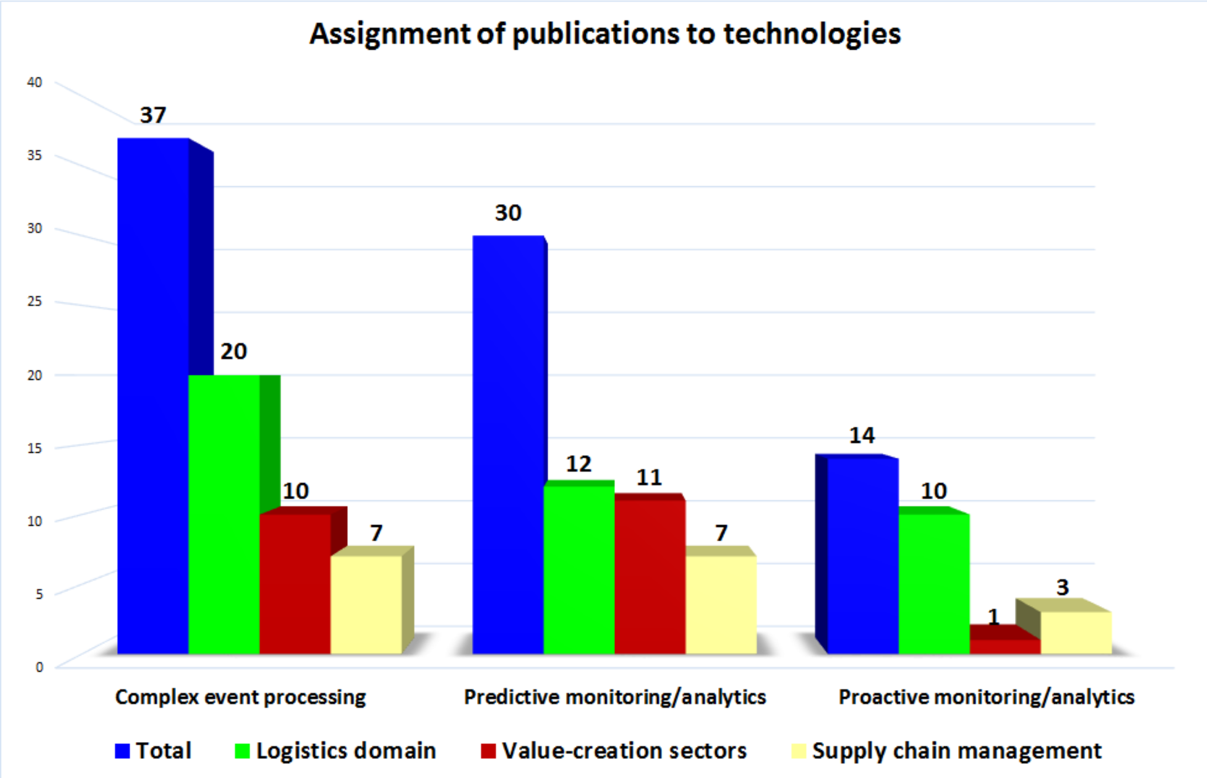

Figure 1. Assignment of publications to technologies

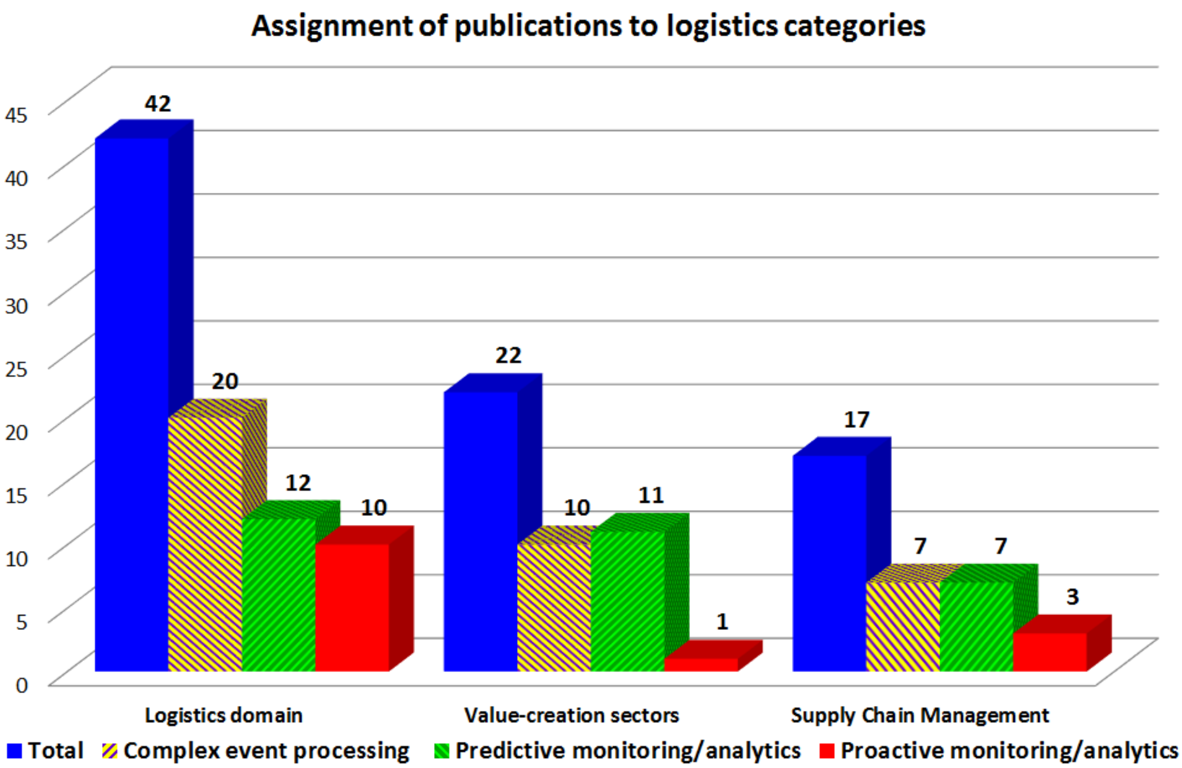

Figure 2. Assignment of publications to logistics categories

One explanation is certainly the stronger focus and drive behind the actors of the logistics domain as they expect considerable efficiency gains in their respective businesses by introducing the technologies. In contrast to the logistics companies, value-creating companies generally do not have a focus on logistics processes. Thereby, efficiency gains in logistics processes are not in the limelight of the decision-makers in the related sectors which again leads to the considerably lower number of solutions and solution approaches researched upon. If at all, it seems to be accepted that the above-mentioned technologies fuel performance enhancements in general supply chain management environments with several stakeholders involved.

When analyzing the results deeper, two of them are striking (see Figure 3): Firstly, there are application in as much as 21 different domain categories which shows a broad applicability of the solutions in different areas of logistics, transportation, and supply chain management. Secondly, most examples examined concentrate on certain areas within the logistics domain while the respective distributions of papers about a certain technology are rather different. Consequently, the different sub-categories feature a heterogeneous status quo with respect to the use of the various technologies.

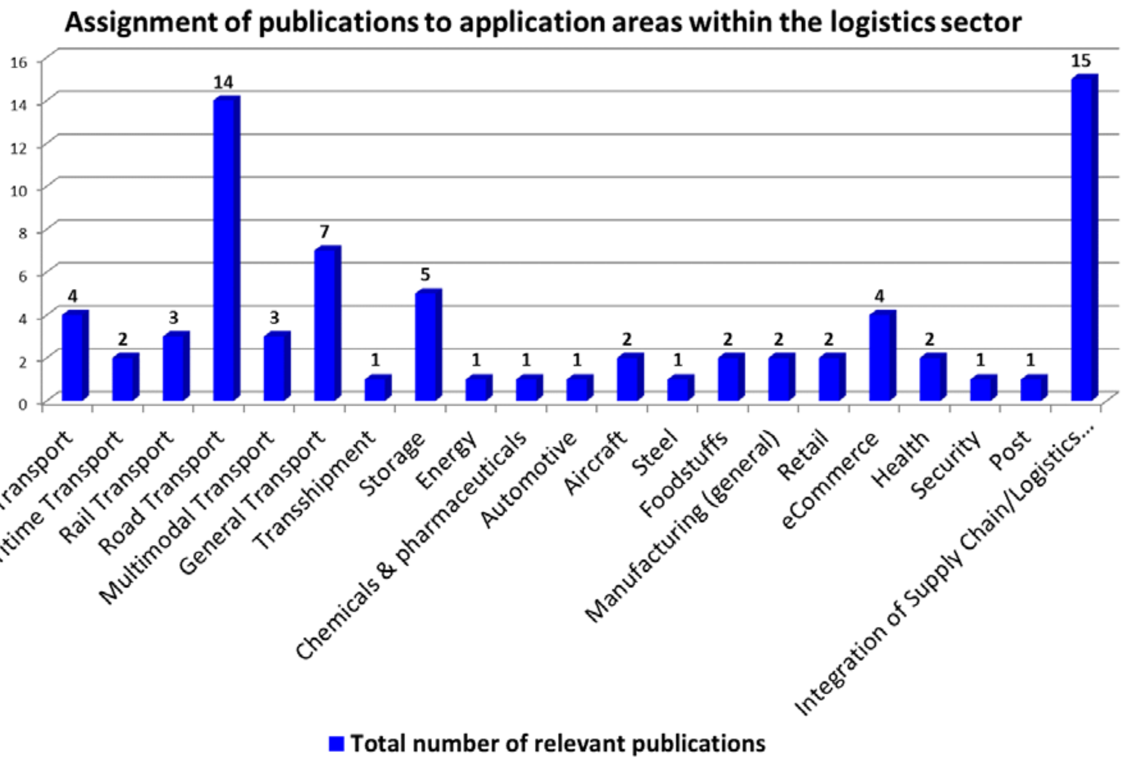

Figure 3. Assignment of publications to application areas in the logistics domain

More precisely, the areas with the highest number of publications in total are rather generic (see Figure 3). Supply chain integration features 15 publications, while implementation in road transport counts 14 papers and general transport solutions still seven papers. This could indicate that the technologies still lack maturity and do not offer apparent benefits in their current condition considering their short history of development to date. In addition, identifying, analyzing and emphasizing the benefits from using the technologies in the respective application areas need to play a more important role in the research and development process.

As can be seen in Figure 4, the application areas with the highest number of CEP solutions are not necessarily identical with the ones with most applications of predictive monitoring and analytics or with those with most proactive techniques applied. Similarly, the most numerous applications with reference to complex event processing are found in road transport, general transport concepts and supply chain integration. Concerning predictive monitoring and analytics techniques, examples from the areas of supply chain integration, air transport, and road transport are the most prevalent ones. In terms of solution approaches based on proactive monitoring and analytics, supply chain integration, multimodal transport concepts and storage processes are in a pioneering role. Deeper research needs to be conducted to comprehend the root cause for the results which will lead to the question of the benefits of each technology in use. An early explanation lies in the respective characteristics of each technology which are reflected in their prevalence within the logistics, transportation, and supply chain management domain. A clear pattern is not visible, however, the trend shows that the three technologies seem to be interesting for rather generic application area categories until now. This is related to the early phase of the research and implementation cycle, mainly feasibility checks, formulation of expectations and initial testing. In the course of time, a wider spread of the solutions and a clearer visibility of the most suitable areas within the domain is expected to evolve.

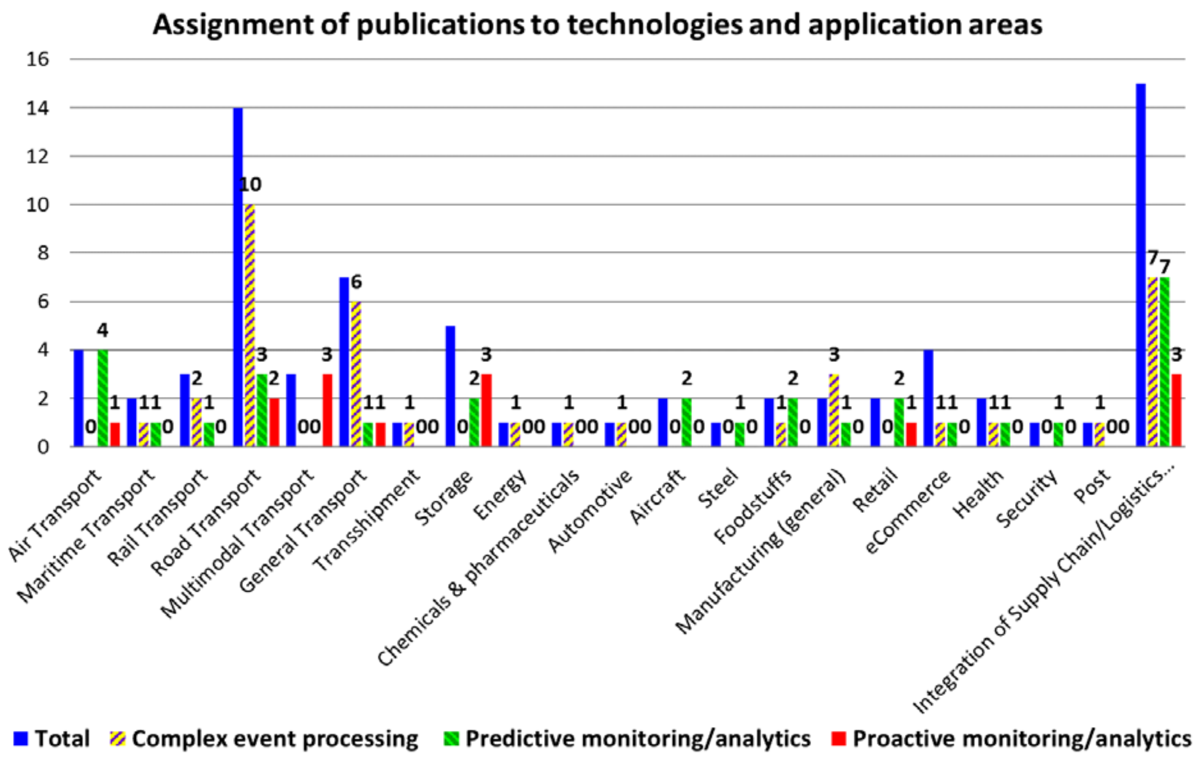

Figure 4. Assignment of publications to technologies and application areas

In conclusion, the three technologies are already spread to a certain extent across the logistics, transportation, and supply chain management domain. Both complex event processing and predictive and proactive technologies have found their way into particular applications and promise further distribution in the domain. Traditionally, transport and logistics is considered to be the most reluctant domain to adopt new technologies (Deloitte & Heads 2015). By highlighting the respective benefits in the various applications environments, the process may be accelerated. For instance, the application of CEP and predictive monitoring in the air cargo industry has exhibited clear benefits for the stakeholders involved, such as increased process transparency and end-to-end supply chain visibility, timely recognition of deviations and errors, immediate response to the deviations and errors detected, and avoiding risks (Metzger et al 2012). After having the identified the benefits for the entire domain and for the respective areas within, the decision-makers can be approached directly and convinced with the help of initial applications and the adoption best-practice solutions.

4 Conclusion and Outlook

In the present paper, the prevalence of complex event processing and predictive analytics in logistics and transportation cases has been investigated with the help of an overview of related scientific literature. The results exhibit an early stage in the process of research and development of suitable solutions for the transport and logistics sector. Furthermore, different application areas appear to expect more benefit from the different technologies. Generally, actors from the logistics domain and the supply chain management field appear to be more active in this particular research process than the value-creating companies from different industries.

After having gained an understanding of the current prevalence and significance of the above-mentioned technologies in the transportation and logistics domain and the distribution of the existing use cases across the different areas within the domain by means of this preliminary literature study, the future research work in the field is the verification of the initial findings from scientific literature by means of three measures: An elaborate analysis of the theoretical findings with respect to application areas in the logistics area by means of a systematic literature review, expert interviews with pundits from the ICT and logistics domain for validation of the findings from scientific literature, and individual case studies, which are supposed to serve as an adequate example of the findings collected earlier and to exemplarily showcase typical benefits.

By these, a profound benefit prediction for the three technologies and the compilation of essential preconditions for a wide acceptance of the technologies throughout the logistics, transportation, and supply chain management domain can be achieved. Thereby, the distribution process is expected to accelerate as soon as decision-makers in the domain comprehend the benefits for their respective organizations' performance.

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