Business Logic for Resilient Supply Chain Logistics

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***Abstract*—Technological advancements of emerging paradigms such as Internet of Things have enabled new modes of system design. The supply chain logistics domain can benefit significantly from advances in monitoring and detection of emergent behavior. This doctoral research aims to investigate how techniques and enterprise architectures can be used in order to improve the resilience of logistics supply chain environments. One of the focus areas is the management and improvement of business logic. The foreseen contributions relate to three business logic design aspects. First is the allocation and scheduling of business logic tasks. The next contribution is related to extracting meaning from colossal volumes of data by accommodating data analytic methods. The last contribution evaluates hierarchical software architectures and the underlying system-wide and individual logistics business process performance. Advise is sought on the prospective role business logic can play to improve real-time decision-making in supply chain logistics.**

***Keywords*-Business Logic; Business Rule; Emergent Behavior; Enterprise Architecture; Internet of Things; Supply Chain Logistics; Multi-agent System**

I. Introduction

The number of uprising systems based on 'smart' technologies is raising tremendous challenges for the supporting software architectures. Key challenges relate to scalability (e.g., coordination of a myriad number of devices), deep heterogeneity (e.g., various types of sensors and actuators), and high dynamics (e.g., unknown network typologies and uncertainty about the features of the networked things) [1]. Among the software architecture paradigms envisioned for emerging systems, the literature suggests no unified or standardized architecture solution addressing these challenges [2].

With the exploding number of data creators and users, intelligence regarding decision-making is more and more made in a distributed manner. To address the aforementioned challenges, it is, therefore, inevitable to allocate business logic close to the point where the actual data is being collected. A recent survey on Internet of Things (IoT) technologies [2] concludes that a considerable amount of data needs to be processed at the end devices before passing it further.

Paradigms such as edge computing and fog computing take advantage of microservice-oriented architectures to allow some, if not all, portion of applications to be moved to subsets of the network [3], [4]. Next generation sensors can perform computational processing supported by artificial intelligence directly on the edge. However, the level of intelligence (i.e., ability to anticipate future events) of business objects carrying smart intelligence, is still limited in many cases. Architectures to support the design of systems that integrate intelligent business logic are needed.

To address these challenges, real-time analytic solutions and consensus based mechanisms for distributed computation and storage among nodes at the 'edge' of the network are rapidly gaining attention [5]. Distributed computing is promising because it allows more fine-grained, immediate, failure-tolerant, and stable control of business objects. Business objects such as smart pallets, are able to monitor, detect, and act upon deviations and disruptions where these actually occur. By doing so, these objects can anticipate to future events locally and prevent events from becoming disastrous at a later point in time. More concretely, monitoring, detection, and response time can be accelerated because of serverless computing and lightweight databases into devices distributed at various (virtual) locations.

In this line of research, we aim to provide such an architecture that incorporates business logic close to the point where the data is actually collected. Typically, in business processes, the start, progress, and end result are determined by reference to a set of rules adhering a certain business logic. Understanding and managing the rules, regulations, and decisions that effect and direct business processes play a major role in achieving an efficient supply chain.

In this work, we design business logic that is adaptive and distributed among physical and virtual business objects. By processing data adequately on the device that actually collects the data, communication costs can be reduced and the overall solution can be more scalable. Further, we provide a comparison of currently existing strategies for adaptive and distributed business logic under a variety of scenarios. Our expectation is that the proposed distributed approach will not displace proven technologies such as cloud computing. It will, however, introduce more resilience and transparency that current approaches lack.

To this end, the field of supply chain logistics seems a promising testbed for the development and validation of emerging enterprise architectures. The examination and

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evaluation of business logic approaches in such architectures remain mostly unexplored in the supply chain domain [6]–[11]. Thus, the supply chain and in particular the logistics domain, will play a prominent role in this projected research.

The remainder of this paper is organized as follows. Section II gives some background information and related work. Section III presents the research design. Finally, Section IV contains some research challenges for which insight is sought.

II. Background and Related Work

This section gives background information and some related work with regard to emerging enterprise architectures, business logic, and supply chain resilience. Also, this section presents some of the expected contributions.

A. Emerging Enterprise Architectures

As stipulated earlier, currently, there is a trend to perform computations and to store data into microservice-oriented software systems. The idea of connecting everything to everything seems simple yet elegance both conceptually and pragmatically. However, the dependency of the common type of client/server architectures in its current form may not be scalable [12]. For example, as the cost of cloud infrastructure and hardware components gets cheaper, the number of connected devices is going to increase exponentially and so will the data that have to be routed through cloud platforms. Furthermore, end-to-end integration of both enterprise level business processes and IoT devices is still lagging behind. Studies still largely lack a unified design for such an integration [13]. Architectures should not only be able to deal with the enormous growing number of devices but also with continuously changing situations.

Sensor nodes embedding sensing, processing, and communication capabilities, executing tasks in a distributed and collaborative manner are becoming ubiquitous in our daily lives [14]. Newly designed (software) architectures applied in supply chains are promising because they enable innovative services based on real-time, smart, and cooperative reasoning and decision-making across physical entities and back-end components on a large scale. The large amounts of data being collected can be used for descriptive, predictive, and prescriptive analytics to plan for and accommodate hazards or caution flags as they arise. Investigating approaches to utilize this data effectively and efficiency is a continuing concern within the field of enterprise architectures.

One of the ongoing challenges related to the increasing number of sensors (and data) in a supply chain is achieving and maintaining sustainable enterprise architectures. The collection and use of data in such architectures must be coordinated based on extensive integration between customers, companies, and suppliers, and above all should be sustainable [15]. The following part of this section moves on to shine new light on these debates through the examination of business logic.

B. Business Logic

Recent developments have heightened the need for modeling real life business objects and their interaction in a sophisticated manner to better align information systems and the actual business processes, and to obtain a greater business resilience. We approach this challenge by exploiting the so-called business logic. In general, business logic is a set of formal or informal statements about how business processes are carried out [16]. Business logic encodes the real-world business rules that determine how processes and data can be created, stored, and changed. It can be represented in the form of business rules, each of which represents a small unit of knowledge of business management [16].

Typically, business logic prescribes how business objects interact with one another and enforces the routes and methods by which business objects are accessed and updated. These business objects (or business entities) can be physical or digital and data sources or data consumers. Essentially, business logic is about determining when, what, and how to exchange data (or information) from one (business) entity to another entity. More precisely, business logic concerns the plan of actions that are planned to be carried out, specifying in detail the proper flow of information.

An example of business logic is as follows. A logistics service provider's business logic may specify that containers, which are transported on a truck, reaching a temperature above a certain limit, say 50 degrees Celsius, be flagged as suspicious. When there is such a flagged container, the truck driver is contacted as soon as possible to confirm the status and to further investigate the case. The policy of flagging such a container is an example of a business rule; the actual process of flagging the container is an example of business logic. Business logic enables such logistics goods to be checked and processed in an efficient manner.

One of the projects that already addressed upon similar concepts some years ago, is the EU funded project CoBIs (Collaborative Business Items) (e.g., see [17]–[19]). CoBIs enables the delegation of tasks originally located in back-end systems down to mobile assets [18]. Collaboratively, smart objects are able to reason on common states and enforce pre-defined conditions with limited support of back-end systems. However, we believe that, still as of today, this concept is in its infancy and requires a more analytical understanding to prove its applicability. Thus, we plan to leverage these underlying concepts to develop smart business objects towards applications in a more matured environment.

C. Supply Chain Resilience

The tendency to design supply chains to become more robust and flexible such that these can remain unaffected or less affected in the face of disruptions is receiving increasing attention recently (e.g., see [11], [20], [21]). Resilience implies that the system can adapt to regain its original state or a new desirable state (recover, or return close to, its original state) after perturbations [22]. These disruptions can originate from within the boundaries of the supply chain or can be external (e.g., natural disasters), and the resulting consequences may be light or catastrophic. Thus, resilience is not just about recovering from mishaps, but should also be considered as proactive, structured, and integrated exploration of capabilities within the supply chain to cope with unforeseen events [22].

The logistics supply chain seems a promising domain for validation of the theories and models we aim to develop (see Section III). In the food industry, for example, relative minor disruptions early in the supply chain can result in tremendous food losses in the end. By considering data flows coming from all types of sensor devices spread across transport modalities and a multitude of other (event) triggers, we may get insights into making the supply chain more resilient against disturbances.

D. Expected Contribution

The increasing number of sensors and other data sources that can be used to determine the conditions of logistics goods, as well as new approaches to control or modify the conditions on time, yield an arsenal of opportunities to real-time control the quality of a supply chain. Our expected research contribution aims to unravel some of the mysteries surrounding the term resilience in a logistics supply chain context. In particular, we intend to determine the extent to which a resilience performance can be achieved by exploiting different levels of business logic. To this end, a combination of quantitative and qualitative approaches will be used to analyze how business logic could be encapsulated in state-of-the-art enterprise architectures.

III. Research Design

In this subsection, we successively describe the research challenges, research objectives, scope of this research, research questions and approach (as inspired from [23]), and thereby stress in more detail on our expected contribution. Lastly, we present the research planning.

A. Research Challenges

This research project provides a great opportunity to advance the understanding of business logic in enterprise architectures and its impact on supply chain environments. Following a similar line of reasoning as the work of [23], in essence, our problem consists of a market with data supplying and demanding entities. Typically, supply chains involve multiple stakeholders, each of which has their decision-making processes about whether or not to share or utilize data. Furthermore, data requests and supplies arrive continuously over time and have different characteristics, which affect the business logic (e.g., origin, destination, accuracy, response time, etc.).

The intention of this doctoral research plan is to focus on real-time decision-making of business objects in supply chain logistics where decisions regarding business logic should be made continuously over time. Decisions involve the management and execution of business logic tasks.

We focus on task allocation and scheduling of business logic in a distributed manner in which business logic is allocated to business objects. Besides that, we consider an appropriate mix of a heterogeneous variety of sensing object types (e.g., 'dump', legacy, smart, etc.), which provides challenges regarding the management of the business logic. Besides looking at these two problems, we focus on the use of historical data to improve real-time decision-making of business logic. By using historical data we may derive insights into emerging behavior that can be used to increase the resilience of supply chain systems. Lastly, by employing quantitative and qualitative modes of inquiry, we attempt to illuminate the evaluation of various scenarios. So, managing the business logic such that the overall system is resilient against disruptions poses a few challenges:

1. **Allocation and scheduling of business logic tasks**
   In developing a distributed system capable of assigning and scheduling of business logic, a few design decisions can be made. Some of the key design aspects relate to (1) which type of business objects to consider, (2) which resources and/or tasks are represented by these objects, and (3) how are decisions regarding the business logic made (e.g., interaction among business objects and infrastructure for hierarchical decision-making). The study of different design alternatives on the logistics supply chain is important to provide insight into the overall performance.
2. **Extract meaning from the huge volume of data to help improve decision-making in supply chains**
   Business logic allocation without taking into account the future consequences of a decision would be inappropriate. In particular when business logic is complementary or substituteable a certain plan of actions may become unfavorable when new business rules appear. To extract meaningful information from the huge volume of data that is being generated, it is appropriate to (1) gather insights into the historical data to better understand the changes that have occurred (descriptive analytics), (2) understand the future (predictive analytics), and (3) provide advise on possible outcomes (prescriptive analytics).
3. **Evaluation of variety of architectures**
   Distribution of business logic among business objects seems promising from various perspectives. However, following a similar line of reasoning as posed in one of the challenges mentioned by [23], it is still unclear

whether and when the system-wide performance of distributed systems will be similar or even better than the performance of more centralized (e.g., cloud) and hierarchically-based systems (e.g., fog). Furthermore, it is challenging to design architectures which embed distributed business logic and yield a stable behavior and desirable quality of service performance. Besides that it would be appropriate to know whether and when what type of architecture is desirable in which logistics environment, it would be convenient to analyze the behavior of collaborative, partly collaborative and non-collaborative business objects. Not only studying the behavior of business objects is relevant, but also evaluating supply chain logistics performance perspectives. Therefore, we need to not only consider the design of different type of environments (e.g., open, closed, mixed, etc.) and architectures but also resilient performance metrics.

B. Research Objectives

We address the aforementioned challenges by the following research objective:

> *To analyze in which way and to what extent business logic can be used for real-time monitoring and detection of emergent behavior in resilient supply chain logistics.*

The objective presented in this doctoral paper is twofold. First, the design of a system (e.g., proof of concept) that allows real-time planning and control of business logic, and second, a system that accurately evaluates the individual business object's performance and the system-wide performance. These two objectives are mutually dependent. On the one hand, to verify the resilience of real-time planning and control protocols, the performance needs to be evaluated properly. On the other hand, for evaluating the performance of various scenarios, it is convenient to consider applicable real-time business logic rules. To this end, we design strategies for business logic under a variety of scenarios.

Throughout the envisioned stream of research in this paper, the terms emergent behavior (also called emergence) and supply chain resilience play a salient role. These terms raise intriguing questions regarding the nature and extent to which they can be related to business logic captured by (distributed) business objects. For example, emergence can be seen as a result of unfamiliar and unique behavior that has occurred or emergence can be considered as unrecognized behavior that has been a possibility from inception [24]. As discussed by authors of [24], providing solely these two terms seems too general and too ambiguous to ascertain exactly what is meant by them. More research on this topic needs to be undertaken before the association between emergent behavior, supply chain resilience, and distributed business objects is more clearly understood. As exemplified in the subsequent part of this research design section, we will propose a taxonomy to define and distinguish different levels of (1) business logic, (2) supply chain resilience, and (3) emergent behavior.

C. Research Questions

To reach our objective, we have composed a succession of research questions which we have to answer. The main research objective, as formulated before, is a guiding theme of this research and can be reached through answering the research questions. For each question, we provide a brief description including the planned approach for answering them. A series of four research questions are formulated:

1. *What is the state of the art on existing enterprise architectures for monitoring and detection of emergent behavior in supply chain logistics?*
   We provide a comprehensive and updated overview on recent advancements in the field of upcoming architectures for resilient supply chain logistics. By focusing on business logic and supply chain logistics, this literature review offers a complementary perspective to the recent studies on, for example, upcoming (middleware) architectures, in that it is more in depth focused on supply chain logistics as a unit of analysis.
2. *How to allocate and to schedule tasks for distributed business logic such that a resilient logistics supply chain is achieved?*
   Having outlined what variety of enterprise architectures exists and what is meant by emergent behavior and business logic, we will now move on to discuss specific design choices in the design of a system for distributed business logic.
   We will propose a multi-agent system where business logic agents are responsible for task allocation and scheduling decisions. Thereby, we consider a variety of design choices, such as (1) reflecting a variety of levels of intelligence of the agents (e.g., learning behavior) and (2) hierarchical planning and control structures (e.g., centralized, distributed, etc.). Together with a profound rationale about supply chain resilience, these design choices will be reflected in a devised taxonomy.
   We aim to apply the model to a real life case study to demonstrate our approach. More specifically, we plan to design and to develop a multi-agent system for distributed business logic at a transport company in the Netherlands.
3. *How to use information on historic data flows to improve business logic strategies for making the logistics supply chain more resilient to disturbances?*
   The huge volume of data generated creates a plethora of opportunities to improve the management of business logic tasks. To this end, we consider gaining insight into potential benefits for employing different

business logic strategies by incorporating quantitative methods at data flows that are being generated.

We plan to develop three data analytic methods to improve business logic strategies. First, we propose a process mining approach in which we study the influence of streams of event data, collected throughout the supply chain (e.g., time, transportation duration, storage conditions, etc.) on a series of resilience metrics. Second, we present a hierarchical structured approach for detecting and monitoring emergent behavior (e.g., outliers and missing events), based on a similar data mining technique. The focus is on understanding what data is relevant to assess likely outcomes. Third, we provide the linkage to the actual business logic and use the first (descriptive analytics) outcome and the second (predictive analytics) outcome to design and develop an approach where business logic is adaptive and dedicated to find the best course of actions for a certain situation (prescriptive analytics).

The benefits of the strategies are mainly evaluated by means of simulation, adhering real-world use cases. The primary focus of these three approaches for improving the business logic strategies is respectively descriptive, predictive, and prescriptive analytics. Furthermore, the results will be condensed into the multi-tiered taxonomy according to different levels of business logic, resilience metrics, and emergent behavior.

4. *What is the impact of different business logic strategies for distributed business objects on the performance?* We propose an agent-based model and we elaborate on improvement strategies. So far, we evaluated the solution approaches separately by studying the performance of the agent-based model and individual improvement aspects individually. We focus on providing insight into the business object's performance versus system-wide performance by enabling them to use the proposed models of the previous research question. In particular, we are interested in comparing our solutions to more established systems such as cloud-based solutions, in terms of resilience. One of the objectives may be to maximize the resilience of the supply chain logistics network while simultaneously managing the monitoring and detection of the emergent behavior. We evaluate a selection of the aforementioned models by using a case study of a Dutch transport company.

D. Research Planning

The steps to be carried out during this doctoral project are visualized in Fig. 1. In the first step, we aim to conduct two state-of-the-art literature reviews. The second step comprises the allocation and scheduling of business logic tasks, which will be designed in a multi-agent system. In the third step, we consider business logic improvement strategies. In this regard, we designed an agent-based process mining architecture in which process models (and in a later phase business logics) are extracted out of data streams of events (e.g., see [25]). This architecture is validated by means of conducting simulation experiments on a logistics case study. A natural progression of this work is to investigate how this architecture can be used for predictive and prescriptive analytics with reference to business logic. The fourth step is designated to the performance evaluation with regard to the envisioned taxonomy.

IV. Advice Sought

The research is still in the early stages and thus, there are a number of challenges ahead for which the doctoral consortium can provide advice on or share similar experiences and insights into. Advice is sought regarding two core concerns. First, *What business logic features should be included in modern enterprise architectures for analyzing emergent behavior?* The focus of this research project is mainly on business logic for monitoring and detection of emergent behavior in a distributed hierarchical structure. However, this project would greatly benefit from expert advice and guidance regarding approaches for integrating business logic in physical and virtual business objects, especially in the area of enterprise architectures. One of the outcomes may be a set of guidelines for selecting an appropriate architecture and set of business rules suitable for a supply chain logistics application at hand.

Second, *What problem variants, solution methodologies, and tools are available and relevant to modeling business logic in supply chains?* We are interested in linking business logic to the actual performance of a logistics supply chain. Particularly, on the encapsulation of resilience performance metrics reflected upon decision made in real-time by the

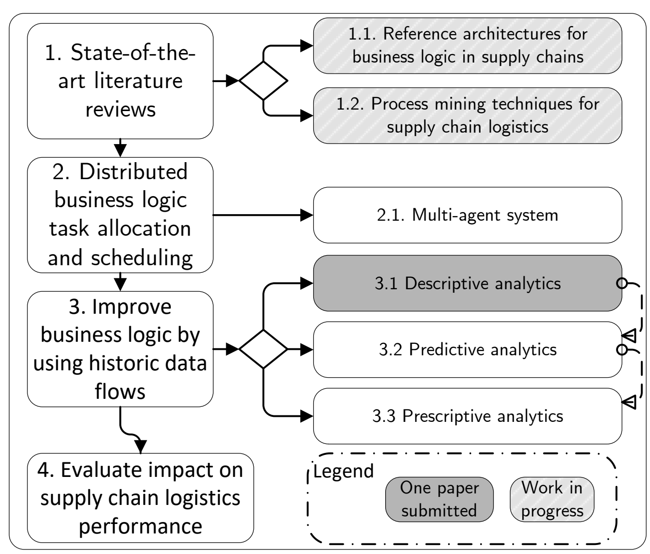

Figure 1. Road map of the planned doctoral research.

logistics business objects. Thus far, we used process mining as an initial attempt to extract business logic features from a logistics case study (see [25]). However, it may be interesting to combine this approach with other data analytic methods or to investigate particular case studies in this regard. Thus, this line of research would benefit from the expert opinions and discussions concerning measures or methodologies that could be used in real-time decision-making involving business logic.

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