Automated Supply Chain Formation – A Theoretical Framework

Florina Livia COVACI
"Babeș-Bolyai" University Cluj-Napoca,
Business Information Systems Department,
Cluj-Napoca, Romania
florina.covaci@ubbcluj.ro

The purpose of this paper is to review the different concepts and approaches regarding automated supply chain formation (SCF) in order to create a theoretical framework and identify gaps in existing research in SCF regarding the complexity of practical implementation in the context of Industry 4.0. The research is conducted through analyzing three perspectives regarding the complexity of the SCF process: 1) the existence of a central authority, 2) the mechanisms employed for communication between entities in the supply chain, 3) one/multi-unit dimension for the traded goods. A theoretical framework was created and the following gaps and issues were identified in the existing research literature: 1) Parameters used in order to pairwise suppliers/consumers are limited. 2) The resulted supply chains are assessed mainly using a profit optimization function for the end-consumer. 3) The possible risks associated with participating entities in the supply chain are not considered.
Keywords: Automated Supply Chain Formation, Theoretical framework, Industry 4.0

1 Introduction

The First Industrial Revolution generated by water and steam powered mechanical manufacturing, evolved into the Second Industrial Revolution in the mid 1800s as mechanical advances gave way to technological growth. The Second Industrial Revolution brought advances in electrical power and enabled the growth of mass production and the factory line. The Digital Revolution, known as the Third Industrial Revolution was characterized by the widespread adoption of new digital technologies used to automate production.

The Fourth Industrial Revolution, Industry 4.0, it is getting us to Smart Factories and hence to Smart Supply Chains. Industry 4.0 is the culmination of several technological innovations: complex sensors, artificial intelligence, cloud computing and advanced robotics.

Industry 4.0 focuses on the creating intelligent products and production processes. In future manufacturing, factories will have to deal with the rapid product development, flexible production and complex environments [7]. Within the smart factory of the future, the algorithms will enable the communication between humans, machines and products alike [8], [9]. As they will be able to acquire and process data, they will control and automate certain tasks and interact with humans by using interfaces.

Due to increased digitization of processes, supply chain formation is also affected by the fourth industrial revolution. Therefore, inside the end-to-end supply chain formation process there is need to focus on agility and precision. As the supply chain formation will be affected by the technological changes, a theoretical framework needs to be created in order to understand whether the existing research literature is able to capture the complexity of real implementations.

Supply Chain Formation (SCF) is defined by [1] being the process of determining the participants in a supply chain (SC), who will exchange what with whom, and the terms of the exchanges.

Based on a structured literature review, a theoretical framework is developed within this paper to understand the complexity of the supply chain formation from multiple perspectives. This analysis will be the basis for further identifying the issues and gaps in the current research literature. This systematic review includes high-rated scientific conferences like Conference on Artificial Intelligence (AAAI), International Joint Conference on Artificial

Intelligence (IJCAI), International Conference on Autonomous Agents and Multi-agent Systems (AAMAS), ACM Conference on Electronic Commerce and international journals which were published since 2000. The following journals were selected according their relevancy with respect to the scientific topic: Advances in Artificial Intelligence, Engineering Applications of Artificial Intelligence, Decision Support Systems, Journal of Artificial Intelligence Research, Computational Intelligence, International Journal of Electronic Commerce, Agent-Mediated Electronic Commerce, Engineering Applications of Artificial Intelligence, Knowledge-Based Systems and The Computer Journal. The articles considered have been identified by searching keywords, afterwards being confirmed to be relevant for our literature review based on the title, abstract and content. Furthermore, the selection of the papers has been made based on the addressed issue and according to their content, with focus on: the type of approach regarding an existing central authority, techniques employed for modelling communication and whether they are addressing or not multiple units in the process of supply chain formation.

2 Identify Key Concepts and Approaches
Supply chains are generally complex usually spread over multiple functions or organizations. Within the context of Industry 4.0, this brings in many challenges for automated supply chain formation and coordination. Supply chain members cannot compete as independent members. The product used by the end customer passes through a number of entities contributed in the value addition of the product before its consumption.
An essential aspect in the successful integration of Industry 4.0 concepts is the digitalization of the supply chain. The machines should

be able to interoperate and communicate with each other in order to push forward processes and make decisions to become human independent. The goal of this paper, is to understand the relevance of the multiple interrelated approaches and concepts discussed with respect to supply chain formation and identify gaps and issues in the research literature. For this purpose, a two-step approach was applied. First, a systematic literature review was performed to create a theoretical framework (Fig. 1).
This framework summarizes frequently discussed technologies and models within the validated literature and allocates them to the identified key concepts and approaches related to supply chain formation. As shown in the framework, the approaches and concepts can be summarized into three perspectives according to the characteristic features. Second, all the approaches were evaluated to understand and identify gaps and issues in the literature and find future research directions for enabling the digitalization within the supply chain formation.

2.1. Approach used regarding a central authority
A. Centralized
The centralized approaches make use of a central authority in order to solve the SCF problem. Within these centralized approaches, there are several contributions in literature, that are using Combinatorial Auctions (CA) [2], [3], [4], [5], [6]. CA provide a negotiation mechanism which is capable to deal with complementarities among the traded goods. As the industry often has to deal with complementarities, CA appears as well suited mechanism towards automated SCF.
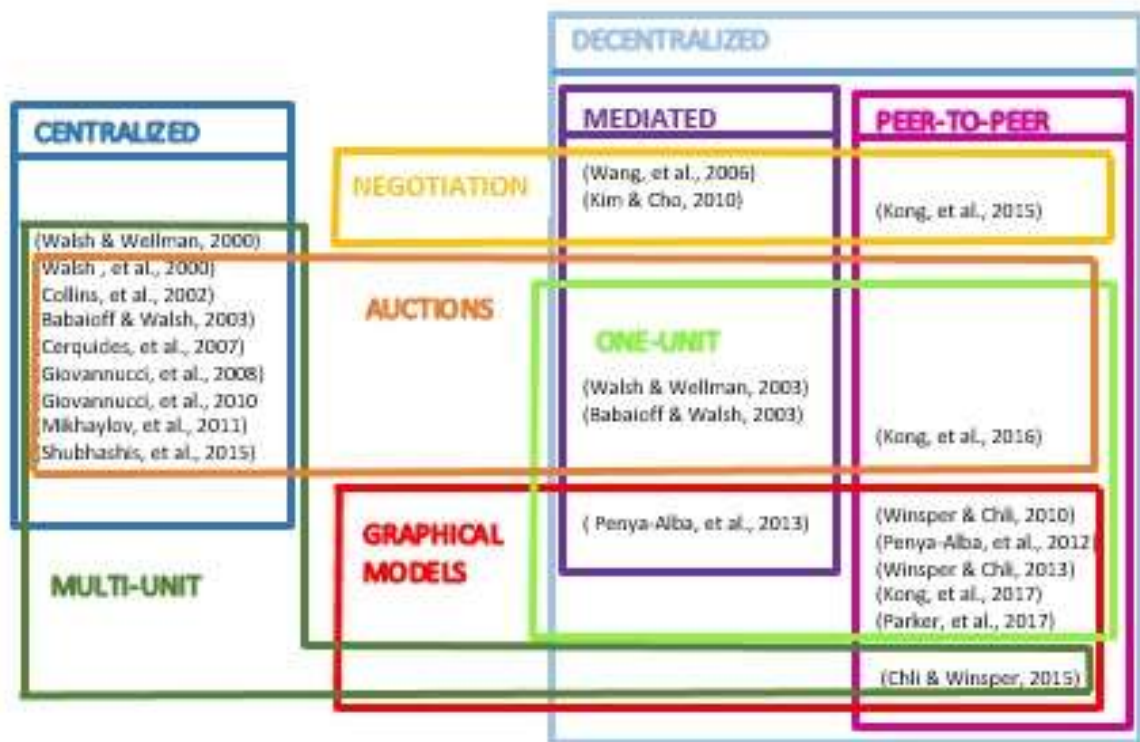
Fig. 1. Theoretical Framework for Supply Chain Formation

This sort of approaches employ an auctioneer that plays the role of a central authority of the system. The auctioneer collects all the bids from all agents in the supply chain. Next, the auctioneer computes the supply chain solution with the best value and notifies all agents if they are active (i.e. take part in the SC) or not and the conditions of their interactions. One such method of centralized SCF that uses CA was proposed in [5]. Moreover, the authors provide analysis over the economic impact that strategically bidding participants might have in the SC. Herein after, a model capable of dealing with precedence and temporal constraints was introduced in [2]. Hence, they provide a schedule as a solution for the execution of the supply chain.

Later on, a more expressive bidding language than the standard CA was introduced in [6] that allowed to incorporate multiple times a transformation in the same bid. Depending on how many times they are performed, the transformations are able at providing multiple units of a good, providing various bundles of trans-

formations and different prices for a transformation. In order to solve the Winner Determination Problem(WDP) using CA, Integer Programming (IP) is mostly employed for achieving that. The input for IP consists in the bids of the participants, the goods that the auctioneer is expecting and a set of readily available goods for the auctioneer. The output of the IP consists in a set of executed transformations corresponding to the accepted bids from the participants. If there are cases when IP is formulated according to a specific order for performing tasks, the output consists in a series of executed transformations for producing a certain required output [6].

In order to improve the computational complexity of the previous approach, the authors in [4], propose solving the WDP by analyzing the problem topology in a formal manner.

Another approach of [3] proposes the solving of the SCF problem using sequential iterations. Hence, first the auctioneer is accepting bids for the goods that are required and subsequently, will accept bids for the goods that were required goods at the previous iterations.

In all the approaches described above, there exist an auctioneer that collects all the required information about the participants that are involved in producing a good and afterwards will determine which are the active participants in the SC. In the process of solving the SCF problem there exist a communication mechanism for the participant agents to communicate with a central auctioneer. In the first step, participants send bids to an auctioneer, then the auctioneer performs computing of the SC configuration and afterwards, the auctioneer sends to each participant the information whether he should be active in the SC or not. We must note that, in centralized approaches there is no communication mechanism between agents that are participating in the SC.

B. Decentralized
In decentralized approaches, the participants in the SC are represented by agents during the SCF process. The agents negotiate directly with each other in a peer-to-peer (P2P) communication or may rely on local markets in mediated approaches, markets where are traded the goods they want to sell or buy. In the following subsections we detail both peer-to-peer and mediated approaches for solving the SCF problem.

B.1 Peer-to-Peer
In these approaches, the participant agents directly communicate with the seller agents for the goods they are consuming and with the buyer agents for goods they are producing [7]. Hence, in the SCF process each agent will communicate with the potential partner agents, the communication process being performed directly between the participants. In [8] an approach that solves the SCF problem making use of P2P communication has been proposed. In this approach the SCF problem is referred as an optimization problem, the max-sum algorithm being employed to provide approximate solutions to the problem. The max-sum algorithm is being applied in functions that can be additively decomposed and it covers three steps. At the first, step, the problem is being mapped into a graph named local term

graph. Afterwards, an iterative message exchanges mechanism is being performed between the graph's vertices. The last step consists in determining the states of the variables. The work in [8] is the first fully decentralized approach however it undergoes several limitations. For instance, the communication requirements are high because each of the participants communicate with all their potential partners. Moreover, the participant agents can decide if they want to collaborate with each potential partner. Hence, in an environment with high degree of competition, the communication requirements for the participant agents will increase as the number of potential partners increases.

In order to overcome scalability issues present in [8] and [7], the authors in [9] provide an approach for decentralized SCF, called the Reduced Binarized Loopy Belief Propagation algorithm (RB-LPB). RB-LBP is based on the max-sum algorithm and is able to simplify the computation of max-sum messages, hence reduces the computation required in P2P SCF to assess SCs.

A negotiation-based task allocation method was proposed in [10] in which every agent owns only a local view and the potential resources are found by consumers through peep-to-peer relationships. Every agents owns multiple resources and a resource can be used only by one task at a moment. As soon as the tasks releases the resource, it can be used by other tasks.

In [11] a decentralized approach in which providers and consumers are modelled as intelligent agents was proposed for group task allocation in dynamic environments. The proposed approach allows agents to enter and leave the environments at any time and the tasks have deadlines, and may need the collaboration of a group of self-interested providers. Each consumer has the role of an auctioneer for itself in order gather all the resources required by its task, no central authority/auctioneer being involved. The absence of a public auctioneer improves the communication and computation requirements and pro-

vides better consumer's privacy because consumer is not required to reveal its private information to a public authority.

A belief propagation-based method, called PD-LBP, was proposed in [12] for task allocation in dynamic environments. It is composed of two phases: a pruning phase that aims at reducing the searched resource providers, and a decomposition phase that decomposes the initial network into several independent sub-networks on which is operated in parallel the belief propagation algorithm. Also PD-LBP approach overcomes the limitation of LBP where only the quotes of the participants are considered, by considering both a reserve price and a deadline for agreement to be accomplished.

A decentralized approach for allocating agents to tasks whose costs increase over time was proposed in [13] aiming to minimize the increase in task. Based on max-sum algorithm, the authors show how a distributed coordination algorithm, can be used for including costs of tasks that grow over time, enabling a wider range of problems to be solved.

B.2 Mediated
These approaches rely on a local market for each of the goods that are being traded in the SC. A mediator is used in each of these markets, hence the seller agents and the buyer agents of the traded good communicate with the mediator. During the SCF solving process, the participant agents communicate only with the mediators of the goods they are interested in selling or buying.

The SCF problem was modelled in [14] as a satisfiability problem, a decentralized method being proposed in order to solve it using local markets and mediators. However, using the proposed method turn out to be very slow even when dealing with small problems. Later on, in order to overcome the poor performance, the authors proposed in [1] a novel decentralized method, called SAMP-SB-D, that was able to provide solutions to the SCF problem relying on mediators. A mediator agent is used for each of the traded goods so the agents are solely communicating with the mediators of the goods they have an interest in buying or selling. Each participant agent is submitting ascending bids to the mediators and each mediator is running simultaneously an auction for the good it is responsible for. As discussed in [7], although this method proved to be economic efficient, it has high communication requirements. This happens because in the running auctions the mediators must re-evaluate and send messages to the winners of the running auctions each time they are receiving a new bid.

A one-shot double auction mechanism, named Trade Reduction was proposed in [15]. Mediators are used for each of the traded goods in a distributed algorithm using a communication mechanism between a central coordinator agent and the mediators in charge.

The authors in [16] use an argumentation based negotiation while in [17] a heuristic-based agent negotiation method is proposed for the supply chain formation problem. The facilitation of allocations through preference, capability aggregation and elicitation is based upon dedicated mediator agents in both [17] and [16].

An algorithm called the CHaining Agents IN Mediated Environments (CHAINME) algorithm, was proposed in [18] as a novel method for mediated SCF, aiming at providing SC configurations that are economically efficient meanwhile having low computational requirements. Compared to standard max-sum algorithm, in CHAINME the computation performance is improved through efficient use of the local terms and employment of message simplification techniques.

2.2. Techniques employed for modelling communication
A. Negotiation
Distributed negotiation is an approach which is well-suited to the modelling of supply chain formation: each individual procurement and sale decision by each participant in the supply chain can be modelled as a multi-party negotiation, with bids or offers allowing participants to express their capabilities and preferences to potential exchange partners. [16] uses argumentation based negotiation for decision making in supply chain formation, while Kim

and Cho (2010) proposes a heuristic-based agent negotiation method for supply chain formation. The results of [17] suggest that their negotiation method is capable of producing reliably near-optimal allocations in their scenario.

In [10] a negotiation-based task allocation method for a dynamic environment was proposed, in which every agents owns multiple resources and a resource can be used only by one task at a moment. After the consumers find the potential resources, they start to negotiate with the resource providers. It is often difficult for agents to decide the optimal contract prices, so the agents have the option to negotiate with more than one potential partner, and thus the de-commitment and penalties are necessary and considered in the negotiation process.

B. Auctions

Several approaches for SCF are modelling the supply chain as a network of auctions, most frequently combinatorial auctions or double auctions. Supply chain formation by means of auctions is an approach that is frequently used because auctions are often encountered in real-world sales situations and most of the times are able to provide satisfactory solutions for the supply chain formation problem. This subsection will review the auction-based approaches.

B.1 Double Auctions

A market protocol with bidding restrictions named simultaneous ascending (M+1)st price with simple bidding (SAMP-SB) was proposed in [1]. It employs multiple simultaneous ascending double auctions in order to produce solutions over multiple network structures that are maximizing the difference between the costs of producers and the values obtained by consumers. However in networks where competitive equilibria didn't exist it encountered difficulties in providing economic efficient solutions. A de-commitment phase was included in a similar protocol, called SAMP-SB-D, that was proposed by the same authors, in order to deal with the dead-ends that ap-

peared in situations where one or more producers acquired partially the required complementary input goods and therefore are not being able to produce their output good. The allocation de-commitment phase was recognized and discussed as not being a perfect approach, due to problems that appeared at delivering the results of auctions as nonbinding. The authors proposed in [15] the Trade Reduction mechanism, a one-shot double auction mechanism. The mechanism was used for determining allocations in a centralized and also in a distributed manner. Moreover, when performed in a distributed manner it makes use of mediators for each traded good and a central coordinator agent.

B.2 Combinatorial Auctions

In order to find allocations using agents' strategic bidding behaviour in [5] a combinatorial auction protocol was proposed. The usage of combinatorial approaches in solving the supply chain formation allows biding for bundles of goods, hence avoiding the problem of dead ends when the agents are dealing with complementary input goods. Although the results of the combinatorial protocol in [5] were not significantly improved compared to the double auction protocol, the authors show that the existing surplus in the network influenced in most part the quality of the found solutions.

A mixed multi-unit combinatorial auctions (MMUCA) for SCF was proposed in [6], in which the authors replaced the combinatorial model of bids for bundles of goods with negotiations over "transformations". These transformations refer to commitments of bidders that having a set of input goods will produce a set of output goods. As MMUCA is using integer programming and suffers from scalability issues, in [4] the authors proposed an improved version of MMUCAs that would make them applicable to SCF problems with an increased number of participants. By making use of structural properties of the network, the authors proposed a mapping of an integer program that proved to improve the computational efficiency of the WDP. Also, within the framework of combinatorial auction, in [4], a

Petri-net formalism was added to the auctioneers, formalism that in acyclic networks leads to optimal solutions.

In [19] an approach for solving the WDP involving multi-attribute combinatorial reverse auctions was proposed, considering two attributes, namely price and delivery rate. The "all-units" discount strategy being applied on both price and delivery rate makes the WDP problem more challenging.

An indicator based combinatorial auction-based approach for task allocation, called ICAA, was proposed in [11]. An indicator is employed for every group, in order to enable the consumer to choose the most appropriate group. Each consumer has the role of an auctioneer for itself in order gather all the resources required by its task and is limited to communicating with its neighbouring agents.

C. Graphical models

Probabilistic graphical models provide means for encoding in graphs probability distributions over a set of variables [20]. There are two types of graphical models: directed and undirected. In directed graphical models a qualitative dependency between variables, as well as quantitative statistical dependence can be represented. The undirected graphical models can be used to represent dependencies between variables that are symmetric.

A distributed and decentralized inference method, called Loopy Belief Propagation (LBP), that uses graphical models, was proposed in [7], in order to solve the SCF problem. It relays on max-sum algorithm and estimates the nodes' marginal probabilities using a message passing mechanism with iterative stages.

The nodes are sending at each iteration to all their neighbours, a message that contains their beliefs about the probability that the recipient node being in each of the possible states. The receiving nodes update their beliefs about their own states using the content of the received messages. The nodes keep sending messages and update their beliefs until they get to a stable state.

As LBP suffers from scalability issues the authors in [9] introduce the Reduced Binarized Loopy Belief Propagation algorithm (RB-LBP). RB-LBP uses binary variables which simplifies the supply chain formation process because each buy and sell decision is decoupled and encoded in a different variable, from the rest of buy and sell decisions. By decoupling the buy and sell decisions the performance of the LBP algorithm has been improved as the algorithm reduces the considered amount of combinations.

A graphical inference method that is able to model supply chains scenarios with multiple units of traded goods was proposed in [21]. The starting point for this approach was the LBP algorithm [7] that was proposed for solving in a decentralized manner the SCF problem. The authors extend it in order to accommodate the multi-unit and variable capacity scenarios.

Based on [7] approach, the authors in [12] proposed a two-phase method that aims to improve the performance of the LBP approach by fast convergence and agile response in highly dynamic and unpredictable environments. The pruning phase provides means for decreasing the number of providers involved while decomposition phase decomposes the network into several independent sub-networks on which belief propagation algorithm can be run in parallel leading to quicker convergence.

2.3.3 Number of units
A. Single-unit approaches

Modelling the supply chains as task dependency networks was first described in [1]. The authors model the supply chain as a bipartite directed acyclic graph having two types of nodes: one type representing the producers and consumers and the other type of nodes representing the goods. The edges describe the possible flows of goods between the producers and consumers. A producer is able to produce one unit of an output good and each consumer may buy a single unit of each good from the set of his input goods.

The formalism described above was transformed into Markov random fields in [8] [7], by eliminating the specific depiction of the

goods in the graph, making it suitable for inference. A message passing mechanism is used instead of the bidding process in auctions, mechanism that allows participant agents to communicate their own beliefs regarding the optimal configuration of the supply chain without the need to reveal more information about cost than they would do in an open auction.

In [9], the computational performance of the approach in [7] was improved by making use of binary variables in order to decouple buy and sell decisions.

Even if they are able to deal only with single unit of goods scenarios, the decentralized and distributed manner in which the algorithms proposed in [7] and [9] operate, bring important advantages for modelling realistic scenarios involving self-interested business entities likewise they are able to provide reliable exact solutions in tree-structured networks and good approximations in loopy networks.

B. Multi-unit

Double and combinatorial auctions are approaches that can be generalized to multi-unit scenarios, although the application of combinatorial auctions to this situations brings in a very hard problem.

The bidding language that was introduced by the authors in [6], increased the expressiveness of standard CA and allowed the modelling of bids containing several times the same transformation.

Depending on how many times the transformations were performed they were able to provide various bundles of transformations, multiple units for the same good and also different prices.

Analysing the problem topology in a formal manner, the authors in [4], were able to improve the computational performance of the WDP by means of an Integer Program. The inputs for the Integer Program are: the bids placed by participants, a set of expected goods and a set of readily available goods for the auctioneer. Also, within the combinatorial auctions framework, in [22] a Petri-net for-

malism was added to the auctioneers, formalism that in certain networks structures leads to solutions that are optimal.

The max-sum based LBP algorithm is applied, in a dynamic scenario using a multi-unit approach as described in [21]. The authors model additional constraints such as input-output ratios and production capacities suggesting that their approach produces reliable solutions for several network structures in a multi-unit problem scenario.

In [19] a multi-attribute combinatorial reverse auction approach was proposed for solving the Winner Determination Problem. In involves multi-attribute with multiple items and considers two attributes, namely price and delivery rate, along with multiple instances of items.

3 Discussion

Among the numerous decision variables that are essential in managing supply chains, the supply chain contracting literature commonly concentrates on those that are related to: pricing, quality, specification of decision rights, quantity flexibility, minimum purchase commitments, lead time, buy-back or returns policies and allocation rules [23]. The values for contract decision variables may give different utility to different supply chain agents'. Utility functions reflect preferences of agents which, in turn, influence their decision criteria. In the existing automated supply chain contracting literature agents are mainly interested in the amount of profit they can obtain. Moreover, in multi-level environment, the contract decision variables at different levels of the supply chain interact with each other. For example the contract adopted by a supplier and a manufacturer is sometimes dependent on the contract adopted by same manufacturer with his/her distributor in the same supply chain. There is a need to explore such relationship and to consider different combinations of contracts at multiple levels of supply chain.

In general, supply chain literature views the agent interactions as transactions where suppliers and consumers exchange goods at multiple levels of the underlying interaction

graph. Due to globalization process and outsourcing practices, the decentralized scenarios are widespread nowadays. Where production is outsourced, decentralized supply chains are being formed; hence the decision making is spread over all the entities involved at multiple levels in the supply chain. Moreover, highly integrated firms adopt some rule-based decision making process within the organization, setting various incentives for internal actors placed at structural level of the organization. Thus a decentralized supply chain inherently appears within such organizations.

When decision making is decentralized, decisions are made by independent participating agents the supply chain, hence the global optima of whole chain might not be aligned with the agents' incentives. Therefore, coordinating the agents' decisions becomes an important issue. By viewing a supply chain a group of rational agents interacting with each other according to pre-specified rules, an improved supply chain management is achieved by designing appropriate contracts coordinating the agents' decisions.

In a decentralized system, due to the incompatibility of the incentives of agents, the decisions that are optimal for the agents may be sub-optimal for the supply chain as a whole. The incompatibility of incentives in decentralized supply chains resides in the fundamental characteristic of the agents: rationality. This rationality of individuals involves that each agent is seeking at maximizing its own utility and each agent is being able to estimate her optimal decisions given the available information, which leads to the maximization of her utility. As a consequence, the agents will assume the supply chain optimal decisions only if they understand that those decisions are also optimal for themselves.

The measurement of supply chains performance can be performed by using coordination as an assessment criterion. In order to obtain an optimal performance of the supply chain, a certain set of actions should be executed and these actions are not always aligned with the interest of the participants. The local optimal value that each decision maker gets by optimizing her objectives doesn't have to be aligned with the global optima for the whole supply chain. The participating entities in the supply chain are mainly focused on optimizing a private objective function, hence the overall supply chain might end in a poor performance. However, the supply chain can get to optimal performance if contracts are being used to ensure the transfer of payments between the participants, such that each participant's aim will be become aligned with the objective of overall supply chain's [24].

The double marginalization problem is a relevant example of this phenomenon, first described by [25] in the economics literature. It has been shown that when a buyer and a supplier are operating independently, they will produce less than an integrated firm, because they get less than the total contribution margin at any given quantity [26]. This is certainly the case where decisions of supplier and buyer that are local optimal are not optimal for the global supply chain problem. Hence, it can be said that the non-integrated supply chain is less efficient, since the total expected profit of the non-integrated supply chain is smaller than the expected profit of the integrated supply chain.

To enable coordination between the members, the supply chain has to rely on contracts. The contracts enable better management of supplier buyer relationship and risk management as they provide means to specify several parameters within which a buyer places orders and a supplier fulfills them.

One necessary condition for a mechanism to be coordinating a supply chain is aggregating the individuals' utility functions in such a way that the supply chain optimal decisions would also be the optimal ones for the individuals. The preferences of the agents are expressed by utility functions, which determine their decision making criteria. The literature regarding supply chain contracts, as a simplification, usually assumes that the agents' utilities are monetary payoffs functions, meaning that agents will only care about the amount of profit they get. However, recent trends consider utility functions that reflect other parameters as well.

Another necessary condition for coordinating is that the individuals must will fully accept the contract and it cannot be forced. There are at least two approaches in the literature that formulate the acceptability condition of a contract. The first approach argues that a contract is acceptable if the utility of each agent is being above a certain acceptable level for that agent. The acceptable levels can be interpreted in different ways: opportunity costs, reservation profits, outside options, or status quo utilities. The second approach claims that besides guaranteeing minimum utilities for the agents an acceptable contract must also divide the extra utilities in a fair manner among them.

There are multiple reasons for solving the SCF problem using a decentralized approach. First, the SCF by being an inherently decentralized problem, no central entity might have the allocative authority to perform such operation [1]. Second, finding a feasible configuration represents an NP-hard problem [14]. Therefore, in large markets, the SCF problems implies complex optimization problems which might turn impossible to be solved the in an exact manner due to computational constraints. Third, centralizing the communication and the computation in a central entity introduces a single point of failure [7]. The decentralized and distributed approaches of [7] and [9] of LBP and RB-LBP also allows for the avoidance of the scalability issues present in centralized approaches, therefore SCF problems are better addressed by some form of decentralization.

In double and combinatorial auctions there exists no scope for participants to change their properties or to enter or leave, each participant places a single set of bids, and the process of computing a solution to the problem begins immediately. Periodic auction-based approaches, such as the SAMP-SB double auction protocol from [1] permit the departure of existing participants or the entry of new ones during the bidding process, and allow participants to change their bids although typically with some restrictions.

The supply chain environment is the collection of external factors affecting the supply chains' decisions. According to [27] some of the most relevant dimensions of supply chain environment are as follows:

Certainty/Uncertainty of environment: The uncertainty of supply chain environment refers to market demand, two aspects being revealed: the deterministic and probabilistic market demand.

In a deterministic system, the timing of orders is emphasized while with uncertain market demand environment the continuous probability functions are mostly considered. Another source of uncertainty in the supply chain environment is associated with the supply chain' uncertain delivery times and uncertain delivered quantities for the input goods.

Sensitivity of environment to supply chain decisions: In many supply chain models, market demand is assumed to be responsive to decision variables that are originating inside the chain. Among others, the stock level, the market selling price and marketing efforts are the most addressed decisions. For example, in addition to deciding on the ordered quantity, a retailer facing price-responsive market demand should also decide its selling price. This is affecting the coordinating ability of the contract between the retailer and its supplier.

Dependencies among agents in the same tier: The individual decisions of agents that are operating at the same level in the supply chain may influence each other. These dependencies add another dimension to the complexity of models. Several participants at the same level in the supply chain in the same market, may compete over their market shares, or may compete over supplier's quotas when the supplier's capacity is restricted.

Hence, in order to automate the supply chain formation, there is need to find mechanisms that are able to capture the complexity of the trading relations and the influence of several factors for decision making process and also to incorporate risk.

4 Identified Issues in Supply Chain Formation Literature

Various perspectives have been presented in the literature for automated supply chain formation. These perspectives and classification

of literature have been presented in section 2 and discussed in section 3. Hence, the following issues and gaps have been identified:

4.1 Limitation on the number of parameters for the contracts

The existing approaches that has been used as a solution for supply chain formation are considering most frequently only price and in some cases one-unit/multiple-unit of goods when pairwise potential suppliers and consumers. Recent approaches incorporate multiple parameters but still they cannot be chosen by every participant in the supply chain. These parameters are set as a constraint in different existing approaches. In Industry 4.0 real scenarios the SCF problem is a complex one and deals with multiple issues that the involved entities are negotiating on (e.g. quality parameters, delivery time, delay penalties etc.). Also these issues may be different from one participant to another and also there might exist some subjective issues that the participant is considering when making decisions. Hence, there is need to find more flexible mechanisms that are able to incorporate several issues that are not the same for all the participants in the supply chain.

4.2 The assessment of the SC obtained

The assessment of SC obtained by using the approaches presented above is done mainly on profit maximization function of the referenced entity in supply chain.

However, within the context of Industry 4.0, the performance of supply chains is measured throughout a coordination criterion. The term coordination considers environments where exists a single decision maker that has the entire information from various decision makers and is able to optimize the network. However, in environments with multiple decision makers that may have various incentives and information, coordination may face difficulties. Decision makers have an aversion for sharing information regarding the cost and demand that may end up with sub-optimal supply chain performance. Each decision maker is interested in a set of parameters, hence he has

the goal to optimize an individual target function. However the local optimal values don't have to be the same as the global optima for the entire supply chain.

4.3 Risk

An issue that arises from the complexity of Industry 4.0 is the increased risks. For example, there might exist a penalty for every day of delay in delivering the product for the principal contractor in his contract with the main client. He will need to decide which supplier to choose for a critical raw material/assembly. It is often a difficult decision on whether using the higher-priced supplier, even it is know that one is reliable or a lower-priced supplier that also is promising that he will successful deliver, although there is a doubt that he cannot rely on that. There is need for taking into consideration if there are any advantages for using the higher-priced supplier by taking into consideration the risk associated with suppliers.

The risk also arises from uncertainties regarding the market conditions. There are markets with high volatility regarding price evolution even in short periods of time. The volatility of prices has an influence for the demand of a certain product, hence when making decision on which suppliers to choose, a participant in the supply chain has to consider the unpredictable evolution of the market they are acting in.

5 Conclusions

During the supply chain formation process, in order to fulfil their tasks, the supply chain participants, are often dependent on the completion of subtasks (the production of their input goods) by producers upstream in the supply chain.

Based on a systematic literature review, we were able to create a theoretical framework for automated supply chain formation with respect to three dimensions: 1) The approach used regarding the existence of a central authority, 2) The techniques employed for communication between entities in the supply chain, 3) The approach used considers or not a multi-unit dimension for the traded goods.

Furthermore we have identified the following gaps and issues in the existing research literature regarding supply chain formation: 1) Parameters used in order to pairwise suppliers/consumers are limited. 2) Automating supply chain formation implies a coordination problem to firms that must simultaneously negotiate production relationships at multiple levels of the supply chain, but in the existing literature the resulted supply chains are assessed only using a profit optimization function. 3) The possible risks associated with participating entities in the supply chain are not considered.

The issues identified, suggest future possible research directions that would lead to getting closer to digitization of supply chain in the context of Industry 4.0 and would enable machines to become human independent and make autonomous decisions.

The digital supply chain represents the core of the Industry 4.0, and it is key to the main operations of every manufacturing or distributing company. For most of the companies the business is dependent upon the supply chain. The digitization of supply chains requires intelligent and efficient algorithms that are able to incorporate the complexity of real scenarios and establish the new end-to-end processes connecting suppliers and customers. Hence there is still needed research to create models that have flexible contract parameters that incorporate risk and asses the supply chains from the perspective of an integrated supply chain.

References

[1] W. E. Walsh and M. P. Wellman, "Decentralized supply chain formation: A market protocol and competitive equilibrium analysis," *Journal of Artificial Intelligence Research,* vol. 19, 2003.

[2] . J. Collins, . W. Ketter, M. Gini and B. Mobasher, "A multi-agent negotiation testbed for contracting tasks with temporal and precedence constraints,"

International Journal of Electronic Commerce, vol. 7, 2002.

[3] B. Mikhaylov, J. Cerquides and J. Rodriguez-Aguilar, " Solving sequential mixed auctions with integer programming," *Advances in Artificial Intelligence,Springer,* pp. 42-53, 2011.

[4] A. Giovannucci, M. Vinyals, J. Rodriguez-Aguilar and J. Cerquides, " Computationally-efficient winner determination for mixed multi-unit combinatorial auctions," 2008.

[5] W. E. Walsh , M. P. Wellman and F. Ygge, "Combinatorial auctions for supply chain formation," 2000.

[6] J. Cerquides, . U. Endriss, . A. Giovannucci and J. A. Rodriguez-Aguilar, "Bidding languages and winner determination for mixed multi-unit combinatorial auctions," 2007.

[7] M. Winsper and . M. Chli, "Decentralized supply chain formation using max-sum loopy belief propagation," *Computational Intelligence,* vol. 29, no. 2, pp. 281-309, 2013.

[8] M. Winsper and M. Chli, "Decentralised supply chain formation: A belief propagation-based approach," *Agent-Mediated Electronic Commerce,* 2010.

[9] T. Penya-Alba, M. Vinyals, J. Cerquides and J. Rodriguez-Aguilar, "A scalable Message-Passing Algorithm for Supply Chain Formation," Toronto, 2012.

[10] Y. Kong, M. Zhang and D. Ye, "A negotiation-based method for task allocation with time constraints in open grid environments," *Concurrency and Computation: Practice & Experience,* vol. 27, no. 3, pp. 735-761, 2015.

[11] Y. Kong, M. Zhang and D. Ye, "An Auction-Based Approach for Group Task Allocation in an Open Network Environment," *The Computer Journal,* vol. 59, no. 3, pp. 403-422, 2016.

[12] . Y. Kong, M. Zhang and D. Ye, "A Belief Propagation-based Method for Task Allocation in Open and Dynamic

Cloud Environments," *Knowledge-Based Systems,* vol. 115, pp. 123-132, 2017.

[13] J. Parker, A. Farinelli and M. Gini, "Max-Sum for Allocation of Changing Cost Tasks," *Intelligent Autonomous System. Advances in Intelligent Systems and Computing,* vol. 531, pp. 629-642, 2017.

[14] W. E. Walsh and M. P. Wellman, "Marketsat: An extremely decentralized (but really slow) algorithm for propositional satisfiability," in *AAAI/IAAI,* 2000.

[15] M. Babaioff and W. E. Walsh, "Incentive-compatible, budget-balanced, yet highly efficient auctions for supply chain formation," 2003.

[16] M. Wang, D. Wang, D. Vogel, K. Kumar and D. K. W. Chiu, "Agent-based negotiation and decision making for dynamic supply chain formation," *Engineering Applications of Artificial Intelligence,* vol. 22, no. 7, p. 1046–1055, 2006.

[17] H. S. Kim and J. H. Cho, "Supply chain formation using agent negotiation," *Decision Support Systems,* vol. 49, no. 1, pp. 77-90, 2010.

[18] T. Penya-Alba, M. Vinyals, J. Cerquides and J. A. Rodriguez-Aguilar, "CHAINME: Fast Decentralized Finding of Better Supply Chains," 2013.

[19] K. S. Shubhashis, M. Malek and S. Samira, "Winner Determination in Multi-attribute Combinatorial Reverse Auctions," *Neural Information Processing.Lecture Notes in Computer Science,* vol. 9491, pp. 645-652, 2015.

[20] D. MacKay, Information Theory, Inference, and Learning Algorithms, 1st ed., Cambridge: Cambridge University Press, 2003.

[21] M. Chli and M. Winsper, "Using the Max-Sum Algorithm for Supply Chain Emergence in Dynamic Multiunit

Environments," *IEEE Transactions on Systems, Man and Cybernetics,* vol. 45, no. 3, 2015.

[22] A. Giovannucci, J. Cerquides and J. Rodríguez-Aguilar, "Composing supply chains through multiunit combinatorial reverse auctions with transformability relationships among goods," *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans,* vol. 40, no. 4, pp. 767-778, 2010.

[23] A. Tsay, "The quantity flexibility contract and supplier-customer incentives," *Management Science,* vol. 45, p. 1339–1358, 1999.

[24] C. Corbett and C. Tang, "Designing Supply Contracts: Contract Type and Information Asymmetry," *Quantitative Models for Supply Chain Management. International Series in Operations Research & Management Science,* vol. 17, 1999.

[25] J. Spengler, "Vertical Integration and Antitrust Policy," *Journal of Political Economy,* vol. 58, no. 4, pp. 347-352, 1950.

[26] O. Hart and J. Tirole, "Vertical Integration and Market Foreclosure," *Brookings Papers on Economic Activity,* vol. 21, pp. 205-286, 1990.

[27] B. Hezarkhani and W. Kubiak, "Coordinating Contracts in SCM: A Review of Methods and Literature," *Decision Making in Manufacturing and Services ,* vol. 4, no. 1-2, p. 5–28, 2010.

[28] R. Anupindi and Y. Bassok, "Supply Contracts with Quantity Commitments and Stochastic Demand," *Quantitative Models for Supply Chain Management. International Series in Operations Research & Management Science,* vol. 17, 1999.

Florina L. COVACI is currently a PhD. student at "Babes-Bolyai" University, Cluj-Napoca. She has a working experience of more than 10 years in .NET related technologies and her areas of competence include Project Management and IT Service Management. She is *Prince2 Practitioner* and *ITIL Foundation and Service Design* Certified. Her current research interests are automated supply chain formation, multi-agent systems and inference in graphical models.