Roles and responsibilities in supply chains
An agent simulation modeling framework

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Abstract— **To predict which supply chain effects will appear when applying governmental control policies, infrastructure investments, and business strategies, multi-agent-based simulation (MABS) can be used. In this paper, we identify abstract supply chain responsibilities, roles and interactions that are argued to be sufficient for representing all types of organizations involved in the processes of buying and selling products and transport services. The identified responsibilities, roles and interactions are organized into a framework together with a set of modeling guidelines, which we relate to the GAIA methodology to simplify the process of developing multi-agent-based supply chain simulation models. To illustrate the usage of the framework, we provide two case studies where we apply it to two different MABS models.**

I. INTRODUCTION

A supply chain can be referred to as the activities and organizations (actors) that are involved in producing, handling and transporting (moving) products from a producer depot to a customer depot. A supply chain may involve many different activities, ranging from mining of raw material, assembling of components, arranging of transport services and terminal activities, etc. We regard a supply chain as either the whole chain from mining of raw material until delivery to the end-customer, or as only one or a few steps in the supply chain, e.g., in production. In this paper we focus on the decision-making processes that are involved when buying (using) and selling (providing) products and transport services. This means that there are supply chain activities, such as customs, which are outside the scope of our work.

Supply chain activities, such as production and freight transportation, cause different types of effects. There are positive economic and social effects, for instance, due to the possibility to consume products that have been produced at far distant locations, and negative effects, such as emissions and congestion. To influence the consequences of supply chain activities, governmental control policies (e.g., taxes and fees), and infrastructure investments are often used by public authorities to reach governmental goals, such as emission targets and sustainable economic development. On a business level, companies take different types of strategical measures to make their operations as efficient as possible, thereby increasing their profit and improving their positions toward competitors. For instance, the location of a production facility may be changed in order to reduce the need for transportation, or to decrease the cost for production. Another example is to change the production strategy, e.g., to produce according to make-to-order instead of make-to-stock. To prevent undesirable effects from occurring, it is important to be able to predict how different types of measures, such as, governmental control policies or business strategies, will affect the supply chain. Predicting the consequences of supply chain measures can be done by using multi-agent-based simulation (MABS), in which the individual actors of a supply chain, their heterogeneity, as well as the decision-making processes can be explicitly modeled [1]. Studying the relationship between supply chain measures and effects is one important reason for simulating supply chain activities, other purposes include gaining knowledge about a system, visualizing certain phenomena, educating persons in the domain, etc. However, the structure of a simulation model and the entities that need to be modeled are basically the same regardless of what is the purpose of the model.

Supply chains can be organized in many different ways; for instance, transportation can in one supply chain be managed by the seller, and in another supply chain by the buyer or a third party logistics provider. This means that activities, roles and responsibilities in different supply chains will appear differently. However, we argue that on some level of abstraction, the same building blocks can be used to represent all types of supply chains.

The purpose of our work is to simplify the modeling of multi-agent-based supply chain simulation models by identifying abstract roles, responsibilities and interactions that can be used to model all types of supply chain organizations, and to organize them in a framework so that they can be used by analysts and designers of multi-agent-based supply chain simulation models. Moreover, in the framework we will include a set of modeling guidelines that can be used together with an agent-based development methodology, such as GAIA [2], to simplify the process of developing multi-agent-based supply chain simulation models.

As already mentioned, one purpose of our work is to develop domain specific guidelines, which can be used to simplify the process of developing (analyzing and designing) multi-agent-based supply chain simulation models. Since we suggest that the guidelines can be used together with agent-based development methodologies, it is here relevant to present a short discussion concerning such methodologies. A development methodology can be general or it can be

specific for a certain domain, a type of model (e.g., simulation model), or a platform/run-time environment. If we disregard the platform dimension, in our context we have four categories of agent-based development methodologies:

1) General purpose methodologies (e.g., GAIA [2] and Tropos [3]).
2) Methodologies for the supply chain domain.
3) Methodologies for general agent-based simulation modeling (easyABMS [4]), which can be applied to the domain of supply chain decision-making, however without giving any domain specific guidelines.
4) Methodologies for developing supply chain simulation models.

In this categorization of agent-based development methodologies, our work relates to the fourth category, and potentially also to the second category. That is, our framework is specific for the supply chain domain. For the fourth category, the literature contains a number of more or less "re-usable" supply chain simulation frameworks and architectures [5], [6], [7]. In comparison to our work, these frameworks are more detailed and aim towards generating concrete simulation models, while our work is more about conceptualizing the simulated supply chain organizations on a rather abstract level in order to guide the developer in the early analysis and design phases without putting any restrictions on simulation platform, implementation, etc.

From our experience of developing a multi-agent-based supply chain simulation model (i.e., TAPAS [1]), we have realized that domain specific guidance during the early phases would have been useful for supporting and facilitating the development of the model. Moreover, the amount of literature concerning methodological approaches for developing agent-based supply chain simulation models is rather limited, which motivates our work.

In the next section we present a framework of supply chain roles, responsibilities, interactions and modeling guidelines, and in the section after that we apply the framework to two agent-based supply chain simulation models. Finally, we discuss the usability and validity of the framework and the paper is concluded with some future work.

II. A FRAMEWORK OF SUPPLY CHAIN RESPONSIBILITIES, ROLES, INTERACTIONS AND MODELING GUIDELINES

In this section we describe a framework of supply chain roles, responsibilities, interactions and modeling guidelines. However, before presenting the framework, a few important concepts will be introduced in order to help unversed readers.

As mentioned in the introduction, a supply chain can be defined as the activities and organizations that are involved in producing, handling and transporting products from a producer depot to a customer depot. In a supply chain, organizations refer to customers, producers, transport operators, etc. Organizations may also refer to sub-organizations within larger organizations, which enables supply chains to be represented internally within organizations, e.g., when production is performed in multiple steps. We define an organization as a set of roles that are represented within the organization,

such as transport planner and order administrator. Different organizations typically include different roles, and just as roles are assigned to humans in real-world organizations, roles are in an agent-system represented by agents. However, the process of assigning roles to agents is outside the scope of our work. Moreover, a role can be defined as a set of (well-defined) responsibilities, and in the context of supply chain decision-making, a responsibility can be defined as a set of decisions.

A. Responsibilities

An important phase during the analysis and design of a system, is to decide which responsibilities should be captured, and how they should be represented in different roles. As mentioned above, a role is defined as a set of responsibilities, and an agent can be defined as a set of roles together with a set of protocols describing how it is supposed or allowed to interact with other agents in the system. Since our focus is on the decision-making processes in supply chains, we have chosen to define a responsibility as a set of decisions concerning some particular aspect or activity. Even though a responsibility is defined as a set of decisions, there are other more concrete activities, such as actual planning processes, which need to be included in the responsibility to enable decisions to be taken. It should be emphasized that decisions may be delegated, and a decision that relates to a responsibility in a particular role can be delegated to a responsibility in another role, either within the same or another organization. An example is Vendor Managed Inventory (VMI) [8], in which decisions about planning and replenishments of customer inventories are delegated to the supplier.

To capture the demand for products and transportation, which resources and infrastructure to use, and how to use the resources on the infrastructure, we have identified two main types of decisions that need to be represented in a supply chain organization; ordering decisions and planning decisions. Since ordering also relies upon effective planning, we consider planning decisions to be the central type of responsibility that should be considered in our framework. In our scope, ordering concerns ordering of products and transportation, and planning concerns planning of production, transportation, and inventories. Many important planning activities, such as shunting, reloading, etc., take place at terminals. When these types of activities are performed by organizations providing transports, they are covered by transport planning. However, sometimes they are outside the control of the transport providers, e.g., when they are performed and planned by terminal personnel. In the latter case they should not be considered as part of transport planning, but their costs and execution times should be accounted for in the planning. Since the focus of our framework is on transport and production activities in supply chains, we do not regard planning of terminal activities as a type of responsibility that should be included in the framework.

Ordering decisions are typically based on ordering policies, such as the Economic Order Quantity (EOQ) model [9],

which takes costs for ordering and transportation into account. Planning decisions, on the other hand, is based on the availability of resources (production facilities, vehicles,...) and on different explicit strategies, for instance, concerning replenishment and load coordination.

In an organization it is typically the case that only some responsibility types are represented. Also, since the decisions included in a responsibility may vary substantially, the same type of responsibility will often appear differently in different organizations. Therefore, it is impossible to give any strict guidelines about which responsibilities and decisions should be modeled in a particular organization. However, below we present a set of responsibility areas (types) that we find relevant to model in a supply chain organization, together with some examples of what decisions might be included in each type of responsibility. Since there are too many decisions that potentially could be included in a responsibility, it is impossible here to provide a complete list of relevant decisions.

- Product ordering. From which product provider should products be ordered? What types of products should be ordered, and in which quantities? In what time window should the products be delivered?
- Transport ordering. From which transport service provider(s) should transportation be ordered? What quantity should be transported and in what time window should pickup and delivery occur?
- Production planning. At which production depot should products be produced? When should products be produced and in which quantities?
- Inventory planning. Which inventory should be replenished? Which quantities should be replenished and when?
- Transportation planning. Which mode of transportation, vehicle type, load carrier and route should be selected? What consignment size is appropriate and when should the transport be performed? Which products should be load coordinated? Should transportation be performed according to timetables or not? When and where should the consignment be loaded and unloaded?

From these examples of decisions related to the identified areas of responsibility, it appears to be difficult to find a general one-to-one mapping between decisions and responsibilities. Instead it has to be up to the designer of the model to use her good judgment when defining responsibilities. Moreover, it has to be assumed that within an organization, decisions are disjoint so that there will exist only one decision regarding the same aspect of an activity or a resource.

Let Dec_o denote the set of all decisions that should be taken in an organization $o \in Org$, where Org denotes a set of organizations represented in a system (or types of organizations in case there are identical organizations). Defining responsibilities can be seen as a partitioning of Dec_o into disjoint subsets $Dec_o^{po}, Dec_o^{to}, Dec_o^{pp}, Dec_o^{ip}$ and Dec_o^{tp}. That is,

$$Dec_o^{po} \cup Dec_o^{to} \cup Dec_o^{pp} \cup Dec_o^{ip} \cup Dec_o^{tp} = Dec_o,$$

and

$$Dec_o^{po} \cap Dec_o^{to} \cap Dec_o^{pp} \cap Dec_o^{ip} \cap Dec_o^{tp} = \emptyset.$$

In other words, in organization o, the partitions of Dec_o define the five responsibilities of product ordering, transport ordering, production planning, inventory planning and transportation planning.

B. Roles

In the framework, we have identified/included supply chain roles on two levels of visibility; on an external level the parts of the organization that are visible for other organizations are modeled, and on an internal level the internal operations of an organization are modeled. On the external level, we define four supply chain roles, which we argue can be used on an intra-organizational level to represent all types of organizations involved in buying (using) and selling (providing) products and transport services:

- Transport User (TU) refers to a consumer, or a buyer, of transport services, i.e., someone who wants to transport cargo.
- Transport Provider (TP) is a provider of transport services.
- Product User (PU) is someone who buys products.
- Product Provider (PP) refers to a provider, or a seller, of products.

In different organizations, these four roles will be represented slightly differently (e.g., since the included responsibilities may differ). We let $Rol_o^{ext} \subseteq \{TU_o, TP_o, PU_o, PP_o\}$ denote the representation of the four external roles in organization o. No internal operations, i.e., the responsibilities that were introduced above, are included in the external roles. However, a few other activities, such as negotiation, have to be represented at this level, but such activities are not explicitly considered in the framework. Moreover, it should be noted here that an organization is allowed to, and typically will, play multiple external roles in a supply chain. For instance, a freight forwarder plays two external roles; the role of a TU as well as that of a TP; it provides transport services to TUs and it consumes transport services from TPs.

To be able to completely model an organization, also the internal operations of the organization needs to be modeled. Therefore, the set of external roles should be complemented with a set of internal planner roles. In an organization there might potentially be one type of planner for each type of responsibility in the framework. The planner roles concern planning of resources or planning of ordering. We suggest that there is one planner role for each type of planning task and the following planner roles are suggested:

- Product Order Planner (POPL)
- Transport Order Planner (TOPL)
- Production Resource Planner (PPL)
- Inventory Resource Planner (IPL)
- Transport Resource Planner (TPL)

In the same way as for external roles, the representation of internal roles in organization o is denoted $Rol_o^{int} \subseteq$

$\{POPL_o, TOPL_o, PPL_o, IPL_o, TPL_o\}$. For future reference we let $Rol_o = Rol_o^{int} \cup Rol_o^{ext}$ denote all roles represented in o. Further, the identified roles can, and probably will, be decomposed into more detailed/specialized subroles, but we argue that on an abstract level these are the only roles that need to be considered.

C. Interaction

In our framework, interaction is considered to be something that occurs between roles, e.g., when a task or activity requires the involvement of two or more roles. Typical examples include sending, receiving and negotiating orders, and exchanging information in order to allow decisions that need to be taken in different roles to be coordinated. Since the framework is defined on an abstract level, the representation of interaction is restricted to identifying those roles that need to interact and defining connections (interaction links) between them. High-level interaction protocols that define the actual flow of messages between interacting roles need to be specified, but that is something that is outside the scope of our framework.

We have identified two types of interactions that are considered in the framework. The first type of interaction concerns external roles, with the purpose of partially capturing the ordering/replenishment processes that take place between organizations. The second type concerns interaction that enables decisions in different roles to be coordinated. It should be noted that the second type of interaction might involve roles within the same organization as well as between organizations in case decisions in different organizations need to be coordinated. To be able to model ordering processes, it is typically necessary to also involve coordinating interaction as will be discussed in the next paragraph. We refer to the first type of interaction as *order connection* since it only concerns interaction between external roles, and the second type as *coordination interaction*.

Since there always exists a connection between the user and the seller of a product or a transport service, it is important to identify those users and providers that potentially will be involved in exchanging products or transport services. To model the interactions that are required to capture the process of buying and selling products and transport services, it is in most cases required to create interaction links between the user roles and the provider roles (i.e., $TU \leftrightarrow TP$, $PU \leftrightarrow PP$). Basically, TUs are allowed to communicate with TPs, and PUs are allowed to interact with PPs. However, in basically all types of ordering/replenishment processes, also different types of coordination interaction need to be involved. As an example, illustrations (from a perspective of roles and interactions) of a "normal" ordering process, where orders are explicitly communicated between buyers and sellers, and VMI where the provider is responsible for planning the inventory of the customer and deciding about replenishments, is given in Fig. 1. To clarify the example in Fig. 1, in the VMI case, the PU role of the buyer only gets the responsibility of providing information (e.g., consumption

forecasts and inventory levels) to the IPL in the supplier (via the PP role).
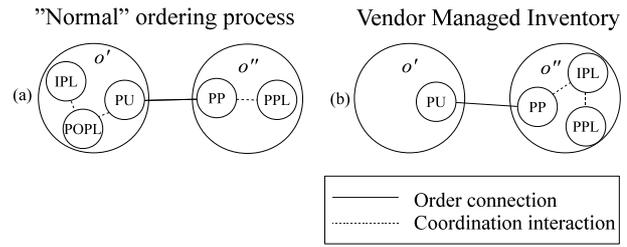

Fig. 1. Illustration of how the differences between a "normal" ordering process (a) and VMI (b) can be expressed in the framework. In the examples, the product buyer is represented by the circles marked o' and the seller by the circles marked o''.

Coordination in decision-making can be recognized as something that occurs between roles in order to allow related decisions to be taken (by different roles). Hence coordination is closely related to interaction, and in fact, coordination has to be achieved by means of interaction. Examples of what is considered to be coordination include, but are not limited to:

- Coordination of product order planning and inventory planning as, for instance, in the EOQ ordering model.
- Coordination of production planning, transport planning, and inventory planning to reduce the need for storages in the supply chain.

The coordination interaction between two organizations o' and o'' can be described as a subset $Int_{o'o''}^{coord} \subseteq \{\{r_i, r_j\} : r_i, r_j \in (Rol_{o'} \cup Rol_{o''})\}$ of the set of all unordered pairs of roles in o' and o''. The order connections between o' and o'' can be seen as a another subset $Int_{o'o''}^{ord} \subseteq \{\{r_i, r_j\} : r_i, r_j \in (Rol_{o'}^{ext} \cup Rol_{o''}^{ext})\}$ only involving external roles in o' and o''. When applying this notation to the example in Fig. 1, the interactions in (a) can be denoted as $Int_{o'o''}^{ord} = \{\{PU_{o'}, PP_{o''}\}\}$, and $Int_{o'o''}^{coord} = \{\{IPL_{o'}, POPL_{o'}\}, \{POPL_{o'}, PU_{o'}\}, \{PP_{o''}, PPL_{o''}\}\}$ and the interactions in (b) as $Int_{o'o''}^{ord} = \{\{PU_{o'}, PP_{o''}\}\}$, and $Int_{o'o''}^{coord} = \{\{PP_{o''}, IPL_{o''}\}, \{IPL_{o''}, PPL_{o''}\}\}$.

D. Modeling guidelines

To make the framework more applicable we have created a set of modeling guidelines that can be used when developing multi-agent-based supply chain simulation models. It is recommended that one of many available agent-based development methodologies, such as GAIA [2] or Tropos [3], is used when developing agent systems. We have chosen to relate the framework to the GAIA methodology, since it is highly developed and accepted in the agent community. The GAIA methodology contains an analysis phase, which is followed by two design phases (architectural and detailed). Our framework mainly relates to the analysis phase (in GAIA), in which organizations are identified, and preliminary role and interaction models are constructed. In the preliminary role and interaction models, those roles and interactions that are expected to be the same regardless of what organizational

structure is chosen for the multi-agent-system, are identified and specified. In GAIA, the preliminary role and interaction models are refined/extended in the architectural design phase with organizational roles and interactions that are consequences of the chosen organizational structure. However, since our framework is defined on an abstract level, we do not consider the process of refining the early design models.

Below we present a set of guidelines, which should be applied in sequence, and that can be integrated in the GAIA methodology to assist the analyst/designer when building a multi-agent-based supply chain simulation model.

1) Identify all supply chain organizations and sub-organizations (or types of organizations in case there are multiple identical organizations) Org that might be involved in buying and selling products and transport services. This guideline directly corresponds to the first step of the GAIA methodology, in which organizations and sub-organizations are identified.

2) For each organization $o \in Org$, identify all decisions Dec_o that need to be taken in o and map them to the different planning responsibilities, i.e., create subsets $Dec_o^{po}, Dec_o^{to}, Dec_o^{pp}, Dec_o^{ip}$ and Dec_o^{tp}. In GAIA, this guideline can be used as a pre-step to the preliminary role model.

3) For each organization $o \in Org$, identify which of the four external roles Rol_o^{ext} it represents, and for the responsibility types that are represented in o, create internal planner roles Rol_o^{int}. In GAIA, this modeling guideline is directly applicable to the preliminary role model since typically this will help identifying most of the preliminary roles.

4) Identify the organizations that are allowed to exchange products and transport services and define which external roles are connected, and how they are allowed to communicate (for an example see Fig. 1). This guideline concerns creating the set $Int_{o'o''}^{ord}$ for each pair of organizations $o', o'' \in Org$. In GAIA, this guideline helps the analyst/designer partially representing the ordering/replenishment process in the preliminary interaction model.

5) Identify roles, and their corresponding decisions, which need to be coordinated, i.e., for each pair of organizations $o', o'' \in Org$, create the set $Int_{o'o''}^{coord}$. Also, define how coordination should be accomplished (e.g., what information need to be communicated). In GAIA, this guideline concerns the representation of coordination in the preliminary interaction model.

It should be pointed out here that even though the framework only concerns the existence of interaction, it is generally a good idea to preliminary define the details of interaction. This means that the analyst need to define how communication in the supply chain should be accomplished (i.e. defining interaction protocols), who initiates and participates in the protocols, what is the expected outcome of the protocols, and what the roles should communicate about.

III. APPLICABILITY OF THE FRAMEWORK

In this section, we illustrate the usage of the presented framework by applying it to two different agent-based supply chain simulation models; TAPAS [1] and a simulation model proposed by Strader et al. [10].

A. Case study I - TAPAS

First we apply the framework to an agent-based simulation model called TAPAS (Transportation And Production Agent-based Simulator) [1]. TAPAS is a micro-level simulation tool with the purpose of predicting the effects of governmental control policies, infrastructure investments and business strategies. For more information regarding the simulation model (including simulated decisions, and hence responsibilities, simulation experiments, etc.), the reader is referred to our companion publications [1], [11]. TAPAS is not an actual contribution in this paper but it has helped us to validate the framework, and therefore it is relevant here to provide a brief description of the simulation model.

In TAPAS the following six supply chain roles are modeled: Customer (C), Supply Chain Coordinator (SCC), Product Buyer (PB), Transport Buyer (TB), Transport Planner (T) and Production Planner (P). Actually, these roles are considered to be functions that are represented in all supply chains, and it might be the case that more than one of these functions are represented in the same organization. To avoid confusion (the concept of a role has been used with a different meaning earlier in the paper), we will refer to them as functions rather than roles. Anyhow, in our framework terminology each of the defined functions can be referred to as a particular type of supply chain organization.

In TAPAS, the agents (each agent represent one function) are assumed to follow a predefined interaction protocol aiming at matching production and transportation in order to fulfill customer orders. The progress of TAPAS is driven by consumption, and the interaction protocol is initiated when a C sends an order request, with a set of different order quantities, to the SCC. After that, the SCC asks the PB to ask the Ps for relevant product proposals, and for each of the received proposals, it asks the TB for matching transport solutions for a set of different predetermined routes (paths). The TB generates transport solutions by asking the Ts for transport proposals for relevant parts of the routes, which are compiled into overall transport solutions. For each of the requested quantities, the SCC then chooses the least cost combination of products and transportation, and informs the C about these combinations. Then the C chooses the quantity, which from a cost perspective is the most beneficial, when minimizing the costs for storage and ordering. Finally, the chosen alternative is booked with all the involved Ps and Ts. Hence it follows that the agents are ordered hierarchically as shown in Fig. 2.

An illustration of how TAPAS applies to our framework is given in Fig. 3. The main responsibilities for a customer are inventory planning and product order planning. The SCC is responsible for product order planning, transport order
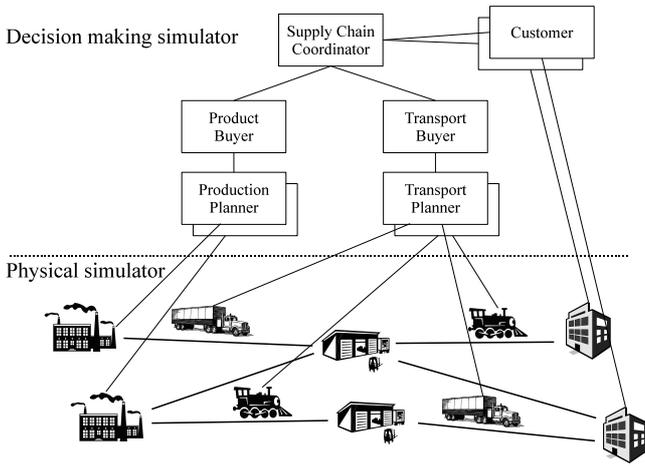
Fig. 2. Illustration of the TAPAS simulation model.

planning, as well as coordination of production and transportation. The Ps are involved in production planning and inventory planning, and transportation planning is performed by the TB, and by the Ts.
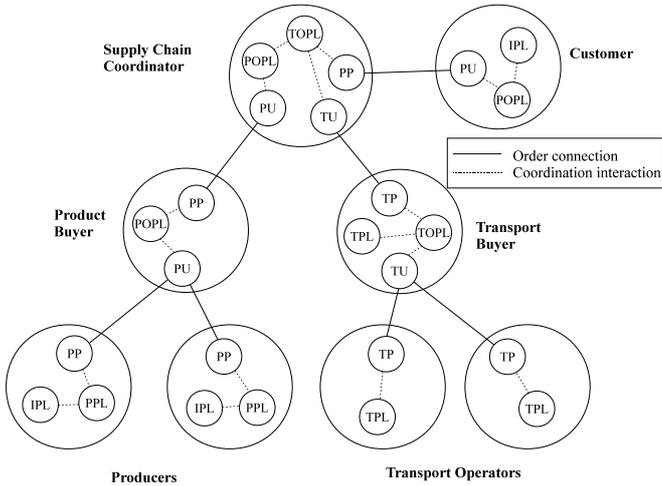

Fig. 3. Illustration of how the framework applies to the TAPAS simulation model.

B. Case study II - Strader et al.

To further validate the framework and demonstrate its generality, we have chosen to apply it to a second supply chain simulation model, which was proposed by Strader et al. [10]. The purpose of their model is to show the importance of information technology for supporting the order fulfillment process, by studying a 5-tier supply chain network under different demand management (e.g., Assembly-To-Order and Make-To-Stock) and information sharing policies. Two basic types of supply chain entities (or organization types) are modeled; entities with and without manufacturing (assembling) capabilities. In Fig. 4, we illustrate how the model by Strader et al. is represented in our framework.

In the actual agent system, the abstract roles defined in

the framework are played by different agent (types) in the following way:

- The roles of PU, PP and POPL are played by *Order Management* and *Supply Chain Network Management* agents,
- the IPL role is played by an *Inventory Management* agent, and
- PPL is played by *Material Planning, Production Planning, Shopfloor Control, Manufacturing Systems*, and *Capacity Planning* agents.
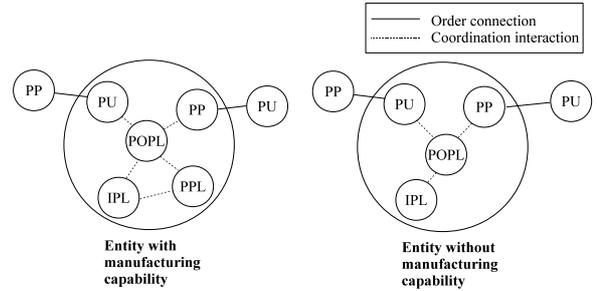

Fig. 4. Illustration of how the framework applies to the simulation model by Strader et al., i.e., the roles, interactions and organizations are illustrated, but not the agents.

From an agent perspective, the major difference between entities with and without manufacturing capabilities is that, in an entity without manufacturing capabilities only Order Management, Supply Chain Network Management and Inventory Management agents are represented, whereas in a manufacturing entity, also Material Planning, Production Planning, Shopfloor Control, Manufacturing Systems, and Capacity Planning agents are represented.

In contrast to the TAPAS model, which models both production and transportation, the model by Strader et al. only includes some of the responsibilities, and hence roles, defined in the framework; i.e. no transport-related responsibilities are represented. This shows that the framework can be applied to models with different scopes, e.g., when the focus is more detailed on some responsibilities while others are excluded.

IV. DISCUSSION AND FUTURE WORK

We have presented a domain-specific framework, which on an abstract level defines which roles, responsibilities and interactions should be considered when representing supply chain organizations in a multi-agent-based simulation model. The framework contains a set of modeling guidelines, which we have related to the GAIA methodology to improve the applicability of the framework.

An important issue that needs to be discussed is what we have done to show the validity and usability of our framework. In our context, validity primarily concerns:

1) The *correctness* of the framework, which relates to if the framework is logical and correct, and
2) the *completeness*, which refers to whether the framework includes all relevant aspects that need to be covered in a supply chain simulation model.

We have identified three main types of measures that can be used to show the validity and usability of the framework:

(1) Confirmation by domain experts, practitioners, etc,
(2) comparison to existing models, and
(3) applying the framework to simulation models.

We have partially validated the framework by applying it to two different supply chain simulation models; the TAPAS simulation model, which has been used in several projects (e.g., [12]) and a simulation model by Strader et al. which has been used to study supply chain information sharing. Therefore, the validation of these simulation models is relevant for the validity of the framework. What measures have been taken to validate the model by Strader et al. is unknown to us since we have not been involved in the development of the model. However, TAPAS has mainly been validated by interviews with experts in policy issues and transport modeling, and practitioners in transportation and logistics. Moreover, simulation experiments of different scenarios have been compared to similar studies, e.g., [13]. However, to further validate the usability, as well as the correctness and completeness of the framework, it needs to be accepted and further used by the agent and supply chain community.

Since our framework is defined on an abstract level, it can be used when creating an early design of a supply chain simulation model. This design is then typically refined in later phases of the design process. When applying the framework, in our case studies, we recognized that the identified roles typically do not directly translate into agents in the actual system, and that is actually expected. Potential directions for future work is to provide guidelines concerning how to refine the early design models, as well as how to assign roles to agents. It would also be interesting to investigate how the framework can be used for validating already existing agent-based supply chain simulation models. Applying the framework to an existing model would give the developer of that model an opportunity to consider the model from a different perspective, and potentially providing validation of the model.

REFERENCES

[1] P. Davidsson, J. Holmgren, J. A. Persson, and L. Ramstedt, "Multi agent based simulation of transport chains," in *Proc. of 7th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2008)*, Estoril, Portugal, May 12–16, 2008, pp. 1153–1160.

[2] F. Zambonelli, N. R. Jennings, and M. Wooldridge, "Developing multiagent systems: The Gaia methodology," *ACM Transactions on Software Engineering and Methodologies*, vol. 12, no. 3, pp. 317–370, 2003.

[3] P. Bresciani, A. Perini, P. Giorgini, F. Giunchiglia, and J. Mylopoulos, "Tropos: An agent-oriented software development methodology," *Autonomous Agents and Multi-Agent Systems*, vol. 8, no. 3, pp. 203–236, 2004.

[4] A. Garro and W. Russo, "Exploiting the easyABMS methodology in the logistics domain," in *Proc. of the 2nd Multi-Agent Logics, Languages, and Organisations Federated Workshops (MALLOW 2009)*, Turin, Italy, Sep. 7–10, 2009.

[5] D. C. Chatfield, J. C. Hayya, and T. P. Harrison, "A multi-formalism architecture for agent-based, order-centric supply chain simulation," *Simulation Modelling Practice & Theory*, vol. 15, no. 2, pp. 153–175, 2007.

[6] D. van der Zee and J. van der Vorst, "A modeling framework for supply chain simulation: Opportunities for improved decision making," *Decision Sciences*, vol. 36, no. 1, p. 65, 2005.

[7] B. Hellingrath, C. Böhle, and J. van Huet, "A framework for the development of multi-agent systems in supply chain management," in *Proc. of the 42nd Hawaii International Conference on System Sciences (HICSS 2009)*, Waikoloa, Big Island, Hawaii, Jan. 5–8, 2009, pp. 1–9.

[8] P. J. Daugherty, M. B. Myers, and C. W. Autry, "Automatic replenishment programs: an empirical examination," *Journal of Business Logistics*, vol. 20, no. 2, pp. 63–82, 1999.

[9] R. Wilson, "A scientific routine for stock control," *Harvard Business Review*, vol. 13, no. 1, pp. 116–129, 1934.

[10] T. Strader, F. Lin, and M. Shaw, "Simulation of order fulfillment in divergent assembly supply chains," *Journal of Artificial Societies and Social Simulation*, vol. 1, no. 2, 1998.

[11] L. Ramstedt, "Transport policy analysis using multi-agent-based simulation," Doctoral Dissertation Series No. 2008:09, Blekinge Institute of Technology, Sweden, May 2008. [Online]. Available: http://www.bth.se/bib

[12] A. Sakalys, P. Davidsson, A. Jarzemskis, J. Kronbak, J. Persson, L. Ramstedt, V. Sturys, and A. V. Vasiliauskas, "Knowledge development on international transport corridor," Vilnius, Lithuania, EastWest Transport Corridor project, Work Package 5 Final Report, 2007.

[13] S. Yngström-Wänn, "Kilometerskatt som styrmedel för tung trafik i Skåne och Blekinge," Vägverket Region Skåne, Kristianstad, Sweden, Publikation 2007:97, Dec. 2007.