CEUR-WS.org/Vol-2074/article_2.pdf

Representing Processes of Human Robot Collaboration

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Abstract S-BPM supports the representation of processes using two levels: the individual subject behaviour level and the subject interaction level. These two levels are helpful when it becomes necessary to specify the individual subject's behaviour in different levels of details. We take a system-of-systems point of view and take a S-BPM specific look on interoperability. We use human-robot collaboration as a motivation and use-case to understand the interoperability requirements of adaptive system-of-systems. However, every type of human robot collaboration has different requirements not only for subject behaviour but also for the interaction level. We present the challenges and advantages of using S-BPM in this setting.

Keywords: Business Process Modelling, Subject-oriented Business Process Modelling, Human Robot Collaboration

1 Introduction

Increased competition is pushing enterprises to become sustainable in economic, environmental and social dimensions. To reach this goal, enterprises must become true smart adaptive systems for being able to react rapidly and flexibly to changing environments. This involves the human system of enterprises as well as the technical. Networked Mobile devices, social networks and edge devices produce great amounts of data. Smart decisions are required to make use of that large amount of information. Next generation information systems need to support the S^3-Enterprise — *Sensing*, *Smart* and *Sustainable* Enterprise which is a system of system where human and artificial systems collaborate [1].

Human Robot collaboration is one area which shows the high potential of the S^3 Enterprise. Sensors are required for understanding the user's position and activities. The robot is controlled by smart algorithms. For becoming sustainable the collaboration needs to be adaptive, reacting to changing products, production processes and customer demands. Since the human and the artificial system are independent and loosely coupled, some coordination of the activities is required. Both systems need an understanding what the counterparts are doing [2]. In the following we take a look at S-BPM and its (dis-)advantages to support interoperability in production-system-of-systems.

The paper is organised as follows. First Enterprise interoperability is presented. The work described here supports modelling and use of systems which are loosely coupled. We take a look on S-BPM supporting interoperability in production-system-of-systems. As a motivation and specific use case, we use human-robot-collaboration to show different levels of interaction in production-system-of-systems.

2 Enterprise Interoperability

Interoperability in general and interoperability on process level specifically is required to have support formation of a system-of-systems. In the following we argue about different levels of interoperability that need to be addressed in system-of-systems to maintain a loose coupling.

"Taking a system-of-systems (SoS) perspective [3], the production system includes all socio, economic and technical systems that are needed to make the production (in the general sense) work. . . . Following [4] we distinguish a system from a system-of-systems by the aspect that a system has a certain purpose to fulfil. In a system-of-systems the purpose remains assigned to each of the systems, whereas elements of a system are an inherent part of the system – they lose their autonomy for the purpose of the system, systems in a system-of-systems, however, remain independent and may leave their super system as autonomous system." [2, p. 2]

In human robot collaboration, using a system-of-systems perspective, one system is of human and the other of artificial kind. Different degrees of integration and interoperability of these systems is possible from working independently to dedicated and task specific enhancement of the workers cognitive or physical capabilities [5,6].

2.1 Degree of Coupling

An integrated system works seamlessly with other integrated systems. However, when taking a system-of-systems (SoS) perspective [3], the system that needs to be addressed, includes socio, economic and technical systems. Enterprise Integration and Interoperability (EI&I) has been developed in the overlapping domains of business information systems and enterprise information systems, production research, business process management, computer science and organisational science.

Current EI&I research is following a system-of-systems approach [7,8]. Based on this basic conceptualisation, EI&I research discusses a continuum of different qualities of integration [9]. Full integration describes systems where elements share the same model. Tight coupling has both advantages and disadvantages. A main advantage of sharing the same model, is that work on interfaces is simple. The evolution of a model is done at the same time with all elements of the integrated system. A major disadvantage of an integrated system is that tight coupling of elements requires any modification (and model evolution) to happen in all (related) elements at the same time. If one part requires some change, all other elements must be adapted to meet this change as well. Loose integration also has its advantages and disadvantages.

"[I]ntegration is generally considered to go beyond mere interoperability to involve some degree of functional dependence" [10, p. 731]. This dependence implies less flexibility and less resilience since it combines the involved systems in order to form a single whole [11]. The integrated systems additionally lose their individual purpose, in order to contribute to the purpose of the super-system.

Loose integration, also referred to as unified interoperability, is an approach to support inter-operation of system-of-systems, where all systems share a common meta-model [12]. That meta-model allows information exchange at least on an abstract level. The common meta-model is mapped by every system to its own meta-model, and no assumptions may be made by other systems on the private meta-models. That preserves the autonomy of the systems. So in order for systems that join a system under this paradigm, a system maps and copies its internal data structures and information to the shared meta-model. The receiving system then maps and copies the received information to its own internal structure. The advantage this is that all systems are clearly separated. Each system may be changed without that change influencing other systems. Due to the layer of abstraction, the change is not observable (per se). However, the meta-model determines (and possibly limits) the interaction capabilities between the systems. And still some situations require the common meta-model to be changed, which then requires the systems to adapt their own models and interfaces.

A third, even more loose coupled approach to interoperability exists. Federated interoperability describes systems of systems, where systems are capable of negotiating interfaces and information-structures at runtime. Only a minimal set of requirements is needed a-priori. This approach is sometimes called late-binding and requires a semantic unification space where concepts that are used by two or more systems can be mapped [9].

For example, domain ontologies, are used for semantic unification [13]. A more recent example of this approach has been developed by [14].

2.2 Semiotic Level of Interoperability

Orthogonal to the degree of coupling are the levels of concern where interoperability barriers (may) occur [8].

Barriers of enterprise interoperability are discussed on business / organisational level, semantic / conceptual level, and technical / data level.

On business level interoperability issues stop tow or more enterprise systems doing business in general. Examples include incompatibilities in legal practice and country dependent laws. On the same level, when processes are not compatible supplier - customer relationships are deadlocked, where both enterprises wait for the other to perform an activity.

On semantic / conceptual level, models used in IT are incompatible. For example different granularity of models stop enterprises from calling others' API to transmit data. Also conceptual barriers like different levels of granularity of exchanged information objects occur (Person objects modelled with a name property vs. objects modelled with a given-name and family-name).

At the technical level, enterprise interoperability barriers include among others, syntactic message formats, service interaction protocols and technical security aspects.

The European Interoperability Framework (EIF) [15,2], as one example, brings together these above discussed levels as illustrated in Figure 1. Here semiotic levels are mapped to the EIF.

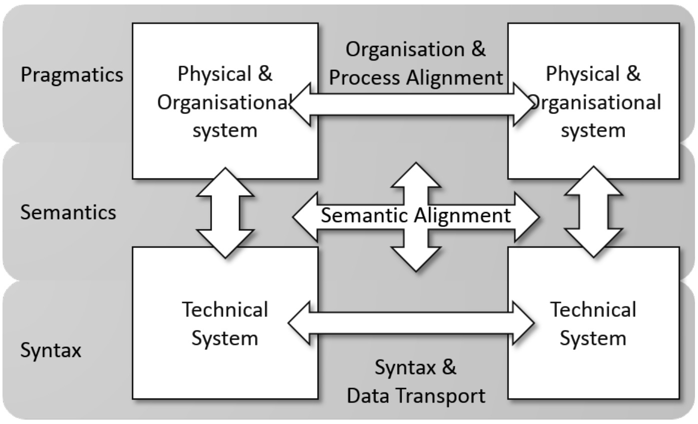

Figure 1. Semiotic Levels of Interoperability mapped to the European Interoperability Framework (EIF)

Organisational semiotics, allows to discuss in more detail the relationship between the model, its use and the addressed reality [16]. In this approach, the levels are separated by norms that are used on that level.

social values of information / impact of signs influencing social behaviour
pragmatic information is used to get things done
semantic meaning of information is made and maintained in the organisation
syntactic data and sign structures and (semi) formal languages
empiric signs are organized into predictable patterns (alphabet);
physical hardware and physical media for signs; economic properties at the material level

In addition to the structural requirements, EI&I is not a one-shot approach. Enterprise integration and interoperability is a continuous process in a dynamic environment. Having interoperability achieved, this state is easily lost due to changing properties in the external environment or simple things like software updates [17]. Already in moderately complex systems, it is not possible to predict all impacts of a single change in one system on other systems. When missing the continuous need for adaptation has lead enterprise application integration (EAI) approaches to produce monolithic software systems [12].

Overall Enterprise Integration and Interoperability is a multi dimensional system-of-systems research approach which facilitates flexibility and adaptability while still having a system for a specific purpose. EI&I is a model-driven approach, discussing not only the technical issues for exchanging raw data, but also the semantics of the models (and meta-models) and the pragmatic aspects in terms of what is triggered in organisations through the information exchange.

With respect to the system-of-systems approach interoperability on technical level, is a pre-requirement for systems to interact. Interoperability on semantic level is required to support a common understanding. However, only interoperability on process level assures that on organisational level tasks are enacted without disturbance.

2.3 S-BPM for Enterprise Interoperability

Before going into more details how to support processes involving humans and robots, we take a look at S-BPMN. S-BPM has been chosen, as it has a formal basis [18] which for example BPMN misses [19].

S-BPM as an approach in general, and the available tools for S-BPM support interoperability. The following Table 1 shows this support for enterprise interoperability by the S-BPM framework itself [20], by existing tools, and by research prototypes [21,22,23,20,24]. The results presented in the table are described in more detail in [25]. It shows that potential of the S-BPM ecosystem on supporting the enterprise in generating loosely coupled integration. This is mainly due to the two layers of inter-subject business object exchange and intra subject control flow.

This table shows interoperability on several levels. However, for human robot collaboration one (among other) interoperability gab exists between the human and artificial system.

S-BPM has also been used in the manufacturing industry, connecting the business process layer with the production process layer [33,24,34]. In that research a S-BPM Subject integrated using OPC UA technology the link to hardware and a production process which involves humans (as usual with S-BPM).

Three types of subjects have been identified in SO-Pc-Pro:

(i) Service Subject
(ii) Human Subject
(iii) Coordination Subject

The Service Subject represents a certain functionality required in the production system. This includes for example the robots and sensors. However, the subject behaviour is pre-specified. This works fine for pre-defined functions, where Business Objects may be used to parametrise the machine.

The Human Subject represents the operator or worker. A user interface needs to be provided to communicate with the worker.

Table 1. S-BPM Support for Interoperability in the Problem Space [25]

Barriers / Concerns	Conceptual	Technological	Organizational
Business	smart4sense2act^3 [21]	Framework^2 [20] S-BPM Design Tools^2 [20]	
Process	Framework (Analysis, Modeling,Validation)^1 S-BPM Design and Execution Tools^1 [20]	Framework (IT-, Organization Implementation)^1 [20] S-BPM Design and Execution Tools^1 [20]	Framework (All Activities)^1 [20] Metasonic Touch^2 [26], Comprehand^3 [27,28,29], S-BPM Design Tool^1, jCPEX!^{1} [30,22], Ad-hoc Deviations^1 [31]
Service	Framework (Validation)^2 Metasonic Touch^2 [26], Comprehand^3 [27,28,29]	S-BPM Execution Tool^1 [20]	Framework (Monitoring)^2 KPI Management Tool^2 [32]
Data		S-BPM Execution Tool as Enterprise Bus^1 [24]	

1 . . . integrated; 2 . . . unified; 3 . . . federated;

"The main task of Coordination Subjects is to coordinate the interaction of the subjects in the production environment to achieve a certain goal. How this goal can be reached is basically defined by a set messages sent to different subjects. These messages then again trigger the execution of concrete task implementations. The coordination subject's responsibility is to sequence these messages based on a defined flow sequence, current state of the system and the execution results." [24, p. 3653]

In our approach this is the responsibility of the production process subject, which takes care of the controlling the interaction between production systems.

From a global perspective in the SO-Pc-Pro approach, the user's workflow and activities are represented as internal behaviour in this approach.

With respect to the machine workflow, either some of the activities are refined to trigger OPC UA connected devices, or a subject is created that has the desired (internal) behaviour to connect the low-level machine control to the S-BPM process. The conceptual and organisational control flow of the former is from the user perspective. There is a single thread of control. From the interoperability considerations above, the work in SO-Pc-Pro [24] is an integrated approach.

S-BPM allows (to some extend) to support the coordination of activities in a system-of-systems involving human and artificial systems. It has a formal basis which supports activities for artificial systems and it is human readable supporting the human system. In the following we take a look at human-robot collaboration specific aspects.

3 Interoperability in Robotic System-of-Systems

So far we have argued that the manufacturing enterprise is a system-of-systems and support for interoperability (in contrast to integration) is required. This is particularly true on the process level.

In the following, Human-Robot collaboration serves as motivation and example to show the advantages and disadvantages of using S-BPM as interoperability support for system-of-systems involving humans and machines.

With respect to manufacturing, one of the most flexible production system are robots in general and human-robot collaboration more specifically in the context of this research paper. It therefore makes sense from a workflow and process perspective to take a closer look on interoperable and adaptive production systems-of-systems with special attention to robotics.

Figure 2 brings together three important aspects for adaptive production system-of-systems:

(a) the production system in fig. 2 is modelled as a system-of-systems, and systems are process-oriented (i.e. for a certain step a specific process instance is implemented)
(b) while the production system-of-systems exhibits the desired modularity and flexibility an overarching process is needed to coordinate the (independent) sub-processes of the systems.

(c) S-BPM can be used to model systems and their internal processes. Interaction of systems takes place through messages containing business objects.

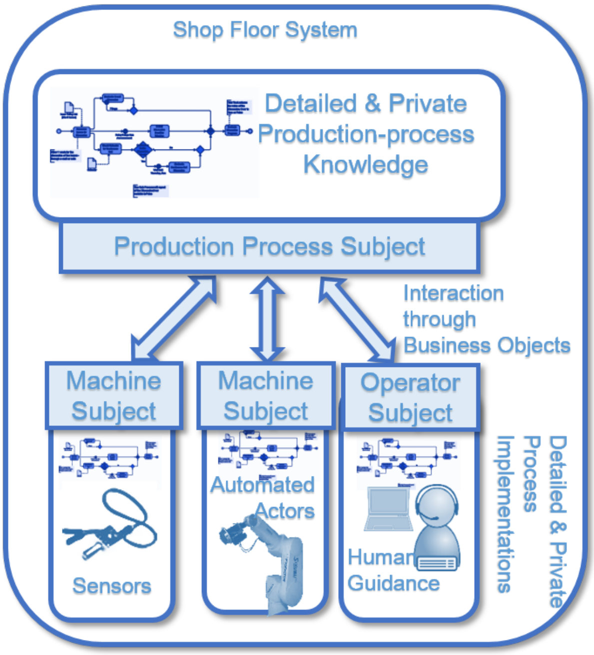

Figure 2. Production System-of-Systems from an abstract S-BPM point of view

In the following we present different degrees of human robot collaboration. The difference is in the synchronization and coordination needs of the collaboration of human and robotic systems. First we present these collaboration scenarios, then we discuss technologies for implementation.

3.1 Human Robot Collaboration Types

Human robot interaction can be understood in different degrees of physical coupling. It is the interaction and the concept used to synchronise activities that specifies the degree [35]:

(i) A simple binary input (e.g. start / stop) from the worker to control the robot is a simple interaction. Point of synchronisation is through the interaction of the worker with the control switches in this simple case.

(ii) Human Robot coexistence is a situation where both operate in close proximity but have no shared or synchronised tasks or work pieces. Here hardly synchronisation is necessary. Both must only make sure to not interfere with the others' work, e.g. collision avoidance is required.

(iii) Human Robot assistance is the situation, where the robot serves the worker without any active part or reasoning, simply obeying the commands of the user. Here the synchronisation between human and robot takes place through the command information transmission.

(iv) Human robot cooperation describes a situation where the operator and the robot work on the same workpiece. Here the synchronisation takes place through the work piece. Both need to be aware where the other one works on the piece and does not take any steps that interfere with the other's work. This requires an understanding of both about the others current and planed tasks.

(v) The most intense interaction occurs when humans and robots share the same task. This situation is called Human Robot Collaboration. The synchronisation requirements here are not limited to the workpiece, but need to synchronise the activities. The timing and location of the worksteps are of importance. Also the upcoming activities of the collaborator. Both (the human and the robot) need a detailed understanding of the activities including their timing.

Figure 3 shows the the simplest form of interaction (i), the worker starts or stops the robot. Due to the simplicity of the interaction no subject behaviour diagram is shown.

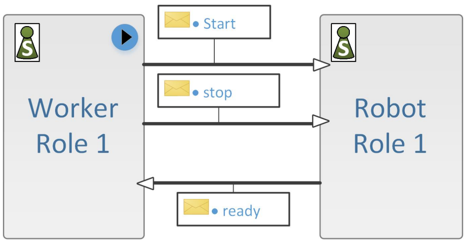

Figure 3. Scenario i: Start / Stop Robot by worker

Figure 4 shows the coexistence scenario (ii) where human and robot share the same workspace but no direct interaction is required. Here a monitoring subject triggers messages in order to warn about collisions. Often that is implemented in the robot itself. However, its possible to have that component as a separate module implementing the required functionality.

Figure 5 shows the assistance scenario (Iii) where human has full control over the robot.

In figure 6 both agents share the same workpiece (scenario iv & v). In the cooperation scenario (iv) the task lists need to be communicated to be able to

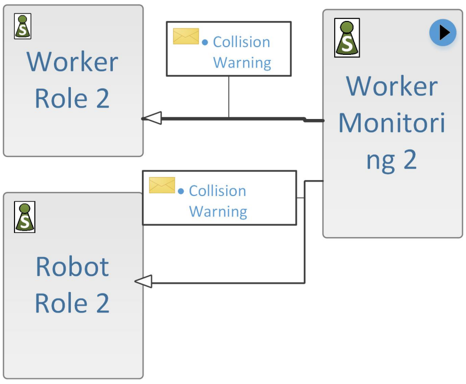

Figure 4. Scenario ii: Coexistence - collision avoidance by monitoring

understand if there is a conflict. A possible conflict would be that both occupy the same area on the workpiece. In advanced settings some planing algorithm might dynamically assign tasks to either party. In another scenario worker chooses a task which is communicated to the robot to then react. As mentioned above (v) in the truly collaborative scenario not only the workpiece is shared but also tasks. While the basic interaction will look similar to the cooperative scenario (iv), the level of detail is much higher. Not only the area on the workpiece, on which tasks take place but also the timing of the tasks needs to be synchronized. Hence, the interaction is time-sensitive. This time-sensitive synchronisation of tasks is only implicitly possible in S-BPM.

3.2 Technologies for Interoperable System-of-Systems

For integration on data and technical level, the OPC UA Standard has been used to integrate PLCs (Programmable Logic Controller) in Business Processes [24,33]. In this approach, information and process models are mapped manually to the OPC UA information model. Through a publish subscribe protocol the PLC receives / pushes information from / to the Business process. This explicit mapping also solves the problem of different information granularities required for information understandable by human and robot.

With respect to the types of human robot interaction, this approach could be used for binary interaction and co-existing interaction (scenario i, ii).

For the assistance scenario (iii) some other approaches exist, that allow to reprogram robots by workers on the fly [36,35]. However, in these approaches a process representation does not exist. It is assumed, that workers and robots are executing a simple sequence of tasks. Focus of that work is on the developments for dynamic reprogramming robots by workers. Hence, advanced workflows where for example parallel executed activities which need some synchronization can not be dealt with.

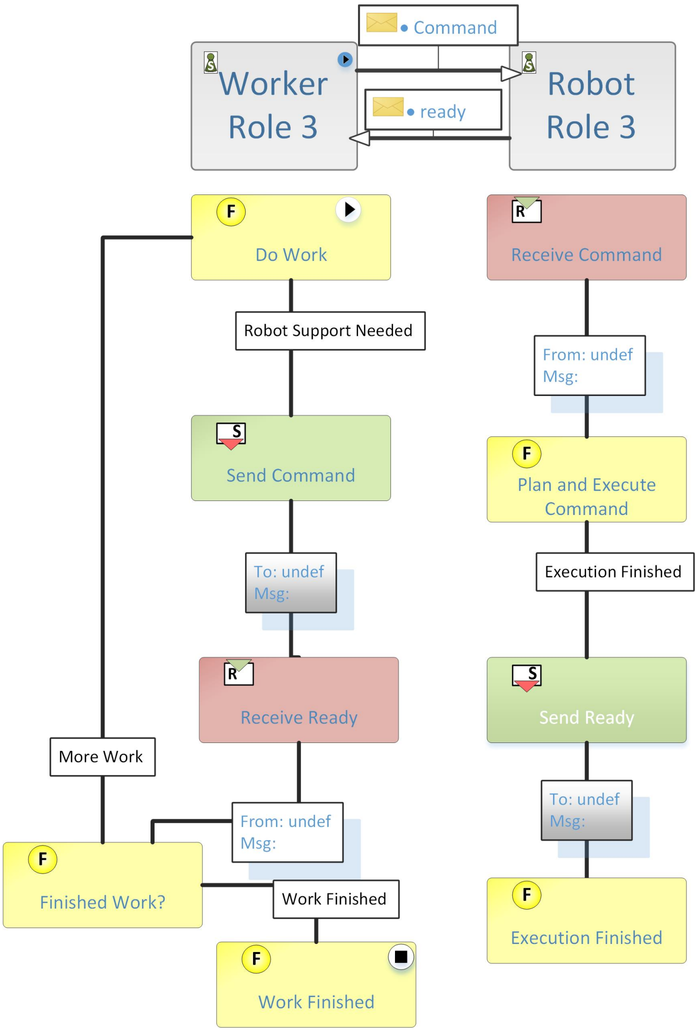

Figure 5. Scenario iii: Assistance - worker in command

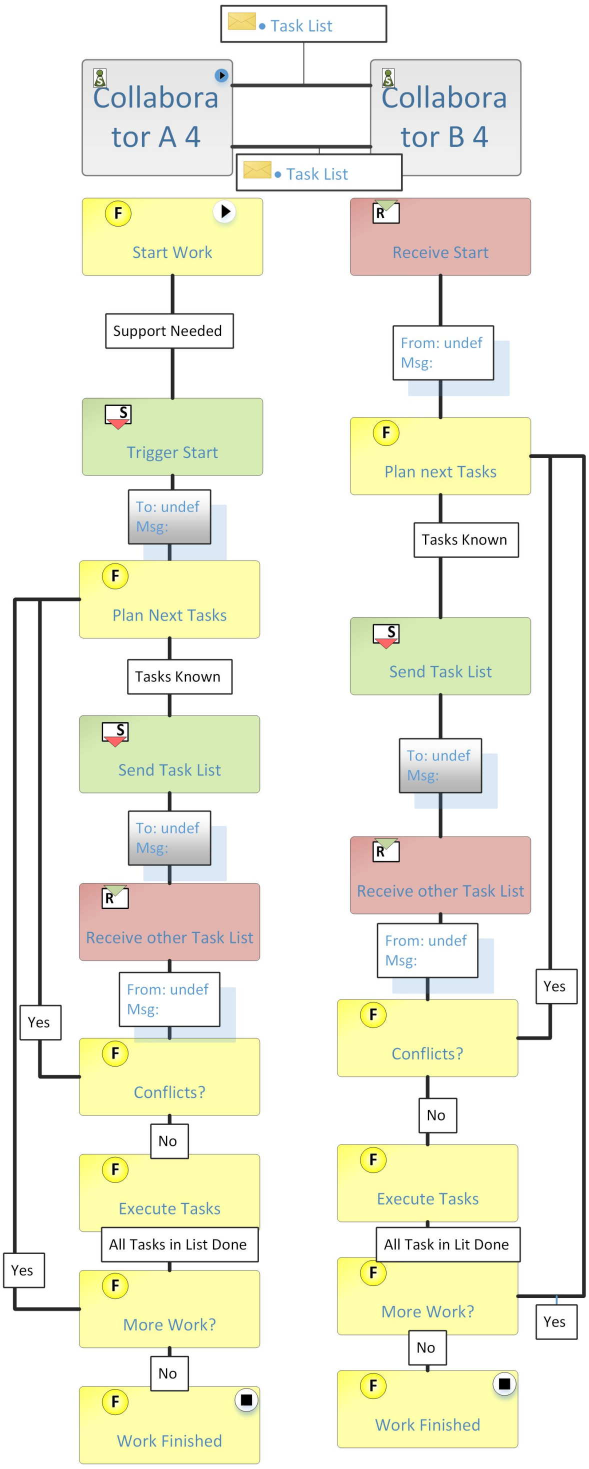

Figure 6. Scenario iv / v: Cooperation - synchronization of tasks / Collaboration - synchronization of tasks and their timing

In some other research technologies for planning and assigning tasks automatically to humans or robots is analysed [37]. Here also a elaborated process point of view is missing, to support more complex assignment and coordination of activities of different agents. This allows simple cooperation (scenario iv) based on simple task lists.

Missing is support for manual design and automated planning of advanced process structures where parts are executed by human and artificial agents.

3.3 Next Steps

S-BPM as basis for human robot collaboration (scenario v) allows to support loose coupling through the two layer approach. Multiple aspects need to be further developed to reach this vision.

On the *Subject Behaviour Layer* the semantics of the different model elements can be determined through an abstract state machine based formal model [20,18]. The formal underpinning allows to specify precisely the model building blocks and control flows. Unfortunately on *Subject Interaction Layer* the business objects are formalised as messages only. For the envisioned support, more detailed meta-models and semantics support in order to increase the interoperability of subjects executing different process segments is required. More specifically, an ontology describing in detail the activities, work-pieces and tools in detail is needed for supporting a shared understanding between multiple agents enacting these subjects.

Another aspect for future research, is to enable automatic re-planing of processes and complex tasks using that ontology to support the detailed specification of robotic arm movements, articulate potential collision situation, specification of human tasks an the required resources, tools.

The third aspect for further research is a common S-BPM meta-model and and information model (e.g. upper ontology) forming a basis for federated interoperability where robot and human negotiate over task distributions on an ad-hoc basis. Federated interoperability also requires a shared meta-model supporting the understanding of systems that may assume several subject “roles”. The shared subject information contains (implicitly) interaction protocols, as subjects only interact with specific other subjects with well defined interaction (send / receive states and business objects exchanged).

This description needs to be shared through some infrastructure services, allowing agents to identify other agents and subjects. This directory service is a basic support for federated interoperability, where agents interact with a priory unknown other agents.

4 Conclusions

We have argued, that production is a system-of-systems. The systems have an individual purpose and a certain degree of autonomy. To keep this autonomy a coordination approach is needed that allows to maintain autonomy.

S-BPM, due to its two level approach of separating the subject-interaction from the individual system behaviour would allow to support process interoperability.

We have used human-robot collaboration as a motivation and use-case to understand the interoperability requirements of adaptive production system-of-systems.

Advanced types of human-robot collaboration requires more information on available other systems, their capabilities, detailed understanding of the others' tasks and activities. Semantic interoperability needs to be established for example using a common high level ontology describing business objects, tasks, processes and services that allow agents to discover that information.

To be able to have the robotic system execute a process, also automated planing needs to take place. As stated above, that in turn impacts planing and scheduling of the overall collaborative processes. Additionally planing and scheduling needs to be able to assign a certain task to a specific agent at runtime.

For highly interactive scenarios, the following is also missing but not discussed in detail:

- time sensitive synchronization of tasks where human and robots have to execute their specific tasks concurrently
- time constraints in general are missing, e.g. to stop activities after some time.
- dynamic assignment of specific subjects that implement a certain subject interaction protocol

Acknowledgement

The research described in this paper has been partially funded by the European Union and the state of Upper Austria within the strategic economic and research program “Innovative Upper Austria 2020” and the projects ”Smart Factory Lab” and ”DigiManu”.

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