

FRAMEWORK FOR COLLABORATIVE MANUFACTURING SYSTEMS BASED IN SERVICES

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Abstract. *Nowadays, there is a trend for industry reorganization in geographically dispersed systems with productive activities distributed in autonomous manufacturing systems. Advances in mechatronics, communication, and information technologies support the viability of this structure. These productive systems are composed by several modules (sub-systems), with specific services, which must maintain collaborative relationship among them in order to assure the expected performance of overall system. In this way, this paper proposes a collaborative distributed framework based on “web services” to assure effective service coordination in the execution of manufacture processes in distributed environment. This framework has special features such as teleoperation and remote monitoring of manufacturing activities, users online request, and shared resources management. Based on the nature of this type of systems they are considered as discrete event systems (DESSs), and techniques derived from Petri nets (PN), including the Production Flow Schema (PFS), can be used in a PFS/PN approach for modeling. This approach has been proven efficient for hierarchical description, analysis and control of DES. The system is approached in different levels of abstraction: a conceptual model which is obtained by applying the PFS technique and a functional model which is obtained by applying PN. Finally, a particular implementation of the proposed framework is presented, in which different and specific issues of distributed manufacturing systems are considered.*

Keywords: *manufacturing system; collaborative system; distributed system; web service; teleoperation.*

1. INTRODUCTION

Nowadays, the pressure on manufacturing enterprises have strongly increased to enhance the global competitiveness and to rapidly react against changing on customer demands. As result, these enterprises are continuously reviewing and updating their structures to improve they flexibility, reconfigurability and interoperability (WU *et al.*, 2008). In general, the new structures need to deal with heterogeneous systems and their communication incompatibility, which increase the complexity of the overall system. Thus, the specialists indicate a modular approach focused on the definition of interfaces. In this sense, various works have adopted service-oriented architecture (SOA), which constitutes a distributed computing system in which the functionality of module calls from other module, either locally or remotely over a communication network. Web service (WS) is a popular instance of this architecture. It relies on a set of standards including: simple object access protocol (SOAP), web services description language (WSDL), and universal description, discovery and integration (UDDI) to support interoperability among applications developed in different languages and running on different platforms or operating systems (CERAMI, 2002). Modeira *et al.* (2008) presented architecture for WS integration enabled devices with enterprise applications. Komoda (2006) summarized different implementations of service-oriented systems in industrial application such as: manufacturing and logistic system, train car management system, control system for the semiconductor processing equipment. Yan *et al.* (2005) presented an environment of remote control instrument using WS, available in an online laboratory. This environment consists of three layers: a top layer related to the concepts of business where it set the specifications of process and management of laboratory, an intermediate layer which specific services to be executed through a network, and a lower layer of the application service, which deals with the processing of data from the remote laboratory. Trifa *et al.* (2008) carried out a coordination of activities between mobile robots according to telecomands sent by a teleoperator. In this context, the collaborative teleoperated systems have arisen as an alternative solution for fulfills actual demands. These systems are a result of the integration among several autonomous components with specialized functionalities that have their activities coordinated in accordance with a defined global manufacture processes. These components are usually installed in a distributed and geographically dispersed configuration (GARCIA MELO *et al.*, 2008). In this context, this research aims a framework for the integration and coordination of manufacturing systems in a service-oriented approach. The design of this framework can be divided in two main steps. First the functionality of the manufacturing system module must be disposed as a service. And second, in accordance to the global manufacture process, it is defined a service to integrate and coordinate different manufacturing system modules. The resulting system is called a collaborative teleoperative manufacturing system (CTMS). In fact, this system is being implemented based on an advanced Internet infrastructure provided by the FAPESP TIDIA/KyaTera¹ program. In special, here is considered the specification problem of CTMS with remote monitoring and control of manufacturing processes. In this sense, initially, the solution

¹ <http://kyatera.incubadora.fapesp.br/portal>

adopted in this work considers collaborative transnational system architecture. The proposal considers also new challenges for the monitoring and teleoperation of the different activities involved with collaborative, distributed and dispersed manufacturing systems in order to improve the overall system performance including human operators support in situations such as: management of services, conflicts arbitration, and interfaces operation. Nonetheless, the CTMS involve different kinds of functions and activities, whose modeling and analysis techniques are not trivial.

Therefore, this paper focuses on a method for CTMS specification. The specification task is based on the characterization of CTMS as a discrete event system (DES); then, techniques derived from interpreted Petri net (PN) are considered for system modeling, and analysis. PN is a graphical and mathematical modeling technique, characterized by their ability to handle operation sequence, parallelism, conflict and mutual exclusion (MIYAGI, 1996). PN has been used for modeling dynamic systems in a wide range of areas. In Junqueira & Miyagi (2006) an environment for distribute modeling and simulation of productive system was proposed. In Kaneshiro *et al.* (2007) it was used to specify a distributed system protocol. In Massuthe *et al.* (2005), a technique based on PN called “open workflow net” is presented, which simplify the WSs definition, integration, and coordination. Additionally, Massuthe *et al.* (2008) developed a computational tool to analyze the interaction of services. In Lohmann (2007) the open workflow nets are used to represent both basic and structured activities of standard coordination of WSs, called business process execution language (BPEL).

The present paper is organized as follows. In section 2 it is described the architecture adopted for the development of this work. Section 3 presents the proposal for the CTMS modeling procedure. In section 4, an example illustrates the proposed procedure. Finally, in section 5, the main conclusions are presented.

2. FRAMEWORK DESCRIPTION

The considered framework is based on SOA, promoting interactions among costumers, teleoperator, and resources involved in a distributed manufacturing system as showed in Fig. 1.

“Costumers” are people who have access to the system through identification and password. Also, users can check the production order states, cancel orders, and make new orders. Order is the customers’ request execution.

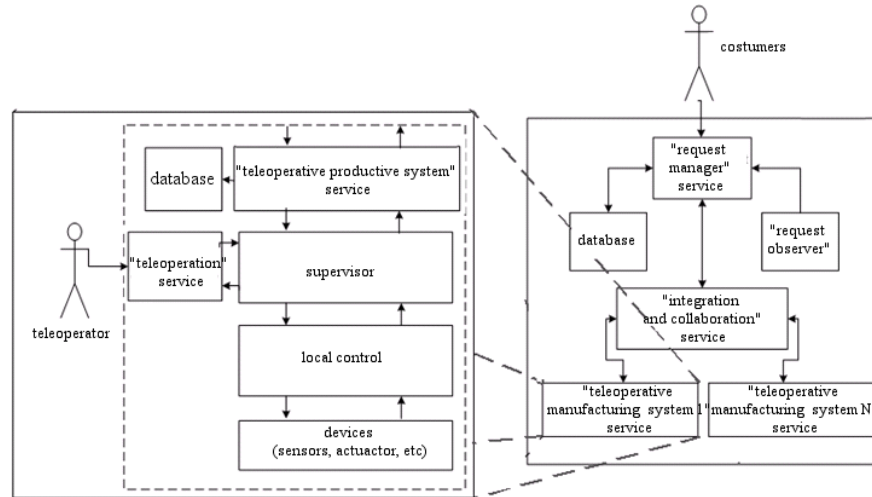


Figure 1. Framework for collaborative teleoperative manufacturing systems (CTMS).

“request manager” service is a WS application, which should interact with the “customers” interface, the “integration and collaboration” service, and other entities such as “database” and “request observer” in order to schedule the “costumer” requests.

“integration and collaboration” service is a WS that orchestrates the involved WSs in the global productive process.

The “teleoperative manufacturing system” service is a manufacturing system module of CTMS composed by its “teleoperators”, “teleoperative productive system” service, “supervisor”, “local control”, “database” and “devices”.

“teleoperative productive system” service is a WS, which exposes one or more functionalities of the manufacturing system module as service enabling the interaction, by command messages, between the module and the “integration coordination” service.

“request observer” ensures that the number of customer order being attended do not exceed the amount of resources available in the CTMS.

“teleoperators” are special users that can choose between two operational modes for the “devices” under their responsibility: teleoperation or monitoring modes. Teleoperation mode means that the “teleoperator” can interact with

the “*devices*” from a remote location to decide about their next actions. On the other hand, in the monitoring mode, “*teleoperators*” are passive elements, and the decisions are previously programmed in the “*teleoperation*” service.

“*supervisor*” interacts with “*local control*”, service “*teleoperation*”, and service “*teleoperative manufacturing system*”, to manage the productive activities, according with operational mode.

“*local control*” contains a set of functional blocks, each one responsible to execute an activity. The “*supervisory control*” requests these functional blocks to assure the normal productive process performance.

“*database*” is the entity that stores information about: WS execution process, “*devices*”, “*customers*”, and “*teleoperators*”. This information is used in all the steps of the process, for example to estimate process time and maintenance time. Moreover, its main purpose is to be a gateway between the fast Internet operations (activities that spend milliseconds or seconds to be realized) and productive operations (activities that spend minutes or hours to be realized).

“*devices*” are control elements in shop floor level such as sensors and actuators that permit develop manufacturing activities.

3. MODELING PROCEDURE APPROACH

The procedure is divided in two parts. The aim of the first one is the modeling and analysis procedure to define the services of autonomous sub-systems (modules) that integrate the CTMS. This part of the procedure is composed of five stages (Fig. 2).

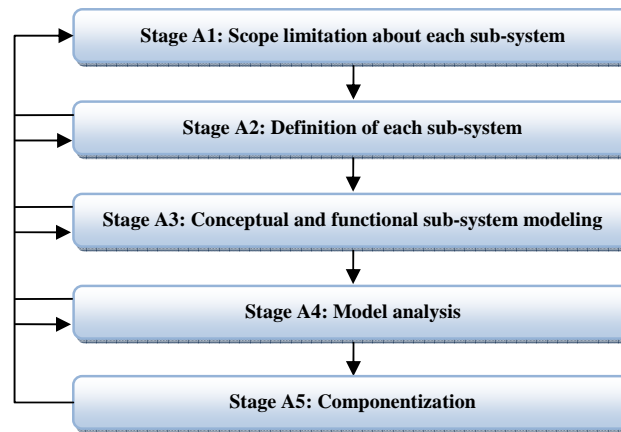


Figure 2. Procedure to model the services of the CTMS modules.

- **Stage A1: Scope about each manufacturing system module**
At this stage, the functional characteristics of each manufacturing system module is identified and documented. The collected information is a way to make a preliminary analysis and identify relevant data of each module.
- **Stage A2: Definition of each manufacturing system module**
The information obtained at stage 1 is used to establish the manufacturing system module requirements. The requirements are converted in functionalities of the system. Those functionalities accessed by other systems or people are provided as a WS. The requirement definitions are carried out using UML².
- **Stage A3: Conceptual and functional modeling of each manufacturing system module**
The modeling of each manufacturing system module, that is, the modeling the control strategies of each module is systematically developed in accordance with a hierarchical approach using the PFS/PN methodology (HASEGAWA *et al.*, 1988). Initially, using the PFS, a conceptual model is developed for the functionality of each module. Then, gradually, a refinement is conducted to obtain its detailed functional model in PN.
- **Stage A4: Model analysis**
Aimed to validate and verify the functional requirements of the modules, the functional models in PN obtained on stage A3 are submitted to a structural and dynamic behavior analyses.
- **Stage A5: Componentization**
Once the manufacturing system module has been defined, the different activities can be arranged, according with their function, in components.

² <http://www.uml.org/>

Next, a complementary part of the proposed procedure is presented. The focus here is the composition and coordination of different activity modules of the manufacturing systems that compose the CTMS. This part of the procedure is carried out in three stages (Fig. 3).

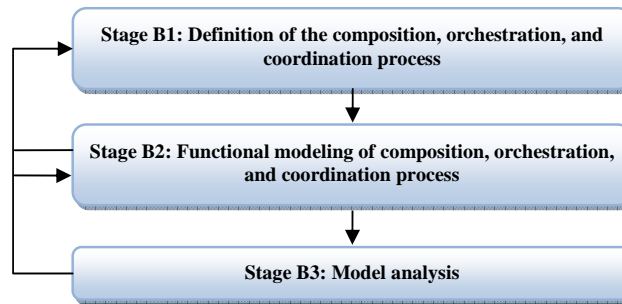


Figure 3. Procedure to integrate and coordinate CTMS modules.

- **Stage B1: Definition of the composition, and coordination process**
This stage should consider the overall production process, or in other words, the sequence of operations from the customers' requests to the finish of the process, obtaining the final product. The sequence of operations is exposed as a service, and for each manufacturing system module involved in the process, it is defined an interface. The requirements of process flow are established using UML.
- **Stage B2: Functional modeling of composition, and coordination process**
Using the PFS/PN methodology, the functional composition and coordination model is obtained. Initially, the activities are defined in PFS. Afterwards, through a refinement of the PFS model that is gradually conducted its functional model in PN is derived.
- **Stage B3: Model analysis**
Once the functional models of CTMS are obtained, the structural and behavior analysis of these models are conducted in order to validate and verify if the requirements and functionalities of CTMS are completed.

4. APPLICATION EXAMPLE

In this example, the CTMS is composed by the following manufacturing sub-system: work-piece supply sub-system, work-piece inspection sub-system, pallet transportation sub-system, and product assembly sub-system. In addition, some interfaces must be considered for teleoperators and costumers interaction. These sub-systems are treated as modules that are interconnected through a communication network and evidently they must work collaboratively to produce a costumers' requested product.

The "work-piece supply module" executes the service that removes a work-piece from a buffer/magazine and puts it in a specified position in the "work-piece inspection module". The "work-piece inspection module" executes services related to quality control and identification of the work-pieces physical characteristic; the approved ones are put on a free pallet of the "pallet transportation module", which movements the pallet to the "product assembly module". When a pallet with a work-piece reaches the "product assembly module", a robot performs different assembly activities. The assembly service is carried out in three stages. Initially, the work-piece is located in an appropriate base where the product assembly is produced. Then, according with work-pieces physical characteristics, some parts are assembled. Finally, the final product is put on a free pallet of the "pallet transportation module" to leave the system. The type and quantity of products to assembly are defined and requested by costumer via Internet. Every module can be monitored and teleoperated via Internet. In monitoring mode, information of each module function is provided to its operator in order to ensure the monitoring of remote production process execution. In teleoperation mode, the operator provides a series of commands for the execution of the production process.

In order to attend the product requested by the customers, it is established a collaborative work among the modules involved in the CTMS.

Due to the limited space available for this text, just a sample of some results is presented here. In this sense, the "work-piece supply module" and its services are used to illustrate the procedure proposed for CTMS modeling.

- **Stage A1: Scope about each manufacturing system module**
The aim of "work-piece supply module" is to provide a work-piece for "work-piece inspection module". The pneumatic actuator devices need a minimum of 6 bar (87 PSI) operating pressure, and electro-mechanical devices need

a 24V electrical energy source. Concretely, three actuators, five electro-valve and six sensors (five magnetic, and one optic) are used to carry the work-piece supply service.

- **Stage A2: Definition of each manufacturing system module**

The information obtained on the previous stage is used to define the work-piece supply behavior and functionalities. These characteristics are represented in a UML use case diagram (Fig. 4). In this sense, this module provides interfaces for the “CTMS” and “teleoperator” actors. The “CTMS” can invoke the “work-piece request” and the “available” functionalities/interfaces. Once “work-piece request” functionality is activated, it calls the “execution request” function to develop the work-piece process. To execute the work-piece process the device activities are activated through the “execution activities” function in accordance with the incoming signal from “telecommand request” function. On the other hands, the “available” functionality indicates the available conditions of the module to attend a request. It consults other two functions responsible to check the status of “devices” and “teleoperator”, i.e., “device available” and “teleoperator available”. The “teleoperator” can request the “teleoperator access” functionality, to access the module under his responsibility, and the “telecommand request” functionality, which he can execute the teleoperation activities.

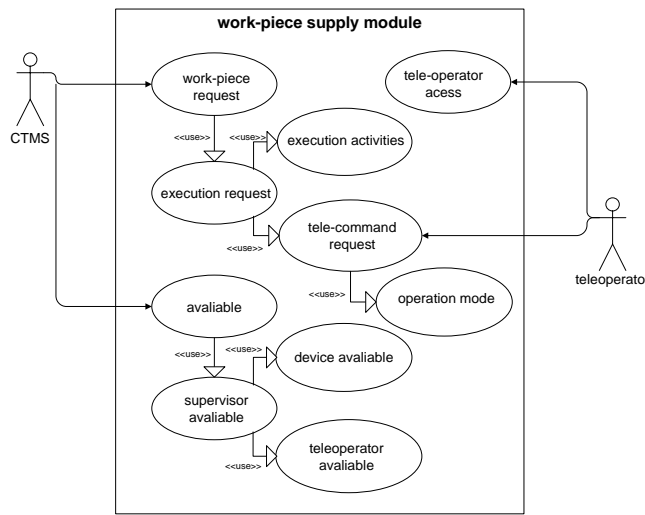


Figure 4. Work-piece supply definition.

- **Stage A3: Conceptual and functional modeling of each manufacturing system module**

In Fig. 5, it is shown the refinement of “work-piece request” functionality. It presents the activities sequence to perform in the work-piece service. First, [incoming work-piece request] activity is activated when a message of request of work-piece is received. Then, [sending execution request] activity prepares and sends a message for activates the [execution request] activity, which is an activity defined that base on work-piece process executes the manufacturing tasks. Following, a stand by state is instanced. Then, [incoming execution notification] activity is activated when a message from [execution request] activity is received with the execution status. Finally, [sending work-piece notification] activity is executed, sending back a message to the CTMS.

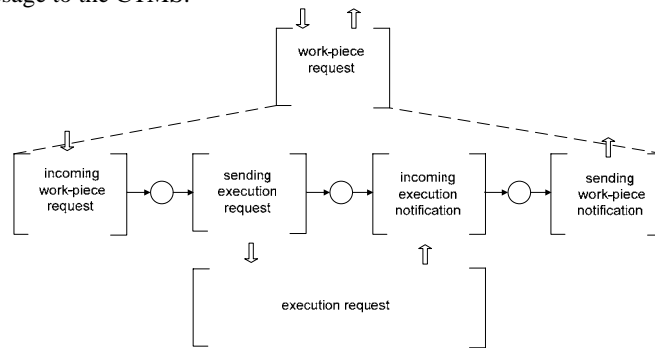


Figure 5. Refinement of the [work-piece request] activity.

Figure 6 presents the refinement of the [execution request] activity. Initially, [incoming execution request] activity is activated when a request message is received. Next, a cycle of process activity requests based on telecommand response is carried out. Therefore, [sending a telecommand request] activity prepares and sends a request message, which activates the [telecommand request] activity. Based on the response of telecommand, received by [incoming telecommand response] activity, a request message is sent by [sending execution request]. Information of state of shop-floor-devices, after the activity execution, is received by [incoming execution notification] activity and it is registered by [tracking device request] activity.

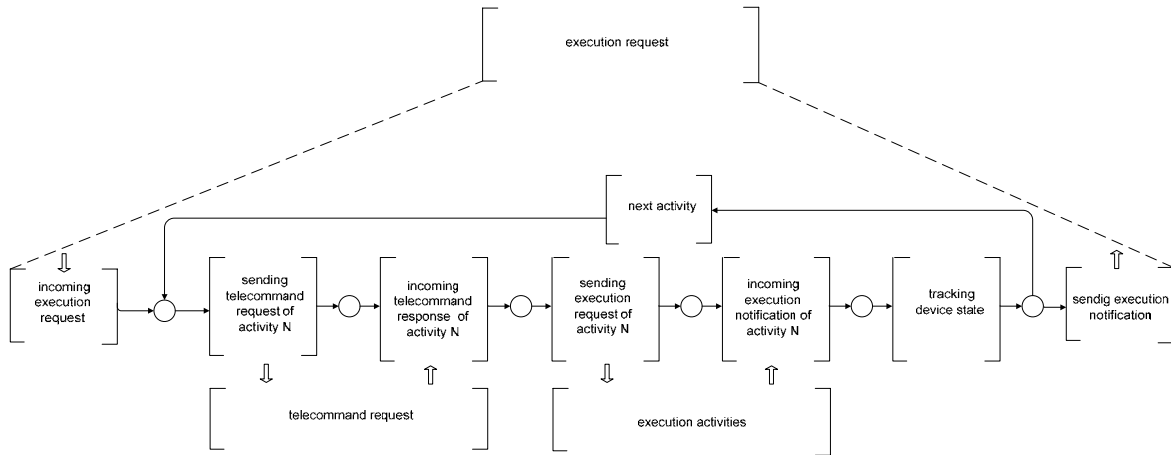


Figure 6. Refinement of the [execution request] activity.

The [telecommand request] activity is detailed in Fig. 7. It is activated when a message is received by [incoming telecommand request] activity. The requester message is registered by [registration telecommand request] activity. Depending of the operation mode, the activation of [monitoring mode] activity or [teleoperation mode] activity is selected. The register of telecommand status is carried out by [telecommand state actualization] activity. Finally, a message with the status of telecommand is sent back by [sending telecommand response] activity.

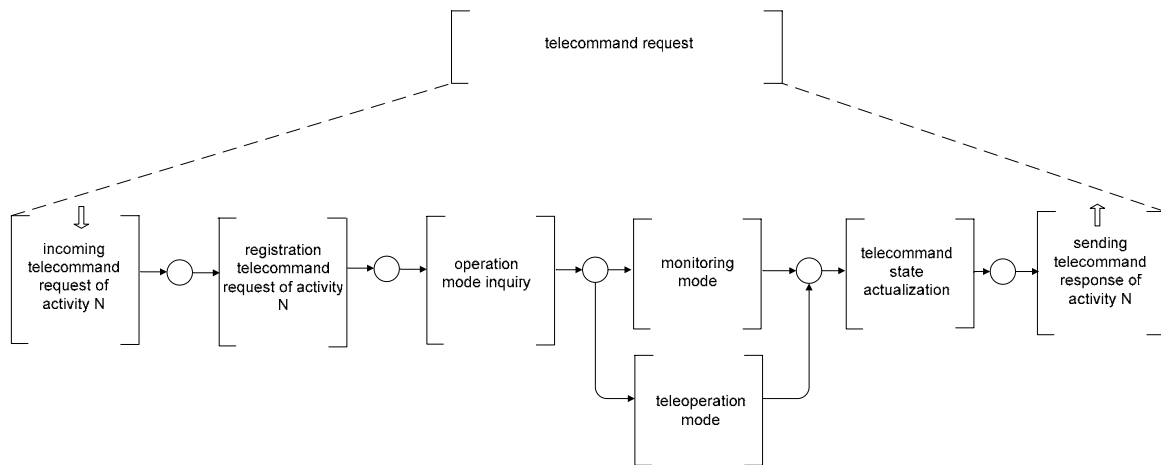


Figure 7. Refinement of the [telecommand request] activity.

Figure 8 presents a refinement of [execution activities] activity, which is developed in shop level. It starts when a request message is received by [incoming execution request] activity. Following, the execution of process operation is carried out by [execution activity] activity. Finally, the status of the devices is sent by [sending execution notification] activity.

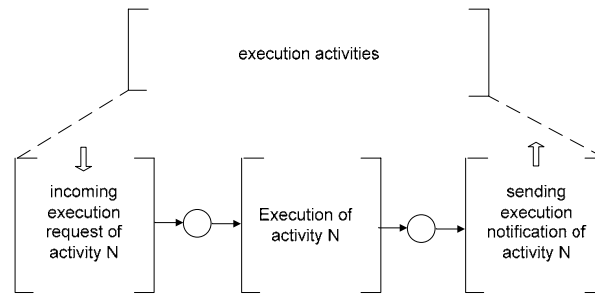


Figure 8. Refinement of the [execution activities] activity.

The [teleoperation mode] activity is detailed in Figure 9a. This activity is developed concurrently with the [teleoperation function] activity. Therefore, its first activity is reached by [incoming telecommand state inquiry] when receives a request message about of state of telecommand, from [sending telecommand state request] activity. Then, a wait state is instanced until [sending telecommand state] activity prepares and sends a status response message to [incoming telecommand state response] activity. Following, it stays waiting until a telecommand message is received by the [incoming telecommand authorization] activity, from [sending telecommand authorization] activity. At this refinement point, a functional model is generated. To compose the PN models the transition fusion approach is used in this work (GOMES & BARROS, 2005). In this way, the requester transition (T1b) sends a telecommand state request to its paired requested transition (T1a). Similarly, the requester transition (T2a) sends a telecommand response to the requested transition (T2b). And, the requester transition (T3b) sends a telecommand authorization message to its paired requested transition (T3a) which received the information.

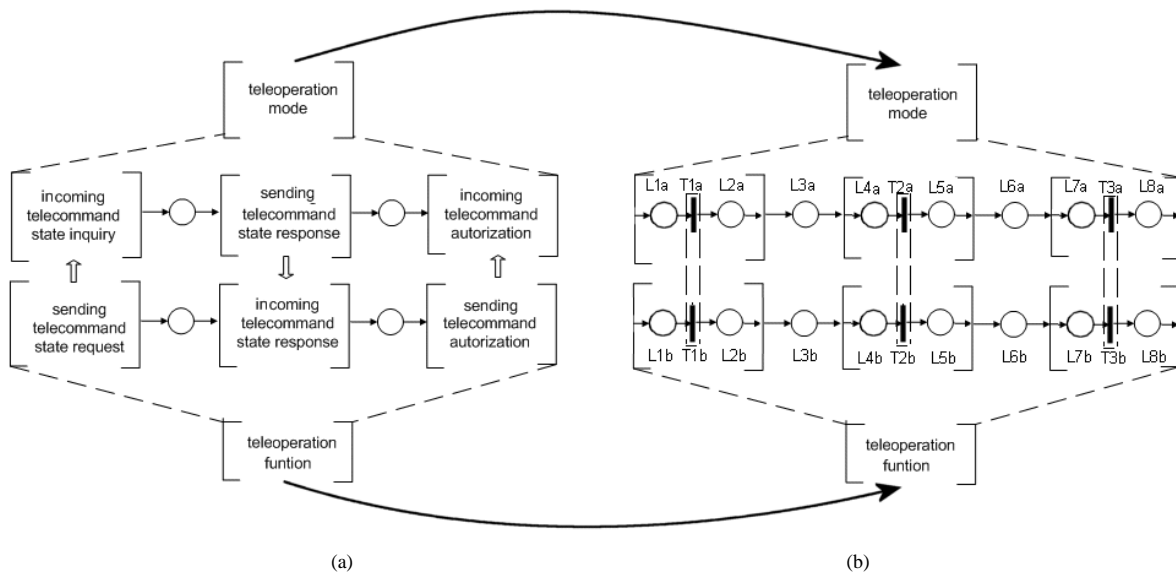


Figure 9. Refinement of the [teleoperation mode] activity.

- **Stage A4: Model analysis**

Exploring PN properties, to validate and verify the functional correctness of work-piece supply services, the state space of the functional model is then generated. Through the resulting state space, behavioral properties of the module are verified. Examples of such properties are the absence of deadlock in the supply service, the possibility of always reaching a given state, and the delivery guarantee of a given service. The PIPE³ tool may be used here for the model simulation, and to validate it.

- **Stage A5: Componentization**

According its functionality, the activities of “work-piece supply module” are classified in five components: service “*teleoperative supply*”, service “*teleoperation*”, “*supervisor*”, “*local control*”, and “*teleoperator’s interface*” (Fig. 10). The service “*teleoperative supply*” is a WS that exposes the functionality of module as a service that can be

³ <https://sourceforge.net/projects/petri-net>

accessed via a communication network. In the same way, the “teleoperation” service is a WS that permits the interaction between “supervisor” and “teleoperator” to set the supply process activity execution. The “supervisor” coordinates the execution of supply process in the “local control”, based on information of received of “teleoperator”. “local control” defines and executes interactions with shop-devices aim to develop the process activities.

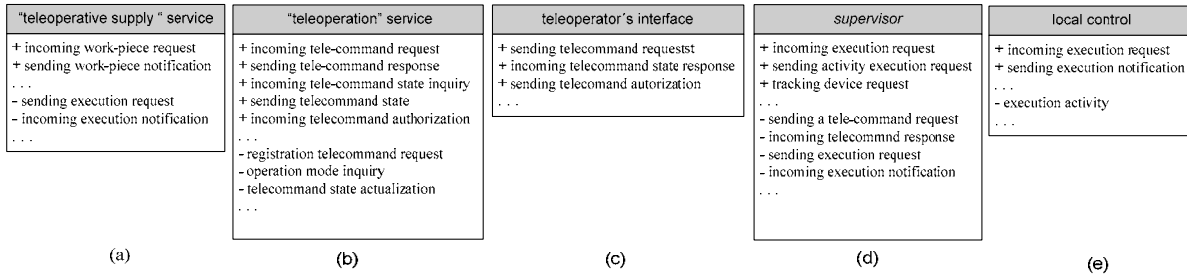


Figure 10. Components of “work-piece supply module”

Following, the proposed procedure is applied to compose and coordinate the services of all modules that compose the CTMS.

• **Stage B1: Definition of the composition, and coordination process**

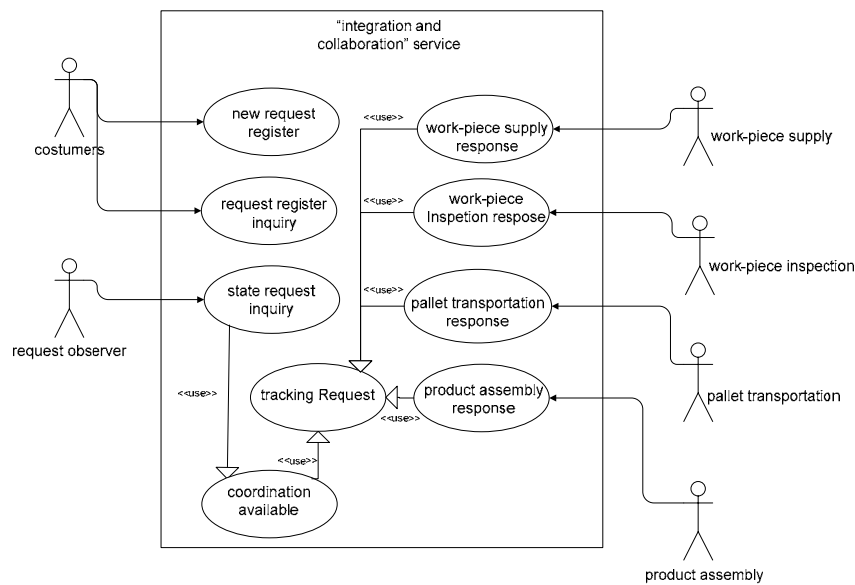


Figure 11. Definition of “integration and collaboration” service.

In the Fig. 11, the “integration and collaboration” service definition is presented. In this way, the composition and coordination of functionalities of different manufacturing system involved in the global process are defined using the UML use case diagram. At this level of abstraction the CTMS is related with the following actors “customers”, “requester observer”, “work-piece supply”, “work-piece inspection”, “pallet transportation”, and “product assembly”. The CTMS exposes the “new request register” and “request register inquiry” functionalities to permit “customers” send a new request of product and monitoring a request previously done. “Request observer” activates the “state request inquiry”, case any request is being attending, “coordination available” is used and an instance of “tracking request” is activated. To permit an incoming response message from “work-piece supply”, where its work-piece process was activated by “coordination available” function, and the “work-piece supply response” function is available. In the same way “work-piece inspection response”, “pallet transportation response”, and “product assembly response” functionalities permit an asynchronous interaction with the actors: “work-piece inspection”, “pallet transportation”, and “product assembly”, respectively.

- **Stage B2: Functional modeling of composition, and coordination process**

Figure 12 shows the [work-piece supply response] activity. It is activated when a response message from “work-piece supply module” is received. In this sense, its first activity is [incoming work-piece supply response]. Following, [sending correlation request] activity prepares and sends a request message to validate the incoming message. Then, the [work-piece supply response] activity waits for the response. If the message is validated the next activity, [sending working-piece inspection request], is activated. Finally, a register of global process execution is carried out with the activation of [sending tracking request] activity and its information through the [incoming tracking notification activity].

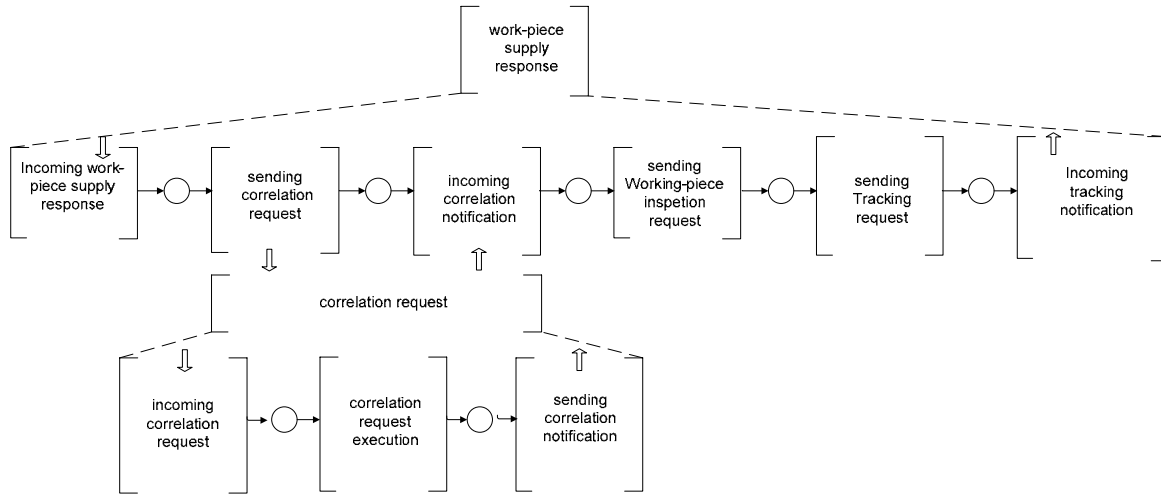


Figure 12. Definition of the [work-piece supply response] activity.

The functional PN model of [sending correlation request], [incoming correlation notification], and [correlations request] activities are shown in Fig. 13, where the requester transition (T1a) sends a correlation request for its paired requested transition (T1b). Then, a state for prepare the correlation is attended (L2b). The incoming message is compared with the customer request being executed to be validated. This procedure is executed in the internal transition (T2b). The response is represented by the pairs of transitions (T2a, T3b), where T3b is a requester transition to send a notification message, and T2a is a requested transition to receive the message.

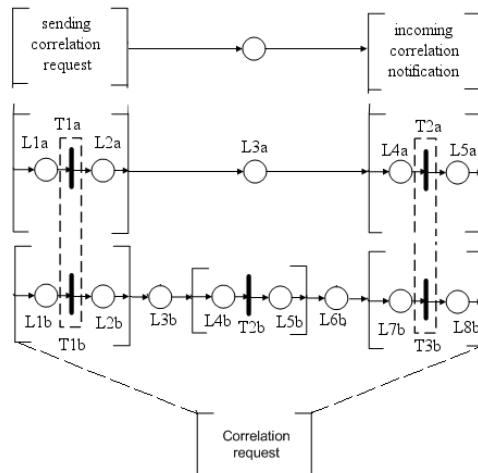


Figure 13. Functional model of [sending correlation request], [incoming correlation notification], and [correlations request] activities.

- **Stage B3: Model analysis**

Once obtained the functional models of CTMS in PN, an analysis of interactions is conducted. The state space allows verifying the global process definition, for example, if the process activity is properly realized, or identify

conflicts in messages broadcast. The validation of the model is carried out through simulation techniques using PIPE tool.

5. CONCLUSIONS

The proposed framework based on services towards a modular and scalable design of distributed manufacturing system was presented aiming the use of the available Internet infrastructure provided by the KyaTera project. In addition, this framework allows monitoring and teleoperation of the modules that integrate a collaborative and distributed manufacturing system, by an operator in a geographically distant place, and facilitates the composition and coordination of the modules services, and requests monitoring by system users. In addition, a modeling and analysis procedure was proposed based on a formal tool, derived from interpreted Petri net, with the purpose of validation and verification of the requirements and functionalities defined in the proposed architecture.

6. ACKNOWLEDGMENTS

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8. RESPONSIBILITY NOTICE

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