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Autonomic Management of Networked Small-Medium Factories

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1. Introduction

This Chapter addresses SMEs that are qualified to perform complementary manufacturing activities as producers, subcontractors or suppliers. They are used to participate in different supply chains taking the form of networks where every node manages in turn its own supply chain. More precisely, there are at least three main models (or viewpoints) to take into account:

- Medium-large company and its supply chain members. When issuing an order the medium-large company should select the most convenient supplier depending on factors like cost, lead time, capacity, supply conditions, distance. These factors are variable over time since every supply chain member has other customers and often its own supply chain to manage.
- Small-medium company and its scattered customers. Many manufacturing companies are moving still more from mass production to small customised batches frequently requested by their numerous and demanding customers. In order to preserve these customers it is necessary to assure faster and more accurate replies to their requests and orders.
- Cluster of small-medium companies behaving as a virtual factory. The cluster intends to show one face to its customers, and to this purpose it must behave as a single organisation. The critical point is actually assuring a fast reaction to customer requests and orders even though decisions are taken through intense communications between partners.

The three models share a number of features: steady composition of supply chains, customer-supplier relations based on consolidated rules, autonomy of collaborating parties. Moreover they suffer the same kinds of problems: time wasted on phone calls and distributed decisions, blind acceptance of unprofitable orders, limited capacity to react fast to unexpected events. In spite of these conditions successful small-medium distributed factories reach high levels of effectiveness. They are able to innovate products by adapting to the changing market demand, their products are normally of good quality, and a significant percentage of their production is sold in other countries thus showing a relevant attitude to stay actively on the global market.

What is often missing is a high level of efficiency. Efficiency relates to aspects such as (a) fast response to customer requests and orders, (b) shift from static to dynamic relations, (c) choice of the most convenient network configurations, (d) collaboration to damp down perturbations, (e) better logistics to minimise transports, and (f) interoperability of information systems. Once the mentioned objectives are achieved by the networked small-medium factories they result in higher productivity and competitiveness. This is of paramount relevance in present years, characterised by a global economic crisis and a very slow recovery path to previous production levels. Investing in the proposed direction is a condition for surviving or even growing and grasping new business opportunities.

It is worth observing that the identified problem affects different industrial sectors. The Authors have experience of networked factories in the mechanical, machinery, fluid power, fashion, building and construction, and automotive sectors. The common feature of these companies is participation in discrete manufacturing of one-of-a-kind products or small batches, which implies flexibility, adaptation and fast response. These are raising requirements since mass production itself is evolving towards small batches of ever more customised products while short and certain delivery time is becoming a fundamental success factor. And SME networks are particularly exposed to risks because of the limited resources their members can divert from the core business activities.

The Chapter reports the achievements of a research project that is developing a software platform with a suite of autonomic services enabling every company in the network to move from a situation where it wastes valuable resources in struggling with its customers and suppliers, towards a rational business environment where communication becomes faster, and operation and collaboration more efficient. The ultimate objective of the project is to set-up, develop, experiment and promote the adoption of a new collaboration practice within networked factories taking advantage of the autonomic model applied to a suite of support software services. This is done to help overcoming the present crisis and having in mind potential economic and industrial scenarios in the next ten years.

The proposed approach is autonomic since the planning, scheduling and decision-making steps as well as the implied data exchanges can be fully automated, and nonetheless each company maintains its autonomy by imposing its policy to the autonomic tools. Thus, once coded the desired behaviour the company is finally relieved from the daily manned interactions with customers and suppliers. Of course, in the analogy with other automation cases it is necessary that each company in the network can switch from the full automatic to the manual mode. This will slow down the distributed decision process but it could be very appreciated, at least during the initial stage, to overcome the expected distrust in such a new technology-supported collaboration model.

More in detail, the research is pursuing a number of operational objectives ranging from the detailed definition of the intended organisational model to the development and experimentation of the relative support functions. The critical research goals are:

- Study the present conditions of networked small-medium factories, taking advantage of the indications coming from the real-life cases examined, to define a new and more efficient collaboration framework highlighting policies and decision points that every single company can customise to express its autonomous behaviour.

- Design and develop an autonomic run-time support for every small-medium factory to efficiently manage its supply chain by fully automating the network planning activity. The resulting plan, obtained by an intense automatic interaction with the homologous function at suppliers, represents the most convenient network configuration for executing a given order.
- Design and develop an autonomic run-time support for every supplier node in the network to efficiently allocate its internal resources by fully automating the devised scheduling activity. The automatic scheduling function is needed to provide real-time estimation of the best execution times and costs for the tasks assigned by the upper-level planning function.
- Design and develop an autonomic run-time support for every small-medium factory to efficiently manage possible exceptions by automatically performing the needed re-planning and re-scheduling activities. The ultimate aim is damping down the perturbation in such a way to minimise its propagation to the other actors in the network.
- Study key performance indicators to measure the behaviour of every node in the network, and of the network itself as a whole, and derive general rules using them to influence decisions about network configuration and partner selection. This means adapting the autonomic decision points to include knowledge from past behaviour.
- Solve the interoperability problem of exchanging data and business documents across the network and between every node and its legacy ERP system, possibly in a multilingual environment, by means of a proper translation and document transformation service based on a reference ontology to annotate the involved information.

The rest of the Chapter is organised as follows. Section 2 justifies the research effort in the addressed field by examining the state-of-the-art to understand what has been done so far and what is still missing to meet the defined goals. Section 3 goes deeper into the research methodology by decomposing the faced problem into its components, namely the aspects and challenges that are taken into consideration to meet the requirements. Section 4 represents the algorithms of the autonomic services from the twofold viewpoint of network leader and network supplier. Finally, Section 5 draws the conclusions by highlighting benefits and possible limitations of the achieved results.

2. Research rationale and related work

In order to achieve the objectives addressed in the Introduction it is necessary to innovate in three main fields, namely collaborative networks, autonomic approach and semantic interoperability. This section describes the reasons behind the proposed approach and presents the state-of-the-art in the three fields together with the progress that our research is pursuing beyond that situation.

2.1 Collaborative networks

Networks in industry have existed for a long time (Dekkers, 2010). Particularly along the last decades, the shift from make-or-buy to co-makership and alliances, the search for flexibility, the emergence of concepts for computer integrated manufacturing, fractal company, holonic manufacturing systems, intelligent manufacturing systems, and balanced automation, all demonstrate a continuous move to more loosely connected industrial manufacturing entities. The industrial networks and concepts of distributed manufacturing are now perceived as potential solutions to the needed flexibility and agility in response to fast changes in market demands.

The advances in the ICT, and particularly the Internet and pervasive computing, have revolutionised virtual collaborations (Ommeren et al., 2009) and enabled and induced the emergence of new organisational paradigms leading to the establishment of the discipline of collaborative networks. This discipline covers the study of networks consisting of a variety of entities (e.g. organisations and individuals) that are largely autonomous, geographically distributed, and heterogeneous in terms of their operating environment, culture, social capital and goals, but that collaborate to better achieve common or compatible goals (e.g. problem solving, production, or innovation), and whose interactions are supported by a computer network.

Nowadays collaborative networks manifest in a large variety of forms. Moving from the classical supply chains format, characterised by relatively stable networks with well defined roles and requiring only minimal coordination and information exchange, more dynamic structures are emerging in industry, science, and services. With the development of new collaborative tools supported by Internet and a better understanding of the mechanisms of collaborative networks, new organisational forms are naturally emerging in manufacturing and services (Camarinha-Matos et al., 2008a). With the consolidation of collaborative networks as a new discipline, more emphasis is being put on the theoretical foundation for the area and reference models that form the basis for further sustainable developments. Projects such as ECOLEAD (http://www.ecolead.vtt.fi) are examples of precursors in this direction.

More recent initiatives, namely projects included in the FInES cluster, such as COIN (http://www.coin-ip.eu) and COMMIUS (http://www.commius.eu), have been contributing important elements for the consolidation and expansion of the area, including interoperability services, semantic mediation, service-oriented computing, security infrastructures, and so on. Nevertheless, the support for collaboration still lacks important elements namely in what regards the behavioural aspects and “soft issues” of collaboration, which are difficult to conceive with current approaches in spite of the potential of the semantic web. Some experiments have been tried with multi-agent systems but no mature solutions are yet made available. Other areas such as CSCW and VR have been developing complementary components (e.g. coordination, argumentation, avatars) but all these developments still lack a deeper understanding of the collaboration needs and important “soft” and “social” aspects of collaborative networks.

Sustainable development of collaborative networked organisations needs to be supported by stronger fundamental research combined with real-world applications. The ARCON reference modelling framework for collaborative networks (Camarinha-Matos & Afsarmanesh, 2008b) is a contribution in this direction. Some important results from this area that are relevant for our research are value systems and benefit analysis models for collaborative networks (Romero et al., 2009), soft modelling techniques applied to complex problems such as rational trust assessment and management (Msanjila & Afsarmanesh, 2008), value systems alignment, negotiation wizards, behavioural modelling, and so on.

The proposed approach takes into account the already extensive empirical knowledge and technological achievements on collaborative networks and known limitations of current ICT support in order to design a new organisational structure and collaboration infrastructure offering support for dynamic composition of supply chains. The collaborative models needed in innovative enterprise networks (Tidd, 2006; Arana et al., 2007) present distinctive characteristics e.g. in terms of duration of relationships (among stakeholders and between service providers and clients), nature of business relationships, scale and territorial coverage, types of participants, that require new organisational forms, contractual models, and new governance models.

2.2 Autonomic approach

The adjective "autonomic" was first introduced to denote the Autonomic Nervous System (ANS or visceral nervous system), that is, the part of the peripheral nervous system that acts as a control system functioning largely below the level of consciousness. Since then it was intended to express the idea of automatic behaviour of functions personalised and then delegated by humans.

The Autonomic Computing Initiative or ACI (IBM, 2010) was launched by IBM in 2001 to develop computer networks capable of self-management for facing the rapidly growing complexity of distributed computing. The essence of autonomic computing is automating low-level management tasks while assuring better performances at the network level. In a self-managing autonomic system, the human operator takes on a new role in fact he/she does not control the system directly but defines general policies and rules that serve as an input for the self-management process. For this process, IBM has defined the following four functional areas: (a) Self-Configuration, for automatic configuration of the network components; (b) Self-Optimisation, for automatic monitoring of resources to ensure their optimal functioning with respect to requirements; (c) Self-Healing, for automatic discovery and correction of faults; and (d) Self-Protection for proactive identification and protection from arbitrary attacks.

Successively the Autonomic Network Architecture (ANA) integrated project (http://www.ana-project.org) moved the focus to network organisation based on the application of the autonomic principle. More recently the CASCADAS integrated project (http://www.cascadas-project.org) developed an autonomic component-based framework to deploy distributed applications capable of coping well with uncertain environments. In general, studies moved from the original idea to the possibility of exploiting the autonomic model in different application directions (Deussen, 2007; Di Ferdinando et al., 2008). Our research identifies the efficient management of manufacturing networks as a promising application field for the autonomic approach. This seems to be in fact the only feasible way to overcome the organisational delays induced by the participation of different members to strictly successive business processes and thus assuring fast response to external and internal signals (Pouly & Huber, 2009).

In this context, as depicted in Figure 1, every company is subject in principle to a double autonomic process, respectively as leader of the supply chain (or network coordinator) and as subcontractor. If leader, whenever reached by a customer order it will perform a planning activity aimed at choosing the most suited network configuration (Self-Configuration) and resulting in task assignments to the selected suppliers; if supplier, possibly of itself, it will manage to optimally schedule the internal resources (Self-Optimisation) to meet the requirements of the tasks assigned by the network leader (Hülsmann & Grapp, 2006). Moreover, in either cases it will undertake the necessary recovery actions (Self-Healing) to damp down the perturbations crossing the network as consequence of exceptions raised by nodes. Finally, it will use performance indicators derived from the past experience (Self-Protection) to tune and correct its planning or internal scheduling decisions.

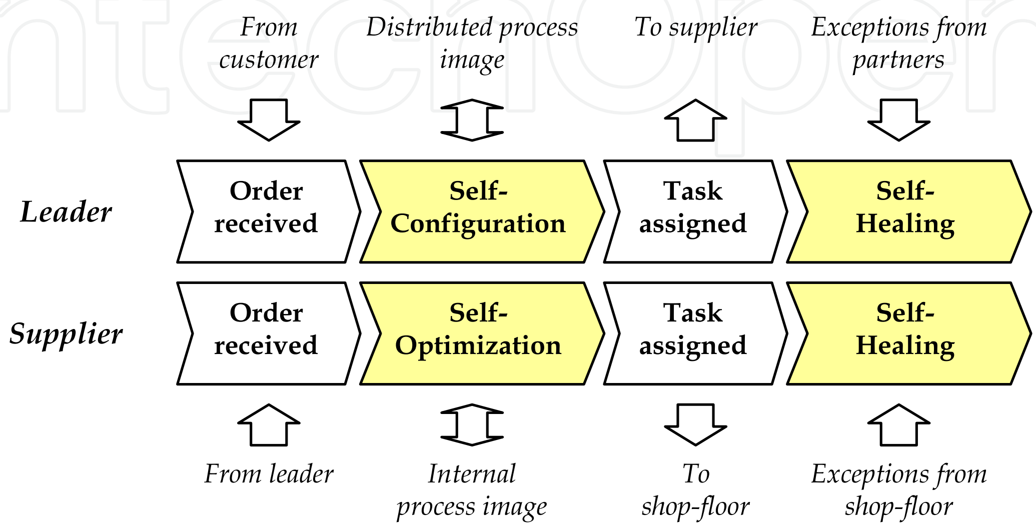

Fig. 1. Autonomic functions in leader-supplier relations.

According to the autonomic principle all these activities can be completely automated while preserving the autonomy of every network node to apply its own policies and habits. The progress brought by our research beyond the state-of-the-art is in the original adaptation of autonomic computation, a still young technology born in the world of technological infrastructures, to a practical and quite common problem of communication and coordination in manufacturing networks (Bonfatti et al., 2010a). If properly promoted and customised at the target companies it could have a dramatic impact similar to that produced by the first MRP systems in the far '60s and '70s.

More precisely, the proposed approach is inspired to some extent to the recent studies on autonomic service composition based on semantic, goal-oriented, pattern-matching (Fujii & Suda, 2006; Quitadamo et al., 2007). Their basic idea is that semantic description can be attached to services expressing what a service can provide to other services and what it requires from other services. In our case this is done by providing every node with the knowledge of distributed processes, if leader, and internal routings, if supplier. On this basis automatic propagation mechanisms for service composition can be enforced in an unsupervised way.

Besides relieving small-medium factories from burdensome and repetitive activities, thus saving resources that could be better employed in their core businesses, the autonomic approach introduces a clearer view of internal and distributed processes and a much deeper awareness of roles and decision policies. The increased effort required in the start-up phase will be paid back in a short time by the valuable benefits generated by the new organisational model. Therefore, the proposed collaboration model introduces as by-product a general cultural shift which is itself a breakthrough for moving the target companies towards a more efficient, profitable and competitive working environment.

2.3 Semantic interoperability

This third innovation area is justified by the intention to provide the autonomic platform with a technology assuring the possibility, for the user companies, to import/export business documents from/to their own legacy systems and to exchange documents with customer and partners adopting different data models and languages. It is well known that this requires the construction of a Reference Ontology – a data model and multilingual vocabulary for the specific application domain – as well as its use to "annotate" (or "map") the concepts of the legacy systems at the network companies and to cross-reference the terms from the origin language to English as "lingua franca" up to the destination language.

The generic WordNet (http://wordnet.princeton.edu) lexicon, the UNSPSC (http://www.unspsc.org) and eCl@ss (http://www.eclass-online.com) product/service standard taxonomies, the UBL (http://docs.oasis-open.org/ubl/os-UBL-2.0.zip) data model for business documents, all them represent good starting points for the construction of the intended reference ontology. What is needed is a strong simplification obtained by focusing on the only concepts and terms that are actually used for communication and document exchange in the devised collaboration environment (Bonfatti & Monari, 2007). This was done, for instance, with the domain ontology developed by the SEAMLESS project (http://www.seamless-eu.org) for the textile and building & construction sectors (Lima et al., 2006), the studies on semantic modelling in the logistics and transport sector (Brock et al., 2005), and the experience gained in the frame of the KASSETTS project (http://www.kassetts.eu) to support transnational collaboration in logistics (Bonfatti et al., 2010b).

Concerning the tools needed to define and manage the reference ontology (editor) and to map it versus legacy system data models (mapper) there are a couple of interesting candidate packages: PROTÉGÉ (http://protege.stanford.edu), the most known open-source editor of OWL ontologies exported in XML format, and MAPFORCE by Altova (http://www.altova.com/products/mapforce/xml_to_xml_mapping.html), a professional mapper of data models producing XSLT stylesheets for XML-to-XML transformations.

Although the document processing steps are well known, very few examples of business document transformations, including simultaneous structure conversion and contents translation, exist to be taken as reference. And the challenge is made even more critical by the need to hide the process complexity under an easy and simple user application. Our research is contributing to the advance of knowledge and technology in the field of semantic interoperability with a work addressed to the practical implementation and deployment of a so-far experimental approach to actual document structure conversion and contents translation. More precisely,

- Much care is taken to minimise and simplify the manual activity of annotating the proprietary or standard data models of the involved legacy systems with the concepts of the reference ontology. In particular, the difficulties arising from representation in research-related languages – such as OWL – are overcome by introducing easy drag & drop user interfaces.

- The run-time document transformation function is completely automatic and transparent to the sender (receiver) user who will maintain its own legacy ERP system and be relieved by the need to know the data model and language of the receiver (sender) user. In other words, the effort spent in ontology construction and manual annotation is widely recovered at run-time.

2.4 The FInES roadmap

In developing the research work towards autonomic management of networked small-medium factories special attention is spent to follow the indications reported in the Future Internet Enterprise Systems (FInES) Research Roadmap (FInES, 2010). First, the concept of enterprise Quality of Being is introduced as an extension of the current notion of enterprise quality. Six distinct FInES Grand Objectives are identified to characterise the enterprise Quality of Being, which are taken as reference by our research activity in term of exemplary quality of future enterprises:

- Inventive enterprise. Flexibility and distributed autonomy are the main features addressed by the research. Very important, the target factories have a partially organised structure with strong delegation to lower operational levels. In addition, the research aims at supporting a distributed control functionality based on feedback mechanisms and autonomous reactive behaviours.
- Cloud enterprise. The autonomic approach directly targets distributed organisations where raw materials and intermediate products are supplied by different organisations (often located in different places or regions) that are in or out depending on the conditions, but with a coordination level that is based on clearly defined agreements about supply time and quality of the supplied goods and services.
- Cognisant enterprise. The research aims at pushing companies towards this quality in two ways. First, it adds further knowledge including formalised process models and decision-support rules. Second, it keeps and elaborates data on performed activities and their effects thus enabling the networked factory to learn from experience and adapt consequently its behaviour.
- Community-oriented enterprise. The intended virtual factory is characterised by transparency and accountability. Transparency is assured by the definition and application of behavioural rules at the company and the network levels, accountability comes from objective measures of performance in the perspective of revising or improving relations with peers and customers.
- Green enterprise. The research explicitly addresses the identification of optimal distributed planning solutions including minimisation of transports between the virtual factory nodes. This will have an immediate positive effect on freight traffic, especially at the regional scale where over 80% of transports occur at a distance of less that 100 km, and the resulting reduction of CO_2 emission.
- Glocal enterprise. The real-life cases taken as reference by the research are all run by virtual factories acting in the global market and however deeply rooted in their territory and culture. In particular, the proposed approach facilitates the target companies in looking ahead to get immediate advantages for future improvements or, at least, to reduce future detriments.

Going deeper into the FInES Research Roadmap the approach we propose is consistent to a large extent with the six operational and two (final) strategic research challenges defined in the document:

- RC1 – Federated open application platform. This is the architectural view of the proposed technology assuring the construction of a federated collaboration environment open to the addition of further value-added services. At the same time the autonomic service platform should be normally provided in Software-as-a-Service (SaaS) mode with no restraint on the place where data are stored and functions are executed.
- RC2 – Awareness and intelligence platform. The ability of an enterprise to understand its status with respect to the market, identify innovation needs and grasp collaboration opportunities requires the adoption of proper modelling methods and tools. The formalisation of this knowledge is a condition to make it available for defining a medium-term development perspective and business process improvement.
- RC3 – Innovation-oriented continuous (re)design environment. Modelling methods and tools in combination with autonomic network configuration and work optimisation tools enable companies to simulate hypothetical organisational changes and estimate their effects, including strategic indications on how to empower the network composition with involvement of further members (or exclusion of inefficient members).
- RC4 – Implementation recasting platform. The proposed solution facilitates the dynamic constitution of manufacturing networks meeting at best, time by time, the current requirements set by customers. This implies configuring the single network instance by selecting the best fitting candidate SMEs, establishing the needed relations between them and making them cooperate and exchange data and documents.
- RC5 – Meta-knowledge infrastructure. The intended services use an underlying meta-knowledge made of two main parts, reference ontology and history of past behaviour. The former provides the network nodes with the necessary semantics to interoperate with no cultural restraints, the latter supports their daily decisions with a clear view of the accessible resources, their features and performances.
- RC6 – Interoperability & cooperation infrastructure. Distributed processes regulate cooperation of distributed entities within a production network. To this purpose the autonomic platform supports document exchange assured by an automatic transformations and translation engine executing the directives resulting from annotation of legacy data models by the concepts of the reference ontology.
- RC7 – The FInES constituent. According to the roadmap definitions our collaboration environment includes: (a) enterprises of different complexity and variously linked and organised, (b) people establishing the rules of play and performing the planned processes, (c) intangibles like knowledge and services dynamically produced and consumed, (d) tangibles represented by the products constituting the final process outcome, and (e) public bodies as possible promoters and multipliers of the new model.
- RC8 – The FInES science base. The devised work on collaborative networks aim at providing sound scientific foundations to the technical work addressed to introduce more efficient collaboration practices and their support functions. This makes the project achievement suited to be adapted to a wide spectrum of practical cases and sufficiently technology-independent to cover the operational needs of the target companies and networks over a long period of time.

3. Research methodology and components

In this section the defined objectives are examined in more detail to show the directions of our research and technological development effort. In particular the research approach and methodology are presented while decomposing the research project into its components, namely the various aspects and challenges that are taken into consideration in order to satisfy the wide spectrum of networked small-medium factory requirements.

The first critical aspect to investigate is the new collaboration practices to make the networked factory and its member companies gain competitiveness in the global (electronic) market. This leads to the definition of a collaboration environment that each networked factory will interpret and adapt to its specific contextual conditions.

The adoption of the new collaboration model calls in turn for developing a suite of software services to be made available to each of the target companies. More precisely, the autonomic tools and their ancillary services are conceived for being provided as functions of a web-based platform published at every networked factory, or possibly at public service providers, and then accessible to user companies in SaaS (Software-as-a-Service) mode.

3.1 Collaboration environment

3.1.1 Collaboration habits, needs and exchanged documents

Even though SMEs are already running production projects together, the collaboration potential of companies belonging to a networked factory is often not completely exploited because of its low organisational efficiency. Other variable factors are industrial sector, company nature and size, local norms and regulations. Therefore a specific investigation was carried out to assess in depth the actual situations represented by a sample of networked factories. This knowledge is the first measurable result of our research, consisting of business and technical specifications to be taken as basis for the definition of the collaboration environment and for the design of the software platform and its functions.

While studying the target collaboration scenarios it was also possible to find out and classify the data and documents the involved actors are used to exchange. This is the condition to assure that the collaboration environment provides the needed communication channels and safeguards, at the same time, the investments in legacy ERP systems of the member companies. Analysing the exchanged documents means documenting their structure and extracting the terms used to express the relevant concepts, both normally coming from the available information systems. The construction of a comprehensive ontology to serve as semantic reference for automatic document transformation was obtained by integrating this information from the sample of small-medium factories.

The characteristics of these first research outcomes are briefly summarised in the following points:

- The first critical aspect of the collaboration model is identifying the decision steps in the frame of the distributed processes, and formalise them so as to enable the network leader and every node to customise their respective behaviours according to habits and preferences. This is of paramount importance to reach the needed level of confidence in an automatic system to which the network nodes will delegate the future operational decisions.

- Concerning the business documents exchanged between the network leader and its nodes much attention was found around requests for quotations and task assignments. Both document trigger an intense communication from leader to suppliers proposing the execution of a certain task, from supplier to leader replying with estimated lead times and costs, and finally from leader to supplier confirming or cancelling the task.
- Finally, the ontology representing the semantics used in the network for communication between parties accounts for an order of magnitude of 300-400 concepts and 700-800 terms, independently to some extent from the industrial sector. For instance, concepts are “company”, “payment mode” or “quotation” while terms are the concept names themselves plus enumerations like “cash”, “direct debit” or “credit transfer” for payment mode.

3.1.2 Process modelling and mapping

A necessary condition for autonomic collaboration in the networked small-medium factory is the formalisation of the knowledge on distributed processes that is normally hidden in the experience of skilled persons and daily operational practices. This requires a preliminary (design-time) effort establishing the correspondence between the distributed process activities as seen at the leader tier and the internal operations generated by those activities at the candidate suppliers tier.

In general the distributed process P(X) for manufacturing the product X can be represented as a typical workflow diagram, like that sketched in Figure 2, including a number of activities linked to each other by sequences, alternatives (e.g. A2 and A5 branches) and parallelisms (e.g. A3 and A4 branches). Moreover, every activity has associated the candidate supplier, or the list of candidate suppliers in case of networks with competing nodes, that could perform it. In Figure 2 the list of candidate suppliers for activity A7 includes the leader (Self) to represent a typical make-or-buy choice.

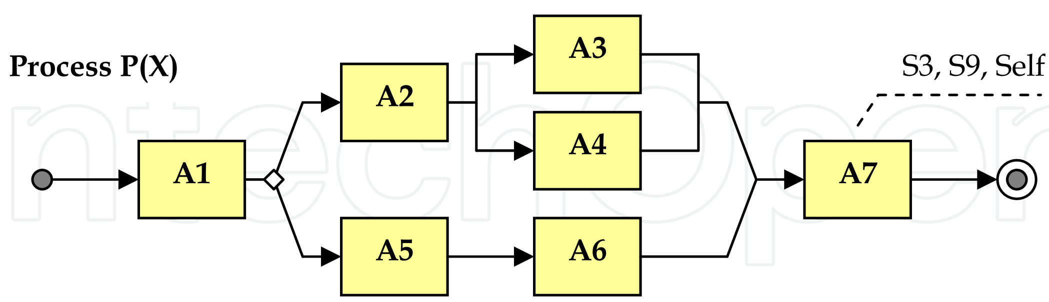

Fig. 2. Example of distributed manufacturing process.

Once defined the distributed processes for all the products offered by the network, and known the candidate suppliers for every activity, two more operations are required to complete the information needed by autonomic services, namely:

- Mapping activities with supplier internal processes. An activity as seen by the leader is normally characterised by a name and a set of parameters expressing in detail its execution conditions. For instance the activity “painting” will specify paint material, painting technique, colour, thickness and other possible parameters. In turn the candidate supplier presents the painting service in its offer, likely represented with a different name and different parameters. These data must be mapper at design-time to establish a clear match for the autonomic algorithms.

- Modelling the supplier internal processes. Every supplier must finally document the offered products and services with the internal operations required by their manufacturing. If leader in turn of a networked factory it will associate each product or service with the relative distributed process. If leaf in the networking structure it will represent the shop-floor operations in terms of routings, phases and resources, that is, the typical information required by a scheduling algorithm as well as by the autonomic Self-Optimisation service.

3.1.3 Key performance indicators

Appropriate key performance indicators (KPIs) are the enabler for decision making activities in our approach. The major decision areas that are based on KPIs include the timely selection of the right supply chain configuration, the set-up of priority rules for resource allocation at the shop-floor tier, as well as triggering events for replanning and rescheduling tasks. These decision areas are not limited to the single factory and are also relevant for the network as a whole. Besides their role for decision making processes, KPIs are used to evaluate the success in terms of factory and network efficiency as well as customer order satisfaction and supply and demand matching accuracy and flexibility.

Therefore a specific analysis of the objectives and requirements of KPIs is inevitable. The analysis consists of technical specifications on functionalities of the proposed approach and the deduction of their KPI requirements. This calls for a differentiation of the KPIs between those that have to be delivered for decision making and those that measure the performance of the autonomic processes, the involved factories and the total network. It is also necessary to find out and classify the quality criteria that KPIs have to meet for being successfully used in the autonomic environment. These criteria include the measurability of KPIs, their real-time availability for decision making purposes and their hierarchical and operational data structure. In terms of measurability the broad application focus of our research in different companies and industries calls for a higher customisable specification.

Therefore KPIs must be classified into those that are critical for the core autonomic functions, those leading to an optional increase in planning accuracy and transparency and those that are only substitutes for other KPIs. The conceptual aggregation of these analysing steps leads to a performance measurement system supporting requirement analysis for KPI definition, deduction of the application areas, quality criteria for KPI definition, process of data collection and interpretation, overall structure of the KPI system and information flow for KPI creation and usage.

3.1.4 Contracts, reliability and dispute resolution

Reaching agreements and contracting are important elements in the process of creating and operating dynamic goal-oriented networks. Research on this issue focuses on indentifying how concerns on conflict-related risks avoidance can be supported by negotiation and contracting. The dynamics of the negotiation process and the necessary support functionalities are influenced by factors such as nature and characters of the involved organisations, their expectations regarding the collaboration opportunity, affective aspects, the governance principles adopted in the networked factory, as well as the historic traces of past collaborations.

Since decision-making as well as the individual and joint behaviours in a collaborative network depend on and are reflected by the underlying value system of network participants, it is important to properly model value systems and devise methods for value systems alignment analysis. Complementarily, the roles of the various participants in the network need to be characterised and taken into account in the negotiation and contracting processes as a basic condition for trust building.

Together with value systems alignment, collaboration readiness is another relevant aspect in partner selection, which is relevant for anticipating potential conflicts. The needed work on collaboration readiness focuses on understanding, reasoning, and measuring how ready an actor is for collaborating with others, and to estimate how well an organisation is likely to perform in a partnership.

3.1.5 Identification and traceability issues

Planning processes are only as good as they can be realised in supply chain operations. By that, matching supply chain planning and supply chain execution is a key factor for the overall efficiency and flexibility of supply networks. This calls for ubiquitous information that forms the link between planning decisions and their operational consequences on the shop floor. Such an objective is influenced by ubiquitous information in three different directions:

- First, ubiquitous information leads to an information effect, what means that operational data needed for KPI formulation and overall transparency can be measured more quickly, accurately and efficient by the use of identification technologies.
- Second, ubiquitous information can be used for gaining automation effects in operational processes. While planning processes are automated by the autonomic approach itself, the automation of their execution can be managed by identification technologies. That can reduce costly media discontinuity, when automated planning results trigger manual execution processes.
- Third, ubiquitous information is often linked with process transformation effects enabling new business models and process configurations in supply chains. When implementing the autonomic system, networks have to meet physical and organisational process requirements including a high level of flexibility and traceability in supply chain operations needed for the execution of dynamic supply chain configurations, relations and processes.

Dealing with these objectives of ubiquitous information in supply chain execution the cause-and-effect relations between the autonomic approach on the one hand and the operational processes in factories and networks on the other has to be analysed. Based on this analysis the requirements on information technologies in terms of information, automation and transformation effects can be defined and afterwards being linked to those technologies like RFID or satellite and indoor telematics, best capable to realise the needed effects.

Knowing about the potential benefits of information technologies for the devised co-manufacturing environment leads to the question of process redesign and technology implementation. By using the insights of the industry partners, reference processes and implementation guides can be formulated for establishing the operational requirements for successful autonomic planning processes.

3.1.6 Risk management and security issues

It is widely accepted that a networked factory is as secure as its weakest element, since an attack against that element can lead to the collapse of the entire supply chain. This makes a holistic approach of risk and security management in a network environment such as the autonomic approach even more important. Security can be achieved in the entire network only if it is borne in mind at an early stage when planning its design. Furthermore, security should not be forgotten in the company everyday life, since even small security gaps may lead to major risk issues. Supply chain security therefore needs to simultaneously address both the entire network and its constitutive elements.

Therefore in the first instance a risk and security management framework is needed that arranges the elements and relationships of the autonomic approach in a high level of abstraction using a selected structuring of reference modelling. This reference model can be arranged into different levels, every level representing a security-relevant view of a networked factory:

- Security strategy. At first, a security strategy for the entire network has to be selected. As the autonomic supply chain configuration should be dynamic, the network precise design is not defined in this level, but in the subordinate ones.
- Network topology. A network topology is derived from the security strategy by defining the number, type, and location of linkages and nodes of the networked factory. By that, the basic policies for automated partner selection, customer acceptance and supply chain configuration functions are determined.
- Linkage. Each linkage within the network is further managed. Security measures for each route are selected that trigger the planning and scheduling routines in the system.
- Node. Each node within the network is further managed, bequeathing the security requirements of the network topology. Security measures for each network member that reflects its individual risk profile and secures the entire network has to be selected.

For the definition and design of each of these security levels the relevant requirements and risk triggers must be analysed in cooperation with the network leader. Afterwards appropriate management approaches and security technologies can be selected to be implemented in the software platform and translated into policies and practical guides for each networked small-medium factory member.

3.2 The software platform

3.2.1 Self-configuration service

Imagine the leader company in the virtual factory is receiving a customer order. This company must activate its supply chain and to this purpose it will carry out a planning activity to decide which tasks are conveniently performed internally, which are better assigned to partners and which are the preferred partners in those specific cases (the same holds to much extent in case of request for quotation). The planning activity requires that the leader company submits to the candidate suppliers the proposals for the tasks it could assign to them, and every supplier replies with its estimation of execution time and cost. Those suppliers leading in turn a supply chain will carry out a similar planning activity with the involvement of further companies to fulfil the proposed tasks (see Figure 3).

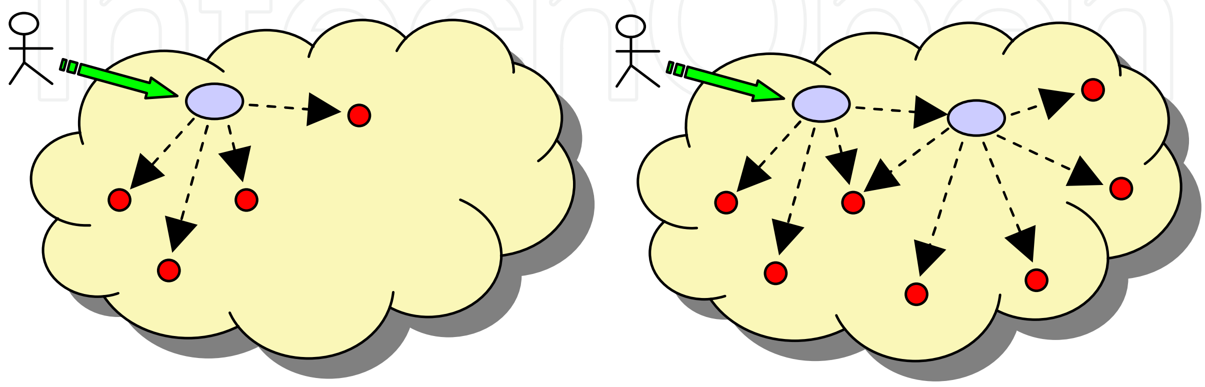

Fig. 3. Order (task assignment) propagation in the networked factory.

According to the received answers and the rules of its policy the leader company will select the best configuration of the working supply chain for that customer order, and will confirm the assigned task to each of the involved partners and a fast and detailed order acceptance to the customer. The configuration will be static if partners are predefined for the tasks to assign, it will be dynamic if partners are selected within constellations of competing companies. Should instead that configuration be not profitable to the networked factory, this will be established in a very short time and on the basis of objective data, and in that case the network leader will cancel the proposed tasks (with propagation to the lower-level networks) and reject the customer order.

It is worth noting that with the autonomic approach no resource has to be diverted from the company core business to manage real-time interactions with partners. The communication flows down from the function triggered by the customer order to the homologous functions of the lower-level nodes that lead in turn a supply chain, and the responses flow back inversely. The final response to the customer and the confirmation of the assigned tasks to the selected partners are fast and accurate when all of them are provided with the same, or equivalent, technology. No interference from other orders is expected to occur in such a brief planning time, therefore the plan is perfectly compliant with the current conditions of the involved companies.

This distributed planning process and its propagation across the ecosystem mirrors the present time-wasting human interactions but it will lead to the devised solution very efficiently. Moreover it can take into account often neglected variables, such as transport times between manufacturing steps, and compare alternative solutions to measure their actual profitability.

Details on the Self-Configuration algorithm are reported in the next section.

3.2.2 Self-optimisation service

During the planning process every supplier company is asked time by time to express its decision about acceptance and conditions for the execution of the proposed task. This decision is related to task profitability and is taken through the estimation of execution time and cost coming from the shop-floor. This requires the availability of a specific tool which, basically, is an internal resource scheduler. Every task is represented as a routing made of a number of operational phases, that is, atomic operations to be carried out by a certain resource type. The resource type is normally composed by a combination of primary and secondary atomic resources (persons, machines, equipment, etc.) for each of which the company has available one or more instances.

Then, scheduling the execution of a task means allocating the internal resource instances that are able to perform the phases of the relative routing. To this purpose the work calendars of the proper resource instances are examined and one or more combinations are identified under the given constraints. The choice of the best combination will be based on the policy established by that company. Further improvements are obtained by periodic revisions of the current schedule aimed at squeezing the resource work calendars to remove possible idle times generated by odd durations or cancellations or modification of the scheduled tasks. Note that this approach results in an optimal solution for the single company and, since combined with the Self-Configuration process, assures the local optimisation of network processes.

If a node in the network is already provided with its own resource scheduler the distributed planning function (Self-Configuration service) will obviously interface it. This will decrease the efficiency and responsiveness of the whole systems unless it is possible operating the legacy scheduler in autonomic mode. Otherwise that company can choose to adopt the Self-Optimisation service of the software platform being thus sure to obtain a full autonomic behaviour.

Details on the Self-Optimisation algorithm are reported in the next section.

3.2.3 Self-healing service

Later, during order execution, the distributed plan will be put in action and the tasks will be progressively carried out by the selected companies employing the scheduled resources. Should a task be affected by problems (e.g. on delivery date or product quantity), these will be taken as exceptions requiring a rapid replanning and rescheduling effort for damping down the perturbation. With respect to the viewpoint of the network leader company the exception could come from two different directions: from the customer in terms of order reduction/extension or changed due date, or from a supplier in terms of renounce, delay or loss of materials. In turn, with respect to the viewpoint of a supplier node the exception could come from two directions: from the network leader behaving as a customer, or from its own shop-floor in terms of missing resource, delay or loss of materials.

The company, dependently on its role, will try to solve the exception and damp down its effects by replanning the supply chain (if leader) and/or rescheduling its internal resources (if supplier). If this Self-Healing effort will be successful there will be no impact on the rest of the network, otherwise the residual perturbation will be properly propagated to the partners that will use the same tools in turn.

Because of the strong need to solve fast those kinds of problems the Self-Healing service should be autonomic even more that others. In fact if managed manually they are very stressing and can seldom take into account all the possible alternatives since their immediate practical objective is finding in any case a solution although not the best one. Instead, autonomic functions can do it as native behaviour. Of course, the autonomic Self-Healing service will rely on the same planning and scheduling algorithms supporting the Self-Configuration and Self-Optimisation phases. Every small-medium factory will be put in condition to customise them further to take into account the additional policies used in critical conditions which, in principles, could differ from those adopted for normal conditions.

Details on the Self-Healing algorithm are reported in the next section.

3.2.4 Self-protection service

The proposed model addresses the construction of self-regulating networked factories where the good practices are not imposed by a global optimisation functions but, on the contrary, they come from the ability of every actor to organise at best itself and the surrounding partners. This ability calls for the computation of proper key performance indexes to feed the partner selection mechanism. Partner selection occurs at both design-time and run-time. Design-time partner selection corresponds to the modelling stage when every company associates the activities of its distributed processes with the suppliers that could perform them. Run-time partner selection occurs during the Self-Configuration stage as consequence of the application of the customised policies autonomously defined by every actor.

In addition to criteria like profitability, execution time and cost, performance indicators play a relevant role in partner selection since they can represent the actual quality of candidates. For instance, under equivalent conditions a reliable supplier is preferred to others; moreover, the selection policy could introduce additional times or costs in presence of underestimating partners. Key performance indicators are conveniently computed from the past network member behaviour that, to this purpose, must be adequately traced. Besides contributing, as actually objective data, to implement a suited trust building mechanism, their values are considered in the policy rules and used by the planning tools. Their periodic update is ensured by the Self-Protection service.

Finally, the knowledge about partner quality, as expressed by the performance variables, must flow across the network, in at least two ways: (a) whenever considering a company as possible partner its quality must be immediately known, and (b) time and cost estimations coming from possible suppliers must be accompanied by the integrated quality measure of the underlying supply chains, if any.

3.2.5 Document transformation service

Business collaboration implies an intense data exchange in terms of business documents. The software platform is provided with a technology realising an easy communication channel taking into account that customers and partners are normally operating different information systems (meaning, with different data models) and possible using different languages.

This requires the construction of a Reference Ontology – a data model and multilingual vocabulary possibly specialised for the specific application domain. The data model is used to "annotate" (or "map") the concepts of every interesting legacy systems while the vocabulary will cross-reference the terms from the origin language to English as "lingua franca" up to the destination language. The experience gained with the already mentioned SEAMLESS project showed that the reference ontology is conveniently built up as a controlled user-defined semantic representation based on the analysis of the exchanged business documents. Once constructed, the reference ontology is passed to an ontology Editor to be stored, managed and updated off-line by the appointed experts. Then the ontology is moved to an ontology Mapper where the data model and vocabulary of every interesting legacy system is put in relation, by a graphic user interface, with the homologous concepts of the reference ontology.

The outcome of the Mapping function is an executable fragment of code that, if applied to an incoming document, assures its structure conversion and content translation from the origin data model (and language) to an internal representation in English and, vice versa, from this internal representation to the destination data model (and language). The Transformation service is applied in two important cases:

- Document import/export. Every document moved from the legacy system of a user company to the autonomic platform, and vice versa, will undergo an automatic transformation process from the origin data model to the destination data model.
- Document exchange. Every document exchanged through the software platform with a customer or a partner will undergo a similar transformations process plus the automatic translation of contents between the origin and destination languages, if different.

While the Editor and Mapping functions are off-line, and used manually once for all at design-time, the Transformation function is automatically executed at run-time by the import/export and document exchange services so as to provide the user with a very easy communication tool hiding the intrinsic complexity of the transformation process.

4. Details on autonomic functions

This section provides some details on the algorithms of the run-time autonomic functions, namely Self-Configuration, Self-Optimisation and Self-Healing, and of the relations between them in the construction of a full autonomic network management environment. Although schematic and neglecting minor aspects, they should be sufficient to show the basic computation and interaction mechanisms that have been developed and are presently tested at networked small-medium factories working in different industrial sectors.

4.1 Self-configuration algorithm

Figure 4 shows the general schema, in form of activity diagram, of the Self-Configuration algorithm processing a customer order (or a request for quotation) received by the network leader. Let us assume that the customer order refers to a single product, that is, is made of just one order line (and the request for quotation as well). Double-line boxes correspond to invocations to other autonomic services.

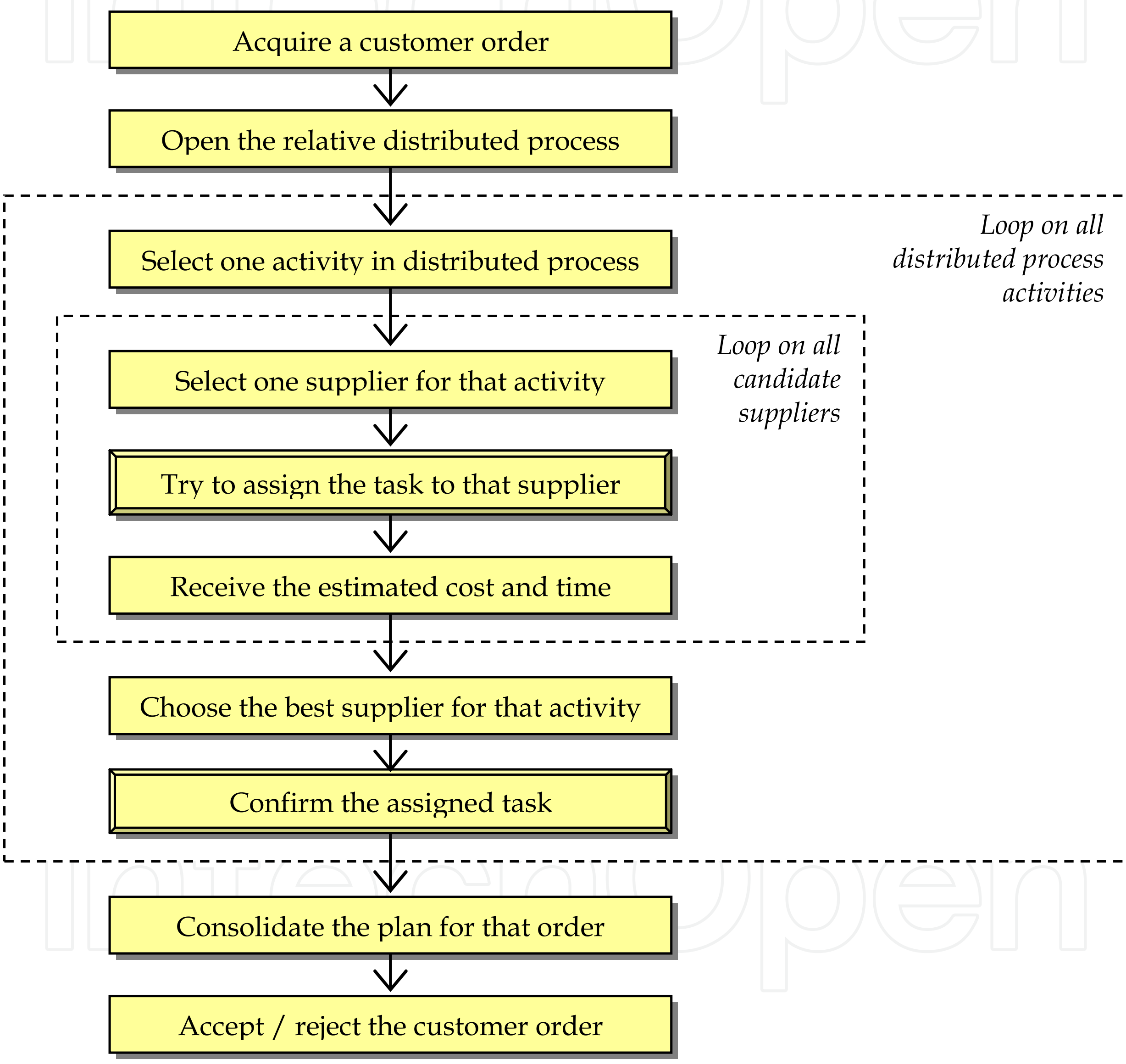

Fig. 4. General schema of the Self-Configuration algorithm.

Some comments and explanations:

- This algorithm holds for both customer order and request for quotation. In the latter case the function "Confirm the assigned task" is removed since there is nothing to confirm until the customer will issue an order. Moreover, the "Accept / reject customer order" is replaced by the simple communication of the estimated lead time and cost.
- The distributed process is scanned one activity at a time. In fact only after an activity has been assigned to the best supplier its end time is known to become the start time for the next activity. In case of alternative branches the algorithm follows the branch corresponding to the given parameters. In case of parallelism its branches are scanned in parallel to determine the overall execution time (the time computed on the slowest branch) to become again the start time for the next activity.
- More precisely, not always the end time of an activity becomes the start time of the next one. In fact, whenever materials must be moved from one company to the other it is necessary to plan the transport and then estimate its duration and cost. The duration is added to the end time of the previous activity to determine the real start time of the next one, the cost is added to the overall process cost for profitability analysis.
- The invocation of all the suppliers under consideration is indeed the moment showing the benefits of the autonomic mechanism. While planning successive customer orders a certain supplier associated to different activities will be subject to many invocations whose only objective is estimating its execution times and costs. Much better if this occurs in a way that is transparent to the company personnel, provided that the supplier autonomic service is certainly applying the established customised rules.
- The choice of the best supplier for a given activity is based on a multiplicity of criteria including cost and lead time but also supplier quality, reliability and correctness. This is in fact one of the decision points that is worth customising so as to mirror the usual human decision mechanisms.
- Once the best supplier is chosen for a given activity its autonomic service is invoked again with the only objective to confirm its booking to perform that assigned task. This occurs within the same transition of the previous invocation therefore the renewed invocation will confirm the same results as before.

It is worth underlying that this process is completely automatic, hence it achieves the devised solution in a very short time having considered a number of alternatives that are completely out of the reach of any human operator. When invoking the autonomic service of a candidate supplier two different situations may occur: (a) the supplier is in turn the leader of a networked factory, then the assigned task will be processed by the same Self-Configuration algorithm; or (b) the supplier directly operates with its shop-floor, then it schedules its internal resources with the Self-Optimisation algorithm described in the next sub-section.

4.2 Self-optimisation algorithm

Figure 5 shows the general schema, in form of activity diagram, of the Self-Optimisation algorithm scheduling a task tentatively assigned to that supplier by the network leader. The Self-Optimisation algorithm has different effects depending on whether it is invoked just to estimate lead time and cost or to book definitely the internal resources. In the latter case the algorithm outcome updates the work calendars of the allocated resources while no change results in the former case.

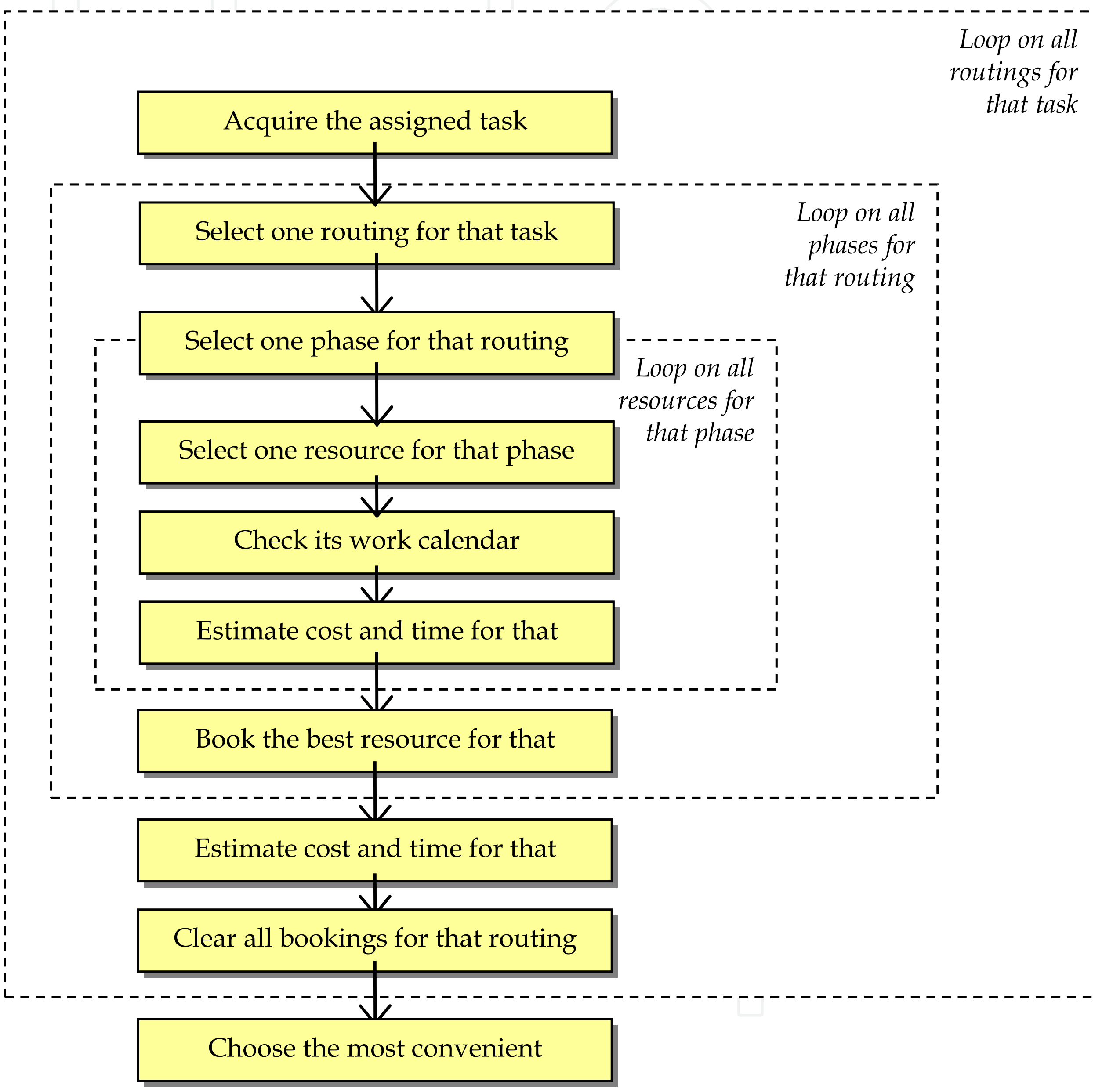

Fig. 5. General schema of the Self-Optimisation algorithm.

Some comments and explanations:

- We assume that, as it often happens, a supplier can perform a certain task according to different routings normally defined for the employment of alternative resources. Therefore the first scheduling loop is intended to verify which is the routing assuring the most convenient solution in the specific case, according to the policy of that company.
- We also assume that a routing is represented as a rule by a sequence of phases that are scheduled following their execution order. Once scheduled one phase its end time is known, which becomes the earliest start time for the next phase. Delays on the latter phase can result from late availability of the required resources or possible lack of the needed materials.
- Then, scheduling a phase means identifying the internal resource instances that are able to execute it, simulate the employment of each of them by checking its work calendar, and eventually choose the best resource instance for that phase. Even in this case the final choice is (automatically) performed according to the company policy and decision criteria coded at the system customisation stage.
- Resource is a generic term. Sometimes it indicates a specific machine whose availability is the only constraint for allocation to a given phase. In other cases it is a combination of primary (finite capacity) and secondary (infinite capacity) resource instances including persons, machines and possibly consumables. In the latter case the scheduling algorithm must ensure that all these components are simultaneously available for that phase.
- Once found out the best resource instance for a certain phase its allocation must result in a booking on its work calendar, so as to mark it as busy in the corresponding time period. In fact when scheduling the next routing phases it might happen that the same resource instance is considered again, therefore its availability must exclude the booked periods to avoid phase overlapping.
- Instead, once completed the scheduling of one routing and produced the expected estimation of execution time and cost, all the bookings of the involved resources shall be cancelled. The reason is that the scheduling of the next routing, for the same assigned task, must start from the same initial conditions found by the previous routings: this is a strict condition to allow a correct comparison of their results.
- At the end of this effort the best schedule on the most convenient routing is finally known, and its data are returned to the invoking Self-Configuration algorithm. If that schedule is afterwards confirmed the scheduling algorithm will be called again, within the same transaction, to just book the chosen resource instances.

This algorithm is not so different from other scheduling functions found on the market. However, it presents two main peculiarities that is worth recalling here: (a) a deep integration with the upper-level Self-Configuration algorithm assuring intense recursive interactions, fast decisions and an overall efficient behaviour of the autonomic system, and (b) the real possibility to be executed with no human intervention while assuring the full application of the customised rule for the benefits of the single user company.

4.3 Self-healing algorithm

Self-healing means enabling every actor in the supply chain to manage exceptions and contribute, according to its role, to damp down the perturbation across the network. This is done by triggering the execution of the proper autonomic services with the purpose of replanning the affected distributed processes and rescheduling the affected tasks.

Exceptions come, for a leader, from a customer or from a selected supplier; in turn they come, for a supplier, from its leader or from its shop-floor. Moreover exceptions are of many types since they include order or task cancellation, advance or delay on the due date, increased or decreased product quantity, and the like. Therefore it is necessary to consider a wide spectrum of cases and the actions that shall be undertaken to face each of them with the maximum level of efficiency.

Let us consider one of the many possible situations of exception (see Figure 6): supplier S4 that had assigned activity A2 of process P(X) informs the leader of a 4-days delay to complete that activity. The leader activates the Self-Healing service that performs the following automatic activities:

- The plan generated by the Self-Configuration service for process P(X) is scanned to find out the activities depending on the A2 results or, however, not started yet (the shaded area in Figure 6) since they are the only activities whose planning can be revised.
- The autonomic services of suppliers S1 and S9, respectively assignees of tasks A3 and A4, are invoked for new estimations of time and cost according to the changed conditions. Once known the new latest delivery time of those two parallel activities, that time is taken as new start time for replanning A7, and the autonomic service of the Self supplier is invoked in turn.
- An alternative, more aggressive, replanning approach consists of two steps: (a) the autonomic functions of suppliers S9, S1 and Self are called to immediately revoke the respective tasks assigned; then (b) a radical replanning of activities A3, A4 and A7 is carried out by means of the Self-Configuration function with the involvement of all the candidate suppliers.
- In either cases the conclusion is a new overall lead time and cost, hopefully compliant with the indications of the customer order. If not, the change shall be communicated to the customer.
- Note that in this situation the perturbation is transmitted to suppliers S9, S1 and Self which could in turn propagate it to the respective sub-networks, if any. Otherwise they shall solve the problem at the shop-floor level by cancelling the scheduled tasks and rescheduling them according to the new conditions.

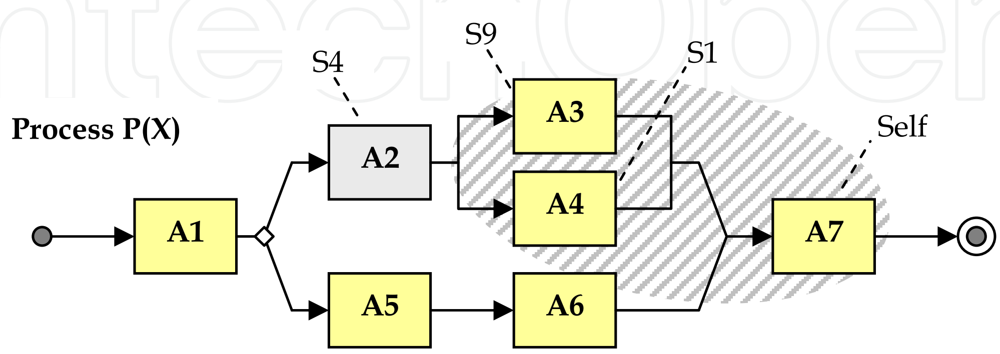

Fig. 6. Partial replanning of a distributed manufacturing process.

Although representing one of the possible cases of exception, this example shows one of the most important benefits brought to the networked small-medium factory by the autonomic approach. Indeed exceptions occur very often and much time is wasted in phone or fax communications between the involved actors to solve the problem. The same or likely a better result is achieved by the autonomic system in a very short time with no human intervention and considering all the available options.

5. Conclusions

To sum up, the vision is for a manufacturing environment where each small-medium factory is provided with the devised software functions to relate with customers and suppliers, and possibly with its shop-floor, in such a way to accelerate its reactivity to orders and perturbations and increase its control over order profitability without the need of diverting resources from the core business:

- The solution is individualised. Even though the autonomic system assures full benefits only when all the network members adopt it, the underlying model is itself an extraordinary opportunity for every company to formalise processes, roles and decision criteria thus increasing its understanding of network management aspects.
- The solution is customised. Each company understands that the software platform reacts automatically, that is, with no human intervention, to customer requests, orders and exceptions. In order to maintain its independence and decision power the company is put in condition to parameterise the autonomic services during the set-up phase to correctly represent its policy.
- The solution is collaborative. Once provided with its own customised software services each company can use them to manage its supply chain and to participate in one or more networks. The adaptation to requirements of different customers is quite simple, and mirrors the present ability of the sales office to establish profitable relations.
- The solution is easy to adopt. Each company can understand the behaviour of the autonomic services, needs a limited support to initialise and customise them, and safeguards its previous investments in ICT having assured the possibility to import/export documents from/to its legacy ERP system (if any).
- The solution is reversible. Should a user company decide to leave the new network coordination environment, it can do it at any time with no restraints or loss of operational data. Rather, it may happen that when leaving the autonomic tools system it will hardly find other ICT solutions able to host the knowledge generated by its use.

The proposed autonomic system is in an advanced development stage. A preliminary version of the devised autonomic and additional services has been developed and is presently under thorough test by some networked factories acting in the fashion, mechanical and global service industrial sectors.

For information completeness sake we can specify that the software platform is a web application developed in open-source technology using Java as programming language, Apache Tomcat as web container, Java Server Faces for UI specification and Ice Faces for its implementation, Hibernate as object-relational mapper, PostgreSQL as relational DBMS, Apache CXF for web service development, Eclipse Rich Client for desktop applications and Spring as configuration and integration platform.

The first on-field experiences highlight most of the foreseen benefits and then represent an encouraging boost to this research project. At the same time they show some problems that are to be considered as precious indications to improve the quality of the autonomic solution and its ability to meet at best the practical need of the target companies. The main problems concern the effort required for platform initialisation and the resistance to delegate important decisions to a software application.

As discussed in Section 3 of this Chapter the initialisation stage must lead to formalise some critical aspects of the interactions within the network. Let us recall them:

- For the leader company: represent products or services produces through the network, associate each product or service with the corresponding distributed process, establish precedence, alternatives and parallelisms between process activities, characterise each process activity with proper parameters and options, couple each process activity with the list of candidate suppliers and, very important, code the network management policy in form of decision criteria and rules to be applied by the Self-Configuration and Self-Healing functions.
- For every supplier company in the network: represent its products and services offered to the network, associate each product or service with the relative routings, split the routings into sequences of operational phases, couple each phase with the resource instances that can perform it, provide each resource instance with its work calendar and, again very important, code the shop-floor management policy in form of decision criteria and rules to be applied by the Self-Optimisation and Self-Healing functions.

This formalisation effort takes time and needs often to be supported by an external advice, thus constituting an objective obstacle to innovation. To this purpose a further research work is presently devoted to minimise the cost of the initialisation stage by offering a library of distributed process templates, pre-coded decision rules and other defined elements among which it will be easy to find out the desired solution.

Concerning the resistance to delegate important decisions to the autonomic platform, experience shows that in most cases there is no explanation or estimation of economic benefits that can overcome it. In order to reach the needed level of confidence in and acceptance of the proposed model there are two complementary initiatives that can positively contribute:

- Document successful cases from other networks possibly operating in the same sector and region. As a matter of fact innovation at SMEs is normally introduced by imposition from main customers or by imitation of neighbouring partners and competitors.
- Introduce for each company in the network the possibility to swap from the automatic to the manual mode until the correct application of its individual policy and, ultimately, the brought benefits will be actually proved by a systemic evaluation of actual system performances. This will slow down the distributed decision process but it could be very appreciated, at least during the initial stage, to overcome the expected distrust in such a new technology-supported collaboration model.

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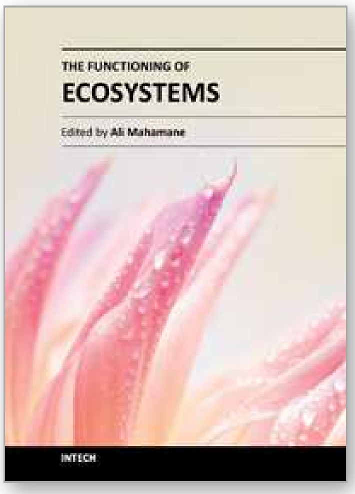

The Functioning of Ecosystems

Edited by Prof. Mahamane Ali

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The ecosystems present a great diversity worldwide and use various functionalities according to ecologic regions. In this new context of variability and climatic changes, these ecosystems undergo notable modifications amplified by domestic uses of which it was subjected to. Indeed the ecosystems render diverse services to humanity from their composition and structure but the tolerable levels are unknown. The preservation of these ecosystemic services needs a clear understanding of their complexity. The role of the research is not only to characterise the ecosystems but also to clearly define the tolerable usage levels. Their characterisation proves to be important not only for the local populations that use it but also for the conservation of biodiversity. Hence, the measurement, management and protection of ecosystems need innovative and diverse methods. For all these reasons, the aim of this book is to bring out a general view on the biogeochemical cycles, the ecological imprints, the mathematical models and theories applicable to many situations.