

Towards a method to deploy systems engineering processes within companies

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Abstract. Systems Engineering (SE) approach is a tried and tested approach that promotes and coordinates all appropriate processes to design, develop and test a system. These SE processes have been defined in many standards which are not always consistent with each other and often provide only generic indications. Therefore, companies seeking to apply the SE approach must answer themselves the following questions: how to tailor these generic processes to their company? What methodology must be applied to deploy SE processes? How to ensure the success of this deployment? The purpose of this paper is to present the two main principles of a SE processes deployment methodological approach currently under development and applied to a helicopter manufacturer. These principles are: 1) The description of the set of activities necessary for the deployment, 2) The main concepts necessary to the approach, gathered and shortly formalised in a global meta-model.

Keywords: Systems Engineering, Process, Interoperability, Aerospace Engineering, Interdisciplinary design, Design Systems, AS-IS model, TO-BE model, Requirement management

1. Introduction

The Systems Engineering (SE) approach is considered today as a tried and tested methodological and interdisciplinary approach for designing, evaluating, optimizing and validating a System of Interest¹. In other words, it allows defining an efficient model of System Used To Design (SUTD)² [1][2]. SE particularly promotes a

¹A system-of-interest (SOI) can be formally defined as “the system whose life cycle is under consideration” [1]. In a more explicit way, a SOI can be defined as any product or service that a company has to provide in order to meet the needs of its market. For instance, among the SOIs of a helicopter manufacturer, we can mention the various helicopters the company provides to its customers but also services like maintenance or supply of spare parts.

² A System Used To Design (SUTD) is a system in charge of organizing, executing and coordinating all activities required for designing a given SOI that, from market’s needs, provides an economical and

collaborative work among project stakeholders having, among other things, different cultures, stakes, organisations, business activities and rules. It guides, structures, and standardizes when possible a set of collaborative processes. Among the numerous benefits, let us notice that the use of processes makes the organization much less sensitive to the different changes happening throughout the company's life (staff turnover, organizational changes, etc.). Moreover, it makes the management and the continuous improvement easier. Finally, the processes advocated by the SE enable a significant improvement of the control of project costs and schedule and development activities [2]. However, prior to be able to apply SE approach, the enterprise has to define what are, how to adapt and how to deploy relevant SE processes tailored to its organisation and needs.

Many difficulties appear when trying to deploy the SE approach within a company. The first major difficulty is the number of available documents (standards, feedbacks, internal reference documents, etc.) addressing SE. Among them, SE handbooks like [2][3] and standards like [1] are certainly the most recognized in the SE field. Unfortunately, they often suggest their own set of processes but without considering the one provided by other reference papers. However, let us highlight that harmonization efforts have been directed by the INCOSE³ since in the latest version of its SE handbook [2], an alignment of its processes with those proposed by [1] is given. So, in practice, instead of selecting a single reference paper and using it as referential, companies deploying SE processes often opt to define their own processes picking up elements in several reference documents, adapting them, and ensuring their consistency.

A second difficulty is the generic nature of reference documents. But for [3] (NASA) and [4] (transport business), reference documents usually aim to be applicable by any kind of organisations. As a consequence, these documents describe SE application at a high-level of abstraction, often limited to the process level, without providing indications about the sequencing of activities and their practical details. Therefore, the implementation within a given company is not obvious at all.

Finally, there is no methodology available describing how to deploy SE within companies. Enterprises must try by themselves, using feedbacks they can get from other companies or the expertise provided by consultants.

The purpose of the proposed research work is to provide companies with a method for the deployment of SE processes and SE culture. Our working hypothesis is that the deployment depends on the interoperability abilities and capabilities of the enterprise knowing that interoperability can be defined as the "*ability of enterprises and entities within those enterprises to communicate and interact effectively*" [5]. Thus, enterprise can be seen as a heterogeneous group composed of human resources (e.g. staff) and non-human resources (e.g. computers, tools, infrastructures, etc.) having to interoperate to achieve the goals of the company. So, any lack of interoperability from these resources constitutes an unacceptable and potential source

competitive solution. It is composed by a set of resources generally located in the design office of the company. The expected output of this SUTD is a completely defined "virtual" solution that best meets the needs of all stakeholders involved in the SOIs entire lifecycle and which can be provided to the "production system" as an input. In order to reduce their design costs and thus be more competitive, companies must homogenise as far as they can all their SUTDs.

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of failures inducing risks, extension of deadlines, supplementary costs, and customers' dissatisfactions. So, a special attention must be paid to the interoperability factor when preparing the deployment of SE processes.

Furthermore, if the company is able to characterize, evaluate and maintain at a high level of maturity its internal (intra company) and external (when collaborating with partners) interoperability abilities, the deployment and the exploitation of efficient SUTDs will be facilitated. That's why, interoperability can be considered as a key factor in the deployment.

This article presents the first two elements of the proposed method for the deployment of SE processes. The section 2 presents a practical set of activities required to prepare the deployment considering the interoperability factor. The section 3 introduces and comment then the meta-model gathering all the concepts necessary for the deployment.

2. Deployment activities

The proposed method is based on a four-phase approach focusing on the specification and the tailoring to the company of the required SE process(es) to be deployed, and on the preparation of its (their) deployment dealing with the specific needs of the enterprise. This approach is intended to be globally iterative: some activities will be performed only one time, but most of them must be executed for each process to deploy. It is up to the company to choose if it deploys one process at a time in order to have a progressive deployment or if it deploys several processes at the same time. This approach can be applied to any of the four categories of processes defined in [1]: *agreement processes*, *organizational project-enabling processes*, *project processes*, and *technical processes*. The various steps of the approach are introduced in Figure 1 and detailed in the following sections.

Phase 1 – Modelling of the ideal SUTD

Considering the SUTD entirely, the team in charge of the global deployment defines what would be ideally the SE processes composing the SUTD. The goal is to provide an ideal model describing the company's vision of what must be the appropriate organization to be developed and what resources are required for optimal functioning of the processes to deploy. Nevertheless, there is no point here of being influenced by the current break-down structure (into departments) of the company or by the current allocation of tasks.

The formalism chosen to describe the ideal SUTD model depends on the company business objectives, size, skills and know-how, resources nature and type, etc. Many methods, languages and tools developed in the frame of enterprise modelling [6] can be used. For instance, the tried and tested GERAM framework [7] can be used as a guide for the modelling. One major criterion for the selection of modelling languages is their easiness to be understood by the different actors to prevent their rejection and to promote their involvement in the project. Moreover, in order to take into account the interoperability criterion when defining processes, it may be appropriate to rely on

existing “interoperability frameworks” which can provide means to characterize the targeted interoperability and its good practices as defined in [8][9][10][11][12][13].

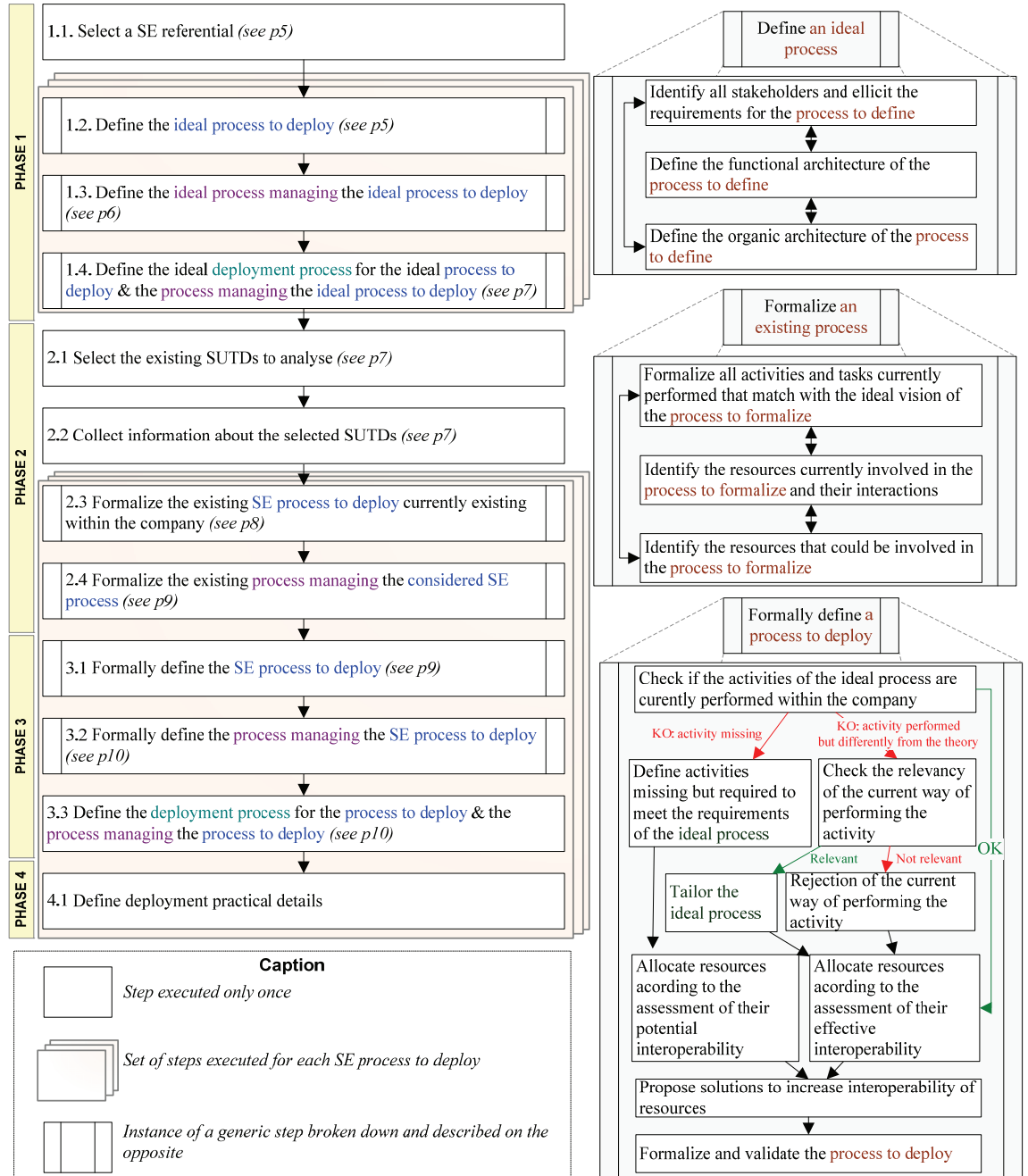


Fig. 1. Overview of the required deployment activities

Sub-phase 1.1 – “Select a SE referential”

SE processes to deploy and their interactions must be specified. To this end, it is convenient to use a SE referential which is a document providing a high-level definition of each process and its interfaces. Many documents addressing SE can be used as referential. For instance, in the context of a helicopter manufacturer, three sources of documents are available:

- standardisation documents – e.g. [1][14][15] and [16]
- documents providing advice and feedbacks – e.g. [2][4][17] and [3]
- aerospace and aeronautics specific documents – e.g. [18][19] and [20].

Unfortunately, all these documents are not always consistent with each other. The set of processes proposed do not have the same names, the same purposes, the same definitions, etc. Therefore, the deployment team must select one reference document and use it as a referential, i.e. try to meet as far as possible its requirements. However, if some elements (e.g. details in the activity and tasks, metrics, etc.) included in other reference documents are relevant for the company, the team can complete the SE referential chosen with them in order to simplify the definition of its SE processes.

Among the available documents which can be chosen as referential, [1] is particularly relevant for three main reasons. Firstly, the processes are clearly identified. Secondly, it is a standard and so, it is an internationally acknowledged document. Finally, as the INCOSE has aligned its processes with those from [1], if the company decides to use [1] as referential, it will be compliant with the INCOSE handbook [2] and thus getting the INCOSE certification for SE experts would be easier if the company is interested in it.

Sub-phase 1.2. – “Define the ideal process to deploy”

This step could falsely appear useless since ideal processes are defined in the SE referential chosen. Nevertheless, these ideal processes cannot be applied directly in a company for two main reasons. Firstly, SE reference documents provide high-level recommendations and so, they often address the process level but much more rarely the activity or tasks levels. Moreover, some topics are not addressed even in a generic way: e.g. the identification of stakeholders of processes, their roles and responsibilities, the outcomes and enablers at the activity and task levels, etc. Secondly, because SE reference documents apply the “one size fits all” principle i.e. they do not consider the specificities and constraints of business areas. For example, mandatory constraints such as those related to aircraft certification/qualification for a helicopter manufacturer, which have to be considered in SE processes, are barely addressed in SE standards even in those specific to aeronautics.

These two points make it necessary for the deployment team to adapt and formalize its own ideal SE processes. To this end, we suggest using the sequence of activities described by SE for the creation of a system (see generic step “Define an ideal process” on Figure 1).

First, the deployment team must identify each stakeholder involved in the SE process to deploy. This identification of resources must be conducted carefully since it ensures the smooth operation of processes. Indeed, any omission of a stakeholder induces a risk of missing specific needs, particularly interoperability needs, which can have harmful direct or indirect effects on the deployment. It is suggested to start identifying the various resources in a rough way and then to refine progressively the

results considering the company's specificities and business area. For instance, the following classes of stakeholders can be identified for the "Stakeholders Requirement Definition Process" of a helicopter manufacturer:

- | | |
|--|---|
| <ul style="list-style-type: none"> - customers (e.g. private individual, state) - subcontractors (e.g. development agencies, suppliers) - regulatory bodies and international authorities (e.g. SAE, RTCA, EASA) - users (e.g. passengers) - operators (e.g. pilots) - maintainers (e.g. aircraft mechanic, spare parts suppliers) | <ul style="list-style-type: none"> - support organizations - enterprise and group decision-makers - program & project managers; - planning teams - design office members (e.g. scientists, subsystems engineers) - society-at-large (e.g. manufacturer, purchasing department). |
|--|---|

This identification enables to capture all the theoretical stakeholders' needs and expectations. In order to consider the interoperability factor, a special attention is paid to clearly define the interfaces between the stakeholders and the processes: who/what are the customers/suppliers of the process and what do they expect from the process? All these needs are then translated into requirements. In order to accomplish that, the deployment team must analyse each stakeholders' need and break it down into a set of characteristics that the process(es) to deploy must respect. Each characteristic must include only one single feasible and realistic idea.

Then, a functional architecture can be built. Activities of the process to define are clearly expressed. Theoretical inputs and outputs of activities are also given. The basis for this architecture is provided by the SE referential.

Finally, the deployment team proposes and validates an organic architecture of the process, i.e. determines what are the theoretical resources or class of resources which have to carry out the various activities described in the functional architecture. Once again, the basis for this architecture is provided by the SE referential.

Sub-phase 1.3. – "Define the ideal process managing the ideal process to deploy"

The deployment of each process to deploy must be accompanied by the simultaneous deployment of a relevant management process which includes activities related to performance assessment, analysis of results, corrective actions definition, and various generation of reports. For this purpose, the generic step "Define an ideal process" on Figure 1 is performed again considering the management expectations.

Sub-phase 1.4. – "Define the ideal deployment process for the ideal process to deploy and the process managing the ideal process to deploy"

Once the SE process to deploy and its management process are defined, a third process must be defined. Its purpose is to support the deployment by identifying the required activities and resources for the deployment. Its design can be done by following again the generic step "Define an ideal process" on Figure 1.

Thus, the chosen SE process(es) and its (their) associated management process(es) can be considered as the SOI(s) on which focuses the approach. The deployment process defined here can thus be seen as the SUDT resulting from the application of the deployment approach.

Phase 2 – Modelling of pre-existing SUTDs

Following the same SE principles, companies having to provide SOIs to their customers have necessarily defined a specific SUTD for each SOI. Even if these pre-existing SUTDs not clearly identified or formalised, it is crucial to study and analyse them. Indeed, while the SE referential provides the theoretical basis for the definition of the processes to deploy, these SUTDs provide information about the company's expertise, know-how, organisation, constraints, and daily way of working. However, it can happen in rare cases that these pre-existing and dedicated SUTDs no longer exist or are no longer complete in the company. An example of this situation can be the case of a company having lost its know-how in the design of a SOI since experts have left the enterprise. In this case, either the company employ new experts in order to get missing knowledge, or it only performs minor technological change in its SOI but that is not a competitive long-term solution, or it stops the exploitation of this SOI.

The deployment team must build an AS-IS model [21] representing either the actual pre-existing SUTDs if they still exist in the company and if the company wants to keep them as a basis; or the current organisation making new SOIs from existing SOIs. The purpose of this AS-IS model is to identify and represent any kind of resources (company's teams, subcontractor, computer applications, etc.) already involved in the design of SOIs, and that could achieve the activities of the ideal SUTD. This AS-IS model must also include description for resources that are not currently involved in SUTDs but which could also achieve the activities of the ideal SUTD. For the purpose of consistency, the formalism used to model the AS-IS model will be the same as those chosen for the modelling of the ideal SUTD. The proposed steps to build the AS-IS model are introduced in Figure 1 and detailed in the following sections.

Sub-phase 2.1 – “Select the SUTDs to analyse”

In the case of a company producing a lot of SOIs, many SUTDs are available to be modelled. However, modelling each SUTD can be a waste of time since they are not necessary all efficient and can be redundant. Consequently, the deployment team must select representative SUTDs among all available in order to limit the scope of the modelling. This step requires a strong knowledge of the company in order to be able to see the big picture. Possible criteria for the selection of the SUTDs are: the fulfilment of objectives (quality, cost, deadlines) by the SUTD, its maturity, the presence of the experts involved in the design of the SOI concerned, or the feeling of actors involved in the SUTD about the smoothness of interoperations within the SUTD they take part in.

Sub-phase 2.2 – “Collect information about the selected SUTDs”

Collecting information consists first in performing a documentary analysis. It is obvious that a gap between the procedures of a company and its daily activities often exists; however the analysis of this documentation enables to get existing formalization of processes. Moreover, the collected information can be used to highlight different points of view and practices having to be commented and argued during the interviews of people involved in processes especially in the design office. A questionnaire is suggested to conduct these interviews for two main reasons: 1/ whoever the interviewer is, the questions asked remain the same; 2/ questionnaire prevents interviewers from forgetting necessary information to collect since all questions are written down. Interviewers can use this questionnaire with both closed and open questions: while closed questions require precise answers from people on specific points, open questions give the person interviewed room to express its own way of working, recommendations, feelings about the process, and propositions for improvement.

Sub-phase 2.3 – “Formalize the existing SE process considered”

On the basis of the theoretical definition of the SE process(es) to deploy given in sub-phase 1.2, the deployment team must identify the activities currently performed within the company that totally or partially match with the ideal vision of the process(es) to deploy. Then, all resources involved (or that may be involved) in the SE process(es) to deploy must be identified. It is also crucial to identify their interactions and to express all their implicit and explicit expectations and constraints which could influence the definition of the new process to deploy. For instance, possible sources of constraints are:

- Standards: SE, safety, security, quality, reliability, disposability, etc.
- Agreements with partners (customers, subcontractors, regulatory bodies, etc.)
- Technology: constraints induced by the technology employed by partners, changing technologies, etc.
- Group and enterprise: strategy, objectives, policies, legacy, culture, Existing way of working and allocation of tasks etc.
- Enterprise internal rules: policies, directives, procedures, instructions and guidelines
- Existing and available resources: employed staff, furniture, tools, etc.

Many methods and tools, which have been developed to support the capture of needs in the context of quality improvement and in the context of SE, can be used for the identification of resources' needs. However, they do not address in detail the interoperability point of view. As a consequence, the interoperability requirements repository developed by [22] can be used as a complement. The authors propose to group interoperability requirements into three categories: compatibility, interoperation and reversibility, and then to refine them according concerns and barriers proposed in [23]. Thus, this classification is a way to identify and to structure resources' needs and requirements regarding interoperability.

Sub-phase 2.4 – Formalize the existing process managing the considered SE process”

In order to manage the process(es) to deploy, a management process must be deployed at the same time. To this end, all activities described in sub-phases 2.4 are performed again.

Phase 3 – Modelling of the SUTD to deploy

The deployment team builds then a TO-BE model [21] i.e. compares the models representing the ideal SUTD and the AS-IS model representing the current organisation in order to perceive significant gaps and thus highlights ways of improving the current organization. The model is built to share the trade-off found between the actual and the ideal organization. The same formalism as the one used in the IDEAL and TO-BE models is used.

Sub-phase 3.1 – “Formally define the existing SE process considered”

During Phase 1, a set of requirements for the (each) theoretical process(es) has been defined. During this step, the deployment team checks that all requirements are met by the activities of the pointed out SE process(es) to deploy. According to the results get for each activity, three main scenarios can be identified.

First scenario: the activity is currently not performed within the company. In this case, the deployment team must define the necessary activity meeting the theoretical requirements in order to correct the situation. The deployment team then tries to allocate internal resources to this activity taking particularly into account financial constraints of the deployment project. To ensure a good interoperability of the resources involved in this new activity, the deployment team appraises their potential interoperability by using existing techniques as illustrated in Table 1. If it is not possible to allocate internal resources to the new activity, the team has to collect the requirements induced by it and to define specifications that external resources will have to honour.

Second scenario: theoretical activity is performed but does not fully match with its definition. For instance, tasks are not the same, expected inputs or outputs are missing, or on the contrary some have been added, etc. In this case, the deployment team must check the relevancy of these gaps between theory and practice and status on the relevancy of the current practices. If they are validated then an adaptation of the ideal process is proposed. Conversely, if activities of the ideal process appears to be better, then the stakeholders of the current process(es) must be convinced of the necessity to change practices. It is crucial to have their approval for change in order to lessen the risk of “resistance to change”. Then the allocation of resources is done according to the assessment of the effective interoperability of the resources currently involved in the process(es) (see Table 1). Here again, if some resources cannot be found internally, specifications are written for future partners.

Third scenario: the activity is currently correctly performed in the company. In this optimal case, the allocation of resources is performed according to the effective interoperability assessment and conversely, specifications are drafted.

After each of these scenarios, solutions to increase interoperability are proposed and discussed with stakeholders. Finally, after trade-offs, stakeholders validate (from technical and organizational points of views) the definition of the process(es) in order to be sure that all their specificities have been considered.

Table 1. The four kinds of interoperability assessment with reference to the papers providing ways of assessment. The definitions of the types of interoperability are inspired by [24].

		Object of the assessment	
		Intrinsic interoperability <i>The ability of a single system to be interoperable (seen as an inherent characteristic)</i>	Extrinsic interoperability <i>The ability of a couple of systems to be interoperable</i>
Kind of interoperability assessed	Potential interoperability <i>The potential ability of one or two systems to be interoperable during a collaboration</i>	The purpose here is to evaluate the ability of the entity to interoperate with any partner. The partner is not known. [23][25][26][27][11][28][24]	The purpose here is to evaluate the future interoperability of the couple during collaborations. The partners know each other but have not started interacting yet. [29][24]
	Effective interoperability <i>The real ability of one or two systems observed during a collaboration</i>	The purpose here is to evaluate the effective ability of the entity to interoperate with a partner. The partner is known but only the interoperability of one entity is assessed. [25][26][30][27][11][28][24]	The purpose here is to evaluate the effective interoperability of the couple during their collaboration. The partners know each other and interact. [31][32][33][34][35] [36][37][38][39][29][24]

Sub-phase 3.2 – “Formally define the existing process managing the SE process considered”

During this step, all the work achieved in sub-phase 3.1 is performed again but on the management process.

Sub-phase 3.3 – “Define the deployment process for the process to deploy & the process managing the process to deploy”

The ideal visions of these deployment processes defined in sub-phase 1.4 are adapted according to the final definitions of the processes they aim to deploy resulting from sub-phases 3.1 and 3.2. The final set of activities and their allocated resources is frozen after the validation of stakeholders.

However, let us point out that during the final definition of SE processes, managing processes and deployment processes, the deployment team must pay a specific attention to:

- their long term evolutions and upgrades
- the required level of interoperability of the different elements of the existing organization (resources, methods, tools, etc.)

- the usability, easiness of understanding, easiness of learning, operability, attractiveness, dependability, user-friendliness of the tools provided to support the new processes.

Phase 4 – Materialise the deployment

If the deployment team has not selected an application perimeter (e.g. a specific project) yet, this is done now. An action plan is defined for the deployment. This plan addresses, among other topics:

- the planning of the deployment
- the definition of the required training activities and the design of training materials
- the activities needed to ensure that the new organization is respected
- the definition of interface and coordination with other programs/projects
- the project communication (in order to get a satisfactory level of understanding of the approach from stakeholders)
- an analysis of the psychosocial effects of the project: resistance to change, lack of performance during change, impact of choices made in the allocation of tasks to humans and technical systems, etc.
- the definition of the transition phase: the mapping between old and new organisation, roles and responsibility, way of working, etc.

3. Concepts required for the preparation and execution of the deployment of SE processes

The approach to prepare the deployment of SE processes involves a lot of concepts: e.g. resource, process, activity, stakeholders, etc. These concepts must be defined as soon as possible in order to facilitate and to guide the work of the deployment team. Indeed, having a common repository of concepts and of relationships between concepts enables a common understanding of each actors of the team and supports the work to be done with all stakeholders involved in the deployment project, especially if they come from different business fields. By defining explicitly the concepts, their semantic relationships, the deployment team lessens then the risks of misunderstandings and thus increases the potential and effective interoperability between these stakeholders. This repository is modelled here in the form of a meta-model illustrated in Figure 1.

This meta-model has been developed together with the approach provided in section 2. Every time it is necessary, the meta-model is improved according to the results of the application of the approach within the helicopter manufacturer.

For the purpose of readability and applicability to other companies, the meta-model proposed here is generic; however, in practice it must be completed and adapted according the specificities of the company (vocabulary, modelling tool, etc.).

This meta-model has been defined using UML since it is a very popular language and thus which can be easily understood by most of stakeholders. It has been realized

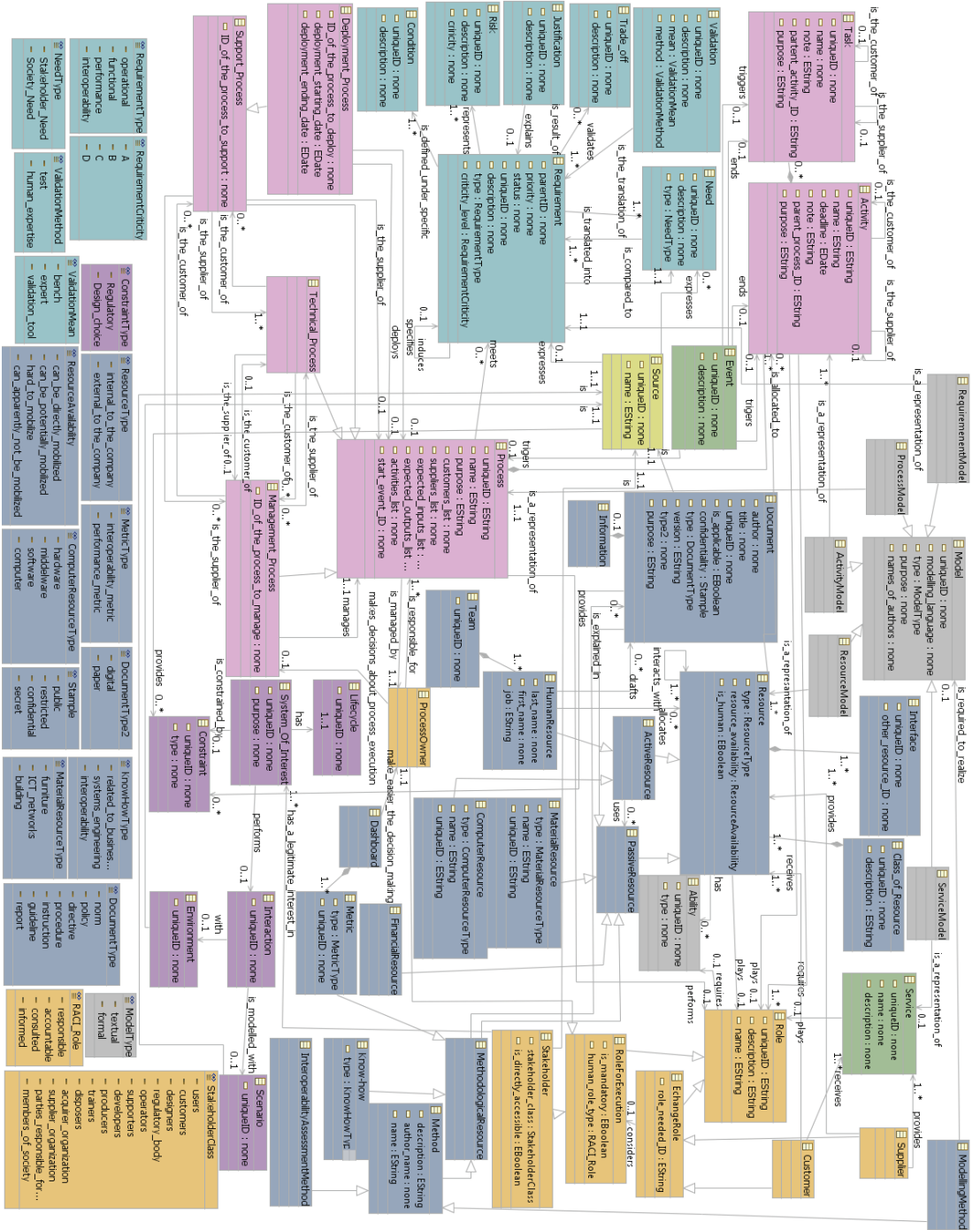


Fig. 2. A metamodel of the concepts required to deploy SE processes

with the Graphical Modeling Framework (GMF) plug-in of Eclipse. This tool has been chosen for the help it brings in the insurance of the models' consistency. Indeed, if we define a meta-model and a graphical definition of concepts, it is possible to start building models which are, by construction, necessary consistent with the meta-model.

The deployment team uses this meta-model as a guide for the modelling: any mandatory attributes defined in the meta-model must be included in the model and only relationships described in the meta-model can be used. Let us illustrate our point with an example: Figure 3 shows an extract of this meta-model highlighting three concepts ("activity", "resource" and "role"); and Figure 4 provides then a simplified model built from this extract representing ideal resources and roles involved in activities required to define stakeholders' needs.

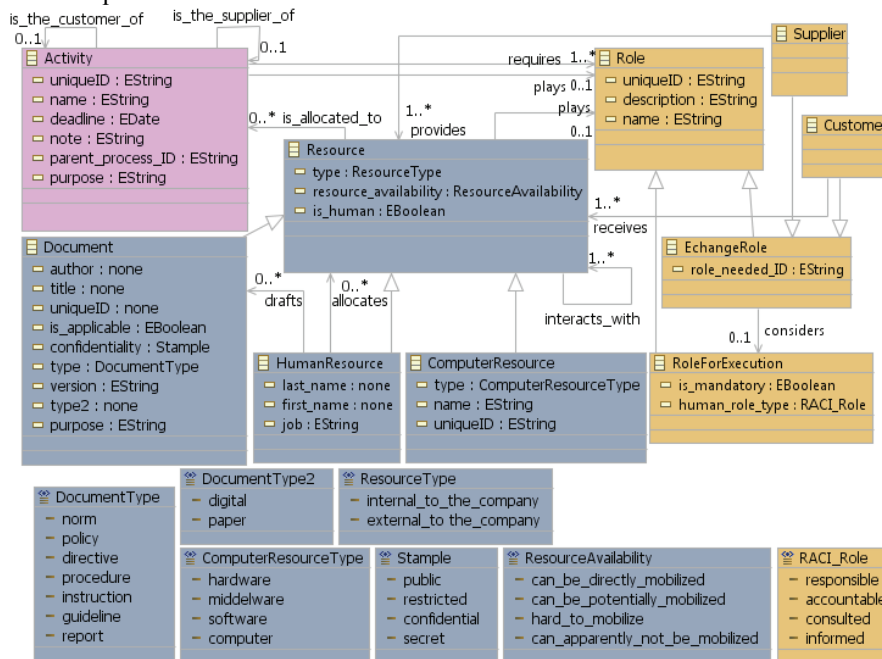


Fig. 3. Extract of the meta-model pointing out the "activity", "resource" and "role" concepts

We recommend implementing a tool in order to assist the deployment team in the application of the approach. This tool would help to meet requirements of each step, would provide advice to modellers and would assist the team in the interoperability assessment of resources. Furthermore, it would centralize all built models and give indications about the current state of progress of the deployment preparation. Let us point out that the tool must be able to support the meta-model and its evolutions. To this end, a functionality of configuration change control must be implemented.

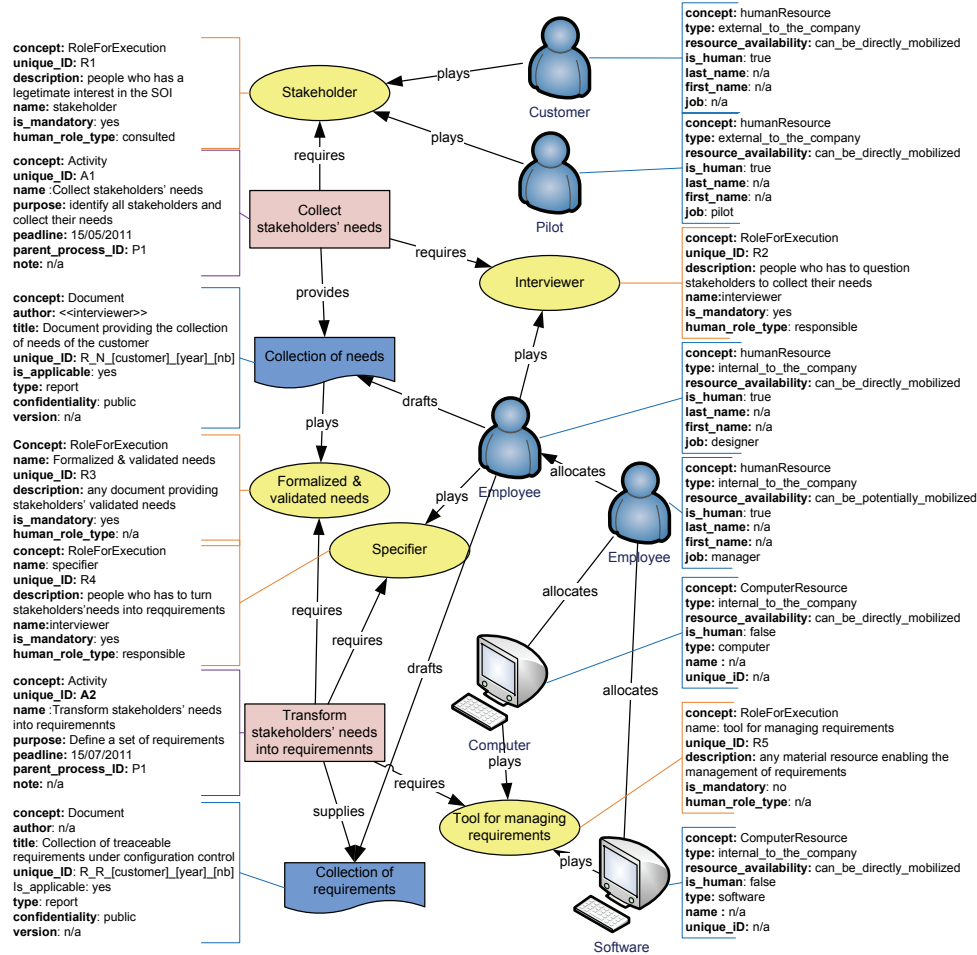


Fig. 4. Example of model built from the extract of the figure 3

4. Conclusion and Future work

This paper presents a methodological approach for the deployment of SE processes within a company. The originality of this approach is to consider that the interoperability is a key factor in the deployment of SE processes and thus, has to be taken into consideration while preparing the deployment. This paper provides the first elements of a deployment method: 1) the set of activities to be done to prepare the deployment and 2) a meta-model characterizing the concepts required for the deployment of SE processes. Upcoming articles will present the tool assisting the application of the approach currently under development.

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