Challenges of Acquisition Planning: Two Large System Acquisition Experiences

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Abstract

Acquisition of software intensive systems demands significant work prior to establishing the contract. One of the significant challenges of pre-contract phase is acquisition planning. The activities such as estimation of required effort and determining proper structures for the acquisition project require unique approaches. In this study, experiences gained from two large innovative military applications are presented.

Keywords: software acquisition, management, business process modeling, information system (IS)

1. Introduction

Software community has developed unique tools and techniques such as size, effort, and cost estimation techniques and tools to address challenges facing the management of software development projects. These tools and techniques are utilized for software development phases starting with the software requirements specification. The phases prior to the software requirements specification, on the other hand, frequently utilize generic acquisition practices for management.

Pre-development phases include tasks such as requirements elicitation and cost estimation for software systems. These tasks are critical for the success of the project and require software engineering expertise. Moreover, these tasks require significant effort and unprecedented organizational structures. Disappointingly, neither generic tools and techniques nor the tools and techniques developed for software project management can be utilized for many tasks of pre-development phases. A good example is the case for size estimation. To plan the pre-development phases we need to estimate size. However, the metrics we use relatively early in the life-cycle such as Function Points cannot be utilized as requirements are not determined yet.

During the last three years, we have implemented a business process model based approach together with a unique set of notations and tools to guide two large military acquisition projects. Our tasks involved business process modeling, requirements elicitation, size and cost estimation and preparation of technical documents for acquisition of Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) subsystems for Turkish Land Forces Command (TLFC). The outcomes of the projects formed the major parts of the Request for Proposals (RFP) currently issued by TLFC.

In this paper, we focus on the management challenges we faced and the lessons we learned while coordinating the efforts of the pre-development phases of the two military projects. In part 2, an overview of the literature on software intensive system acquisition and management, and in part 3, the descriptions of the cases are given. Part 4 explains the activities performed for managing the RFP preparation phase of the acquisition life cycle; including project organization, resources utilized, planning and tracking practices. Finally, in part 5 we present the lessons learned from managing the projects.

2. Acquisition Planning

According to Federal Acquisition Regulation (FAR), acquisition means “the acquiring by contract with appropriated funds of supplies or services (including construction) by and for the use of the agency through purchase or lease, whether the supplies or services are already in existence or must be created, developed, demonstrated, and evaluated”. Acquisition begins at the point when agency needs are established and includes the description of requirements to satisfy agency needs, solicitation and selection of sources, award of contracts, contract financing, contract performance, contract
There are several models and practices that guide the agencies in acquiring software-intensive systems. These include Software Acquisition Capability Maturity Model (SA-CMM), Capability Maturity Model Integration (CMMI)’s Supplier Agreement Management process area, and IEEE’s Recommended Practice for Software Acquisition.

The Software Acquisition Capability Maturity Model (SA-CMM) offers a framework for organizational improvement, and it focuses on building the acquisition process capability of an organization. It defines five levels of software acquisition process maturity. The first (“initial”) level holds no key process area. The second (“repeatable”) level focuses on basic project management and includes key process areas such as software acquisition planning, solicitation, requirements development and management, project management, contract tracking and oversight, evaluation, and transition to support. The third (“defined”) level has a focus on process standardization, and includes key process areas such as process definition and maintenance, user requirements, project performance management, contract performance management, acquisition risk management, and training program management. The fourth (“quantitative”) level focuses on quantitative management, and holds key process areas such as quantitative process management, and quantitative acquisition management. The final and the fifth (“optimizing”) level focuses on continuous process improvement and includes key process areas such as continuous process improvement, and acquisition innovation management.

The SA-CMM’s Project Management key process area at Level-2 describes required commitment, abilities, and activities to perform acquisition management as well as practices for measurement and analysis and verifying implementation. It is intended to manage the activities of the project office and to support organizations to ensure a timely, efficient, and effective acquisition. Project Management involves planning, organizing, staffing, directing, and controlling project activities, such as determining project tasks, estimating effort and cost, scheduling activities and tasks, training, leading the assigned personnel, and accepting products. It begins when the project office is officially chartered and terminates when the acquisition is completed.

The CMMI’s Supplier Agreement Management process area is targeted to manage the acquisition of products from suppliers for whom there exists a formal agreement. It has a context for system and software acquisition, and remains more generic when compared with other models. It includes the practices for determining the type of acquisition that will be used for the products to be acquired, selecting suppliers, establishing and maintaining agreements with suppliers, executing the supplier agreement, accepting delivery of acquired products, and transitioning acquired products to the project.

The Software Engineering Institute (SEI)’s models and practices specified above describe what characteristics the acquisition process should possess, and do not mandate how the acquisition process should be implemented or who should perform an action. In other words, neither of them provides a guide to an acquisition life cycle. IEEE’s Recommended Practice for Software Acquisition offers a life cycle for a typical software acquisition process, which primarily includes planning, contracting, product implementation, product acceptance, and follow-on phases.

IEEE defines and relates one or more steps to each of these phases. The planning phase includes steps such as planning organizational strategy, implementing organization’s process, and determining the software requirements and is completed by releasing the RFP. The contracting phase follows steps such as identifying potential suppliers, preparing contract requirements, and evaluating proposals and selecting the supplier, after which the contract is signed. The product implementation phase includes a step for managing supplier performance, and the product acceptance phase includes the step of accepting the software product. Finally, the follow-on phase holds a step for using the software. It should be noted that these steps might overlap or occur in a different sequence, according to organizational needs. This recommended practice, however, does not provide guidance on the management of the acquisition process.

The models or the practices described above focus on the implementation and/or management of the acquisition process as a whole. But neither of them specifically focuses on the management of the planning phase of the acquisition, which is actually very critical. This is the initial phase in which the domain knowledge is gathered, the business processes are identified and enhanced, and system requirements are determined, which serve as a basis for the entire acquisition process.

3. Description of the Cases

We have implemented the planning phase of the acquisition life cycle in the context of acquiring two
large innovative military applications for TLFC. TLFC is a part of the Turkish Armed Forces, and consists of 4 armies, 1 training-and-doctrine command, and 1 logistic command. The projects targeted RFP preparation for two different, but closely related C4ISR sub-systems for TLFC. METU Project Office, as depicted in Figure 2, counseled TLFC Project Office for preparing the technical contract of the system to be acquired.

Throughout the paper, we coded these projects as A and B. Due to security constraints names and descriptions of the organizational processes are not provided. We briefly define the characteristics of the projects to provide insight on the implementations of the acquisition planning process.

The domains of project-A and project-B were different but complementary with a high-degree of data exchange requirements. There are four other C4ISR subsystem projects that are planned to be integrated with these two. Therefore, not only the functional requirements of each subsystem domain, but also the integration requirements of project-A and project-B with these projects had to be considered.

Both projects required taking a system viewpoint to map domain requirements to hardware, software, and telecommunication components. The duration of project A and B were 8 and 13 months, respectively. The number of staff involved was 11 persons for project-A and 9 persons for project-B. The total effort utilized by METU Project Office for the acquisition planning process for project-A was 18 person-months and 9 person-months for project-B. The effort utilized by TLFC Project Office is not included as the collected data were not consistent. We estimated the sizes of the software components of project A and B as 10,092 FP and 25,454 FP, respectively.

The processes we implemented for acquisition planning are shown in Figure 1, and summarized in the following paragraphs.

**Planning and Managing Acquisition Planning Project:** Part 4 explains the practices and details related to project planning and management.

**Eliciting System Requirements:** We performed a business process based requirements elicitation approach to define software-intensive system requirements. We determined user-level functional requirements for software components of the systems, non-functional system requirements, commercial off-the-shelf (COTS) product requirements, and hardware and telecommunication infrastructure requirements for both systems.

**Estimating Software Size, System Development Effort and Cost:** We estimated the sizes of the software components of the systems based on the functional software requirements elicited in the previous step and using Mark II Function Points Analysis method. Effort and cost for the system development were also estimated by using software size estimates.

**Preparing Statement of Work for System Development:** We described system and software development life cycles, which are to be applied by the supplier organizations, together with engineering process steps and their outputs. We used IEEE’s system and software engineering standards and recommended practices as a reference in describing the templates for process outputs.

**Preparing RFP:** We gathered system requirements, system development estimates, and the statement of work. Then we integrated these with the acquisition planning process.
regulations of the TLFC in the form of a RFP. We included acquisition schedule, management practices, and deliverables; quality requirements for system and software development and management processes; quality assurance requirements for the deliverables; and qualifications of the system and software development and management staff in the RFP to be issued for the system development.

In this study, we will discuss the details of the acquisition planning management activities of the pre-contract phase of two software-intensive systems.

4. Managing Acquisition Planning

The management activities were performed to plan and track the progress of the acquisition projects. In this section we summarize the management activities under project resources, project planning, and project tracking.

4.1. Project Resources

Both projects required various resources to be utilized including human resources, process modeling notations and tools, and domain specific materials such as books and guidelines. The characteristics of the resources utilized in project-A and project-B and their organizations were similar, since not only the purpose of both of the projects was to acquire C4ISR subsystems, but the customer was TLFC in both cases, as well.

Human resources included Project Coordination Committee, the staff of METU and TLFC project offices, domain experts, and the current executives and representatives of the military units where the system would be used. The organizational charts of the projects is given in Figure 2.

Project Coordination Committee coordinated and monitored the tasks of the METU and TLFC project offices and was in coordination with the coordination committees of other C4ISR sub-system projects of TLFC in order to depict the system interfaces.

METU Project Office counseled TLFC for preparing the technical contract of the system to be acquired within the boundary of the project and included a project manager, and software and hardware/telecommunication analysis teams. Analysis teams modeled the business processes and specified the software, hardware, and telecommunication requirements.

TLFC Project Office executed the processes of the project and included a project manager, externally involved domain experts who have the domain knowledge, executives, and current representatives of the military units, who would use the system to be acquired.

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**Figure 2 Organizational Charts of Projects**

In project-A, the project staff consisted of 7 part-time persons from METU Project Office, 4 graduate students of METU who have military background, and 5 part-time persons from TLFC Project Office. In addition, 2 domain experts, and 4 representatives of the organizational units, where the system would be used, joined the validation activities.

In project-B, the project staff consisted of 9 part-time persons from METU Project Office, and 9 part-time persons from TLFC Project Office, who are also domain experts. Not all the TLFC Project Office staff participated in the workgroup meetings at the same time. They participated in an interchangeable manner. In addition, 7 more domain experts, who are not the members of TLFC Project Office, and 2 representatives of the organizational units, where the system would be used, joined the validation activities.

Other resources we utilized in the projects included process modeling notations and tools, and the domain books and documents.

We proposed that the candidate tool for business process modeling should support definitions for process, process flow, input/output, input/output flow, role, and responsibility entities at minimum. Specifically in these projects, Architecture of Integrated Information System (ARIS) concept and ARIS toolset were used as the modeling tool. ARIS is frequently used by consultants and companies in creating, analyzing, and evaluating organizational processes for business process reengineering.

While modeling the business processes, Organizational Charts, Function Trees, Extended Event Driven-Process Chain (eEPC) diagrams, Access diagrams, and Network Topology diagrams were used as basic process modeling notations. The
Organizational Chart reflects the organizational units (as task performers) and their interrelationships, depending on the selected structuring criteria. ‘Business processes’ consist of complex functions that are divided into sub-functions and ‘basic functions’ represents the lowest level in semantic Function Tree diagrams. The procedure of a business process is described as a logic chain of events by means of an event-driven process chain. Events are triggering functions and are the result of functions. By arranging a combination of events and functions in a sequence, eEPCs are created. Totally, 210 distinct diagrams in project-A, and 295 in project-B were created to model existing business processes of different levels of organization units by using the eEPC notation.

In project-B, in order to generate user-level functional system requirements by KAOS tool\(^{14}\), we derived and used a special notation while modeling target business processes. This notation differed from project-A’s in the way that color codes and specific rules for the naming of functions, inputs and outputs were used.

Hardware components and their high-level relations for each organizational unit were modeled by using the ARIS Access Diagram notations. The assignment of software components to hardware components, and the domain users of these hardware components were also modeled by using the same type of diagram notations. ARIS Network Topology diagram notations were utilized to represent the system architecture.

Military books and instructions were among the basic resources, especially when domain experts had uncertainties and disagreements related to the concept of the processes. Throughout the requirements elicitation process of project-A and project-B; 15 and 9 military books and guidelines related to the domain were utilized, respectively.

### 4.2. Project Planning

At the start of the project, a project management plan was prepared, in which the activities of the project and the responsibilities of the project staff for each activity were described. The top-level project activities included:

- Orientation of METU and TLFC project offices
  - Determination of the content and boundaries of the projects
  - Examining the resources (military books and instructions)
  - Examining the master plan (only for project-A)
  - Preparation of the project management plan
  - Determination of the content of RFP document
- Analysis and modeling of current business processes
- Validation of current business process models
- Analysis and modeling of target system
  - Analysis and modeling of target business processes
  - Identifying system architecture
- Verification and validation of target system models
- System requirements definition
  - System breakdown structure preparation
  - User-level functional system requirements definition
  - COTS requirements definition
  - Non-functional system requirements definition
  - Hardware and telecommunication infrastructure requirements definition
  - System requirements integration
  - Verification and validation of system requirements
- Size, effort, and cost estimation of the software system to be acquired
- Cost estimation of the system to be acquired
- Statement of work preparation for system development
- RFP document preparation

At the beginning of each project, we held an orientation meeting in order to get knowledge about the domain, detail the sub-activities of the top level project activities, and schedule them. TLFC Project Office together with METU Project Office attended the meeting. TLFC Project Office provided short presentations about the domain and answered the questions of METU Project Office. In this meeting, we identified the key stakeholders; the top executives, executives, domain experts, project managers, and end users, who would join the workgroups for analyzing and modeling the current and target business processes, and system requirements definition activities. The outcome of these activities was the initial management plan.

As the projects progressed, we updated this initial management plan based on the results of the tracking activities that are discussed in the next section. In order to reflect more realistic figures to the management plan, we continuously made effort estimation throughout the project. For re-planning, we utilized the project effort metric database. Since the effort for different categories was being recorded and continuously updated in this database, the average productivity value of staff to model one business process converged to a more realistic productivity value as the projects progressed. We used this productivity value and the number of lowest-level functions in each business process model to estimate the effort required per business process. In addition, we derived percentage effort coefficients between “as-is” modeling effort and “to-be” modeling effort, verification and validation effort, and user-level functional system requirements definition effort.
Accordingly, we predicted the total effort required for project completion. The sample table shows how we utilized these metrics in order to estimate the required effort for the modeling of the remaining processes and for defining the user-level functional system requirements (see Table 1).

**Table 1 Effort estimation during the projects**

<table>
<thead>
<tr>
<th>Business process</th>
<th>Productivity*</th>
<th>Number of functions</th>
<th>As-is modeling</th>
<th>To-be modeling (as-is effort*0.4)</th>
<th>V &amp; V (as-is effort*0.12)</th>
<th>Defining user-level functional system requirements (as-is effort*0.1)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18 functions/ 8 person-hour</td>
<td>932</td>
<td>414</td>
<td>166</td>
<td>50</td>
<td>41</td>
<td>671</td>
</tr>
</tbody>
</table>

*(Productivity=Average number of functions modeled/person-hour)*

Sometimes, it was not possible to get sufficient information on each new process and find the number of the lowest-level sub-processes. Therefore, we needed to make analogy to estimate the required effort for them. The similarities and differences between the new and completed processes were found and adjustments were made to relate the effort required for these processes.

**4.3. Project Tracking**

We utilized periodic meetings, progress reports and project effort metric database to track the performance of the projects.

During each of the projects, we held weekly meetings among project team members, monthly meetings with the Project Coordination Committee, and whenever needed, meetings with the other project’s coordination committees.

These periodic meetings helped to track the projects’ progress as well as enabling visibility of the projects to the stakeholders. For both projects, we held 7 coordination meetings with the Project Coordination Committee. In project-B, additionally, 3 more coordination meetings with the other project’s coordination committees were held.

For tracking purposes, we prepared 1 progress report for project-A and 5 progress reports for project-B. These reports were utilized to decide on the new activities or new resources needed during the periodic meetings among project team members and with the Project Coordination Committee. We reflected the efforts utilized to the project management plan.

We also utilized our project effort metric database to track the performance of the projects. The database included *team member name, type of work, activity name, date, and effort* attributes. Each team member entered these attributes on a weekly basis. During the periodic meetings among project team members, the effort utilized was compared with the planned. The effort required for the remaining activities were estimated by using the procedure discussed in the previous section. Accordingly, we updated the management plan whenever needed.

**5. Lessons Learned**

Modeling existing business processes took significant time and almost half of the total project effort, but other than being a baseline for requirement, it helped the stakeholders to identify the bottlenecks and the improvement points needed in the business processes. It also enabled us to create an early consensus with the representatives of other C4ISR projects.

Identifying domain experts and reaching them as scheduled were among the most challenging tasks. Orientation meetings at the start of the projects, and regular progress meetings between METU and TLFC project offices enabled effective communication throughout the projects. These meetings provided the opportunity to discuss conflicting issues, to notify demands on resources, and to re-plan the work under progress.

Another challenging task of working with domain experts was their orientation for business process modeling. Domain experts needed assistance in thinking in terms of business processes, and in identifying and decomposing the key business processes using specific notations. Almost all domain knowledge was documented in books, instructions, guidelines, or reports. The existence of written resources helped in understanding the context of the domain in detail, and speed up the orientation of consultants to the domain. However, identifying and modeling business processes by TLFC Project Office following these resources were stringent, since the domain knowledge is captured in terms of business work products rather than business processes in these resources. In other words, there was confusion between preparing a domain document and executing the
processes behind it. For example, documenting the sections of a domain report actually requires executing the steps of a business process that generates that report. This confusion between business work products and business processes slowed down the modeling from time to time, and frequently required elaboration of what business process modeling is.

In both projects, orientation was provided via meetings and frequent discussions. However, regular formal training sessions might have been better to save overall effort in such projects. Since TLFC Project Office had been staffed by domain experts, we needed to assist them on the details of business process modeling and system requirements elicitation throughout the projects. This assistance was one of the most important indicators of success, and was therefore provided with great care, as to proceed within context but not to restrict the expectations of the domain.

During requirements elicitation process, we generated functional requirements manually from target business process models in project-A, and automatically from target business process models by using KAOS Tool14 in project-B. For project-A, size of which was estimated to be 10,092 Mark II FP, the manual generation of requirements document took 2 person-months. After modeling target business processes using the notation’s conventions at required detail, KAOS Tool generated functional requirements of project-B, which was 25,454 Mark II FP in size, in 30 minutes. Thus, the planning of the target system modeling and functional requirements generation processes were made according to whether the requirements generation would be made manually or automatically.

During both projects, we maintained a project effort metric database. The team members entered data related to type of work, activity name and effort attributes into this database. This helped to reflect more realistic figures to the management plan as the projects progressed, since we utilized this database to estimate the effort needed for modeling the remaining business processes.

The domains of project-A and project-B were different but complementary with a high-degree of data exchange requirements. In addition, project-B had numerous integration points with other C4ISR subsystem projects. Therefore, in project-B, we organized coordination meetings with other TLFC project committees, which helped us to solve many issues related to integration.

Currently, the systems for which we completed acquisition planning have entered into the development phase. The TLFC has decided to integrate the development of projects A and B, since corresponding systems are complementary, and their requirements are easy to integrate due to definition at similar levels of granularity. The TLFC has suspended the release of the RFP, and decided to complete system and software requirements specification stages on its own, specifically by assigning responsibility to one of its departments that develops in-house systems and software. The development group has used elicited system requirements as a basis for their planning as well as for requirements specification. They are currently generating use case specifications and scenarios based on user-level functional system requirements.

Our observations show that, pre-development processes need research studies for development of systematic approaches15. We believe that extensive research on pre-development methodologies including processes, notations, heuristics as well as tools and techniques to support such methodologies are required. These methodologies should also systematically link the development phases with the work products of the pre-development phases. Specifically, we are currently working on refining the acquisition planning process we described based on the experiences we have gathered. We are also working on size estimation for pre-development and early development phases. We will improve the size metric for pre-development phases – the number of lowest level functions – by means of a more precise definition and we will check its validity for different domains by means of case studies. We have also observed that size estimation approach we have utilized for the development phase can be partially automated and we are currently working on such an estimation tool.

6. References

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