CAPABILITY AND MATURITY MODEL FOR SIMULATION-BASED ACQUISITION: CASE STUDY IN KOREA

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ABSTRACT
Modeling and simulation (M&S) and simulation-based acquisition (SBA) methods are widely used in the military sector for weapons system acquisition. Capability and maturity measuring models are also widely accepted in processes of software development. These capability and maturity models, which evaluate strategies to drive results and improve SBA-related processes, are required to perform successful SBA. This study proposes a framework of capability maturity models for M&S development and SBA. We also define processes related to M&S development and stages of SBA in entirety. The ultimate purpose of the proposed model is to improve these processes. We provide applications and survey results to verify the proposed model.

Keywords: capability and maturity models, process improvement, simulation-based acquisition, modeling and simulation, needs planning

1. INTRODUCTION

Modeling and simulation (M&S) enhances innovation in defense acquisition processes in the military sector (Johnson, McKeon and Szanto 1998). The M&S paradigm is advantageous in a number of ways, including that it enables continuous appraisal of system development, rapid conceptual design, reduced time for making prototypes, continuous user participation in the development process, efficient manufacturing planning, and the provision of reusable software and hardware in training simulators (Fallin 1997; Zittel 2001). Acquisition activity based on the M&S paradigm had been also defined as simulation-based acquisition (SBA). Recently, unifying of those two terminologies, M&S is only used by many countries. Nevertheless, since the 'SBA' is still used in Korea, we also employ the terminology in this paper. Existing research on utilizing M&S and SBA intends to make active progress for the performance of efficient defense acquisition (Chadwick 2007; Keane, Lutz, Myers, and Coolahan 2000; Kratz and Buckingham 2010; Sanders 1997). To perform successful SBA, maturity models for measuring and appraising the capacity of associated processes are needed to ensure continuous process improvement.

Maturity models are used for process appraisal and improvement in a variety of fields. Examples of maturity models include the capability maturity model (CMM), capability maturity model integration (CMMI), and ISO/IEC 15504 (software process improvement and capacity entertainment, also known as SPICE). Among these models, we have identified the CMMI as having the proper method for process improvement, because the CMMI incorporates the advantages of the other models in one complete methodology. This paper, after examining the existing maturity models, proposes an efficient maturity model for SBA. As the first step, the framework of a capability and maturity model for SBA and M&S development is constructed, and the processes related to those areas are defined. Subsequently, we provide an instance for application to the needs planning stage of the model, which is an important step of SBA lifecycle procedures..

In brief, our proposed model can be regarded as an expansion of the CMMI model. Although our model is based on the CMMI, our research makes new attempts for the sake of efficiency. Considering suitability and flexibility, we develop a framework for our model, and divide the model into each of the steps of the SBA lifecycle. We also define the proposed processes, and accordingly, develop best practices related to the SBA lifecycle and M&S development. The advantage of our model is that we introduce a logical and proper model, based on the CMMI, which has been verified and is currently used publicly. In addition, our modeling considers actual circumstances to enhance the applicability of the final result. The model can be employed by communities or military agencies to improve both organizational and individual capabilities.
The paper is divided into six sections. Section 2 introduces the existing maturity models and examines their characteristics. Section 3 constructs a framework for our capability and maturity model for SBA and M&S development. Section 4 provides some examples of sub-models, which are used as guidelines for process improvement. Section 5 illustrates numerical results from surveys of M&S experts, and section 6 concludes our study and discusses future work.

2. EXISTING PROCESS MATURITY MODELS

We examine various maturity models in order to explain the concept of the maturity model and confirm its applicability to M&S. Details of CMMI and ISO/IEC 15504 are discussed and other maturity models are presented.

2.1. CMMI Model

Various difficulties such as quality, schedule, and cost are encountered in software development projects. To overcome these problems, the Department of Defense (DoD) in the United States, together with the Software Engineering Institute (SEI) at Carnegie Mellon University (Paulk, Curtis, Chrissis and Weber 1993; Paulk, Weber, Garcia, Chrissis and Bush 1993) developed the software-CMM (SW-CMM), which is a capability and maturity model for process improvement in software development. A study by Humphrey (Humphrey 1989) established the concept of SW-CMM based on the five-level model for the organization of quality management originally suggested by Crosby (Crosby 1979), and applied this model to organizing software development. Expanding the SW-CMM to system development and integration in 2002, DoD developed CMMI Ver.1.1. Three versions of this model – CMMI for Development (CMMI-DEV) (Chrissis, Konarad and Shrum 2006; CMMI Product Team 2010), CMMI for Acquisition (CMMI-ACQ) (CMMI Product Team 2010; Gallapher, Phillips and Richeter 2008), and CMMI for Service (CMMI-SVC) (CMMI Product Team 2010; Forrester, Buteau and Shrum 2009) – classify the CMMI into areas of development, acquisition, and service. In summary, CMMI is a process improvement maturity model for those three areas.

A special feature of the CMMI model is its methods of representation of maturity levels. The CMMI model has two methods for representing maturity. The methods are the continuous method and the staged method, both of which are illustrated in Figure 1. The staged method indicates the organizational level, while the continuous method indicates the area of process capability. The staged representation depicts the maturity of the whole organization, appraising the maturity level of an organization based on the accomplishment of objects for process areas in each stage. Since each maturity level is the basis for the next level, process improvement is obtained along a hierarchical structure. The visible advantage of the staged representation method is the possibility of comparison among organizations to indicate the regular abilities of the organizations. In the method of continuous representation, the level of capability is assessed in discrete process areas. The purpose of this method is to improve a particular process area. In the application of these two methods together, the CMMI achieves an appropriately complete method for assessing the conditions of organizations.

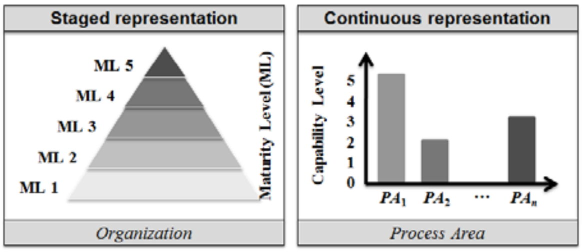

Figure 1: Two Representations of Maturity Levels Used in CMMI

2.2. ISO/IEC 15504 Model

The ISO/IEC 15504 reference model, also known as SPICE, includes processes and process properties to acquire, supply, develop, manage, and support the software in a specific organization (Doring 2007; El Emam and Brik 2000). During process assessment, assessors establish a suitable process assessment model based on a reference model in order to build up a common basis for decision making. To ensure compatibility between the assessment model and the reference model, SPICE describes the requirements for application. The common reference model provides a standard of assessment among results.

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2.3. Other Models

Other process maturity models are described in Table 1.

Table 1: Other Process Maturity Models

Model	Purpose
ISO/IEC 12207	Assess software lifecycles
ISO/IEC 15288	Assess system lifecycles
ISO 9001	Assess quality management systems
Malcolm Baldrige	Strengthen business competition in America
European Quality Award	Promote efficiency and efficacy of European businesses
Deming Prize (Japan)	Statistical quality control in Japan
Quality Management Prize (Korea)	Quality management in Korea

2.4. Consideration of Maturity Models for Simulation-based Acquisition

Given the typical structure of maturity models, all maturity models have two common properties. First is their common focus on process, and second is their common objective of process improvement. Because these two common features are coincident with the purpose of maturity models for SBA, we adapt these features to our proposed model. We examine the applicability to SBA of two typical maturity models, CMMI and SPICE, by observing their advantages and disadvantages. Table 2 shows their relative merits based on their properties. The underlined and boldfaced columns in Table 2 give the strengths of each model, for application to SBA, based on their properties. For example, the concept of a defined process in CMMI suits the procedures of SBA in that its use of identical process models decreases the cost of model development. SPICE allows flexibility because its process models are developed based on the target. With SPICE, however, there can be extra development costs and the imprint of the developer may affect the objectivity to the model.

Table 2: Properties of CMMI and SPICE

	CMMI	SPICE
Defined process	**Yes**	No
Reference model	**Identical**	Depends on the target
Assessment base	**Mostly identical**	Depends on the target
Flexibility	Weak	**Strong**
Costs	**Assessment costs**	Development and assessment costs
Factor of objectivity	**Assessor**	Model developer and assessor
Relative comparison	**Definite criteria**	Depends on the models
Training	**Periodical**	For each assessment

Considering these properties, our proposed model for SBA is a reference model that maintains the system of the CMMI model. Consequently, our model includes the advantages of CMMI as follows. First, CMMI is a set of best practices drawn from the successful completion of numerous projects and organizational processes. Next, the process areas in CMMI are analogous to SBA. That is, a number of process areas in SBA are related to process areas of CMMI-DEV and CMMI-ACQ. This similarity makes it possible to derive the core processes of SBA directly from the CMMI model. Furthermore, using already defined processes can reduce costs and support objectivity, which are advantages that cannot be achieved with SPICE. The defined processes also guarantee that definite assessment criteria are always identical and visible. This transparency makes it possible for anyone to be an assessor with simple training.

3. PROPOSED CAPABILITY AND MATURITY MODEL FOR SIMULATION-BASED ACQUISITION

3.1. Model Framework

This section describes the model framework of our maturity model for SBA, which is based on the CMMI model. To distinguish M&S development procedures from overall acquisition procedures, we use different terms. Specifically, M&S is the term for M&S development procedures, and SBA is the term for overall acquisition procedures. Accordingly, we classify capability and maturity models into SBA and M&S development according to their process properties. Figure 2 shows the framework of a capability and maturity model for SBA. The framework includes the model for M&S. This framework makes it possible to assess the M&S development of an organization, as well as to assess the main acquisition agencies.

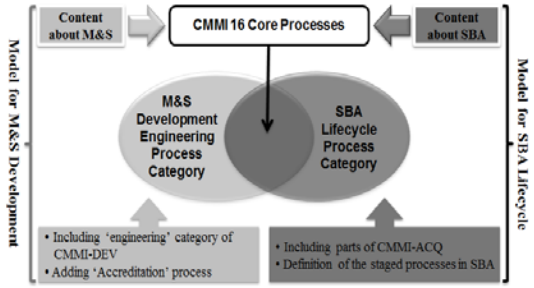

Figure 2: Framework of the Capability and Maturity Models for SBA

There are sixteen common core processes in CMMI-DEV, CMM-ACQ, and CMMI-SVC, which are directly applicable to every field without any modifications. Our model maintains these processes and adds specific processes of SBA and M&S development.

Adapting the category of engineering from CMMI-DEV to engineering for M&S development, we construct the maturity model for M&S development to additionally include the accreditation process that is requisite for developing M&S.

The entire category of SBA lifecycle processes includes some processes from existing CMMI models in order to retain their advantages. Defining the processes by phases in the SBA procedure, we reconstruct a process category that is specific to the SBA lifecycle.

Figure 3 illustrates the framework of the proposed model from a process viewpoint. The framework describes both process categories and processes in each category. In SBA, the integrated product team (IPT) controls all procedures of acquisition. The aspect of integrated product and process development (IPPD) makes it possible for the pending acquisition to take into account both the enhancement of overall military force and the performance of discrete weapons systems. The IPPD is a technique used by stakeholders for the procedure of acquisition in its entirety, to organize the IPT and to optimize the design, production, and maintenance processes of weapons systems. Therefore, our model connects the IPT to the area of organizational process definition (OPD). The OPD, which is a combination of processes supporting the SBA lifecycle, also includes acquisition support, which is defined as a process category. The OPD is one of the CMMI core processes, with an objective of establishing and maintaining organizational process assets and work standards.

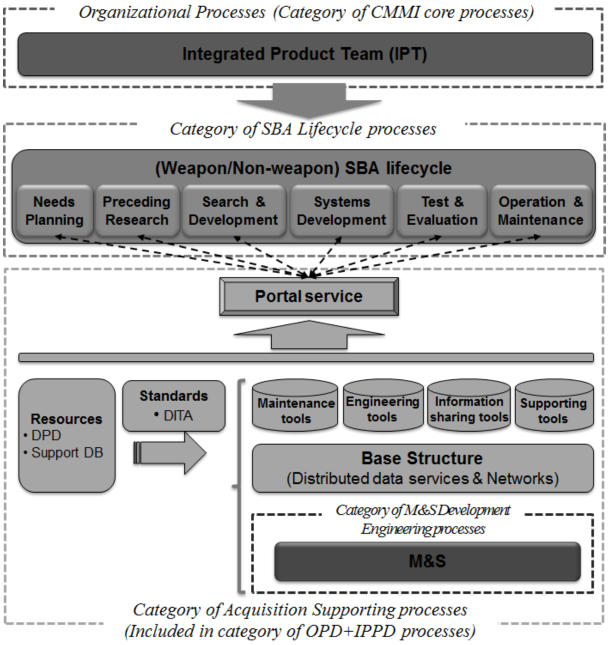

Figure 3: Framework of the Proposed Model from a Process Viewpoint

Table 3 defines the process categories that characterize the acquisition lifecycle. The SBA lifecycle consists of needs planning, preceding research, search and development, systems development, production, and operation and maintenance processes. To establish a reference for process improvement, we have defined appropriate process areas for each category as shown in Table 3. Because the initiative agency of each procedure in SBA is not uniform, we need to divide the model into six categories to assess relevant procedures. For example, if the Joint Chiefs of Staff require processes of needs planning, then the processes that fall within the "Needs Planning" category of the model's sixteen core processes can be used. The processes in each category are derived from existing CMMI models appropriate to corresponding SBA categories. The process with the same name as its category includes specified goals and best practices for successful achievement.

The process areas indicated in bold type are the specified processes related to each step of the SBA lifecycle. The rest of the process areas are derived from core processes of existing CMMI models.

Using or developing M&S is critically important for successful SBA. Fortunately, we can easily derive the processes of M&S development from those of CMMI-DEV due to their similarities.

Table 3: SBA Lifecycle Processes

Process category		Process area
SBA lifecycle	Needs Panning	Requirement Management
		Requirement Development
		Technical Solution
		Verification
		Validation
		Needs Planning
	Preceding Research	Requirement Management
		Requirement Development
		Solicitation and Supplier Agreement Development
		Technical Solution
		Verification
		Validation
		Preceding Research
	Search and Development	Requirement Management
		Product Integration
		Technical Solution
		Verification
		Validation
		Search and Development
	Systems Development	Product Integration
		Technical Solution
		Verification
		Validation
		Systems Development
	Production	Product Integration
		Technical Solution
		Verification
		Validation
		Production
	Operation and Maintenance	Requirement Management
		Requirement Development
		(Acquisition) Technical Solution
		(Acquisition) Verification
		(Acquisition) Validation
		Operation and Maintenance

We define several processes of M&S development engineering as shown in Table 4. The best practices from CMMI-DEV engineering can be applied without modification. Verification, validation, and accreditation (VV&A) are arguably the most important processes in M&S development (Balci 2003; Kilikauskas and Hall 2005). Accordingly, we define the accreditation process as the only process previously undefined by CMMI. The M&S development engineering model is independent from the SBA lifecycle model because it deals exclusively with M&S development. If an agency needs or wants to make a new M&S tool, this model is applicable to projects or organizations developing the tool.

Table 4: M&S Development Engineering Processes

Process category		Process area
M&S development enginerring	CMMI-DEV Engineering	Requirement Management
		Requirement Development
		Technical Solution
		Product Integration
		Verification
		Validation
	Accreditation	Accreditation

3.2. Hierarchical Structure

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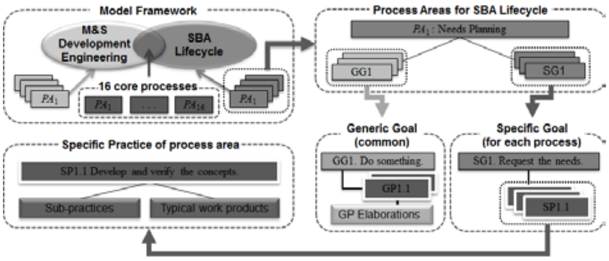

Figure 4: Hierarchical structure of the proposed model

The hierarchical structure of our proposed capability and maturity model is shown in Figure 4. As shown in the figure, the left topmost level is the framework, which includes the SBA lifecycle, the processes of M&S development engineering, and the sixteen core process areas. One process area that is called out in the figure is "Needs Planning", which the next section deals with as a specific model. Each process area consists of generic goals (GGs) and specific goals (SGs). These are standard units for determining and representing the assessed level of maturity. GGs are commonly applied to every process area, but each discrete process area has singular SGs. For example, "SG1. Request the needs" in Figure 4 is the first SG of the "Needs Planning" process area.

Because GGs and SGs are abstract requirements, concrete standards, called practices, are also needed for determining the capability of a process. Generic practices (GPs) and specific practices (SPs) support GGs and SGs. These practices are requisite conditions to achieve the larger goals (that is, the GGs and SGs). Therefore, satisfying the GPs or SPs implies the consequential achievement of associated GGs or SGs. For instance, "SP1.1 Develop and verify the concepts" in Figure 4 is an expected condition for accomplishing "SG1. Request the needs". Nevertheless, because the GPs and SPs are comprehensive, they must be supported by more informative activities. The activities are sub-practices, and their outputs are defined as typical work products. If the conditions of these activities are met, then the GP or SP is satisfied, and in turn, the GG or SG is achieved.

4. DETAILED INSTANCES

This section describes in detail instances of the proposed model for process improvement. The first step in the acquisition of weapons systems is needs planning. Needs are determined through the process of needs planning, which is a quite important step in the SBA lifecycle. Therefore, in order to describe the model in detail, we discuss some specific instances of the needs planning process. Table 5 shows specific instances of the "Needs Planning" process area.

Table 5: SGs and SPs in the "Needs Planning" Process Area

Needs Planning	
SG1	Request the needs : Make and request the needs
	SP 1.1 Develop and verify the concepts
	SP 1.2 Create the optimal needs
	SP 1.3 Analyze and evaluate the needs
SG2	Determine the needs: Investigate and determine the needs
	SP 2.1 Investigate the needs

The "Needs Planning" process consists of two SGs, each of which has three SPs and one SP, respectively. The process of needs planning is divided into aspects of requesting needs and determining needs, which equate to the specific goals of "Needs Planning". Each SP is an expected condition of achieving the corresponding SG. Most of all, the supporting informative activities are necessary for achieving the goals. We describe sub-practices and work products below.

The first SG is "Request the needs". The practices in this SG are arranged to appraise or improve the process, "Needs Planning". There are three SPs that describe the expected conditions for achieving SG1. Each SP is supported by informative activities, or sub-practices, some examples of which are subsequently described for each SP.

In SP 1.1, before developing the needs, the standard concept corresponding to the joint vision must be established. Next, the operating and functional concepts, as well as the integration of both concepts, should be developed in consideration of aspects of future wars (such as naval wars, ground wars, cyber wars, and space wars, among other examples) and the corresponding elements of force integration. Any joint operations concepts should be analyzed and operating scenarios should be developed through the utilization of theater models. Then, the operating and integration concepts should be investigated using mission, engagement, and engineering models. Engineering models are used to examine functional concepts. Finally, an integrated architecture based on the concepts should be reconstructed and verified around the interoperability of concepts integration (DiMario 2006; Sauser, Ramirez-Marquez, Magnaye and Tan 2008).

SP 1.2 describes the aspects of identifying optimal needs. To discover the optimal needs, we must identify the functions of battlefield alternatives, such as the functions of information, firepower, command and control, communication, and survival. Subsequently, the optimal solution should be determined by performing warfighting experimentation for these functional alternatives. Warfighting experimentation considers optimal strategy configurations and field operating conditions. The last step of determining optimal needs, after materializing the initial capability document for the systems which are to be developed or improved, is to draw up the optimal needs portfolio examining the acquisition criteria, including the time of weapons arrangement, method of acquisition, and quantities required.

SP 1.3 is the final step to analyze and evaluate the needs before formal request. To analyze the needs, performance measures for analysis and verification should be defined, including a measure of effectiveness (MOE), measure of performance (MOP), and measure of outcome (MOO). The MOE is produced by engagement models, MOP by engineering models, and MOO by mission or corps models.

The second SG is "Determine the needs", which introduces the needs for investigation, and determines the needs. To achieve SG1, we should satisfy SP 2.1, which describes the practice for investigating the requested needs. Specialized analysis tools should be developed in order to investigate the needs scientifically and rationally.

More detailed description of those instances such as typical work products and subpractices are also available for each special practice in accordance with CMMI structure. For example, the charts of MOE, MOP, and MOO should be provided for SP 1.3 as typical work products. Those work products can be a basis or an index for quantifying the qualitative measure.

The instance described in this section is a part of the "Needs Planning" category, which composes a model for the optimal handling of needs planning processes. The model for needs planning consists of sixteen core processes and six special processes in the "Needs Planning" category, as shown in Table 3. That is, for successful needs planning, those particular processes should be improved. Because the other processes in this model are derived from the CMMI, the processes can be utilized as they are, with no modification required. Consequently, we can construct six models that are applicable to all of the steps of the SBA lifecycle, as shown in Table 3.

5. VERIFICATIONS

5.1. Survey and Statistical Model

To verify our proposed process models and practices, we conducted a survey with experts in SBA and M&S. We assessed expertise by simultaneously considering quantitative and qualitative indices in order to increase the objectivity of assessment. As quantitative indices of expertise level, the numbers of completed projects and published papers were used. We used four different academic degrees and three levels of self-evaluation of expertise as the qualitative indices.

The survey questions were organized as follows. First, after we introduced the "Needs Planning" process, we provided examples of SGs and SPs. For each SP, we listed questions for evaluating the importance of our developed practices as measured on a 5-point scale. At the end of the questions, we provided blank lines for respondents to fill in original recommended practices. We developed several versions of the question charts, corresponding to each of six categories and M&S development. However, since we focused only on the "Needs Planning" category as an example in the previous section, this section provides only its results.

To integrate and evaluate the importance of practices from the answers of respondents, we developed a method of integrated expertise and weighted average. This method integrates expertise as a weight, and calculates weighted average. Notations are defined as follows:

D_i : academic degree (1, 2, 3, 4)
M_i : number of SBA-related projects respondent has been responsible for
C_i : number of SBA-related projects respondent has been involved in as a participant
T_i : number of months in holding an SBA-related occupation
P_i : number of published papers relating to SBA
R_i : self-evaluated level of expertise (1, 2, 3)
n : total number of interviewees

To calculate the expertise of respondents, we used the standard formula,

$$M'_i = \frac{M_i - M_{\min}}{M_{\max} - M_{\min}} \quad (1)$$

where M_{max} and M_{min} indicate the maximum and minimum values of the M_i's. Applying this formula to C_i, T_i, and P_i identically, we get C'_i, T'_i, and P'_i, the values of which vary from 0 to 1. Subsequently, we calculated S_i, the integrated expertise for interviewee i (i = 1, …, n), as follows.

$$S_i = D_i + 2M'_i + C'_i + 2T'_i + 2P'_i + R_i \quad (2)$$

To convert this value into a weight, we used

$$W_i = \frac{S_i}{\sum_{j=1}^{n} S_j} \quad (3)$$

where W_i is the weight of interviewee i. Finally, to calculate the weighted average, we used

I_{Qi}: level of importance from interviewee i for question Q (1, 2, 3, 4, 5).

Then, we calculated the weighted average by

$$IL_Q = \sum_{i=1}^{n} I_{Qi} \times W_i \quad (4)$$

where I_{Qi} is the final importance level of question Q. This final evaluation can be a basis of decision that the practice is effective to improve the corresponding process.

5.2. Results and Analysis

Based on the expertise integrated and weighted average technique, the results of the survey on SP1.1 about the "Needs Planning" process are shown in Table 6. The interviewees were selected from approximately 60 specialists in SBA and M&S. Figure 5 is a graphical representation of the information in Table 6. The column labels – from Pr. 1 to Pr. 6 – are the sub-practices described in Section 4. In Table 6, the first row represents results from the whole sample of interviewees (labeled "All interviewees"). Using the top 30 percent of the interviewees that ranked highly in expertise, we recalculated the importance levels of the proposed practices. The results of the recalculation are shown in the second row (labeled "Selected high rankers (30%)"). Since the values are similar to each other (by row), we confirm that experts commonly recognize the importance of each practice. All the measures for importance levels are relatively high, indicating that our proposed practices are coincident with the opinions of experts.

Table 6: Numerical Results from the Integration of Expertise Using the Weighted Average

	All interviewees	Selected high rankers (30%)
S.P 1.1	4.02	4.00
Pr.1	4.13	3.99
Pr.2	3.79	3.83
Pr.3	3.99	3.92
Pr.4	3.80	3.68
Pr.5	4.03	3.85
Pr.6	3.88	3.75

The results of SP1.2, SP1.3, and SP2.1 are omitted from further discussion because of their similarity with the results of SP1.1. The results of surveys about other processes are also omitted. All of the results show that our proposed models are applicable for improving the corresponding processes. Important recommendations from respondents collected in the blank lines section of the survey questions are included among our models. We are ready to verify the models again.

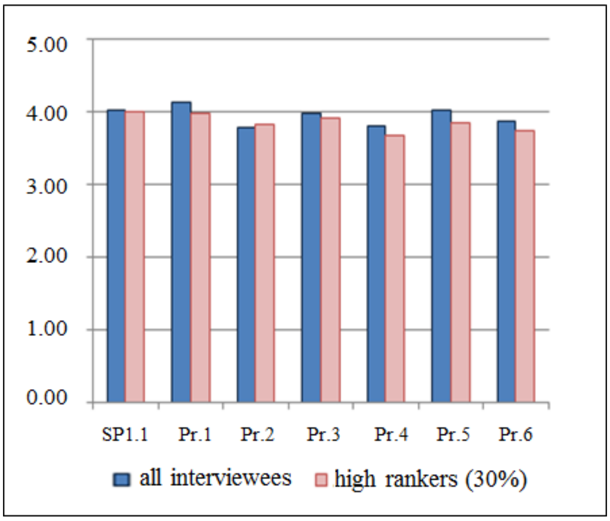

Figure 5: Graphical Representation of the Results, the Integration of Expertise Using the Weighted Average

6. CONCLUSIONS AND FUTURE WORKS

This study introduces a capability and maturity model for SBA. The proposed model is an expanded version of the CMMI model previously introduced by SEI. We defined the processes of the SBA lifecycle and set SGs to improve the processes. Subsequently, we developed SPs that describe important activities for achieving the SGs. Finally, we verified our model with M&S and SBA expert surveys. The proposed SPs can be used not only as assessment tools, but also as tests for process improvement.

By maintaining the advantages of existing models, we tried to overcome the limits that can occur while developing a maturity model for SBA. We also provided a flexible model framework to cope with new technologies. Our proposed M&S capability and maturity model can be used in various fields for acquisition of defense systems. For instance, companies developing weapons systems or M&S tools can apply our model to assess and improve their processes.

To enhance the proposed capability and maturity model for SBA, we must find and secure more sub-practices in support of every SP. In addition, since the proposed practices are appropriate for the Korean defense circumstances, more generalized practices which meet the common requirements of other countries should be developed. The active and positive participation of SBA agencies and M&S users in the real world is also extremely important in developing the model. Our research aims to provide a more advanced capability and maturity model for SBA in future studies.

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