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Developing a Model for Measuring Project Performance with Software Life Cycle Process Metrics and Calculating Project Success Score

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Abstract

Despite the developments in the process and tool infrastructure in the software world, project success has not significantly improved. In software projects, the definition of project success means to produce products that the customer desires in the planned effort, time and budget. To achieve this goal, planning, analysis, design, coding, integration, testing and delivery processes are operated interactively from the beginning to the end of a software project. Metrics of these processes are used to measure the performance of software projects. Since the literature review shows that project management process metrics such as budget, effort, schedule, customer satisfaction, product quality are used in measuring project performance, more comprehensive and effective criteria are needed to be defined and applied in measuring project performances. Due to the importance of the project performance evaluation, a general evaluation model was created in this study. The proposed model is designed for use in the software industry. In terms of project performance, a model has been developed that focuses on management of project, requirement, risk, quality and configuration, development, verification and validation processes. The purpose of this article is to present a model that evaluates the performance of software projects and expresses project success with a numerical value. Analytical hierarchy process (AHP) was used to calculate the relative importance of each process metric criterion and sub-criteria that provide input to the performance evaluation. Statistical process control method was used in the evaluation of project performance and calculation of the project success score. It was operated in an R&D organization to verify the proposed model and the performance of a project in delivery phase to the customer was measured. It is thought that the model presented in this study will help the managers, who monitor the project status, to evaluate project performance, as well as provide the numerical comparison of performance between projects.

Keywords: Project Performance Evaluation, Project Success Score, Analytical Hierarchy Process, Statistical Process Control

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1. INTRODUCTION

Policies in Turkey have been established to support technological product investments and clustering efforts in priority sectors such as energy, health, aviation, space, automotive, rail systems, IT, defense, information security and public digital transformation [1-3]. There is a huge increase in the number of software projects launched in these areas. Successful completion of these projects is of great importance.

The beginning of modern project management dates back to 1950. In the last 50 years, processes, methodologies, standards, good practices and many tools and techniques have contributed to the field of project management [4]. Despite the developments in the process and tool infrastructure in the software world, the number of projects that have failed is high [5]. One of the biggest causes of project failures is that software life cycle processes are not fully and correctly operated. Software life cycle processes are an interactive management system that defines activities and instructions for the procurement, planning, requirement analysis, design, coding, integration, review, testing, delivery and disposal stages of software projects [6]. These processes define process steps and responsibilities for analysts, software developers, integrators, operators, maintainers, managers, quality assurance managers and end users who will use the software in a software project. The software lifecycle first begins with the planning phase. At this stage, all processes that a software project should operate are planned. In the second stage of analysis, the functions and requirements expected from the software to be developed are defined. In the design phase, the first and basic version of the software that will be the solution to the needs determined in the analysis phase is created. At this stage, coding activity is not performed. Implementation stage can be detailed as coding, unit testing, code review and integration. Reviews on project documents and software components are made in verification phase. Software requirements are tested during validation. During the testing phase, errors in the software are corrected. The software defined in project contract is delivered to the customer and the maintenance phase is started. During the maintenance phase, operations such as troubleshooting and updating are performed in the software installed in the customer environment [6].

The metrics used in this study were used to measure the performance of software lifecycle processes. Project time, budget and effort metrics were used in the project management process. In the requirements management process, metric related to the volatility of the requirements is used. During the development process, defects, improvements, requirements changes and average open times and rates of these metrics were used. The verification and validation process is divided into two sub processes, review and test. Metrics related to the effectiveness, efficiency and error intensity of the reviews, on the other hand, the percentage of capture and detection of defects found in the test process were used as metrics. Although the objectives of the quality and configuration processes are different, their metrics are similar. In both processes, deviation from the audit plan and the average open time and rate of the nonconformities found in the audits were used as metrics. In the risk management process, the risk review rate was determined as metric.

The aim of this study is to present a new model for performance evaluation of software projects. As a result of the performance evaluation, the success of the project is shown with a numerical value. Structured interviews with experts were used to identify process criteria that affect project success. Analytical Hierarchy Process (AHP) was used to find the relative importance of the criteria in order to find the contribution of the determined criteria to the project success. The Statistical Process Control (SPC) method was used to analyze the metric measurement results collected from the projects.

In order to have sufficient decision making capacity, it is necessary to determine the relative importance of the criteria that affect the success of the project [7]. In this study, the judgements are taken from expert project managers and researchers working in an R&D organization. It is rule that weights have reflected the relative importance of the individual criteria. Therefore the AHP method is chosen to calculate the relative importance of criteria and the sub-criteria in consistent with the judgments of experts.

It is considered that this proposed model that evaluates the performance of software projects and calculates project success points will help project managers and senior executives to take decisions on projects success.

The paper is organized as follows. The next section provides literature review on project performance evaluation and project success factor. Section 3 describes the methods used in modeling. Section 4 presents project performance evaluation and project success score model, explains hierarchy of project metrics criteria, data collecting environment and finalizes the model. Section 5 explains the implementation of the model. Finally, conclusions are presented in Section 6.

2. RELATED STUDIES

In the literature, there are studies on the determination of project success criteria and project performance evaluation by using these criteria. In this section, these studies will be briefly mentioned. Table 1 summarizes most commonly used methods with references. On the other hand, Table 2 gives the set of process success criteria already employed.

Akyol [8] stated the parameters affecting the project success in software organizations with different scales and features. Number of employees in the project, experience and graduated university of the project manager, resource rate allocated to the requirements and test process, ratio of employees leaving the job, number of words in requirements, and number of lines of code are stated to affect the success of the project. Ayyıldız [9] identified software complexity, function point, reusability, project budget, technology used, employee competence, working environment characteristics, productivity status and product features as metrics. Radujković et al. [4] introduced Work Breakdown Structure for process factors. The factors were divided into three groups: project management competence, organization and methodology. In WBS project management competence consists of project manager competence, project team competence and coordination factors. Again, organizational factor consist of structure, culture, atmosphere and competence of the organization as a sub-factor. The methodology factor consist of the methods used, project management software, project management tools, decision-making techniques, risk assessment tools and information communication support tools. Sanchez et al. [10] discussed the key aspects of project success from a multi-level perspective with using correlation and regression analysis. Project size, duration, postponement, project team size, involvement of the team and formal strength of the project manager were determined as success factors. Mir et al. [11] conducted a research testing the relationship between project management performance and project success by using regression analysis. Todorović et al. [12] presented a framework of project success analysis based on critical success factors and performance indicators by using correlation and regression analysis. Verner et al. [13] conducted a study to identification of factors that affect project success and failure. Customer, requirements, estimation and scheduling, development process/team, project manager factor were analyzed with correlation and logistic regression methods.

Garousi et al. [14] investigated the correlation between software project success and critical success factors. According to the results of the analysis, the factors affecting the project success the most are the experience of the project team in the project development methodologies, the field expertise of the project team and the project monitoring control. Wadugodapitiya et al. [15] proposed a multidimensional performance measurement model for projects in the construction industry. In the study, project performance indicators were weighted by AHP. AHP results showed that customer satisfaction and project efficiency were the most important indicators on project success. Ilbeigi et al. [16]

developed a model that evaluates project management performance and calculates a numerical performance value. Cost Performance Index, Billing Performance Index, Schedule Performance Index, Safety Performance Index, Quality Performance Index, and Environment Performance Index parameters are used for success criteria to calculate project management performance. AHP method was used for relative importance of success factors. Koelmans [17] has grouped the factors by using WBS method in terms of customer, project team and society. Project scope, quality, schedule, cost, project team morale and customer satisfaction were determined as project success factors. Sen Leu at al. [18] improved the performance of traditional Earn Value Management (EVM) by the introduction of statistical control chart techniques. Bauch at al. [19] presented SPC tool includes charts that monitor time, cost, and technical performance-related project parameters. Bower at al. [20] used EVM as a project performance evaluation technique. Shahzad at al. [21] identified cost, time, team size, requirement change, reusable code, quality and risk management as success factor in large scale projects and implemented correlation and reliability analysis on the factors. Viglioni at al. [22] proposed a performance evaluation model for software industry based on a multi-criteria approach by using measuring attractiveness by a categorical based evaluation technique. Doskočil at al. [23] presented a new expert decision-making fuzzy model for the evaluation of project success. EVM metrics, total value of project risk and quality were identified as success factors. Shashi at al. [24] conducted impact analysis of resources such as cost, time, and number of developers towards the successful completion of the project as allocated by the project manager during the developmental process.

Table 1. Most Commonly Used Methods with References

Techniques	Reference	Author Name and Year	Key Topics
Statistical Process Control (SPC), Earn Value management (EVM)	[16] [18] [19]	Ilbeigi at al. (2009), Sen Leu at al. (2008), Bauch at al. (2001)	Critical and effective indices were defined develop a model, by which the project management performance can be evaluated.
Earn Value management (EVM)	[20]	Bower at al. (2009)	Use of EVM criteria in project performance evaluation
Analytical Hierarchy Process (AHP), Balanced Scorecard (BSC)	[15] [16]	Wadugodapitiya at al. (2010), Ilbeigi at al. (2009),	Multidimensional performance measurement model for project performance evaluation by integrating BSC and AHP tools.
Work breakdown structure (WBS) evaluation	[4] [17]	Radujković at al. (2017), Koelmans (2004)	Indicators are developed into a work breakdown structure (WBS)-like chart to demonstrate success indicators
Correlation, Logistic Regression Analysis	[13] [14]	Garousi at al. (2019), Verner at al. (2007)	Correlation study of project variables and project outcome and logistic models to predict failure
Correlation, Regression Analysis	[8] [10] [11] [12]	Sanchez, at al. (2017), Todorović (2015), Mir at al. (2014), Akyol (2014)	Multi-dimensional frameworks are used to measure PM performance and project success
Empirical study, Data analysis	[24] [28]	Shashi at al. (2014), Bryde at al. (2005)	Impact analysis of resources such as cost, time, and number of developers towards the successful completion of the project
Correlation analysis and reliability analysis	[21] [27]	Gomes at al. (2016), Shahzad at al. (2014)	Statistical analysis of defining project success criteria
MACBETH Multi-criteria decision making method	[22]	Viglioni at al. (2016)	Performance evaluation model by measuring attractiveness by a categorical based evaluation technique
Fuzzy modeling	[23]	Doskočil at al. (2016)	Use of fuzzy logic in the evaluation of project success

Table 2. A Set of Process Success Criteria Already Employed

Criteria	Reference	Author Name and Published Year
cost	[10, 14, 17, 22, 23, 25, 26, 27, 28, 29, 30]	Garousi (2019), Sanchez (2017), Badewi (2016), Mossalam (2016), Gomes (2016), Viglioni (2016), Doskočil (2016), Bryde (2005), Jugdev (2005), Koelmans (2004), Baccarini (1999)
time	[10,14, 17, 22, 25, 27, 28, 29, 30]	Garousi (2019), Sanchez (2017), Badewi (2016), Gomes (2016), Viglioni (2016), Bryde (2005), Jugdev (2005), Koelmans (2004), Baccarini (1999)
quality	[10, 14, 17, 22, 25, 28, 29, 30]	Garousi (2019), Sanchez (2017), Badewi (2016), Viglioni (2016), Bryde (2005), Jugdev (2005), Koelmans (2004), Baccarini (1999)
scope	[10, 17, 22, 23, 26, 27, 29, 31, 32]	Sanchez (2017), Gomes (2016), Mossalam (2016), Viglioni (2016), Doskočil (2016), Besner (2006), [Koelmans (2004), Jugdev (2005), Lim (1999)
human resources	[4, 11, 14, 22, 29, 32, 33, 34]	Garousi (2019), Radujković (2017), Viglioni (2016), Radujković (2014), Mir (2014), Jugdev (2005), Cooke-Davies (2002), Lim (1999)
satisfaction of stakeholders	[14, 15, 17, 22, 23, 27, 35, 36]	Garousi (2019), Gomes (2016), Viglioni (2016), Doskočil (2016), Wadugodapitiya (2010), Müller (2012), Koelmans (2004), Bryde (2003)
organizational benefits	[32, 37]	Chou (2013), Lim (1999)
technical, financial, educational, social, professional elements	[27, 38]	Gomes (2016), Ellatar (2009)
project management tools and techniques	[4, 14, 37, 39]	Garousi (2019), Radujković (2017), Chou (2014), PricewaterCuppers (2012)
organizational structure	[4, 14, 33, 40]	Garousi (2019), Radujković (2017), Radujković (2014), Feger (2012)
risk assessment	[4, 27]	Radujković (2017), Gomes (2016)
requirements	[13, 23, 27, 41, 42]	Gomes (2016), Doskočil (2016), Keil (2012), Verner (2007), Taylor (2006),
leadership, personnel, politics and strategy, partnership and resources	[27, 36]	Gomes (2016), Bryde (2003)
project life cycle management process	[36, 45]	Bryde (2008), Bryde (2003)
return and profit, market share, repute	[27, 43, 44]	Gomes (2016), Al-Tmeemy (2011), Blindenbach-Driessen (2006)
competitive edge	[43, 44]	Al-Tmeemy (2011), Blindenbach-Driessen (2006)
project management standards	[4, 37, 46]	Radujković (2017), Nahod (2013), Chou (2013)
total competencies of project manager	[4, 13, 33, 40, 47, 48, 49, 50]	Radujković (2017),Radujković (2014), Ramazani (2015), Feger (2011), Turner (2009), Ika (2009), Verner (2007), Radujković (2000)
organizational culture	[4, 14, 51, 52]	Garousi (2019), Radujković (2017), Westerveld (2003), Skulmoski (2001)
project managers' emotional intelligence	[46, 53]	Nahod (2013), Yang (2011)
purpose	[23, 26]	Mossalam (2016), Doskočil (2016)
project team factors	[4, 11, 13, 14, 17, 22, 27, 33]	Garousi (2019), Radujković (2017), Gomes (2016), Viglioni (2016), Mir (2014), Radujković (2014), Verner (2007), Koelmans (2004)
earned value management key performance indicators	[12, 16, 22, 23]	Viglioni (2016), Doskočil (2016), Todorović (2015), Ilbeigi (2009)
estimates	[13]	Verner (2007)
customer factors	[13, 14, 22]	Garousi (2019), Viglioni (2016), Verner (2007)

In the literature, studies related to the determination of the criteria affecting the success of the project and the project performance evaluation models in which these criteria are entered have been seen. When the literature is analyzed, it has been observed that configuration management, quality management, verification and validation and development process metrics are not evaluated as project success criteria. It is thought that using software life cycle process metrics as the project success factor in this study and using it in the project performance evaluation model will contribute to the literature by innovating.

3. THE METHODOLOGY

3.1. Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is a multi-criteria decision making method developed by

Thomas L. Saaty in 1970s. AHP allows the decision maker to correctly and logically apply data, experience, understanding and intuition by modeling a complex problem in a hierarchical structure by showing the relationship between goals, objectives (criteria), sub-goals and alternatives [54]. It needs a hierarchical structure to modeling the decision problem and pairwise comparisons to determine relations between objectives [55].

There are different AHP implementations in literature regarding with prioritizing process success criteria sets [15]. This study uses AHP to solve two decision problems: 1) creating hierarchical structure that assess project success criteria; 2) determining relative importance of each criterion in the hierarchical structure.

AHP consists of three main stages: Separating the problem or establishing the hierarchy, comparative judgments and synthesis [55]. The first stage of AHP implementation is to develop a hierarchy by taking the complex problem into sub-problems. Goals, objectives, and alternatives are three basic levels of the hierarchy [56]. Starting from the top, the goal of the decision, the objectives, the intermediate levels and the alternatives at the lowest levels should be structured hierarchically [57]. Saaty, taking into account the limits of human cognitive abilities, recommends the number of elements in the each hierarchy level as 7 ± 2 [58].

The comparative judgments help decision makers to do pairwise comparisons of the relative importance of criteria in the hierarchies. In this study, judgments are gathered from the project managers, department managers and quality assurance managers who have worked in the R&D organization. After creating the hierarchy, the decision makers separately evaluates the importance of each decision criterion in the hierarchies and make pairwise comparisons at each level to calculate how many times the criteria (relative importance) are important to each other by using the scale given in Table 3.

Finally, the AHP synthesis the judgments obtained from the experts to provide a set of overall priorities for the hierarchy structures. The synthesis step includes calculation and normalization of the largest eigenvalue and the corresponding eigenvector. Although there are various methods of normalizing, the elements of each column are divided into column sums and the resulting row totals are divided into number of elements in this row. This method is widely preferred [59]. The consistency of judgments is calculated with using the following formula [60].

$$A \, x \, W = \lambda_{max} \, x \, W \quad (1)$$

A shows the pairwise comparisons matrix, W is the normalized weight vector and λmax is the maximum eigenvalue of matrix A. The maximum eigenvalue is used to estimate consistency in a matrix. Formula 2 gives the consistency index (CI) measured for the inconsistency.

$$Consistency\ Index\ (CI) = (\lambda_{max} - n)/(n-1) \quad (2)$$

The corresponding ratio (CR) is calculated by dividing the CI value by Random Consistency Index (RCI). In this calculation depending on the number of n alternatives random index (RCI) numbers are used [60]. Pairwise comparisons are considered to be consisted if the corresponding ratio (CR) is less than 10%. The AHP study in this article aimed to calculate the relative importance of the process metrics to be input in the project performance evaluation model. Because of there are no alternatives, sensitivity analysis in classical AHP method was not performed in this study.

Table 3. The Fundamental Scale [55]

Value	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor over activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of

Value	Definition	Explanation
		the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

3.2. Statistical Process Control (SPC)

SPC is a tool that applies statistics to the control process. There are different kinds of methods for SPC: scatter diagrams, run charts, cause and effect diagram, histograms, bar charts, Pareto charts, and control charts [18]. SPC control charts can be a successful tool for manufacturing and software process improvement [61]. In this study, control chart has been used to determine the lower and upper control limits of the process metrics.

The variation in a process may be due to common causes or assignable causes. The common cause variation is the normal variation related to the result of normal interactions of people, machines, environment and methods. Assignable cause change results from events that are not part of the normal process. Those causes occur sometimes and can be prevented [62]. If all process data are plotted within the control limits and without any particular tendency, the process is regarded as being in the controlled state [62].

In SPC, control charts are widely used for monitoring and controlling the process. There are different types of control charts in statistics [63-65]. In software processes, the data points are not generally as frequent as in manufacturing processes [66]. Each data point is plotted and evaluated individually. Therefore, the most used control chart in the software engineering area is Individual (I) and Moving Range (MR) control charts.

I-MR control charts consist of two basic features; centerline and sigma value. Centerline is the average value of data points, and sigma is the standard deviation of these data points. In I charts, data points are separate values in the charts, while in MR graphs, the data is obtained by calculating the absolute difference between two successive values. In these control charts, upper and lower control limits are calculated generally with three sigma values from the centerline [61], which covers 99% of all data.

4. MODEL DESIGN

In this study, literature research, determination of criteria, suggesting the model and application of the model have been done within the framework of scientific principles. In this section, the whole activities are specified in Figure 1 according to the workflow.

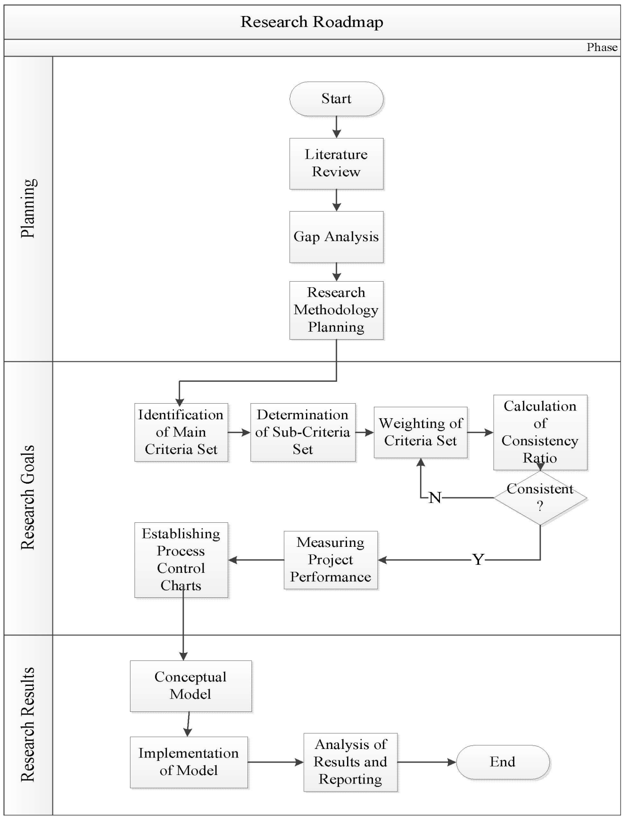

Figure 1. Research Flow Chart

4.1. Hierarchy of Process Metric Criteria

The software life cycle process metrics were determined as a result of interviews with the process improvement team and project managers in an R&D organization and the analysis of the current processes of the organization. The identified metrics are considered as process success criteria in this study. Process metrics are organized as main criteria and sub-criteria for AHP study. The hierarchy of criteria is shown in Figure 2.

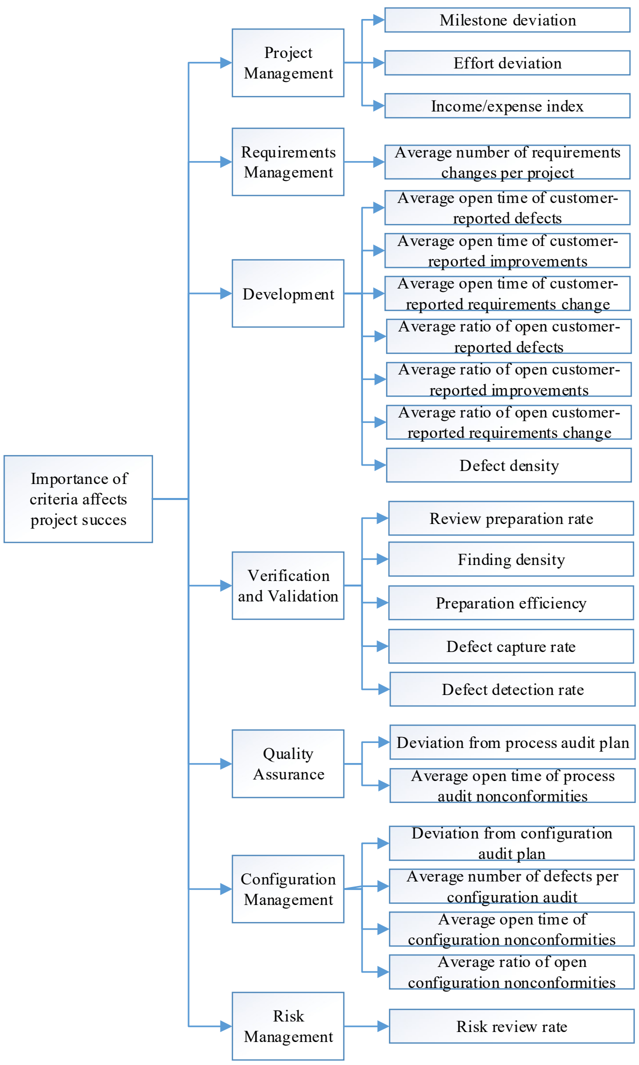

Figure 2. Hierarchy of Process Metric Criteria

As a result of the literature review, it has been observed that there is not enough study on the process metrics in the software life cycle in determining the factors affecting the project success. In the metric determination study conducted with expert project managers and quality managers in the R&D institution, it has been evaluated that measuring and analyzing the critical activities of the processes operated in the project life cycle will affect project success. In this context, an application has been made to verify the proposed model by deciding the weighted contribution of the criteria specified in Figure 2 to the success of the project.

4.2. Data Collection

A questionnaire including process metric criteria was designed to determine relative importance of criteria given in Figure 2. The process metric criteria consisted of 7 criteria at level 2 and 23 sub-criteria al level 3 was assessed according to the level of importance to the organization.

Project performance is measured through collecting and analysis of process metrics results. The data as a result of implementing processes were collected from a total of 25 projects in an R&D organization which develops software and system projects in the defense and civilian sectors. The R&D organization has more than 400 engineers. Process metric measurements are taken from the development tools used in projects. The project development tools that applied in the R&D organization are given in Table 4.

Table 4. Project Development Tools

Process Name	**Tool Name**
Project Planning and Task Management	Atlassian JIRA
	Atlassian Confluence
	IBM Rational Team Concert
	SAP and MS Project
Requirements Management	IBM DOORS
	IBM DOORS Next Generation
	Atlassian JIRA
Analysis and Design	Enterprise Architect
	IBM Rational Rhapsody
	IBM Rational Software Architect
	Altium Designer
Coding	Eclipse, Visual Studio
Unit Test	Junit
	Google Code Pro
	Quick Test Professional
Build and Integration	Atlassian Bamboo
	Jenkins
	Ant
	IBM Rational Team Concert
Test Management	Rational Quality Manager
Configuration Management	IBM Rational Team Concert
	SVN (Subversion)
	GIT
Task Management	Atlassian JIRA
	IBM Rational Team Concert
Review	SmartBear Collaborator
Software Quality Evaluation	Understand
	Sonar Source

Process metric values are generated as a result of operating the workflows in the project development tools. The relationship between metrics and tools related to workflows is given in Table 5.

Table 5. Project Process Workflows and Related Tool

Workflow Name	Related Tool	Related Process Metric
Task activities	IBM Rational Team Concert, Atlassian JIRA	Milestone and effort deviation Income/expense index Defect capture and detection rate
Change requests	IBM Rational Team Concert, Atlassian JIRA	Open ratio and time of customer reported defects, changes and improvements Number of requirements changes
Defects/ bugs	IBM Rational Team Concert, Atlassian JIRA	Defect density
Risk forms	IBM Rational Team Concert, Atlassian JIRA	Risk review rate
Process audits	IBM Rational Team Concert, Atlassian JIRA	Deviation from process audit plan
Work product conf. audits	IBM Rational Team Concert, Atlassian JIRA	Deviation from configuration audit plan
Reviews	SmartBear Collaborator	Preparation efficiency and rate Finding density
Corrective actions	IBM Rational Team Concert, Atlassian JIRA	Open ratio and time of process and configuration nonconformities

4.3. The Model

Figure 3 shows the project performance evaluation model with using process metric criteria. The project phases indicated in Figure 3 may vary from organization to organization. The process metrics measured at each project stage may also vary according to the business objectives of the organizations and the product and process performance objectives.

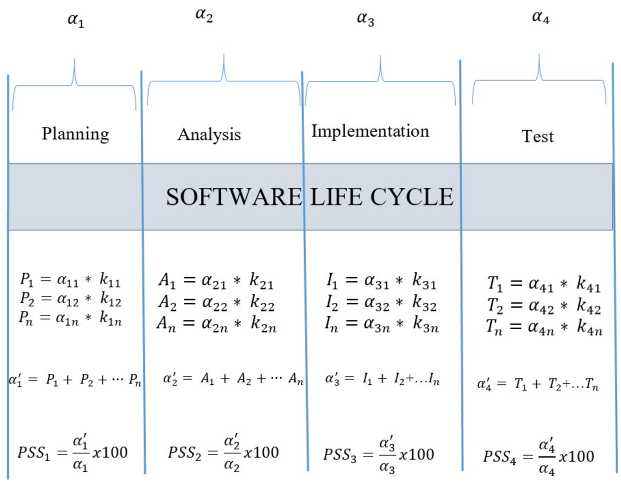

Figure 3. Project Success Score Calculation Model

k_{ij} is a metric weight coefficient calculated by AHP method.

$\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are expected success scores. The expected success points are determined by the weight totals of the process metrics operated at the relevant project stage.

$\alpha_{1n}, \alpha_{2n}, \alpha_{3n}, \alpha_{4n}$ are measured process metric values.

P_n, A_n, I_n, T_n are measured metric success score value of the project relevant stage.

PSS_n are project success scores at the relevant project stage.

The metrics that will be input to the model during the planning, analysis, implementation and testing stages of the project are given in Table 6. The metric codes are defined in Figure 4.

Table 6. Metric Criteria Entering the Model

Project phase	Metric criteria entering the model
Planning	PM1.1,PM1.2, PM1.3,QA1.1, QA1.2, VV1.1, VV1.2, VV1.3, RM1.1
Analysis	PM1.1,PM1.2, PM1.3,RM1.1,DEV 1.3, DEV1.6, QA1.1, QA1.2, VV1.1, VV1.2, VV1.3
Implementation	All process metric criteria
Test	All process metric criteria

Project performance success score is calculated by summing the metric values and metric weight coefficient multiplication results. The process metric criterion which is out of control does not contribute to the project success score. In order to calculate the success score, the metric measurement values were compared with the related process control charts. The process metrics within the upper and lower control limit values contribute to the project success score by their own metric weight.

5. IMPLEMENTATION OF THE MODEL

5.1. AHP Results

AHP methodology was carried out in an R&D organization to weight process metrics in terms of their impact on project success. A series of meetings were held with experienced Project Managers, Department Managers and Quality Assurance Managers in the organization. For this purpose, a structured survey was given to the experts. The experts were asked to evaluate the importance of process metrics on the project success. They have made pairwise comparisons at each hierarchy level by using scale given in Table 3. Geometric mean method is used to aggregate these individual judgments for the final group decision. The results of the pairwise comparison surveys from the participants were evaluated and in cases where the inconsistency rate was greater than 10%, re-interviews were conducted with the relevant participants for reviewing their individual opinions and making corrections. The corrected values from the experts were analyzed. The analysis results and inconsistency rates of the main criteria are given in Table 7. The fact that CR is close to zero means that judgments from experts are more consistent and acceptable.

As can be seen in Table 7, the requirement management process is the criterion that has the most important impact on project success with 21.7%. The development process with 21.5%, the project management process and configuration management with 11.9%, and the verification and validation criteria with 15.1%, respectively follow this. The risk management process with 9.5% and the quality assurance process with 8.4% take the last places. The consistency between the pairwise comparisons has been checked at level 3 for sub-criteria. According to Figure 4, all CR values are close to zero. Sub-criteria weights are given in Figure 4.

Table 7. Main Criteria Weight Results

Process metrics (success criteria)	Weights
Project management	0.119
Requirements management	0.217
Development	0.215
Verification and Validation	0.151
Quality assurance	0.084
Configuration management	0.119
Risk management	0.095
CI = 0.00963	CR = 0.00730

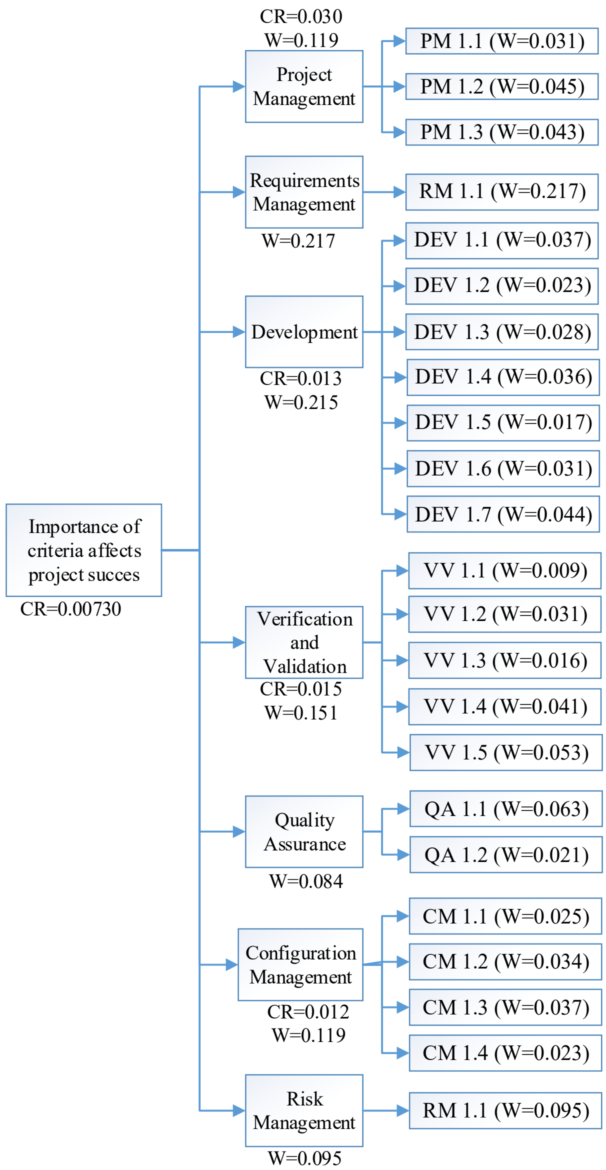

Figure 4. Weights of the Process Metric Criteria

The ordering of the process metric sub-criteria according to their importance is given in Table 8. According to Figure 4 and Table 8, the most important criterion affecting project success is average number of requirements changes per project. This result emphasizes that the high number of requirement changes while the project is continuing prevents the success of the project.

The risk review rate is the second most important criterion in terms of impact on project success. This criterion shows the degree of management of the risks in the project from the beginning to the end of the project. The higher the risk review rate, the higher the chances of project success.

Average open time of process audit nonconformities criterion is the third most important criterion. The experts emphasized that the prolonged closing times of nonconformities found in products and processes as a result of quality audits have a negative effect on project success.

Again, the percentage of defect detection is the fourth most important criterion. The fewer defects that detected by customers, the more successful the project will be.

The effort deviation is fifth in importance. If the planned effort is exceeded, it will have a negative impact on project success, as the total cost will increase. Defect intensity ranks sixth in terms of impact on project success. Since the defect intensity is high, correcting the errors will require additional labor and time, so it will have a negative impact on the project budget and schedule.

The fact that the income expense index, which is in the seventh place, is greater than 1 indicates that it has a positive effect on the success of the project. The defect capture rate that is in the eight place, gives the ratio of the number of defects captured before the software product is delivered to the customer, in the total number of defects. The higher rate means that the product is delivered to customer with fewer defects. This situation has a positive effect on project success. The average open time criterion of configuration non-conformities is important in ninth place. The prolongation of this period decreases the success of the project.

The tenth and eleventh rank metrics are related. The fact that the average open time and rate of defects reported by the customer is high has a negative effect on the success of the project. Similarly, experts emphasized that the high values of all metrics between twelve and twenty one have an adverse effect on project success.

The twenty-second and twenty-third metrics are metrics related to software and documentation reviews. Experts thought these metrics were least important.

Table 8. Ranking Table of Process Metric Criteria

Rank	Criteria	Weight
1	Average number of requirements changes per project	0.2166
2	Risk review rate	0.0953
3	Average open time of process audit nonconformities	0.0633
4	Defect detection rate	0.0531
5	Effort deviation	0.0447
6	Defect density	0.0435
7	Income/expense index	0.0428
8	Defect capture rate	0.0414
9	Average open time of configuration nonconformities	0.0371
10	Average open time of customer-reported defects	0.0370
11	Average ratio of open customer-reported defects	0.0362
12	Average number of defects per configuration audit	0.0335
13	Finding density	0.0314
14	Milestone deviation	0.0313
15	Average ratio of open customer-reported requirements change	0.0307
16	Average open time of customer-reported requirements change	0.0275
17	Deviation from configuration audit plan	0.0253
18	Average ratio of open configuration nonconformities	0.0230
19	Average open time of customer-reported improvements	0.0229
20	Deviation from process audit plan	0.0211
21	Average ratio of open customer-reported improvements	0.0172
22	Preparation efficiency	0.0165
23	Review preparation rate	0.0087

5.2. Using Process Performance Control Charts in the Model

Process performance control charts is established for each process metric indicated in Figure 2. In this section, the process control chart for the review preparation rate criteria, which is related to the review process, is explained. Review preparation rate results have been collected from a total of 25 software projects in the organization in order to create a review preparation rate process control chart.

Review preparation rate measurement aims to determine the central tendency of the time allocated for review activities. Preparation rate equals size of material per preparation hour. If the reviewed material is a document then size is number of pages. If reviewed material is source code the size is logical lines of code. Logical line of code means the code size without comment lines. The data for 24 months collected from the projects in the R&D organization are shown in Table 9. The value for each month is the median average of the review preparation rate for all projects in the relevant month. In the software world, U chart or I-MR control charts are used as control chart type [67]. If the distribution of the data is suitable for the poisson or binomial distribution, the U control chart can be used. If there is no clear idea about the distribution of data, I-MR chart is used [67]. In this study, I-MR control chart graph has been used to create control chart in Minitab tool.

Table 9. Review Preparation Rate Measurements

Months	**Review Prep. Rate**	**Months**	**Review Prep. Rate**
2017-January	21	2018-January	485
2017-February	24	2018-February	33
2017-March	80	2018-March	7
2017-April	90	2018-April	1507
2017-May	26	2018-May	86
2017-June	24	2018-June	28
2017-July	19	2018-July	41
2017-Augost	97	2018-Augost	40
2017-September	19	2018-September	89
2017-October	18	2018-October	76
2017-November	13	2018-November	103
2017-December	158	2018-December	25

After the first iteration the points outside of the control limits have been deleted and the control chart was re-established with the remaining data. Continuing in this way, the data remaining as a result of the third iteration has created a stable process control chart. The control chart generated is shown in Figure 5.

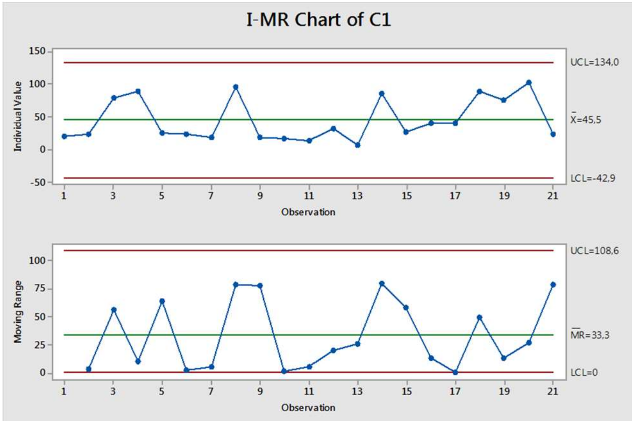

Figure 5. Review Preparation Rate Control Chart - Third Iteration Result

As shown in Figure 5, the process has become stable by eliminating all points that are out of control. In this study, process control charts have been created for all process metric criteria in the software life cycle. The upper and lower control limits of the control charts created for the process metric criteria specified in Figure 2 are given in Table 10. The value of the lower control limit, which is calculated as negative value, is shifted to zero; since it is logically impossible to have a negative value for review preparation rate metric [68].

Table 10. Process Metric Criteria Lower-Upper Control Limit Values

Metric Name	**Lower Control Limit Values**	**Upper Control Limit Values**
Milestone deviation (day)	0	30
Effort deviation (%)	0	10%
Income / expense index*	>1	
Average open time of process audit nonconformities (day)	0	15
Deviation from process audit plan (day)	0	15

Metric Name	Lower Control Limit Values	Upper Control Limit Values
Average open time of customer-reported defects (day)	0	30
Average open time of customer-reported improvements (day)	0	30
Average open time of customer-reported requirements change (day)	0	30
Average ratio of open customer-reported defects (%)	0	10%
Average ratio of open customer-reported improvements (%)	0	10%
Average ratio of open customer-reported requirements change (%)	0	10%
Defect density (#/KLOC)	0	1.40
Deviation from configuration audit plan (day)	0	15
Average defect per configuration audit (number)	0	5
Average open time of configuration nonconformities (day)	0	30
Average ratio of open configuration nonconformities (%)	0	10%
Risk review rate (%)	90%	100%
Average Number of Requirements Changes per Project (number)	0	15
Review preparation rate (size/hour)	0	134
Finding density (#/size)	0	0,19
Preparation Efficiency (#/hour)	0	0,08
Defect capture rate (%)	57%	100%
Defect detection rate (%)	60%	100%

*Note: Analysis has been made according to the case of being larger or smaller than 1.

5.3. Results of the Model Implementation

The model has been applied with a real project data in an R&D organization. In project planning, analysis, implementation and test stages, which are the software lifecycle stages, project performance evaluation has been performed. As a result of each evaluation, a numerical project success score has been created.

Process metric measurement results collected from the project in the acceptance test phase are given in Table 11.

Table 11. Real Project Measurements

Metric Name	Metric value
Milestone deviation (day)	47
Effort deviation (%)	15
Income / expense index*	0.83
Average open time of process audit nonconformities (day)	11
Deviation from process audit plan (day)	0
Average open time of customer-reported defects (day)	24
Average open time of customer-reported improvements (day)	22
Average open time of customer-reported requirements change (day)	18
Average ratio of open customer-reported defects (%)	8
Average ratio of open customer-reported improvements (%)	7
Average ratio of open customer-reported requirements change (%)	8
Defect density (#/KLOC)	1.1
Deviation from configuration audit plan (day)	7
Average defect per configuration audit (number)	2
Average open time of configuration nonconformities (day)	15
Average ratio of open configuration nonconformities (%)	6
Risk review rate (%)	100
Average Number of Requirements Changes per Project (number)	14
Review preparation rate (size/hour)	80
Finding density (#/size)	0,12
Preparation Efficiency (#/hour)	0,05
Defect capture rate (%)	61
Defect detection rate (%)	70

The metrics to enter the model during the planning phase are given in Table 12. If the related process metrics measured in the project planning stage are within the upper and lower control limits, the total weight of the metrics is 0.355. The weight value of the process metrics that are out of control is assumed to be zero. The analysis phase total weight of the metrics is 0.630. While performing the performance evaluation during the project's implementation and testing phase, all of the software life cycle process metrics are inputs to the model. So both total metric weights equals to 1.

In the real project measurement results, milestone deviation, effort deviation and income / expense index values of the project have been found to be outside the limits of the relevant control charts. Other process metric values have been found within the control limits. In this case, the total weight values of the metrics within the control limits have been calculated as 0.236. The total expected metric weight of the project is 0.355. The ratio of these two values to each other and multiplied by 100 gives the success score for the planning phase of the project.

$$\text{Planning phase project success score} = \frac{0{,}236}{0{,}355} x100 = 66 \quad (3)$$

As of the planning phase, the project meets 66% of the expected success.

The reasons for the deviation of the process metric values from the targeted limits in this project were analyzed by Ishikawa diagram and root causes have been found. As a result of the analysis, it has been concluded that due to technical difficulties in the project, the milestone of the project is extended and in this case the effort value increases. As an applied corrective activity, an experienced employee has been assigned to the project. Again, the results of the evaluation made at other stages of the project are given in Table 12.

Table 12. Results of Model Implementation

Project phase	Metric criteria entering the model	Calculated project success score
Planning	PM1.1,PM1.2, PM1.3,QA1.1, QA1.2, VV1.1, VV1.2, VV1.3, RM1.1	66
Analysis	PM1.1,PM1.2, PM1.3,RM1.1,DEV 1.3, DEV1.6, QA1.1, QA1.2, VV1.1, VV1.2, VV1.3	81
Implementation	All process metric criteria	88
Test	All process metric criteria	88

6. CONCLUSION

The project management philosophy has been supported by international standards and turned into a methodology. With the principle of common understanding, which is one of the most important results of this standardization, minimum requirements for project management activity steps are determined. In line with the researches, it is observed that these activities are intended to form a common understanding about measurement, analysis, evaluation, improvement, but some gaps in this matter have been observed and discussed in this study. As a result of the literature research, it has been concluded that the project success factors are determined in general terms, but when these are discussed on a sector basis, these general lines should be further customized. In other words, when the literature is analyzed, models for measurement, analysis and evaluation have been created predominantly in the production and service sectors, but it has been observed that there are no models and application examples for the software R&D sector.

The purpose of this paper is to develop a model to evaluate project performance with software life cycle process metrics and calculate project success score. The project success factors, which are seen as deficiencies in the literature, were discussed with experts, who have advanced experience and competence in R&D organization, the project success criteria, which were felt deficient, were determined, and these measurements have been proposed in the study.

In order to create a project performance evaluation model from these criteria, judgements were collected from experienced researchers and project managers in an R&D organization. The relative importance of the process metrics was determined by AHP method. As a result of the calculations made with the judgements of the experts, the weighting of each criterion was found and its effect on the model was revealed. As a result of the main criteria weighting, it has been observed that the requirement management process will have 21.7% impact on the project success. The development process with 21.5%, the project management process and configuration management with 11.9%, and the verification and validation criteria with 15.1%, risk management process with 9.5% and the quality assurance process with 8.4%, respectively, follow this. As a result of the sub-criteria weighting, the effect of each process metric on project success was revealed.

AHP was used because of the ability to 1) establishment of a hierarchical decision structure for the solution of the problem, 2) enables the assessment of multiple expert opinions, 3) pairwise comparison advantage, 4) no need for decision-making groups to engage in lengthy discussions, 5) ability to address inconsistency in expert judgements. On the other hand, the process takes a lot of time when new criteria are added.

A case study was conducted from an R&D organization to observe the proposed model applicability and the effects of obtaining the results. As a result of this application example, process control charts were created and process performances were evaluated. In case the process metric measurements exceed the upper and lower control limits on the control charts, project managers can investigate the cause of that situation with root cause analysis and aim to increase the project performance by initiating corrective action if needed.

This study has important implications for project managers and senior managers. First, this study created a list of project success factors to be used in project performance evaluation. This list will help project managers understand the key process success criteria that are important to project success. Secondly, this study provides project managers with a model to measure the success of their projects. The model can serve as a tool for project managers to improve the process performance of projects.

This study is limited to the context of the R&D organization and therefore the results may only be considered valid in this particular context. Other organizations can collect data from their own software lifecycle processes metrics and set up their own project success score calculation model.

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