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A FRAMEWORK FOR MEASURING CRITICAL SUCCESS FACTORS OF LARGE - SCALE SOFTWARE SYSTEMS

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ABSTRACT

Large-scale software systems (LSS) are complicated due to their huge size and the number of applications and services they provide. Implementations of such systems are surrounded by a group of influential factors, termed as Critical Success Factors (CSFs). High cost of implementation is always associated with LSSs coupled with high efforts. Consequently, assuring a successful large-scale software system implementation is not an easy job. We introduce "CSF-Live!" which is a new method for measuring critical success factors of large-scale software systems, e.g. ERPs. CSF-Live! allows for monitoring and controlling the implementation of large scale software systems based on continuous measurement. Our measurement model is based on the Goal/Question/Metric paradigm (GQM) which yields a flexible framework enabling the measurement of one or more of the critical success factors during a particular implementation. We present measurement formulas for three CSFs: data accuracy, top management support, and project management.

Key words: ERP, Critical Success Factors (CSF), Measurement, GQM, data accuracy, top management support, project management.

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1. INTRODUCTION

Many organizations replace their current information systems with large-scale software systems [1], which are fully integrated enterprise management systems covering functional areas of an enterprise such as logistics, production, finance, accounting and human resource. Such systems usually require huge and sophisticated hardware infrastructure such as servers, databases, large number of users and stakeholders, and huge volumes of data to be managed. An example of these large-scale systems is Enterprise Resource Planning systems (ERPs) such as SAP and Oracle [2] [3]. They are large and complex systems and presented a multiple levels of difficulties during implementations; it's been normal for organizations to face many obstacles during ERP implementation projects [4].

It has been observed that there are several factors that affect the success of implementing large-scale software system which have been known as Critical Success Factors (CSF) [4, 5, 6]. A well rounded definition of CSFs can be as in "Critical success factors are those few things that must go well to ensure success for a manager or an organization, and, therefore, they represent those managerial or enterprise area, that must be given special and continual attention to bring about high performance. CSFs include issues vital to an organization's current operating activities and to its future success." [7]

The aim of this research is to device a framework for measuring CSFs and to develop the necessary formulation for measuring and monitoring their effect during an implementation. Measurement allows for direct monitoring and, thus, controlling the progress of the project by preventing any derailment early on the project. Not only it is an important tool to support the decision making process in which projects can be monitored and controlled, but it can answer questions and identify the strengths and weaknesses of many aspect of the implementation. We apply the Goal/Question/Metric Paradigm (GQM) [8] as the basis of our measurement model.

This paper is organized as follows: in Section 2 we give a short a background about ERPs, critical success factors, and the Goal/Question/Metric Paradigm (GQM). CSF-live! Framework for measuring critical success factors is discussed in Section 3, where we present in sections 3.1 & 3.2 how to apply GQM and then the CSF-Live! method respectively. Section 4 presents a case study, and the conclusion is in section 5.

2. BACKGROUND

2.1. ERP's & CSFs

Large-scale software systems (LSS) are huge and difficult to deal with in all aspects of project management, requirement analysis, design, implementation, testing, and maintenance [1]. Each of these steps needs to be handled separately and differently by competent persons. Enterprise Resource Planning Systems (ERP) [4] is common examples of large-scale software systems. An ERP is a business management software that a company can use to collect, store, manage, and interpret data from many business activities including administrative, functional, financial management, procurement, and warehouses in companies and institutions, as shown in fig. 1.

Figure 1 ERP Modules [9]

Several studies and research discussed [4, 10, 11] the fact that many ERP implementations have failed or faced serious delays during implementations. Several problems and obstacles appeared in the performance of these tasks (described at the beginning of this section) within the ERPs [12]. It was observed that there were several factors that led to such outcomes, which is known today as Critical Success Factors (CSFs) of large-scale software systems [4].

More than 66 critical success factors have been reported [4], which were viewed to have an effect on ERP implementations. Further studies have consolidated the long CSF list to a minimum of only 18 factors as shown in Table 1.

Table 1 List of Consolidated Critical Success Factors [4]

Data accuracy	Testing	Vender Support
Top Management Support	Project Champion	Change Management
Project Management	Number of customizations	Consultants
Goals	Training	Business Process Re-Engineering
Implementation Team	Cost	Communication
IT Infrastructure	Package Selection	Maturity

While there has been some isolated attempts to measure or identify some aspects of ERP CSFs [14, 19, 20], there has not been a measurement framework to include all known critical success factors.

2.2. GQM

Our CSF measurement framework is based on the Goal/Question/Metric paradigm (GQM) measurement model [8]. GQM allows measurement of some goal, which maybe an object, according to the following 3-step approach:

- Identify (a) goal(s) to be achieved

The 1st step is at the conceptual level in which we define a goal for a particular object in a specific environment, using different quality models and for a variety of reasons from various points of view.

- Ask questions with respect how the goal can be achieved

The 2nd step is at the operational level in which we use of a set of questions to determine the goal of the project and determine the characteristics of the evaluation or accomplish a specific goal.

- Identify metrics

The 3rd step is at the quantitative level in which a set of metrics, based on the models, is associated with every question in order to answer it in a measurable way.

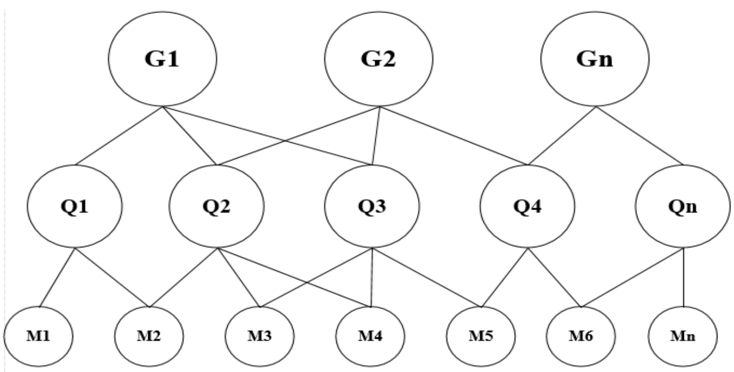

Figure 2 GQM Model Hierarchical Structure

Goals are at the top of a GQM model and they are explored and refined by asking many questions. Successful questions level will be in most cases a loop of questions for which answers eventually lead to measurable "metrics". A single metric maybe the answer for more than one question and thus can be used by more than one goal, as shown in fig. 2. In addition, a GQM model provides a set of templates for guiding the construction of goals and questions. It also provides advice on how to study the relation between metrics and reach a formulation.

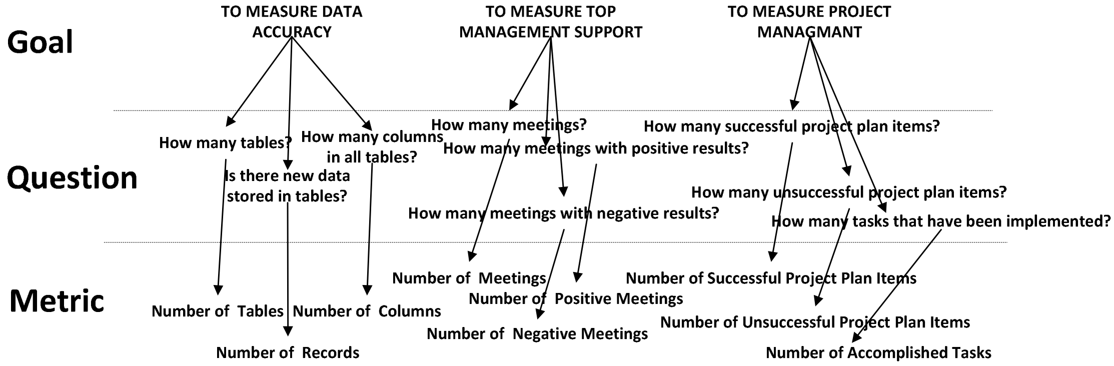

Figure 3 GQM Analysis for critical success factors

3. A FRAMEWORK FOR MEASURING CRITICAL SUCCESS FACTORS

A framework is a conceptual structure to support or guide for executing something that expands the structure to achieve the desired goal [16]. In this research, we devise a framework model for CSF measurement during ongoing implementation projects of large scale software systems. A continuous measurement of critical success factors during an implementation enables close tracking, monitoring, and controlling of factors that may hinder the implementation. In this paper, we show how to derive, apply, and use our proposed framework for CSF measurement based on the GQM paradigm on a selected subset of the eighteen CSF's as listed by a recent study [4]. Specifically, we focused on three CSF's,

1. data accuracy (DA),
2. Top Management Support (TMS), and
3. Project Management (PM).

While values for data accuracy (DA) are systematically collected by monitoring some database, TMS and PM present a different challenge since both are of subjective nature. Although we present a case study on the the three above CSFs, our framework is applicable for all eighteen CSF's.

3.1. Applying GQM

Measurement is the assignment of a number to an indicator of an object or some event, which can be compared with other objects or events and the scope and application of a measurement, is dependent on the context and discipline [18]. Goal/Question/Metric (GQM) approach is a measurement model that enables quantified assessment of goal achievement. In the succeeding section we show how to apply GQM paradigm on a selected subset of CSFs resulting in a set of metrics directly linked to specific CSF to enable monitoring and controlling capabilities.

We first created a list of goals based on GQM templates. Each goal represented a single CSF, such as data accuracy, etc., as shown in Table 2.

Table 2 GQM Goal for 3 Critical Success Factors

Critical Success Factor	GQM Goal
Data Accuracy	To analyze data accuracy for the purpose of evaluation with respect to data precision / data correction from the point view of project manager / project sponsor in the context of legacy software system.
Top Management Support	To analyze top management support for the purpose of evaluation with respect to successful project completion from the point view of project manager / project sponsor in the context of new large-scale software systems development.
Project Management	To analyze project management for the purpose of evaluation with respect to effectiveness from the point view of project sponsor in the context of new large-scale software systems development.

For each of the GQM goals above we conducted a GQM-sessions that were attended by expert matter who participated in generating questions and answering them leading to a set of metrics for each goal. fig. 3 shows a sample of GQM process we followed and the final metrics found are shown in Table 3.

Table 3 GQM Metrics for Critical Success Factors

Critical Success Factor	Metrics
Data Accuracy	Number of Tables Number of Records Number of Columns Size of DB Number of Empty Cells/Table Number of Lookup Tables Records Number of Empty Mandatory Fields Number of Duplicated Records Number of Batches
Top Management Support	Number of Meetings Number of Positive Meetings Number of Negative Meetings Number of Approved Top Management Support Requests Number of Rejected Top Management Support Requests Number of Change Requests by Business Owner (BO) Level of BO Satisfaction
Project	Number of Successful Project Plan Items (As Prepared By The PM)

Management	Number of Unsuccessful Project Plan Items (As Prepared By The PM) Number of Accomplished Tasks Number of Unaccomplished Tasks Number of Completed Features in the New System Number of Completed Milestones Number of Reports Number of Weekly Meetings With Project Team Members Degree of Communication Skills Number of Delay Days per Phase Budget Deficit Number of Solved Risks Number of Unsolved Risks

3.2. CSF-Live! Method

The CSF-Live! Method is a 6-step process, see fig. 4, that allow for measuring, tracking, monitoring, and controlling CSFs within a large-scale software system implementation, i.e. ERP implementation. By applying our CSF-Live! method one can *lively visualize* any CSF as a chart diagram at any point in time during implementation.

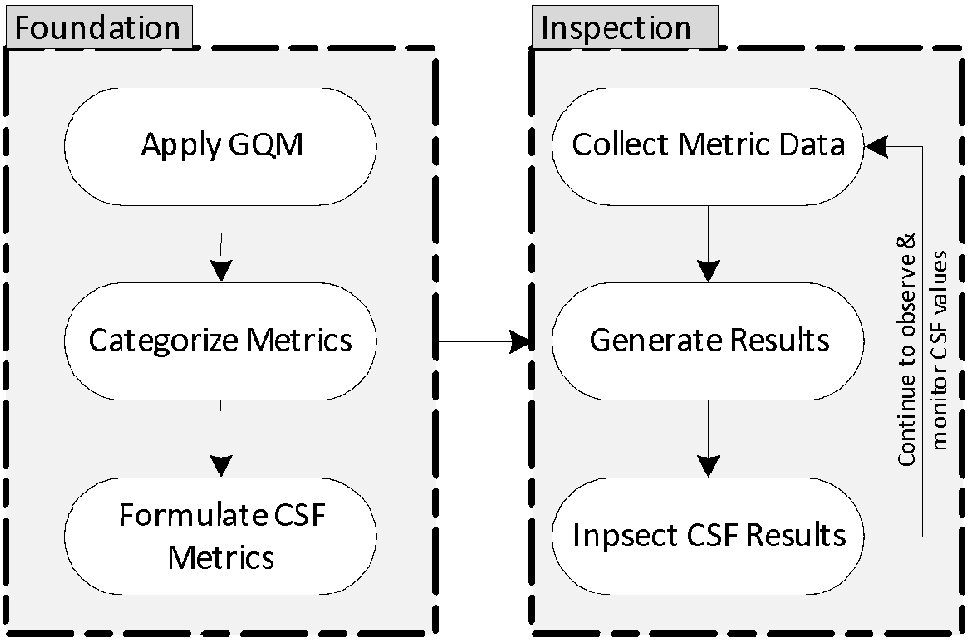

Figure 4 CSF-Live! Method

3.3. CSF-Live! Explained

The *foundation* part of CSF-Live! method is comprised of activities needed to establish the measurement scheme and formula for a CSF of choice. We give below a description of each activity.

3.3.1. Apply GQM

This activity includes the following steps and produces *a list of metrics*:

- Construction of a goal solely comprised of a single CSF (as shown in Table 2)
- Conduct a questioning session attended by group of experts in the subject matter.
- Identification of metrics that may be used to quantify the goal (as shown in Table 3)

3.3.2. Categorize Metrics

The result of the questioning session will be a collection of metrics. It has been the case that one or more of these metrics may combined together to present a stronger meaning to the data to be collected. As a result, during this step of the method two or more metrics are categorized and maybe consolidated. For instance, Meeting Quality Index (MQI) is driven from two metrics Number of Positive Meetings and Number of Negative Meetings. MQI is an essential part of the final top management support (TMS) formula.

3.3.3. Formulate CSF Metrics

During this activity careful analysis of each metric and its relation to other metrics is performed. For example, an increasing metric value during measurement of top management support (TMS) is associated with a positive meaning over the final TMS measurement. There some metrics, however, that may be associated with a negative value on the over the final values of the formula, e.g. Number of Change Requests Metric values are subtracted from the final TMS values because they represent negative values. After a complete metrics analysis and their interrelations they can be used to formulate the final CSF equation. We call this activity the *formulation step*. For example, after carefully analyzing the metrics for each CSF as shown in Table 3, we determined that formula for the critical success factor Data Accuracy (DA) can be given by:

$$DA = TCR + RCR + CCR + SCR + ECCR + LTRCR + EMFCR + DRCR + BCR \quad (1)$$

where

TCR:	Number of Tables Change Ratio,
RCR:	Number of Records Change Ratio,
CCR:	Number of Columns Change Ratio,
SCR:	Size of Database Change Ratio,
ECCR:	Number of Empty Cells Change Ratio,
LTRCR:	Number of Lookup Tables Records Change Ratio,
EMFCR:	Number of Empty Mandatory Fields Change Ratio,
DRCR:	Number of Duplicated Records Change Ratio,
BCR:	Number of Batches Change Ratio.

Data accuracy scores are bounded between the interval [0..9]. A data accuracy score of 9 (or close to 9) means that the data and/or its structure has been changed. On the other hand, a data accuracy score of 0 (or close to 0) means that no new (few) changes have made to the database. In summary, high DA scores signals low data accuracy levels. We suggest that adding new changes to a legacy system database is not a recommended practice and may lead to a decline in the total accuracy of the data. For each score that we got for the data accuracy we calculated the percentage of how much the data accuracy was changed.

The formula for the critical success factor Top Management Support (TMS) can be given by:

$$\mathbf{TMS = ADM + MQI + RAI + BOSI - CRI} \quad \mathbf{(2)}$$

where

ADM:	Average Daily Meetings,
MQI:	Meeting Quality Index,
RAI:	Request Approval Index,
BOSI:	BO Satisfaction Index,
CRI:	Change Requests Index.

TMS scores are bounded between the interval [0..10], where a score of 10 (or close to 10) means high top management support and a score of 0 (or closer to 0) means low support. Finally, the formula for the critical success factor project management (PM) can be given by:

$$\mathbf{PM = PCI + PAI + SFI + CMI + RI + WMI + CSI + RRI - PDI - BCI} \quad \mathbf{(3)}$$

where

PCI:	Project Completion Index,
PAI:	Project Accomplishment Index,
SFI:	System Features Index,
CMI:	Completed Milestones Index,
RI:	Report Index,
WMI:	Weekly Meetings Index,
CSI:	Communication Skills Index,
RRI:	Risk Resolution Index,
PDI:	Project Delay Index,
BCI:	Budget Deficit Index.

Both of (2) & (3) have been normalized [9], i.e. bounded, to map their minimum and maximum values to the interval [0..10] .

The second part of CSF-Live! method is *inspection*, in which activities are geared towards data collection and continuous monitoring & control. In the inspection part are listed below:

3.3.4. Collect Metric Data

During this activity, data for each of the metrics must be regularly collected and prepared for analysis. For example when calculating (2), Change Requests Index (CRI) is s the average daily number of change requests by BO since project initiation calculated as the cumulated average daily number of change requests by BO divided by number of weeks. Another example is the System Features Index (SFI), which is part of the (3). SFT is the average daily number of completed features in the new system since project initiation calculated as the cumulated average daily number of completed features in the new system divided by number of weeks.

3.3.5. Generate Results

In this activity, all metric data are substituted in the final CSF formula to produce a numeric value for each of the CSFs. Some metric data must be consolidated so that it can be used correctly in the final CSF formula as in the examples given in “Collect Metric Data” subsection.

3.3.6. Inspect CSF Results

Now that we have quantified values for the CSFs of interest, we inspect obtained CSF values and continue to “generate results” and then plot the values to inspect the chart of a particular CSF of interest on a specific period of time. For each CSF we should write recommendations based on current values and what expectations and/or precautions we may have on the progress of the implementation.

The inspection part of the method should be repeated periodically (e.g. every week) in order to continue observing and monitoring the CSF values during the implementation of the large scale software systems.

4. CASE STUDY

We applied the final formulation for each of the three critical success factors shown above, namely: data accuracy, top management support, and project management on three different datasets and examined the results. For data accuracy, we created a collection of scripts that monitored a live database of a human resource system (HR) at an enterprise level organization which maintain more than 10,000 employees. The database consisted of 130 tables from which our scripts collected 189 days' worth of data for each of the metrics that comprised (3).

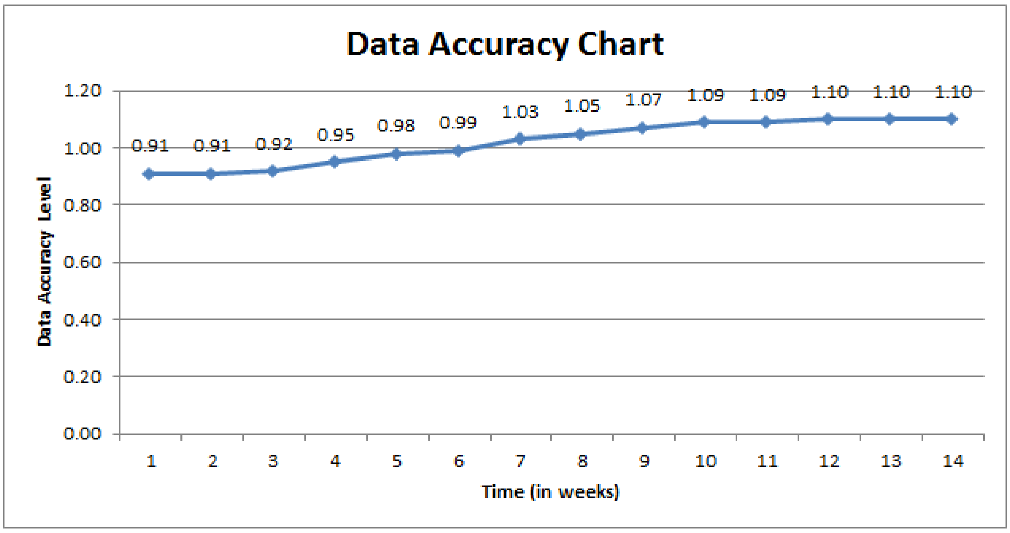

Figure 5 Chart of Data Accuracy Formula Scores.

Data accuracy is calculated in two weeks intervals and accumulated every two weeks until the 27th week. Based on the results of HR database, we notice that the Number of Batches Change Ratio has the highest influence on the performance of data accuracy while the Number of Duplicated Records Change Ratio, Number of Empty Mandatory Fields Change Ratio and Number of Empty Cells Change Ratio did not affect the performance of data accuracy in this legacy system. In addition, we notice that the data accuracy did not change in the first four weeks but after that increased in the next 20 weeks because of the increase in some values of the change ratio metrics. Also, the data accuracy did not change during the last 3 weeks as shown in fig. 5. The final DA score for this database was found:

Data Accuracy = 1.1

which indicates that after 27 weeks of data collection, data accuracy has declined by 12.22%

4.1. TMS

We were not as fortunate when collecting data for the top management support (TMS) formula as we didn't have access to a current ERP implementation. In addition, previous implementation wouldn't have produced suitable data for our formulas. Consequently, we resorted to hypothetical values that represented data for 11 weeks duration.

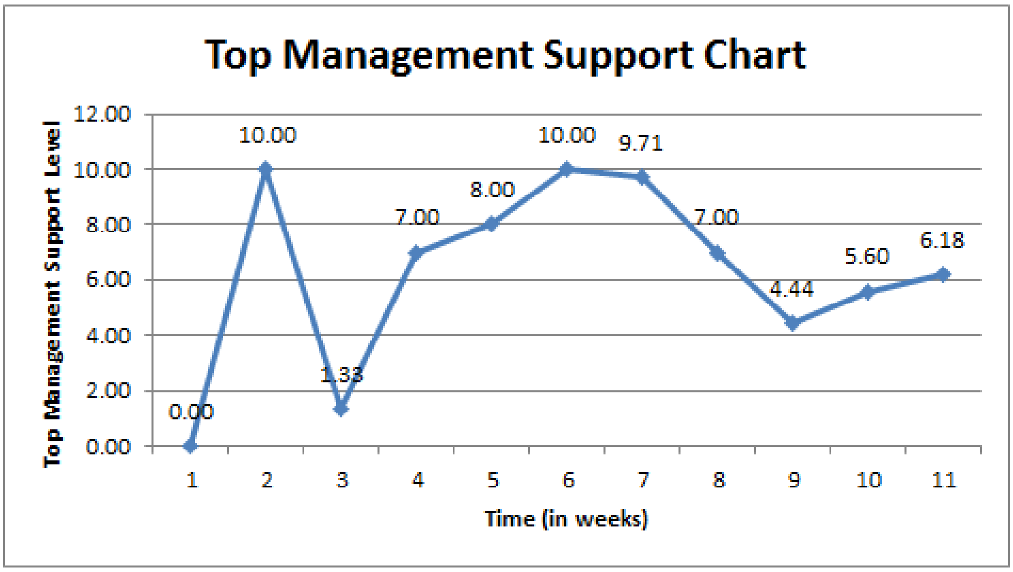

Figure 6 Chart of Top Management Support Formula Scores.

As shown in fig. 6, TMS was at its best at the 2nd and 6th weeks at which

Top Management Support (TMS) = 10,

scoring the best possible TMS value. On the other hand, the 1st, 3rd, and 9th weeks were the worst since TMS scores were 0, 1.33, and 4.44 respectively.

4.2. PM

Using assumed data for project management (PM) that represented 11 weeks. We measured the value of metrics in each week independently until the 11th week. It was noticed that the PCI, PAI,SFI and CSI have the highest influence on the performance of project management. PM formula results for the period of 11 weeks is shown in fig. 7, at which PM was at its lowest level during the beginning of the 2nd week and took a slightly better position at the end of the 3rd week. As shown in the fig., PM was at its best during the last two weeks, namely 10th and 11th week respectively.

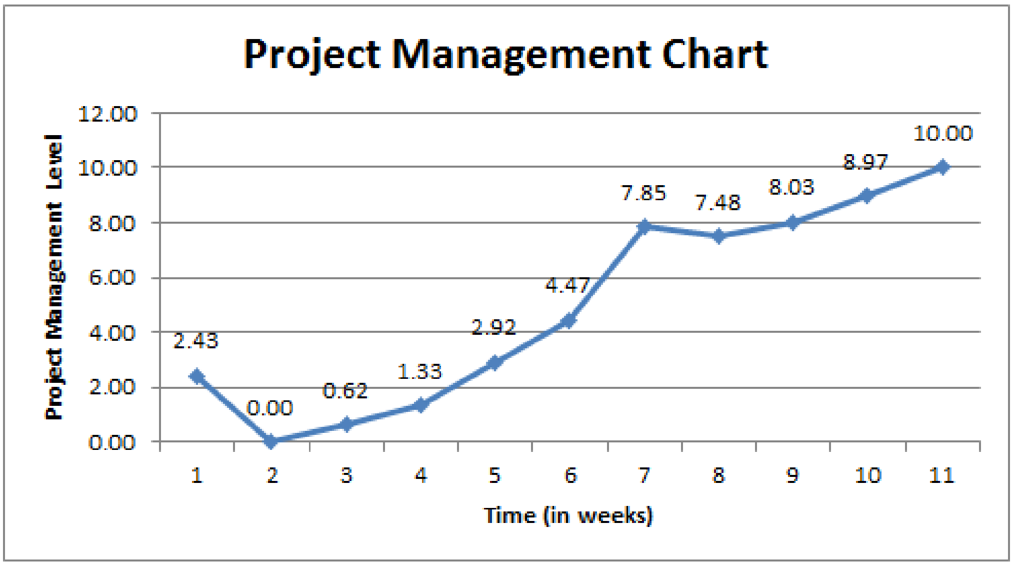

Figure 7 Chart of Project Management Formula Scores.

5. CONCLUSION

Large-scale software systems (LSS) are complicated because of its size, amounts of hardware, lines of source code, numbers of users, volumes of data, diversity of services and applications they provide. Several factors play role in achieving a successful LSS implementation which are known as the critical success factors (CSFs) of large-scale software systems. We introduced a framework for measuring these critical success factors and studied three CSFs and showed their impact on large-scale software system implementation (Data Accuracy, Top Management Support and Project Management). We introduced CSF-Live!, a new method for measuring and monitoring CSFs that may affect the implementation of large-scale software. Our method is based on a flexible framework that will enable measuring the rest of the 15 known CSFs and is based on the Goal/Question/Metric Paradigm (GQM). Finally, we generated formulas representing each of the three CSFs under study, collected data, and presented a case study that explores and explains the results.

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