

Establishing a Generic and Multidimensional Measurement Repository in CMMI context

Edgardo Palza, Christopher Fuhrman, Alain Abran

*École de Technologie Supérieure - ETS
1100 Notre-Dame Ouest, H3C 1K3 Montréal Québec, Canada*

edgardo.palza-vargas.1@ens.etsmtl.ca, christopher.fuhrman@etsmtl.ca, aabran@ele.etsmtl.

ABSTRACT

We propose a measurement repository for collecting, storing, analyzing and reporting measurement data based on the requirements of the Capability Maturity Model Integrated (CMMI). Our repository is generic, flexible and integrated, supporting a dynamic measurement system. It was originally designed to support Ericsson Research Canada's business information needs.

Our multidimensional repository can relate measurement information needs to CMMI processes and products requirements. The data model is based on a hierarchical and multidimensional definition of measurement data. It has been developed based on the concept of a data warehouse environment. Reporting features are based on the definition of queries to On Line Analytical Process (OLAP) cubes. OLAP cubes are created as materialized views of the measurement data, and the user functionalities are implemented as analytical drill-down/roll-up capabilities and as Indicator and Trend Analysis capabilities.

1. Introduction

Organizational performance measurement systems are designed and developed to improve understanding, planning and control of productivity, effectiveness, quality and timeliness of projects and products. They must be based on shared views of the organization and must include a *performance measurement repository* that organizes and stores historical measurement data to be used for trend analysis and monitoring, to improve both products and processes.

The CMMI establishes several requirements about process and product quantification. Establishing and maintaining an organization's measurement repository is referenced in the CMMI maturity level 2 (in Measurement and Analysis process area), established

as a specific practice and referenced in maturity level 3 (in Organizational Process Definition and Integrated Project Management for IPPD process areas), and is considered an essential element for establishing a quantitative understanding about the quality and process performance in maturity levels 4 and 5.

The Multidimensional Measurement Repository (MMR) tool is designed to facilitate the mapping of the information needs to the indicators proposed to satisfy those information needs. It contains both product and process measures that are related to the Organization's Set of Standard Process (OSSP), which contains the information of the processes that guide all activities in an organization.

Today, organizations are competing in complex and dynamic environments. Static measurement models are inadequate for estimation and performance management in dynamic and rapidly changing business environments. What is required is a system measurement model with a generic, flexible and integrated process to allow managers to handle continuously changing business conditions [1].

Frequent re-engineering of business units and product lines often renders obsolete a significant amount of critical historical data stored in predominantly static measurement systems. In today's ever changing technical and business environments, there is now a critical need for the re-design of measurement systems to give them the flexibility to be reconfigured continuously, while preserving the value of historical data initially organized along outdated organizational structures.

This paper reports on the design, development and implementation of generic and flexible Multidimensional Measurement Repository tool to support a dynamic measurement system with CMMI requirements in a changing and dynamic environment, such as that of Ericsson Research Canada.

The MMR tool was expected to meet further criteria and constraints for a better fit to the Ericsson context:

- Design of a coherent and consistent model of enterprise performance evaluation.
- An integrated and generic multidimensional measurement platform.
- Individual and team performance measures aligned with organizational goals.
- Ability to allow managers to extract value from the vast amounts of data and information in the organization.
- Improvements to the quality of the software engineering measures.

2. Measurement Repository and CMMI

It is obvious that in an environment of continuous improvement, the measurement of the software processes and products is essential. The commonsense rule of “what you cannot measure, you cannot manage” in a context of software process improvement will be understood like “what we cannot measure we cannot improve” [2].

In the CMMI context, measurement has a clearly defined purpose, which is expressed in specific goals (SG), generic goals (GG), specific practices (SP) and generic practices (GP) as well as in particular work products into given processes areas. Our intention in this paper is to present a tool to facilitate the establishment of the measurement collection, storage, analysis and reporting, according to CMMI specific goals and work products, in defined maturity levels.

In the next subsections we will show some comprehension about how MMR tool could facilitate the implementation of different CMMI maturity levels in an organization.

2.1 MMR tool and Maturity level 2

It is important to note that Measurement and Analysis (MA) is one of principal process areas that have direct impact of all process areas in the CMMI. The purpose of MA is directly related to information needs. The CMMI states that the purpose of MA is to develop and sustain a measurement capability that is used to support management information needs. It means that the measurement capability is expressed in terms of the support of information needs. The MMR tool was designed to help decision makers evaluate objectively the evolution of the products and processes related to defined information needs in software organizations and projects.

MA recommends storing project-specific data and results in a repository. The CMMI states that when the data of this repository is shared more widely across projects, the data may reside in the Organization’s Measurement Repository. This repository is used to make available data on processes and work products, particularly as they relate to the Organization’s Set of Standard Process (OSSP). The repository contains or references actual measurement data and relates information needed to understand and analyze the measurement data [3]. This is the principle that we adopted to develop our MMR tool: the capability of the repository to store different types of related measurement data in the context of an integrated environment.

The core of the MMR tool contains a database structure that does not presuppose any particular measures or relationship between them; the measures themselves are treated as data. We call this characteristic *metadata* -- data that represent measurement data of products and processes for different maturity levels in CMMI context.

The MMR tool is based on the definition of characteristics of MA process area. The MMR tool allows specifying and tracking measures based on base measures and derived measures. This is inspired by the Practical Software Measurement - PSM [2] and ISO 15939 [4]. The data collection and storage mechanisms are based on a database system. The data analysis and reporting indicators are based on Structured Query Language (SQL) and Online Analytical Process (OLAP) cubes.

The MMR tool was constructed, as ISO 15939 requires, following the principle that the Software measurement process is flexible, tailorable and adaptable to the needs of particular users.

In the CMMI, the MA SP 1.1 indicates that measures should be related to organizational needs and objectives. Measures should have a clear purpose and not be employed only to accumulate data. The data should answer the questions about processes and products.

The MMR tool is designed to facilitate the integration of the concepts of a Measurement Information Model and a Measurement Process Model. According to PSM [2] and ISO 15939 [4] a Measurement Information Model is a structure linking information needs to the relevant entities and attributes of concern. Entities include processes, products, projects and resources. The Measurement Information Model describes how the relevant attributes are quantified and converted to *indicators* that provide a basis for decision-making. Figure 1 illustrates the key relationships in the Measurement Information Model.

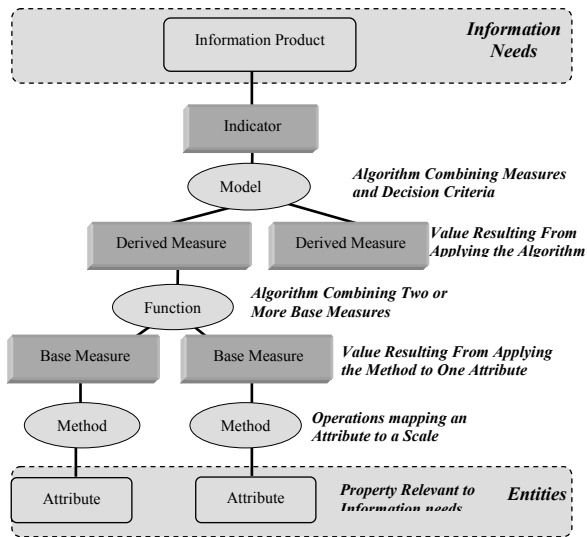


Figure 1. Measurement Information Model key concepts.

The MMR tool allows the collection and storage of measurement data directly related to the information needs of the project. The MMR tool set these measurement data in a flexible and tailorable hierarchy. This hierarchy is composed of an association's levels to facilitate the ever-changing information needs of the organization. The PSM states that a Measurement Process Model describes a set of related measurement activities that are generally applicable in all circumstances, regardless of the specific information needs of any particular situation. The MMR tool is composed of a set of Measurement Process activities that are inspired from Software Process Measurement Standard (ISO 15939) [4] and PSM [2].

The MMR tool only store base measures. Derived measures – those involving one or more measures and a computation process to calculate their value – will be handled by the Analytical Engine, that is, the OLAP services.

ISO 15939 standard explains that the Process Measurement consists of four iterative measurement activities: establish, perform and evaluate measurement and each activity is related to specific tasks that contribute towards achieving the purpose and outcomes of the software measurement process. This standard supports the management and improvement of software processes and products. It is important to note that our MMR tool facilitates the implementation of the software measurement of processes and products. In figure 2 we described how the MMR tool support different activities and tasks of the ISO 15939 standard.

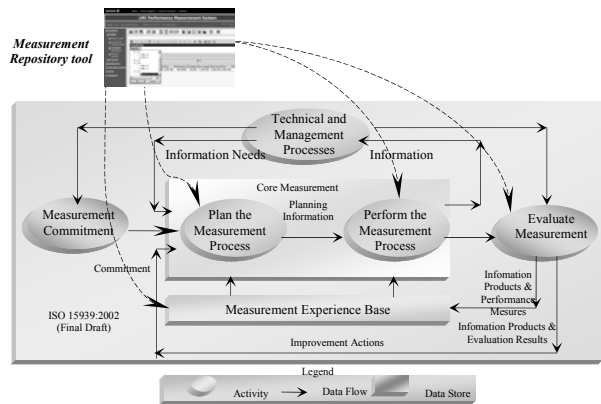


Figure 2. Mapping the MMR tool with ISO 15939

2.2 MMR tool and Maturity level 3

In Maturity level 3 of the CMMI, the implementation of a Measurement Repository is used to establish and maintain a usable set of organizational process assets (MA SP 1.4). The repository in this context contains product and process measures that are related to the OSSP. Additionally it contains or refers to the information needed to understand and interpret the measures and assess them for reasonableness or applicability.

An OSSP contains definitions of the processes that guide all activities in an organization. These process descriptions cover the fundamental process elements that must be incorporated into the defined processes that are implemented in projects across the organization. At this stage the MMR tool can be integrated across the organization and tailored to particular contexts in projects. Furthermore, it can facilitate the storing, retrieving and analyzing of measurements across the organization. Additionally the MMR tool provides measurement data about the typical work products, such a set of product and process for the OSSP, etc. The commonly used measurements provided by the MMR tool are as follows: estimations of effort and cost, peer review coverage, test coverage, number of defects found, severity of defects, etc.

One of the principal characteristics of the MMR tool is the flexibility to change the measure's definition and implementation, as the organization's needs change. This characteristic is cover by the definition of a *meta-model* structure of the measurement data. This property allows, for example, the addition and retirement of measures at any time without affecting the integrity of the measurement data. The MMR tool incorporates the capability of monitoring and

controlling the organizational processes against the plan for performing the processes, to allow decision makers to take the appropriate corrective action (MA GP 2.8). This characteristic is implemented in the MMR tool, for example, by measuring the process elements of the OSSP or by measuring the percentage of projects using the process architectures and process elements of the OSSP.

The MMR tool facilitates the institutionalization of the CMMI generic practice Collect Improvement Information (MA GP 3.2). The MMR tool allows the collection of measures, the measurements results and derived information (indicators) about the planning and executed processes.

The Integrated Project Management for IPPD process area of the CMMI establishes the use of a measurement repository for estimating and planning the projects activities (SP 1.2). The MMR tool allows using the historical measurement data for estimating the project's planning parameters, by finding similarities and differences between the current project and past projects, and then building custom indicators based on, for example, application domain, operational environment, experience of the people, etc. Of course it is possible to take measurements of effort by phase, effort by project, cost (actual vs. planned), schedule (actual vs. planned), staffing, etc.

2.3 MMR tool and Maturity level 4

Maturity level 4 is composed of two process areas: Organizational Process Performance and Quantitative Project Management. These process areas are strongly based on process measurements. In this stage the MMR tool has a capital role to success of the CMMI implementation.

Organizational Process Performance (OPP) process area establishes and maintains a quantitative understanding of the performance of the OSSP in support of the of quality and process-performance objectives, and provides the process performance data, baselines, and models to quantitatively manage the organization's projects [3].

The MMR tool collects measurement data from several projects and allows analyzing them to establish a process performance baseline for quality and process performance in the organization. The MMR tool facilitates the understanding of the divergence between the organization's performance and the performance required for an ever-changing market. The MMR tool can quantitatively determine the status of the processes; it can monitor and detect changes in the performance and then decision-makers can implement corrective actions as necessary. The MMR tool offers the option of establishing both process measurements (e.g.,

efforts, cycle time, defect removal effectiveness) and product measurements (e.g., reliability, defect density).

The purpose of Quantitative Project Management (QPM) PA is to quantitatively manage the project's defined process to achieve the project's established quality and process-performance objectives [3]. With the MMR tool we have the option, for instance, of measuring the performance of actual results achieved by following a process. It is possible to establish a minimum set of measures for processes and products in the organization. The MR tool offers the possibility of establishing estimations based on historical measurement data, as well as providing an understanding of the nature and extent of variation experienced in process performance. The MMR tool can measure quality attributes such as mean time between failures, number and severity of defects in the released product, number and severity of customer complaints concerning the provided service. Examples of measures in process performance that the MMR tool could implement are as follows: percentage of defect removed by product verification activities, percentage of rework time, and severity of defects by product. The MMR tool offers the possibility of exporting the data in different file formats for statistical analysis, if an more specific evaluation is required.

2.4 MMR tool and Maturity level 5

Maturity level 5 contains two process areas: Organizational Innovation and Deployment (OID) and Causal Analysis and Resolution (CAR). The purpose of the OID is to select and deploy incremental and innovative improvements that measurably improve the organization's process and technologies. The improvements support the organization's quality and process-performance objectives as derived from the organization's business objectives [3]. The MMR tool provides a quantitative understanding of organization's quality performance and facilitates, by the establishment of the pertinent measures, the estimation of the improvement in quality and process performance resulting from deploying the process and technology improvements. Examples of pertinent measurement are effectiveness of process activities, customer satisfaction, etc.

OID SG 2 states that measurable improvement to the organization's process and technologies are continually and systematically deployed. The MMR tool can help to establish measures to determine the value of each process and technology improvement with respect to the organization's quality and process-performance objectives. OID SP 2.3 seeks to measure the effects of the deployed process and technology improvements. The MMR tool facilitates the measures

of actual cost, effort, and schedule for deploying each process and technology improvement. Additionally, it is possibly establish a measure of the progress toward achieving the organization's quality and process-performance objectives.

The CAR process area seeks to identify causes of defects and other problems and take action to prevent them from occurring in the future [3]. A measurement process based on the MMR tool can be used for gathering relevant defect data, e.g., defects reported by the customer, defects found in peer reviews, defects found in testing, etc. In SP 2.2, Measures of performance and performance change are establishes as typical work products. The MMR tool can provide measures, for example, to relate to peer review before and after the improvement has been made.

3. MMR tool Design – Overview

To meet the constraints of a dynamic business environment, the MMR tool must have a generic database repository with a high level of flexibility. This requires then that the definitions of the measures, and of their and relationships, be stored in the repository in a metadata entity. The metadata are a level of abstraction of the measurements rather than the measurements themselves. The metadata entity can then provide the flexibility required by the ever-changing needs of the organization.

The set of relationships among entities are defined and stored as another entity in the repository to support both hierarchical and multidimensional views of data. This allows taking advantage of the OLAP (On Line Analytical Process) services such a drill-down/drill-up, for the measurements associated with a lower-/upper-level entity, and from an aggregated value to its atomic components. Analytic and drill-down facilitates provide the users with the possibility of making data analysis at different levels of granularity.

The OLAP services play an important role in the MMR tool. In particular, OLAP pulls together data from multiple sources in the organization and stores that data in a form convenient for further analysis and decisions support [5]. These services allow creating, querying and maintaining OLAP cubes, which are materialized views of the information. This is a way of pre-computing summaries of data, so that requests can be answered quickly [6].

To provide the multidimensional feature, the OLAP pivoting cubes approach was selected to dynamically display and rearrange multiple dimensions of data. To provide data collection, communication and diffusion of Performance Measurement, according to CMMI requirements (MA SP 2.4), a portal approach was selected for the Performance Measurement

Repository tool. The portal provides a dual perspective of overall corporate performance information and individual performance information [7].

Of course, a security mechanism according to a level of responsibility and authority (MA GP 2.4 AB 3) has to be designed and implemented in the MMR tool. This mechanism prevents unauthorized access to, accidental modification or destruction of data. It also provides audit mechanisms and for quality assurance purposes (MA GP 2.9 VE 1 and 2.10 VE 2).

3.1 Measurement collection

According to Measurement and Analysis Process Area of the CMMI (SP 1.3), the MMR tool design provides for two modes of collecting measurement data:

- **Automated** via an Extraction, Transformation and Loading (ETL) tool for high volume-high periodic measurements, such as those collected through the time reporting system or the trouble reporting system.
- **Manual** via a data-entry, web-based form, for low frequency-low volume data such as turnover rates and hourly rates.

3.2 Measurements indicators

The repository facilitates the mapping of the information needs of the organization to the indicators proposed to satisfy those Information Needs (MA SG 1 and SP 1.1 and 1.2), and [2, 4]. The business indicators initially proposed by Ericsson were as follows:

- **Effectiveness & Efficiency:**
Are we delivering the right products at the right time at the promised cost?
- **Financial:**
What is the cost of our operations? Are expenditures growing or declining? Are we meeting the goals of the efficiency program?
- **Quality:**
Are our products satisfying our customers? Does (the tool) provide support for TL 9000 certification? [8], [9]
- **Strategic goals:**
Can we monitor the specific goals set for the month/quarter/year?

4. Software Architecture

This section presents the architecture selected for the deployment of the functionalities of the MMR tool. See Figure 3.

The Indicators and Trending capabilities, for Management needs, present the information based on predefined reports and charts navigable in a web page style to facilitate the implementation of the Measurement and Analysis process area, SP 1.4 and 2.2. A home page will display the names of the different reports available using an indented structure from which it will be possible to jump into the selected report.

The Analytic and drill-down/drill-up capabilities are designed to support Middle Managers and Operations Development personnel with dynamic reports, Excel export capabilities and drill-down/drill-up functionality similar to that provided in on-line analytical applications.

The administration and quality control interface allows the person designated as administrator to define new measures, grant privileges and audit the quality and timeliness of the data entered into the system (MA SP 3.1).

The analytical engine (OLAP technology) provides the capability to compute derived measures and aggregate them across multiple dimensions. The Measurement Repository itself provides, of course, permanent storage for the measurements taken and the metadata necessary to administer them (MA SP 2.3).

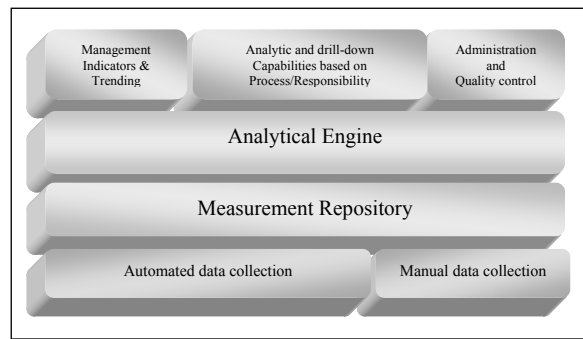


Figure 3. Performance Measurement System Architecture

The design of the data model for the MMR tool is, of course, critical. The design of the Repository tool incorporates an object-oriented measurement meta-model [10]. The object-oriented data model with all the class diagrams and associations for the Repository tool is illustrated in Figure 4 and Table 1. Table 1 presents a brief description of the entities involved in the object-oriented data model. Detailed information of all of the entities considered in the model are presented in [11].

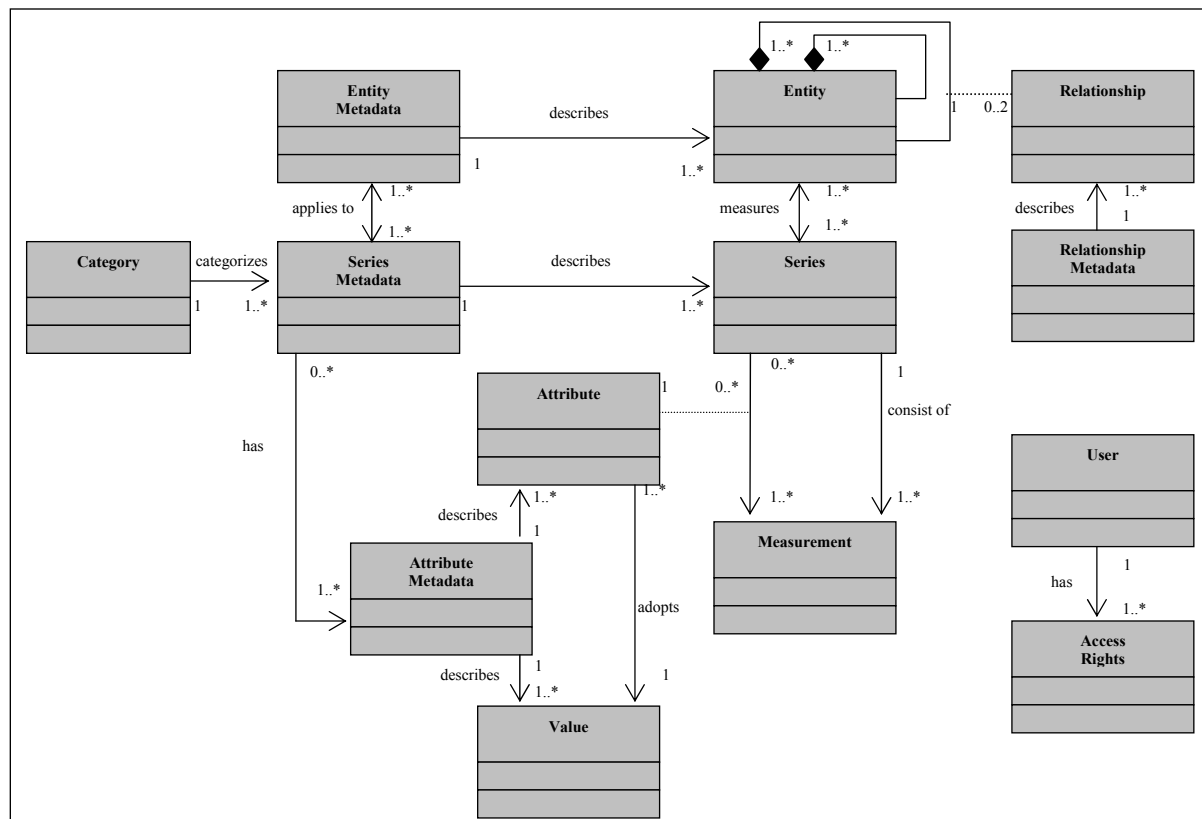


Figure 4. Depicts the entities and the relationships that conform the repository

Table 1. List of the Measurement classes

Class	Description
Entity Metadata	Instances of this class store all common data associated with a given entity type, i.e. Organization, Unit, Product, Project, Version.
Entity	Instances of this class Entity store all data associated with a specific Unit, Product, Project, or any other entity type defined by entity metadata.
Relationship	This associative class is used to model arbitrary relationships between two entities. The nature of the relationship is given by the relationship metadata.
Relationship Metadata	Instances of this class store the nature of the relationship.
Series	Instances of this class are a chronologically ordered collection of measurements representing the value of a measure over time.
Measures	This n:n relationship links a specific series to the objects or objects being measured by it.
Measurement	Each instance of this class captures the value of a measurement, as well as the date on which it was taken.
Series Metadata	This class describes the measures being captured by the series.
Attribute	This associative class qualifies the measurements according to different attributes. For example, of the 5 TR's (Trouble Reports) recorded on Oct. 7 2002, three could be of severity "A", one of severity "B" and another "C".
Attribute Metadata	This class describes the attributes that classify the measurement in a series.
Value	Instances of this class store the admissible values for a given attribute.
Category	Describes the categories, ex. Quality, Cost, which measures are categorized.
Applies To	The n:n relationship defines the applicable set of measures for each object type.
User	This class captures the user ids of those authorized to access the repository. Access to this table is restricted to the database administrator.
Access Rights	Indicates the specific object and relationship instances to which a given user has access and what he or she can do with them, i.e. Create, Change, Delete. Access to this table is restricted to the database administrator.

5. Prototype Construction and Experimentation

In this section we present relevant aspects of the MMR tool construction, such as analytic and drill-down capabilities for support decision makers, the construction of the management indicators-trends and the definition and administration of the Performance Repository Analytical Engine.

OLAP multidimensional capabilities are used to define several components of the MMR tool such as Entities, Entities Metadata, Aggregations, Series, Series Metadata, Measurement, Measures, Attributes, Categories, and Associations.

5.1 Repository software technology

We used the following Microsoft products for construction of the MMR tool:

- MS Windows 2000 Server
- MS SQL 2000 Server
- MS Analysis Services Enterprise Edition
- MS Internet Information Server
- ASP technology and Pivot Table Services (PTS)
- Intranet Share Portal Server (planned for the next phase)

5.2 Multidimensional data measures construction

The MMR tool consists of a collection of multidimensional data cubes (OLAP cubes). These data cubes contain the aggregation data on which multidimensional measurement analysis is based. Aggregations are pre-calculated summaries of measurement data that improve the efficiency and response time of user queries. The MMR tool is based on the concept of a star schema. The star schema represents a multidimensional model, which consists of

a central fact table and several dimension tables. The fact tables contain records that represent measures (facts) to be analyzed. Each fact table references multiple dimension tables, each one representing a dimension of interest, such as unit, project, product, etc. This is shown in the following figure:



Figure 5. Measurement fact table and associations

5.3 Measurement management & trends

OLAP technology provides graphical representation of multidimensional measures in the MMR tool. This is an important functionality to determine why certain trends or patterns are occurring. The next figure shows the visualization of cubes (Earn Value and Failures) in the MMR tool:

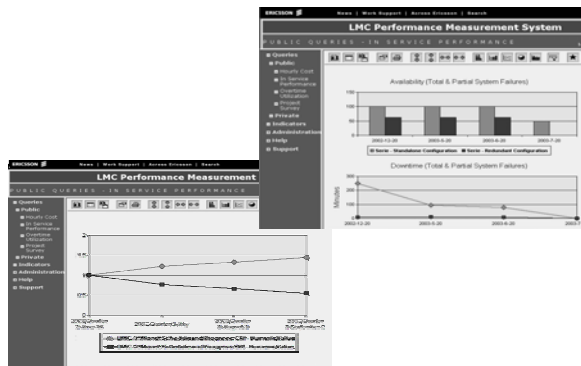


Figure 6. CPI/SPI chart and Downtime failures chart cubes

The user is able to invoke sequences of OLAP operations interactively by starting from a cube. Figure 7 shows the visualization facilities for a specific multidimensional measurement cube in the MMR tool:



Figure 7. Multidimensional cubes manipulation

5.4 Measurement data collection

Measurement data for the repository are collected principally in a manual way. We have developed a web interface for collecting data manually from managers in the Ericsson Intranet environment. Data are collected directly to OLAP dimension tables. In the next phase of the project, we plan to build an interface for collecting data from client/server databases and legacy systems.

5.5 Measurement Indicators

The MMR tool incorporates the possibility to establish indicators based on hierarchical measurement data stored in the in the meta-model database system. The tool is designed to accept a customized definition of the parameters, e.g., the definition of trigger alerts if a maximum value is reached. The following figure shows the application module for defining the configuration parameters for the indicators.

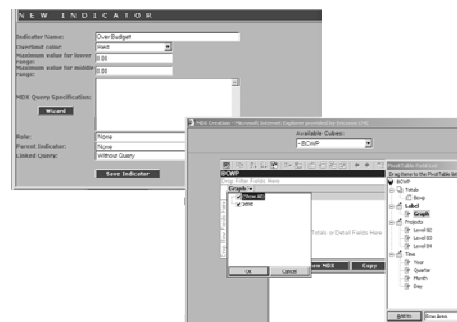


Figure 8. Measurement Indicators

5.6 Measurement Diffusion – The Portal

The MMR tool allows decision-makers to identify, prioritize, track, and communicate objectives and to associate issues at all levels within the organization. Figure 9 illustrates the components interaction between the Performance Measurement Repository and the Portal Server. The Portal Server is a facility to be implanted in the next phase of the project.

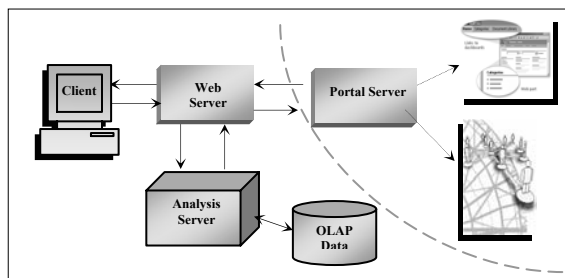


Figure 9. Repository Measurement and Portal Server

Conclusion

In this paper we have presented our approach for designing and developing an integrated, generic, flexible, Multidimensional Measurement Repository tool, which facilitates the implementation of CMMI in an organization. The MMR tool is based on a multidimensional measurement and meta-model concept. This object-oriented model is an abstraction of measurement and organizational structure relationships, which is the source of its flexibility. It is inspired by the Practical Software Measurement (PSM) methodology and the Software Measurement Process (ISO 15939), which are also the basis for many aspects of the CMMI.

We have built the MMR tool prototype in a Microsoft environment. Despite the ease of use and rapid deployment of many Microsoft technologies, our development team had never used many of these technologies and considerable effort was required to understand their use.

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