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ARTÍCULOS

FACILITATING MEASUREMENT INDICATORS IN SOFTWARE IMPROVEMENTS PROJECTS

FACILITANDO LA CREACIÓN DE INDICADORES (MÉTRICAS) EN PROYECTOS DE MEJORAMIENTO DE SOFTWARE

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ABSTRACT

This paper reports on the design and development of a Measurement Metamodel to facilitate the Implementation and Monitoring of Software Improvement initiatives.

The Indicators provided for the Measurement Metamodel are building on a Data Warehouse environment. The Measurement Metamodel is designed based on the International Standard ISO 15939 – Software Measurement Process [1].

The Measurement Metamodel supports Practical Software Measurement (PSM) [2] approach and Capability Maturity Model Integrated (CMMI) [3] implementations. The Measurement Metamodel is based on the principle that Software measurement process must be flexible and tailorable to the particular information needs of decision makers.

Keywords: Metamodel, Indicators, CMMI, Measurement, Software.

RESUMEN

Este artículo presenta el diseño y desarrollo de un Metamodelo de Métricas que facilita la implementación y monitoreo de una iniciativa de Mejoramiento del Software en las Organizaciones.

Los Indicadores proporcionados por el Metamodelo de Métricas están construidos en un ambiente Datawarehouse. El Metamodelo de Métricas está definido según el estándar ISO 15939 – Procesos de Métricas del Software [1].

El Metamodelo de Métricas soporta la implementación del enfoque «Practical Software Measurement» (PSM) [2] y del modelo «Capability Maturity Model Integrated» (CMMI) [3]. El referido Metamodelo de Métricas está basado en el principio de que los procesos de métricas del Software deben ser flexibles y adaptables a las particulares necesidades de información de los responsables de tomar las decisiones.

Palabras clave: Metamodelo, Indicadores, CMMI, Métricas, Software.

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1. INTRODUCTION

Organizational performance measurement systems are designed and developed to improve understanding, planning, control of effectiveness, quality and timeliness of projects and products.

They must be based on shared views of the organization and must include a *performance measurement database* that organizes and stores historical measurement data to be used for trend analysis and monitoring, to improve both products and processes.

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, while preserving the value of historical data initially organized along outdated organizational structures [4].

The Measurement Metamodel (MM) 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.

The MM is designed to facilitate the mapping of the information needs to the indicators proposed to satisfy those information needs according to ISO 15939 (Software Measurement Process) Standard and PSM (Practical Software Measurement) approach. The MM contains both product and process measures that are related to the CMMI (The Capability Maturity Model Integration[SM]).

2. THE CMMI

The CMMI is a model that intended to provide guidance for improving the organization's processes and their ability to manage the development, acquisition, and maintenance of products and services. CMMI places proven practices into a structure that helps organizations assess their organizational maturity and process area capability, establish priorities for improvement, and guide the implementation of these improvements.

The CMMI is best known for its five levels of organizational maturity (see figure 1). Each level represents a set of best practices organizations are expected to implement as they become better at what they do.

Maturity Level	Process Areas
5 OPTIMIZING	• Organizational Innovation and Deployment • Causal Analysis and Resolution
4 QUANTITATIVELY MANAGED	• Organizational Process Performance • Quantitative Project Management
3 DEFINED	• Requirements Development • Technical Solution • Product Integration • Verification • Validation • Organizational Process Focus • Organizational Process Definition • Organizational Training • Integrated Project Management for IPPD • Risk Management • Integrated Teaming • Integrated Supplier Management • Decision Analysis and Resolution • Organizational Environment for Integration
2 MANAGED	• Requirements Management • Project Planning • Project Monitoring and Control • Supplier Agreement Management • Measurement and Analysis • Process and Product Quality Assurance • Configuration Management
INITIAL	

Figure 1. The Capability Maturity Model Integrated (CMMI).

The CMMI also include, as illustrated in figure 2, process areas (PA), specific goals (SG), generics goals (GG), specific practices (SP), generic practices (GP) as well as in particular work products into given processes areas.

3. ISO 15939

ISO 15939 is a standard for a Software Measurement Process. It standard explains that the Process Measurement consists of four iterative measurement activities: establish, plan, perform and evaluate measurement (see figure 3) 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.

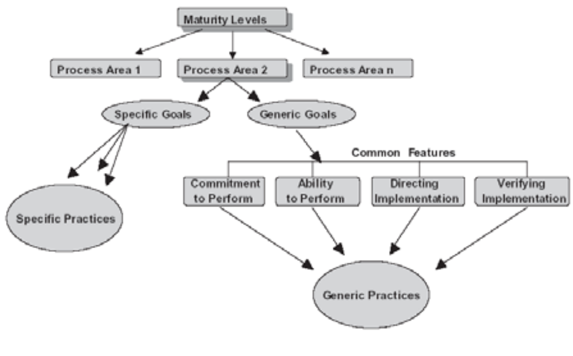

Figure 2. CMMI Model Components (Staged Representation).

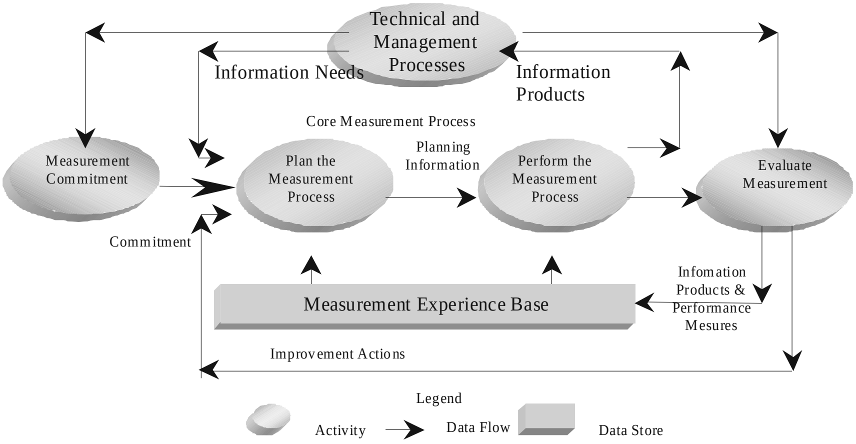

Figure 3. The ISO 15939 Standard.

4. MEASUREMENT METAMODEL AND ISO 15939

The MM is designed to facilitate the integration of the concepts of a Measurement Information Model and a Measurement Process Model. According to PSM and ISO 15939 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 4 illustrates the key relationships in the Measurement Information Model.

The MM allows the collection and storage of measurement data directly related to the information needs of the project. The MM 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 MM 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.

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].

5. THE MM AND CMMI

In the CMMI context, measurement has a clearly defined purpose, which is expressed in different components as exposed in figure 2. Our intention here is to present how the Measurement Metamodel could facilitate the establishment of the measurement

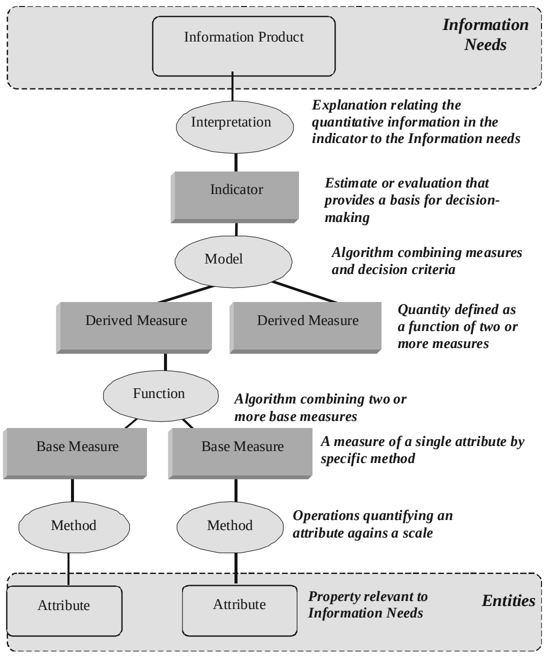

Figure 4. Measurement Information Model key concepts.

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 MM could facilitate the implementation of different CMMI maturity levels in an organization.

5.1. The MM 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 MM 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 database. 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 Database. 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 OSSP contains the information of the processes that guide all activities in an organization.

The Metamodel 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 MM: the capability to store different types of related measurement data in the context of an integrated environment.

The core of the MM 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.

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.

5.2. The MM and Maturity level 3

In Maturity level 3 of the CMMI, the implementation of a Measurement Repository Database is used to establish and maintain a usable set of organizational process assets (MA SP 1.4). The MM 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 MM 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 MM database 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 MM 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 MM 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 (see figure 5). This property allows, for example, the addition and retirement of measures at any time without affecting the integrity of the measurement data. The MM 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 MM, 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 MM facilitates the institutionalization of the CMMI generic practice Collect Improvement Information (MA GP 3.2). The MM 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 database for estimating and planning the projects activities (SP 1.2). The MM 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.

5.3. The MM 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 MM database 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 MM 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 MM facilitates the understanding of the divergence between the organization's performance and the performance required for an ever-changing market. The MM 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 MM 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 MM 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 MM 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 MM could implement are as follows: percentage of defect removed by product verification activities, percentage of rework time, and severity of defects by product. The MM offers the possibility of exporting the data in different file formats for statistical analysis, if an more specific evaluation is required.

5.4. The MM 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 MM 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 MM can contribute to establish measures to determining the value of each process and technology improvement with respect to the organization's quality and process-performance objectives. OID SP 2.3 refers to measure the effects of the deployed process and technology improvements. MM facilitate 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.

CAR process area refers 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 MM can be used for gather relevant defect data, for example: defects reported by 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. MM can provide measures, for example, to relate to peer review before and after the improvement has been made.

6. MM DESIGN – OVERVIEW

To meet the constraints of a dynamic business environment, the MM 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 MM. 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 is proposed for the Performance Measurement Repository Database.

The MM facilitates the mapping of the information needs of the organization to the indicators proposed to satisfy those Information Needs (MA SG 1, SP 1.1 and 1.2), and [1, 2].

7. SOFTWARE ARCHITECTURE

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

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.

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 MM itself provides, of course, permanent storage for the measurements taken and the metadata necessary to administer them (MA SP 2.3).

The design of the data model for the MM is, of course, critical. The design incorporates an object-oriented measurement meta-model [7]. The object-oriented data model with all the class diagrams and associations for the MM is illustrated in Figure 5 and Table 1. Table 1 presents a brief description of the entities involved in the object-oriented data model.

8. PROTOTYPE CONSTRUCTION AND EXPERIMENTATION

In this section we present relevant aspects of the MM prototype, 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 MM such as Entities, Entities Metadata, Aggregations, Series, Series Metadata, Measurement, Measures, Attributes, Categories, and Associations.

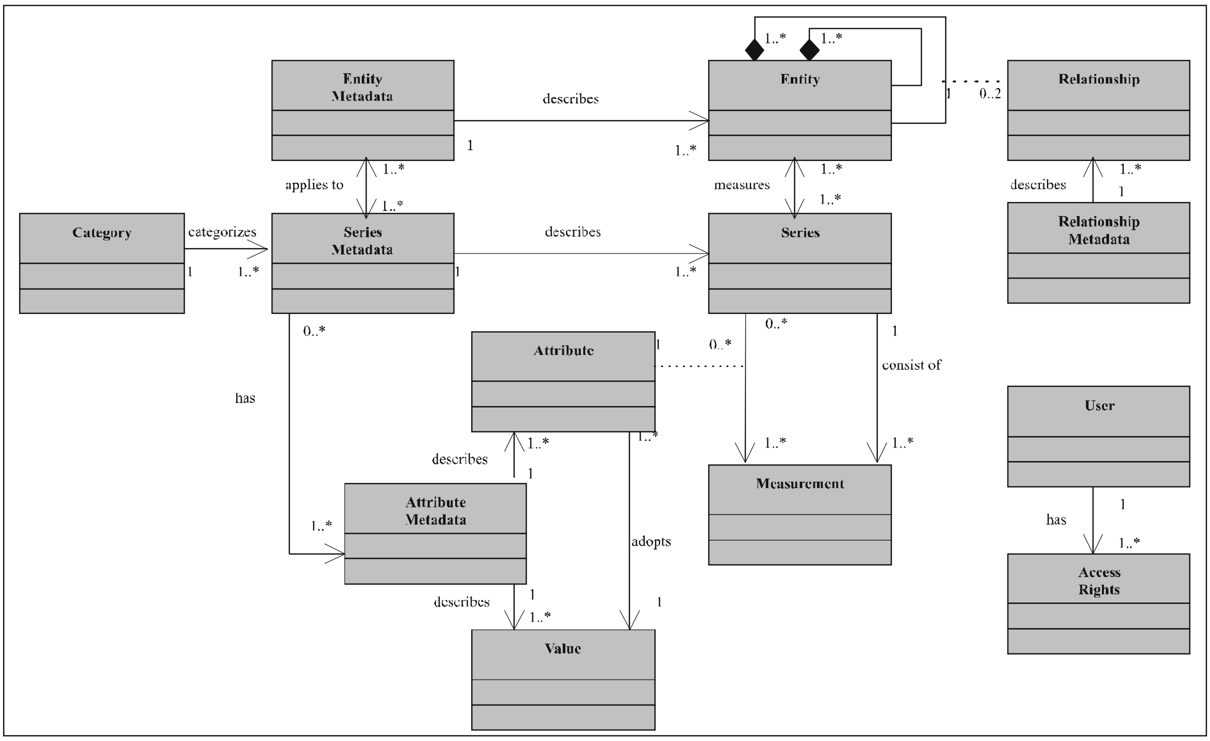

Figure 5. Depicts the entities and the relationships that conform the Measurement Metamodel.

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	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.

8.1. Repository software technology

We used the following Microsoft products for construction of the MM prototype:

- MS Windows 2000 Server
- MS SQL 2000 Server
- MS Analysis Services Enterprise Edition
- MS Internet Information Server
- ASP technology and Pivot Table Services (PTS)

8.2. Data measures construction

The MM 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 MM 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 6.

8.3. Measurement management & trends

OLAP technology provides graphical representation of multidimensional measures in the MM. 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 MM:

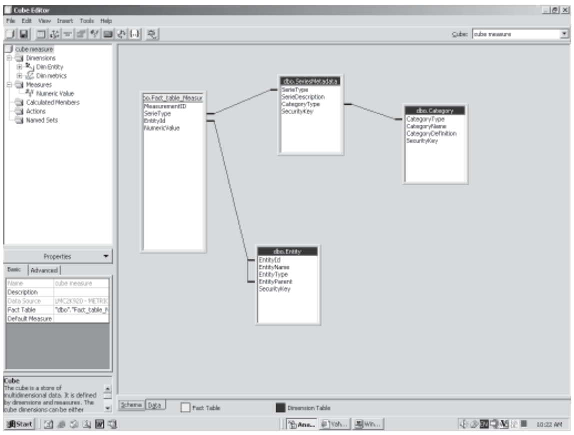

Figure 6. Measurement fact table and associations.

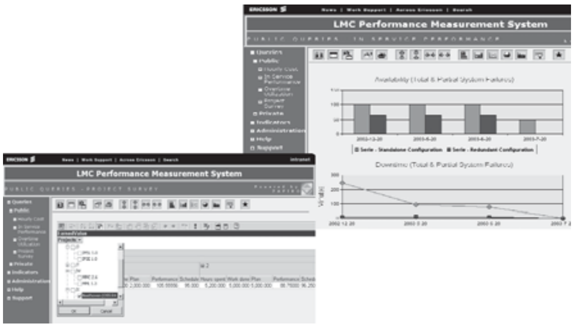

Figure 7. CPI/SPI chart and Downtime failures chart cubes.

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 MM.

8.4. 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.

8.5. Measurement Indicators

The MM 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.

Conclusion

In this paper we have presented our approach for designing and developing an integrated, generic, flexible, Multidimensional Measurement Database, which facilitates the implementation of CMMI in an organization. The MM 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.

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