BUSINESS PROCESS WAREHOUSE FOR MANUFACTURING COLLABORATION

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Abstract: One of important changes in manufacturing industry is that competition among individual companies has been extended to competition among the manufacturing networks surrounding the companies. Most manufacturing companies participate in various forms of collaboration to enhance competitive advantages in their arenas. In this paper, we introduce a data warehouse system that is designed for a manufacturing collaboration support system, named i-manufacturing. Just as enterprise information systems, the collaboration system also needs the functions for performance measurement and monitoring. For that reason, we propose a new approach to measuring and evaluating collaborative performance of manufacturing collaboration. Specifically, we first present a methodology of measuring collaborative performance of manufacturing collaboration. We next design a data schema of business process warehouse to store data of performance indicators and monitor collaboration performance from the indicators. Finally, we implement a prototype system of business process warehouse to implement the collaborative performance management and monitoring. The proposed methodology of monitoring and analyzing collaborative performance of manufacturing collaboration can contribute to effectively maintaining and continuously improving collaboration in manufacturing industry.

Keywords: Manufacturing Collaboration, Business Process Management, Data Warehouse, On-Line Analytical Processing (OLAP), Performance Measurement

1. Introduction

Recently, as the competition among companies has been extended from competition among individual companies to competition among the manufacturing networks surrounding the companies such as a value chain, there has surfaced a form of virtual enterprises based on collaborative networks [1]. Most manufacturing companies participate in various types of collaboration to enhance competitive advantages in their arenas. Comparative advantage of a manufacturing company is significantly influenced by its performance in collaboration in the virtual enterprise network such as a value chain [2].

For this reason, an effective methodology of measuring and analyzing the performance of manufacturing collaboration needs to be developed [3]. This can enable manufacturing collaboration to manage and enhance relationships among all participants as well as improve the performance of individual companies in order to gain competitive advantages such as efficiency, quality, innovation and customer responsiveness [4]. To support efficient collaboration, novel collaboration information systems are also needed to provide functions for effective performance measurement and monitoring.

In this paper, we introduce a data warehouse system which is designed and implemented in an information system, named i-manufacturing, to support manufacturing collaboration [5]. The i-manufacturing project aims at developing a manufacturing collaboration system to support the collaboration network for manufacturing partners from product planning and development, design, purchase, production, and services. Just as enterprise information systems, the collaboration support system needs to be equipped with performance measurement and monitoring functions. To meet this requirement, we present a new approach to measuring and evaluating collaborative performance of manufacturing collaboration.

We first develop a methodology for measuring collaborative performance. The main components of the methodology are collaborative critical success factors and collaborative key performance indicators (cKPI). Next, we design a data schema of business process warehouse in order to store data of indicators and monitor
collaboration performance based on the indicators. Finally, we implement a prototype of business process warehouse to develop collaborative performance management and monitoring based on the proposed methodology. As an illustrative example, we consider an engineering design change process to collect manufacturing collaboration performance data. Business process cKPI data is then stored in a database from which data of interest is extracted using the process warehouse. This cKPI monitoring system is implemented using pivot tables and dashboard which are supported by On-Line Analytical Processing (OLAP) systems.

The proposed methodology for monitoring and analyzing collaborative performance can contribute to effectively maintaining and continuously improving the collaboration in the manufacturing industry.

2. Related Work

Lee et al. [6] develop indicators to measure collaboration performance of multiple manufacturing partners on the basis of the supply chain operations reference (SCOR) model. The partners who participate in collaboration can agree on cKPI, when first beginning the collaboration. Also, a modified sigmoid function is proposed as a desirability function to reflect characteristics of service level agreement (SLA) which is determined in a contract between partners. The performance indicators and the desirability function can provide a way to measuring collaborative performance quantitatively. They derive cKPIs for manufacturing collaboration processes from supply chain metrics of Level 2 in SCOR model.

Chowdhary et al. [7] present a model-driven data warehousing (MDDW) approach in the area of business performance management. The purpose of MDDW is to bridge the gap between the business process models and the data warehouse models, thus enabling rapid adaptation to changes in the business environment. They suggest a modeling framework comprising of the various modeling elements and meta-models that capture both business and IT data artifacts.

3. Business Process Warehouse

In this section, we present design aspects of the business process warehouse for manufacturing collaboration. Fig. 1 shows the framework of business process warehouse. The main components of the business process warehouse include a BPM system, a business warehouse, an OLAP server, and a performance dashboard. A BPM system, which is composed of BP models, a BPM engine, and a work item handler, provides work environments based on BP models. The data which is gathered from the BPM system are stored in a data warehouse. A data warehouse plays a role in a repository which stores star schema to analyze multi-dimensional data and provides analytic data for business managers and analyzers. From this data warehouse, specialized data can then be extracted using cube and multi-dimensional expressions (MDX) in OLAP server. A dashboard displays performance data of business process execution.

3.1. Example of Manufacturing Collaboration

More often than not, manufacturing collaboration plays a crucial role in an engineering design change process which involves multiple manufacturing enterprises. Fig. 2 shows a typical engineering design change process represented with business process modeling notations (BPMN) which includes two participants: a leading company ordering a part and a supplier manufacturing the part. The process shown in Fig. 2 describes activities such as an engineering design change request by a leading company and a review for the request by a supplier on an automobile component. Table 1 illustrates an example of cKPIs and their corresponding calculation methods.
Table 1. Example of cKPIs and their calculation methods

<table>
<thead>
<tr>
<th>cKPI</th>
<th>Definition</th>
<th>Calculation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part engineering design change cycle time</td>
<td>Total lead time or part engineering design change in collaboration</td>
<td>(design change cycle time of leading company) + (design change cycle time of part company) + (design change cycle time of mold company)</td>
</tr>
<tr>
<td>Numbers of engineering design change request</td>
<td>Total number of requests for engineering design changes due to design errors or omissions</td>
<td>(# of design change requests due to additional requests) + (# of design change requests due to part design errors) + (# of design change requests due to mold design errors)</td>
</tr>
<tr>
<td>Rate of engineering change request approval</td>
<td>Rate of approval for engineering design change requests</td>
<td>(# of design change approvals) / (# of design change requests of part company) + (# of design change requests of mold company)</td>
</tr>
<tr>
<td>Loss cost by engineering design change</td>
<td>Part company’s fulfillment rate by due date pursuant to leading company’s order</td>
<td>(loss cost by design change of leading company) + (loss cost by design change of part company) + (loss cost by design change of mold company)</td>
</tr>
</tbody>
</table>

3.2. Star Schema Design

For the purpose of extracting specific data of interest about a business process, we design a star schema using Fig. 3 shows a part of star schema for a business warehouse. The star schema consists of two types of
tables: dimension and fact. First, four dimensions, product, organization, partner, and time, are proposed for the system design. Product_dim with a unique part number contains data on a part, sub assembly, processing, basic model, model, and cad_sw. Org_dim contains data on gender and experience distinguished by a unique employee identification number. Partner_dim with a unique partner code contains data on partner_name and country. Time_dim with a date code stores day, week, month, quarter, and year. Second, the only fact table, Design_change_fact, includes data which stores review time, execution time, reflection time, cycle time, num of custadd, num of customer, num of supppr by pi_id, part_no, emp_id, partner_code and date.

**Fig 3. Star schema for business process warehouse**

### 3.3. Cube Design
To implement the star schema design described in section 3.2, we design a cube which extracts specialized data in a data warehouse. A cube supports extraction, measuring of data using extensible markup language (XML) and storing such data in OLAP server. Fig. 4 shows the cube code for a business process warehouse. A cube corresponds to specialized data and its occurrence data by number. A cube collects dimension data such as product_dim, org_dim, partner_dim, and time_dim and calculates average measures of design change fact data.

```xml
<?xml version="1.0"?>
<Schema name="bpw_dashboard1.xml">
  <Dimension name="Product">
    <Hierarchy hasAll="true" allMemberName="All Products" primaryKey="PART_NO">
      <Table name="PRODUCT_DIM"/>
      <Level name="part" column="PART" uniqueMembers="true"/>
      <Level name="subassy" column="SUBASSY" uniqueMembers="true"/>
      <Level name="processing" column="PROCESSING" uniqueMembers="true"/>
      <Level name="basicmodel" column="BASICMODEL" uniqueMembers="true"/>
      <Level name="model" column="MODEL" uniqueMembers="true"/>
      <Level name="cad_sw" column="CAD_SW" uniqueMembers="true"/>
    </Hierarchy>
  </Dimension>
  <Dimension name="Employee">
    <Hierarchy hasAll="true" allMemberName="All Employees" primaryKey="EMP_ID">
      <Table name="ORG_DIM"/>
      <Level name="gender" column="GENDER" uniqueMembers="true"/>
      <Level name="experience" column="EXPERIENCE" uniqueMembers="true"/>
    </Hierarchy>
  </Dimension>
  <Dimension name="Partner">
    <Hierarchy hasAll="true" allMemberName="All Partners" primaryKey="PARTNER_CODE">
      <Table name="PARTNER_DIM"/>
      <Level name="partner name" column="PARTNER_NAME" uniqueMembers="true"/>
      <Level name="country" column="COUNTRY" uniqueMembers="true"/>
    </Hierarchy>
  </Dimension>
  <Dimension name="Time">
    <Hierarchy hasAll="true" allMemberName="All Times" primaryKey="DATE">
      <Table name="TIME_DIM"/>
      <Level name="Day" column="DAY" uniqueMembers="true"/>
      <Level name="Week" column="WEEK" uniqueMembers="true"/>
      <Level name="Month" column="MONTH" uniqueMembers="true"/>
      <Level name="Quarter" column="QUARTER" uniqueMembers="true"/>
      <Level name="Year" column="YEAR" uniqueMembers="true"/>
    </Hierarchy>
  </Dimension>
  <Cube name="Performance">
    <Table name="DESIGN_CHANGE_FACT"/>
    <DimensionUsage name="Product" source="Product" foreignKey="PART_NO"/>
    <DimensionUsage name="Employee" source="Employee" foreignKey="EMP_ID"/>
    <DimensionUsage name="Partner" source="Partner" foreignKey="PARTNER_CODE"/>
    <DimensionUsage name="Time" source="Time" foreignKey="DATE"/>
    <Measure name="Cycle Time" column="CYCLETIME" aggregator="avg" formatString="#,###.##"/>
    <Measure name="Num Of Change Request" column="NUM_OF_CHANGEREQ" aggregator="avg" formatString="#,###.##"/>
    <Measure name="Accept Rate" column="ACCEPT_RATE" aggregator="avg" formatString="#,###.##"/>
    <Measure name="Total Cost" column="TOTAL_COST" aggregator="avg" formatString="#,###.##"/>
    <Measure name="Deadline Hit" column="DEADLINE_HIT" aggregator="avg" formatString="#,###.##"/>
  </Cube>
</Schema>
```

**Fig 4. Cube code for business process warehouse**
3.4. MDX Design

To implement the cube design described in section 3.3, we design MDX which extracts specialized data for dashboard development using java server pages (JSP). Fig. 4 shows a part of MDX code for the business process warehouse. MDX extracts dimension data and measurement data using a data query technique similar to structural query languages (SQL).

```xml
<jp:mondrianQuery id="query01" jdbcDriver="org.hsqldb.jdbcDriver" jdbcUrl="jdbc:hsqldb:hsql://localhost/" jdbcUser="sa" jdbcPassword="" catalogUri="/WEB-INF/queries/bpw_dashboard.xml">
  select {[Measures].[Cycle Time], [Measures].[Num Of Change Request], [Measures].[Accept Rate], [Measures].[Total Cost], [Measures].[Deadline Hit]} ON columns,
  Hierarchize ([(Product].[All Products], [Employee].[All Employees], [Partner].[All Partners], [Time].[All Times])) ON rows
  from [Performance]
</jp:mondrianQuery>
```

Fig 5. MDX code for business process warehouse

4. Prototype System of Business Process Warehouse

4.1. Prototype System Architecture

The prototype system architecture of a business process warehouse is shown in Fig. 6. The architecture is composed of data resource, an HSQL server, a data warehouse, and a monitor/analysis display module. Data resource provides process data that is collected using an open source BPM system, uEngine. To collect process data, we run an engineering design change process with uEngine process designer, and generate data of KPI and cKPI using a work item handler. The HSQL database is used as a repository which stores process data based on the star schema design. The data warehouse supports design and implementation of cube and MDX using XML and JSP from the star schema in OLAP server. The monitor/analysis display module provides monitoring environment which shows performance data using a dashboard.

4.2. Prototype System development for Business Process warehouse

To develop a collaboration performance monitoring system, we implement a performance dashboard. The dashboard consists of pivot tables and charts. Dashboard pivot tables are used to manage data on product, organization, partner, and process. Dashboard charts display process performance data in a graphical manner. Fig. 7 shows a cycle time monitoring dashboard by product type. This cycle time dashboard shows all the product process results which are collected during the process of engineering design change of a part. Fig. 8 shows a deadline hit monitoring dashboard by day type.
4. Conclusion

To this date, much effort has been made to monitor and manage key performance indicators within a scope of one manufacturing enterprise. In an era when collaboration takes place among manufacturing enterprises in various forms, there is an increasing need for a new methodology of measuring and monitoring performance of manufacturing collaboration.

In this paper, we introduce a business process warehouse which is developed for the purpose of performance analysis of manufacturing collaborative processes. Also, we implement a prototype system to monitor performance of manufacturing collaboration and design a database to save data which is gathered during the collaborative process. The system enables to extract specific data of interest in a process model and build a performance monitoring environment by using the data warehouse.

Our research provides a methodology which is specialized in manufacturing collaboration environments. It enables operational and strategic managers to analyze collaboration performance easily and make decisions more rapidly. The proposed methodology of monitoring and analyzing performance of manufacturing collaboration can thereby contribute to effectively maintaining and continuously improving collaboration which involves ever increasing number of partners.

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References