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An Enterprise Process Performance Management System based on Business Process Intelligence

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Abstract: To ensure efficient and effective implementation, conventional business process management solutions primarily focus on modeling and automating business processes. As automation expands, enterprises are focusing on monitoring and optimizing process execution. This paper introduces a business process intelligence (BPI) framework that employs activity-based management (ABM) measurement models to facilitate the dynamic evaluation of process performance. The framework evaluates six critical process flows—activity, information, resource, cost, cash, and profit—to provide company managers with insights for process enhancement. The evaluation process considers seven critical aspects: time, quality, service, cost, speed, efficiency, and significance. The efficacy of the proposed method has been shown by the creation of a prototype system that facilitates dynamic modeling, process flow analysis, and performance forecasting.

Keywords: Business Process Intelligence (BPI), Enterprise Process Performance, Process Flow Analysis, Activity-Based Management (ABM), Process Optimization, Dynamic Process Evaluation, Enterprise Information Systems (EIS)

Introduction

The decision-making arms of the enterprise need advanced tools to understand and optimize business processes within any intelligent enterprise information system (EIS). Efficient management of business processes becomes essential for adjusting to changes in the business environment. Modern enterprises use business processes models within their EISs for better process management.

There are various methodologies for improving process performance, like PDCA (Plan-Do-Check-Act), IDEAL, QIP (Quality Improvement Paradigm), and CMM (Capability Maturity Model). Then there are others, like Goal-Question-Indicator-Measures (GQIM) framework, which are aimed at methods to measure, evaluate, and enhance process performance.

Business Process Reengineering (BPR) denotes an entire school of thought concerned with the redefinition of business processes for enhancing business efficiency and effectiveness. Different models, generally relevant to conceptual frameworks for supply chain process innovation, have contributed to optimizing enterprise processes.

In an age of heightened automation in business operations, company decision-makers pursue advanced modeling and management solutions to enhance performance. Conventional business process management systems (BPMS) prioritize process automation; however, the demand for real-time monitoring and performance assessment has led to the development of Business Process Intelligence (BPI) (Tan et al., 2008). BPI amalgamates enterprise process modeling, process data mining, and performance assessment to deliver dynamic insights for organizational operations. Previous studies have presented methodologies like Plan-Do-Check-Act (PDCA) (Deming, 1986) and the Capability Maturity Model (CMM) (Bate et al., 1995), which are fundamental frameworks for process enhancement. Recent studies emphasize dynamic enterprise process modeling (DEPM), which integrates activity flow, resource flow, cost flow, and profit flow to facilitate real-time decision-making (Tan et al., 2008).
Business process performance evaluation incorporates multiple dimensions, including time, cost, quality, service, efficiency, and importance. These criteria enable enterprises to optimize their workflows and identify inefficiencies. The application of process simulation, online analytical processing (OLAP), and artificial intelligence techniques such as multi-agent systems (Shen et al., 2005) has further enhanced the ability of organizations to conduct real-time performance assessments. Process intelligence systems also facilitate supply chain optimization, enabling improved scheduling and coordination within virtual enterprises (Feng et al., 2007).

This paper explores the integration of dynamic process modeling with business intelligence techniques to enhance enterprise process performance management. It builds upon existing methodologies such as activity-based management (ABM) (Ostrenga et al., 1992) and enterprise information systems (EIS) (Moller, 2007) to present a comprehensive approach for optimizing enterprise workflows.

Business Process Intelligence Methodology

Business Process Intelligence (BPI) is all about improving how organizations manage and optimize their processes. It brings together different approaches, like recommendations, frameworks, systems, and IOPM (Integrated Operational Performance Management), with IOPM being the highest level. It focuses on enhancing process performance by making smart, data-driven decisions. Performance management, as explained by Amaratunga and Baldry, is about using information to drive positive changes in a company’s culture, systems, and processes. This is done by setting clear goals, prioritizing activities, assigning resources effectively, and helping managers decide whether to stick with current policies or make changes to meet the set goals.

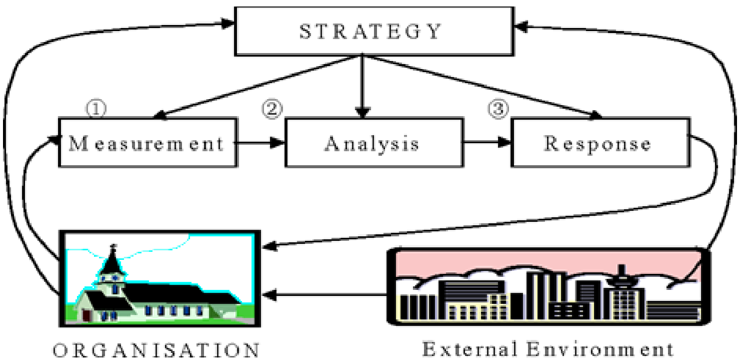

Fig. 1 Schematic depiction of the performance management procedure.

Fig. 1 provides a simple visual of the performance management process, which includes three main stages: measurement, analysis, and response. These stages are influenced by both internal strategies and the external environment, with managers adapting them based on the organization's needs and the factors at play outside the company.

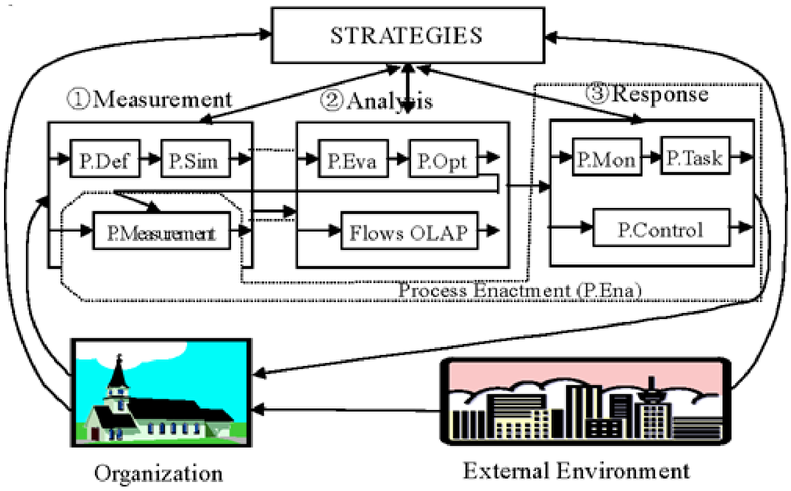

Fig. 2. Framework of business process intelligence for performance management

We present a methodology that links Business Process Intelligence (BPI) to performance management, as seen in Fig. 2. This paradigm features two primary methods for assessing performance:
1**. Process Simulation (P.Sim**) - This involves conducting simulations of a virtual organization to gather metric data. The company's process models must be precisely outlined and validated for accuracy within the process definition environment (P.Def).
2**. Process Enactment Technology (P.Measurement)** - In this context, empirical data from management information systems is employed to evaluate the performance of actual business processes.

For the analysis stage, two methods come into play:

1. **Automated Business Process Assessment (P.Eva) and Enhancement (P.Opt)** - These methods evaluate the processes automatically and make adjustments to improve them.
2. **Online Analytical Processing (FlowsOLAP)** - This approach analyzes the flow of processes using data stored in Process Data Warehouses (PDW) to understand patterns and insights.

Finally, the response stage has two main parts:

1. **Process Monitoring** - Keeping track of how processes are performing in real-time.

2. **Task Scheduling and Process Control** - Making sure the right tasks are completed in the right order and making adjustments to keep things on track.

By applying these Business Process Intelligence methodologies, companies can fine-tune their processes, optimize performance, and stay aligned with their goals, all while being responsive to changes in both internal and external factors.

Implementation of Business Process Intelligence Methodologies

The proposed methodology for business process intelligence (BPI) was operationalized through a prototype system. This section details the implementation framework, focusing on three core components: measurement models for six process flows, a dynamic evaluation methodology, and the system architecture.

A. Six Process Flows Analysis

To enable comprehensive process performance management, six interconnected flows—activity, information, resource, cost, cash, and profit—are analyzed. These flows collectively capture the operational, financial, and strategic dimensions of enterprise processes.

1. **Activity Flow**

   The activity flow, encompassing its sequence, timing, and structural relationships, dictates the execution order of all activities inside the corporate process life cycle. This is referred to as the structure of the process model. The former may be represented using a Gantt chart. Activity flow represents the parallelism inherent in both the operational and structural aspects of a company. The activity flow serves as the foundation for the enterprise's business operations, from which other data streams are modeled. The examination of activity flow will enhance both collaborative business management and enterprise concurrent engineering.

   The data pertaining to the life cycle of a business process reveal that the activity flow reflects deficiencies regarding the sequence of execution of activities, their temporal aspects, and structural relationships. This delineates the framework of the process model. A Gantt chart may be utilized to illustrate the aforementioned. Activity flow represents the parallelism of business operations concerning run-time and structure. Activity flow constitutes the cornerstone of corporate business operations, serving as a paradigm for other data streams. Activity flow analysis can enhance both collaborative business management and enterprise concurrent engineering.

2. **Information Flow**

   The product information flow and the data flow represent two distinct categories of information flow. Similar to activity flow, product information flow comprises two dimensions. The vertical dimension of the enterprise process delineates the generative relationships between products from inception to completion. The product tree structure can be referenced from the subprocess model through process tracking. It functions as an effective record that underpins quality enhancement and monitors the accountability in product manufacturing. The horizontal perspective at the input or output of any enterprise operation illustrates the product information flow, reflecting the product inventory status of that activity. The product heap quantity queue in horizontal product flow may be analyzed for "zero inventory" and "just-in-time" inventory management. It might indicate the degree of cooperation or balance between production and consumption activities for the product.

   Data flow describes the time sequence that is intended to characterize changes in data within a database or file system and the behavior model. Such data flows have little meaning unless they are considered chronologically to help ascertain the processes' execution. The horizontal data flow produced by this endeavor is comparable to the flow of product information, permitting analysis of the operation of the behavior model in the process model. In the analysis of the behavior model in the enterprise model, the data changes vertically in the process model at one point in time. This in reality is just an aspect of management and analysis of data flow and product information flows, or more commonly referred to as supply chain management in businesses.

3. **Resource Flow**

   Resource flow describes how the use of resources varies over time as a result of business operations. For instance, personnel flow deals with the movement of resources in regard to personnel. The specifications of resources required for an activity define resource consumption; therefore, activity flow can, in turn, measure resource flow. Resources only assist in the activities; they cannot be changed or worked upon. This sets information flow apart from resource flow. Therefore, resource flow is only concerned with the horizontal aspect, which entails looking at how many different types of resources are being consumed as the activity of the enterprise is carried out.

   Quantifies resource utilization over time. For resource r, utilization is computed as:

   $$ResUsed(a, r, t) = card(ActivityClone(a, t)) \times N_{Used}(a, r)$$

   Where, $ActivityClone(a, t)$ denotes concurrent instances of activity a at time t, and N_{Used} is the per-instance resource demand. Aggregating across all activities yields the total resource consumption.

4. **Cost Flow**

Cost flow refers to the chronological succession of expenses associated with a business process. Generally, these expenses can be classified into two categories: expenditures associated with resource use and those pertaining to source products, sometimes referred to as material costs. It is utilized to indicate the total expenses incurred during the duration of a process.

Combines resource costs and material expenses. Resource cost for r over $[t_1, t_2]$ is:

$$Cost(ps, r, t_1, t_2) = ResUnitCost(r) \times \int_{t_1}^{t_2} NoR(ps, r, t)\, dt$$

Where $NoR(ps, r, t)$ is the resource usage of $r\ in\ the\ ps\ at\ time\ t$.

5. **Cash Flow**

One indicator of a company's financial health is cash flow. It is equal to net profit plus sums deducted for amortization, depletion, and depreciation, or cash receipts less cash payments over a specified time period.

Cash flow, defined as the aggregate cash influx and outflow of an organization over a designated period, signifies the amount that varies during its activities. This case will examine the discussion around income generated from a business venture. The comprehensive business process model must include all its sub-processes, such as the primary production plan, product design, manufacturing, financial management, human resource management, material procurement, sales, and others. The sales sub process is a process model that generates all revenues from clients. The expense of intermediate products is ascertained by aggregating the costs of their source products and the production expenses related to the processes required to convert these source items into the intermediate product. Thus, cash flow in an enterprise process is dictated by the expenses incurred for all final products. To evaluate the volume and attributes of cash flow, a corporation must analyze revenue inside the sales sub process. This sub process includes all items classified as goods, which are then priced according to their defined cost.

Reflects financial health through net cash movement. Income from sales subprocesses is calculated as:

$$Income(ps, t_1, t_2) = \sum_{i=1}^{k} Price(p_i) \times N_{Sale}(ps, t_1, t_2, p_i)$$

Where, p_i denotes sold goods.

6. **Profit Flow**

Profit is the favorable outcome coming from an investment or business activity after deducting all cost associated. Profit is the opposite of a loss. Net profit for a company is derived from deducting all costs from all revenues. It gives an indication of how much the company has earned (or lost) in a specific period, which is typically a year. It is also known as net earnings or net income.

Net gain from operations, computed as:

$$Profit(ps, t_1, t_2) = Income(ps, t_1, t_2) - Peost(ps, t_1, t_2)$$

Where, The sale income of a process $ps\ in\ [t_1, t_2]$ is represented by income (ps, t_1, t_2), while the cost of a process $ps\ in\ [t_1, t_2]$ is represented by $P_{cost}(ps, t_1, t_2)$.

Cash flow and profit flow throughout the business process can be determined by partitioning the execution time of the process into n parts and calculating profits for each segment. Projecting cash flow or profit flow is essential for a business to make investment and process reengineering decisions. The initial stage in this computation involves evaluating the economic longevity of the firm. Income and expenses for each life phase are calculated and listed below.

Environment external to investment and process realization are factors that come into play on the overall profitability of enterprises while executing an enterprise process, such as management and revenue policies. Thus, the actual profits of the enterprise will be described according to the profit flow.

B. Dynamic Enterprise Process Evaluation Methodology

The proposed evaluation method can be used to two forms of dynamic modeling for enterprises: stream-oriented and project-oriented. Stream orientation may consist of randomly discrete sequences that represent a specific distribution of source product arrival frequency, applicable in mass manufacturing processes. Project orientation signifies the commencement of an event and concludes with another event, which may represent individual productions or technical endeavors.

Varied procedures require varied evaluation standards, and these standards ought to vary as well. Dynamic, time-wise cost efficiency, quality, service, speed, effectiveness, and significance are all aspects of the process that may be measured by the potential assessment system set up to assess company processes.

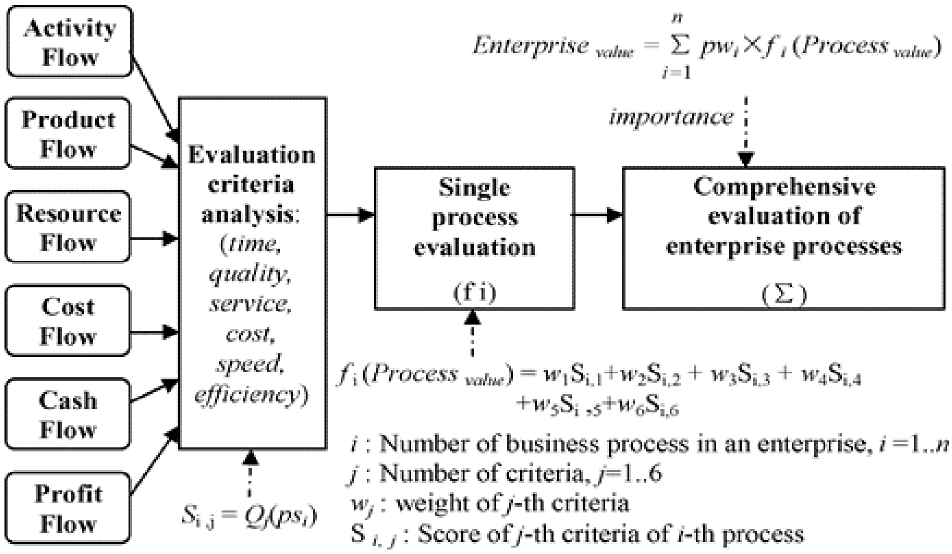

Fig. 3. Schematic depiction of a thorough assessment of organizational processes

Figure 3 depicts the strategy for evaluating enterprise processes. It is essential to identify the modeling aspects of the enterprise-level decision model, including corporate objectives, their weights, and the importance of the business process, for this evaluation. 1) Discusses the assessment framework and previous criteria. Cost will serve as the economic evaluation criterion, while corporate process performance will be assessed based on time, quality, service, efficiency, and speed. The importance will function as a weight coefficient for the evaluation of process value and will be utilized for a comprehensive assessment of enterprise processes.

1) Models for Evaluating Enterprise Processes: The flow of resources, goods, and activities is intrinsically linked to the evaluation of process performance. Thus, the assessment of process performance incorporates the following criteria: Quality (cost structure utility), Speed (product throughput utility), Efficiency (resource utilization utility), Time (process duration utility), and Service (customer satisfaction).
In this case, time denotes time-to-market, which is the value generated by the activity flow throughout the process duration.

$$Time = Q_t(ps) = \frac{1}{m}\sum_{i=1}^{m} \frac{\left|\sum_{j=1}^{n} D(a_i, i) - T\_ex_i(ps)\right|}{T\_ex_i(ps)}$$

Where,

- m is the number of the end products in the process

- T_ex_i is the anticipated duration for the ith product in picoseconds
- $D(a_i, i)$ Is the actual duration of the jth action on the primary time-critical path of the ith product in ps?

The speed of enterprise processes refers to the capability of those processes. It is the full capacity of all operations as defined by usefulness of the product heap or the time input products stand waiting in line for handling by the Stream-Like process's specified operations ps. It might easily be computed as follows from the flow of products in ps:

$$Speed = Q_s(ps) = \frac{1}{m \times n} \sum_{i=1}^{n} \left(\sum_{j=1}^{m} \frac{Q\_L(p_i, t_j)}{L(p_i)} \right)$$

Where,

- $Q\_L(p_i, t_j)$ is the queue length about an intermediate product p_i in p_s
- $L(p_i)$ is the expected security value for the product p_i in p_s
- m is the number of segments into which the total execution time of process p_s can be partitioned.
- n is the number of intermediate products.

Efficiency quantifies resource utilization during a process's execution and serves as an indicator of the effectiveness of resource usage. It is a critical criterion for evaluating a business process. It can be derived from the resource flow of process p_s using the following formula:

$$Efficiency = Q_e(ps) = \frac{1}{k.m} \sum_{i=1}^{k} \sum_{j=1}^{m} \frac{RN(r_i) - NoR(ps, r_i, t_j)}{RN(r_i)}$$

Where,

- k represents the quantity of resource kinds in process p_s.m is the number of segments into which the entire project cycle can be divided.
- $RN(r_i)$ available amount of resource r_i;
- $NoR(ps, r_i, t_j)$ = the actual usage at time t_j.

Efficiency is a measure of the actual utility of resource usage in a process, determined by averaging all resource utilizations over a specified time period. Efficiency diminishes with the enhanced utilization of resources.

C. System Architecture and Functions

1) Business Process Intelligence Architecture: By employing dynamic enterprise process modeling (DEPM) and process data mining (PDM) technologies, BPI assists enterprise decision-makers in the insightful analysis of business process evolution. The Software Engineering Institute at Beihang University in China has developed four fundamental subsystems: process definition (P.Def), process simulation (P.Sim), process optimization (P.Opt), and process enactment (P.Ena). Figure 4 illustrates the architecture of the BPI, highlighting its emphasis on process performance management and the evolutionary dynamics of enterprise processes, with grey arrows indicating the direction of movement. Ascending from the base of Fig. 4 are approaches for analyzing business process data mining for process flow evaluation. The deployment of BPI, specifically supervised by DEPM, PDM, and flow analysis and forecasting, is presently developed.

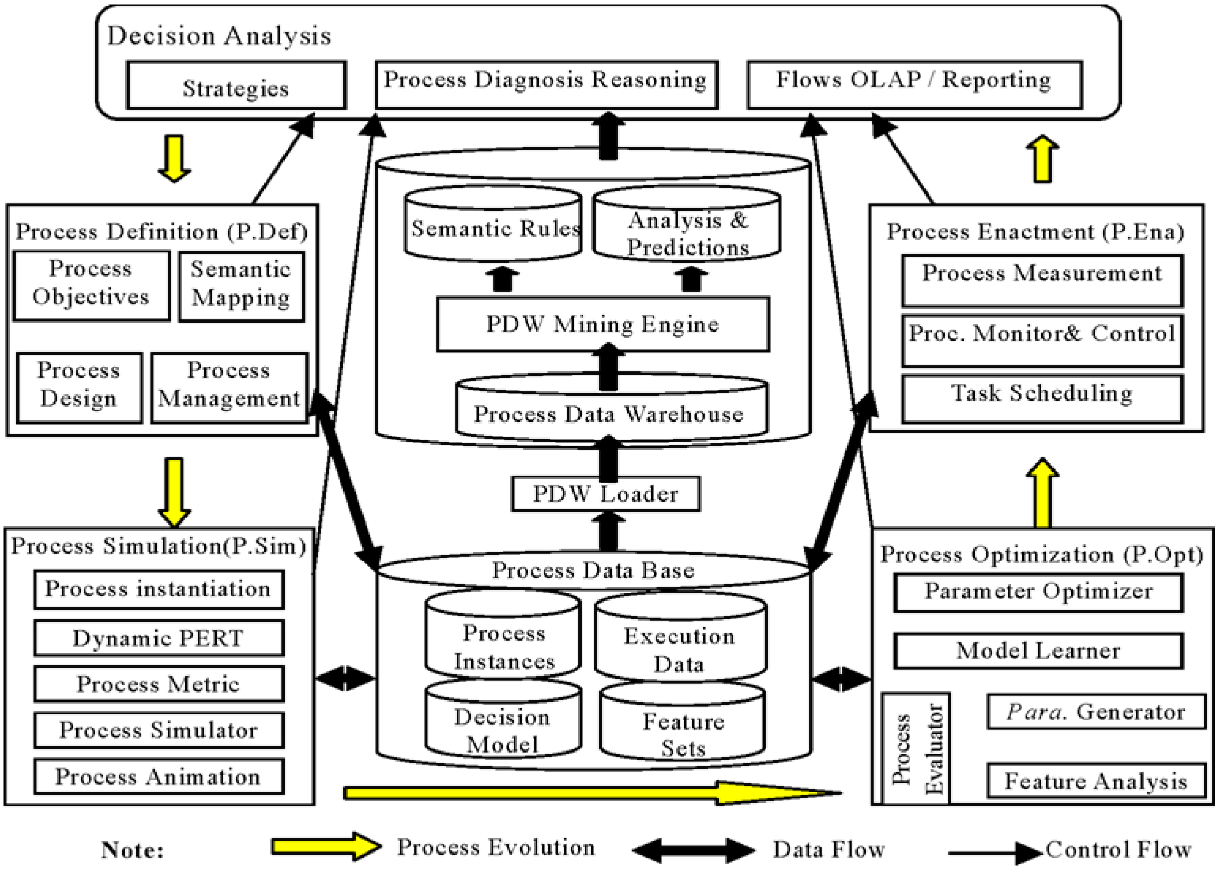

Fig 4. The architectural framework for business processes Intelligence for the management of process performance.

1) Functions of Business Process Intelligence

a) **DEPM**: Business Process Intelligence revolves around four fundamental technologies: process definition, process simulation, process optimization, and process enactment.

Process Definition (P.Def) encompasses the design, administration, establishment of objectives, and semantic mapping of processes. The Process Design Tool is a graphical interface that guarantees accurate syntax and semantic verification. Process Management facilitates the development of models according to precise definitions and enables swift modeling through industry-specific reference models and component-based architectures. Process Objectives and Process Semantic Mapping delineate the aims of business processes and articulate their semantics for enhanced comprehension and alignment throughout the enterprise.

Process Simulation (P.Sim) analyzes enterprise processes, providing real-time insights and dynamic information for managers. This includes process instantiation, simulation, dynamic project evaluation techniques (e.g., PERT), process metrics, and animation, all aimed at improving decision-making.

Process Optimization (P.Opt) focuses on improving business processes using advanced algorithms. This tool evaluates processes, learns models, generates process parameters, analyzes features, and optimizes parameters. The outcome includes optimized process models and recommended strategies to assist decision-makers. The best model can be executed in Process Enactment (P.Ena) for monitoring and controlling enterprise processes.

Process Enactment (P.Ena) integrates the functions of process measurement, task scheduling, monitoring, and control. During execution, if changes in the external environment are detected, the process may need adjustments, which are fed back into the process definition step via strategic changes for continuous improvement.

The measurement of various process flows, including activities, products, resources, and costs, is conducted in Process Simulation (P.Sim). Additionally, the Process Evaluator (P.Eva) plays a key role in helping managers analyze and optimize processes. It evaluates the data generated by simulations, applying specific methodologies to assess the performance and value of business processes.

Two primary components in Process Optimization (P.Opt) are the Model Learner and Parameter Optimizer. The Model Learner uses a training set to apply the Fletcher Reeves algorithm for identifying optimal solutions by learning from data, aiming to find the best and worst solutions to guide the optimization. The Parameter Optimizer uses a modified Tabu Search algorithm for global optimization, speeding up the process by avoiding previously explored suboptimal regions.

The combination of the Model Learner and Parameter Optimizer creates the FR-TS algorithm, which efficiently tracks process evolution, improving business processes over time.

b) PDW and Data Mining Engine:

In recent years, data management and decision analysis have experienced substantial expansion, emphasizing data integration to deliver precise, fast, and valuable information. Data warehousing is crucial in this integration process. The establishment of a data warehouse often adheres to a Data Warehousing Process (DWP) approach. Presently, numerous approaches exist in the data warehousing domain owing to the lack of standardized, platform-agnostic DWP standards. The establishment of such standards is essential. An examination of diverse commercial data warehousing methodologies has yielded insights into conventional practices employed in system development, requirements analysis, architectural design, data modeling, extract, transform, and load (ETL), data extraction, and user application design, alongside the identification of critical areas for future research.

To facilitate business process intelligence, a firm must construct a Process Data Warehouse (PDW). A PDW encompasses a diverse array of collected data that delineates standard performance measures. The PDW Loader aggregates data from the process instance repository, encompassing taxonomy definitions, enterprise model details (including processes, behaviors, resources, and organizational structures), process instance state information (such as changes in process states and resource/service activities), and performance metrics of the processes. The PDW Loader can be activated at regular intervals or on demand, ensuring data consistency throughout the loading procedure. Upon loading, the data in the PDW is instantly accessible via commercial reporting tools, enabling analysts to utilize OLAP tools to get process execution information, including diverse process flow indicators. The PDW Mining Engine provides "intelligent" analysis and forecasting through the application of data mining methods to the PDW. This enables analysts to comprehend the determinants of particular behaviors and formulate predictive models for process performance, activities, and resource allocation. The mining engine typically follows four steps:

Process Data Preparation: A process analysis table is established to retrieve particular process instance data and behavioral information for the classifier. This table features a row for each process instance, with columns denoting pertinent attributes of the process instances.

Behavior Analysis Preparation: During this step, a process- and behavior-specific perspective is created by integrating the process analysis and behavior tables. This perspective supplies the essential data for classification instruments to formulate classification criteria.

Mining: Various data mining and classification tools are available on the market. In this step, a component or classifier is designed to map the behavior analysis problem into a classification problem. The classifier generates classification rules, which are stored in an "Analysis and Predictions" database for future use.

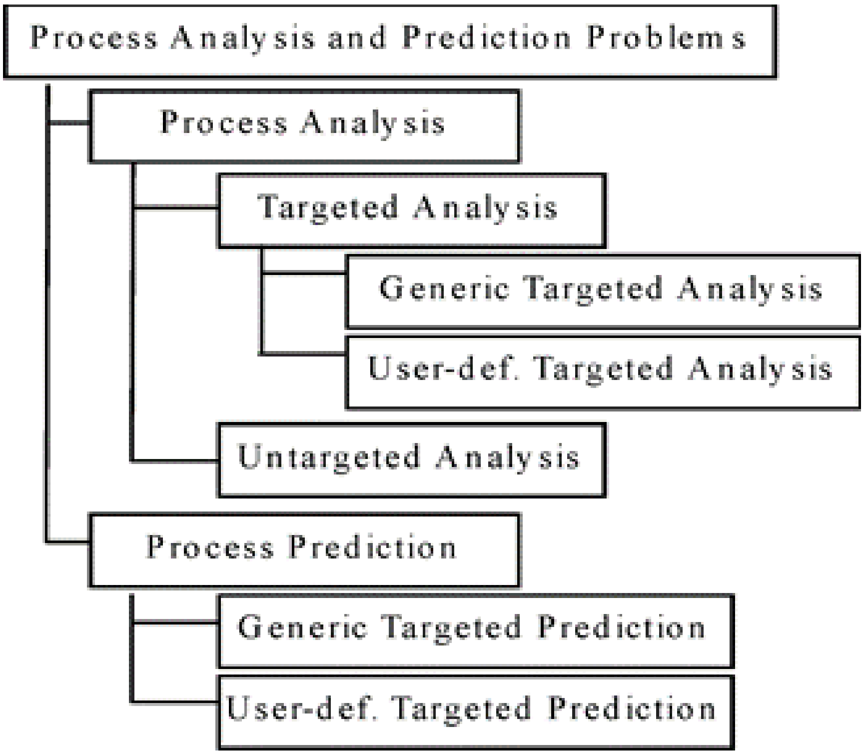

Fig. 5. Classify of processes analysis and prediction.

Interpretation: Classification rules are presented in formats like decision trees to assist analysts in comprehending the underlying reasons of specific actions. Analysts may opt to re-execute the classification by excluding specific variables from the training dataset, enabling the classifier to concentrate on particular qualities of interest.

C) Process Flows OLAP Analysis and Prediction

Decision analysis plays a crucial role in helping managers select the most effective enterprise process model and optimize workflows through analysis and forecasting. Choosing the right evaluation technique for assessing both human and automated systems requires a clear understanding of task objectives and a realistic environment to measure performance. One approach to predicting system efficiency involves analyzing how humans and robots collaborate in repetitive tasks to estimate overall system performance in such scenarios.

To provide meaningful insights into metrics and future projections, process diagnosis tools utilize data mining techniques. These tools evaluate various aspects such as analysis versus prediction, generic versus user-defined metrics, targeted versus untargeted focus, and the status of different instances. A decision tree model is commonly used for analyzing and predicting processes.

OLAP-based process flow analysis enables comprehensive reporting on process statistics while offering advanced functionalities for explaining and forecasting various process behaviors and performance metrics. By integrating data mining methods and dynamic PERT applications, businesses can gain deeper insights into workflow trends and improvements.

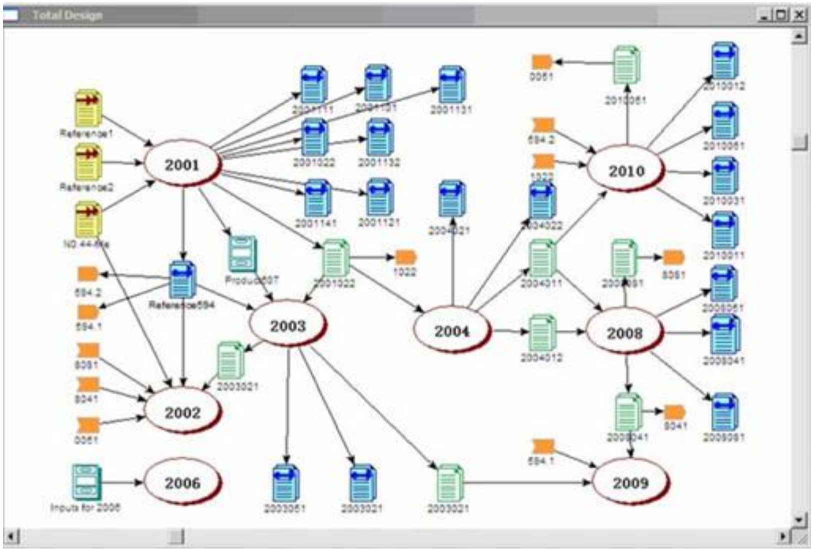

Fig. 6. Total design process of an airplane.

Process flows analysis involves identifying significant patterns in process execution and explaining the conditions under which these patterns arise. This analysis can be classified as targeted or untargeted. In targeted analysis, Business Process Intelligence (BPI) systems help determine why specific process metrics reach certain values. Depending on enterprise needs, targeted analysis can be further divided into general targeted analysis and user-defined targeted analysis. Additionally, businesses may seek to uncover hidden trends or anomalies that indicate unrecognized situations.

Process prediction, on the other hand, focuses on forecasting outcomes for ongoing or future process instances. For example, it can predict the number of orders expected the next day or estimate total order values. The metrics used in process analysis and prediction fall into two categories: general and user-defined. General metrics apply across various processes and are essential in multiple analytical scenarios, while user-defined metrics cater to specific aspects of particular workflows, making them less generalizable but more tailored to business-specific needs.

Case Study

Business Process Modeling and Simulation for Airplane Design

A practical business process was utilized to illustrate a project-oriented modeling approach for designing an airplane. This prototype system served as a validation tool for the proposed methodology. The business process consists of two primary components: **Total Design** and **Draw a Design**.

The **Total Design** phase is broken down into ten subprocesses, including integrated design, weight analysis, geometrical shape modeling, differential coefficient calculations, and the design of air intake and exhaust pipes. Each subprocess involves multiple activities contributing to the overall design framework. The outputs from this phase are then used to create the final design model. Due to confidentiality concerns in aircraft design, only a general discussion of the business process models and their essential elements is provided.

Decision Model and Process Evaluation

For real-world applications, a decision model must be established based on industry-specific requirements and project objectives. This model allows for the prioritization of evaluation criteria, ensuring efficient decision-making. The model editor enables quick customization of importance weights assigned to different factors based on process simulation results and industry experience.

Fig. 7. Example of decision model definition.

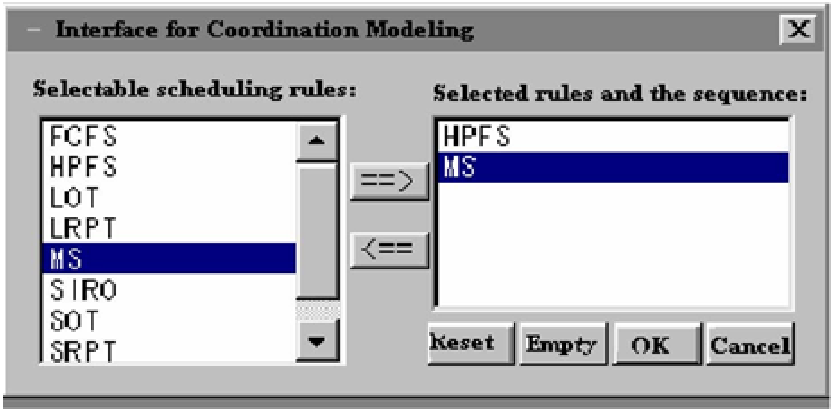

Fig. 8. Interface for coordination modeling.

In this scenario, the decision model considers four key objectives:

- **Efficiency (3/10)**
- **Speed (3/10)**
- **Time (2/10)**
- **Cost (2/10)**

Additionally, constraints such as a predefined time limit of **1000 hours** and a cost cap of **¥75685.99** are set. Once the design process is analyzed, the system generates a process diagnosis report, offering recommendations for process reengineering and redesign to improve future airplane design projects.

Process Simulation and Scheduling Strategy

To gain valuable insights into workflow efficiency, process simulation and flow analysis techniques are employed. These simulations generate various types of data, including Gantt charts of activities, resource efficiency metrics, process cost breakdowns, and cost flow information. The scheduling strategy follows a **four-level hierarchy** and incorporates eight fundamental scheduling rules.

Before running a simulation, coordination rules must be established. The scheduling options include:

- Highest Priority First Serve (HPFS)
- Minimum Slack Time First Serve (MSFS)
- First Come First Serve (FCFS)
- Service in Random Order (SIRO)
- Shortest Operation Time (SOT)
- Longest Operation Time (LOT)
- Longest Remaining Processing Time (LRPT)
- Shortest Remaining Processing Time (SRPT)

Simulation Findings

The process simulation executes enterprise workflows based on the selected scheduling rules. The results indicate:

1. **For non-resource-matching scenarios**, the best performance is achieved using the composite rule **HPFS/LRPT/FCFS**, while *HPFS/MS/ or HPFS/FCFS/SOT** follows closely behind.
2. **For resource-matching scenarios**, the most effective combination is **HPFS/MS/***, with **HPFS/LRPT/FCFS** ranking as the second-best option.

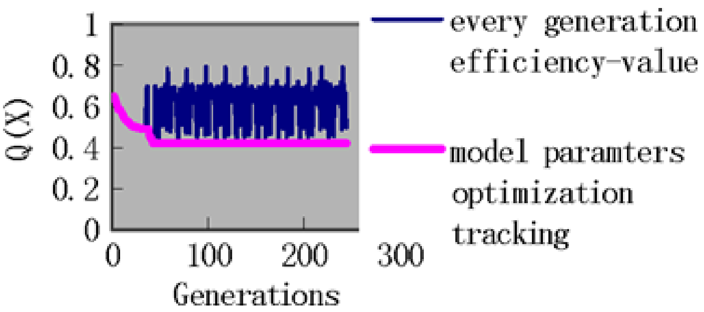

Fig. 9. Q versus generations using FR-TS method.

After implementing the intelligent optimization module in the airplane design process model, the workflow was enhanced through resource reconfiguration. The application of the **FR-TS method** effectively accelerated local optimization tracking while overcoming limitations associated with local optima, ultimately leading to a globally optimized solution.

A comparison with actual data from the airplane design process revealed that scheduling the design workflow using the **HPFS/LRPT/FCFS** rule, integrated with a dedicated software system, reduced the overall process duration by more than **1250 hours**.

Observations and Recommendations

Upon applying the proposed system to various manufacturing and service enterprises, key insights and recommendations were derived:

1. **Research Projects** – The **HPFS/LRPT/FCFS** rule is particularly effective for managing research-based projects, as research activities often lack predictable timelines.
2. **Customization Projects** – The **HPFS/MS/FCFS** rule is well-suited for projects involving customized production, especially in industries with well-established techniques, such as construction.

3. **Service Industries** – The **HPFS/FCFS/*** rule is optimal for managing service-based industries, such as transportation, where scheduling efficiency is crucial.

Conclusion

This paper introduces a comprehensive framework of concepts and technologies aimed at enhancing business process intelligence for process performance management. The proposed approach facilitates enterprise business process reengineering (BPR) while enabling process flow analysis and predictive modeling. The key contributions of this study include:

1. **Introduction of New Concepts** – A structured approach to integrating business process intelligence with performance management.
2. **Process Flow Measurement Models** – A methodology for evaluating six critical process flows: **activity flow, product flow, resource flow, cost flow, cash flow, and profit flow**.
3. **Dynamic Enterprise Process Evaluation** – A performance assessment model based on seven essential criteria: **Time, Quality, Service, Cost, Speed, Efficiency, and Importance**.
4. **Validation Through a Prototype System** – Demonstration of the proposed methodology via a **Dynamic Enterprise Process Management (DEPM) system**, enabling analysis and prediction of process flows for improved performance management.

Designed as a business process performance management tool, this system is particularly beneficial for small and medium-sized enterprises (SMEs), offering intelligent process analysis and support for business process reengineering (BPR). However, the current system has certain limitations when applied to large-scale enterprises due to its reliance on event queuing theory and predefined cooperative scheduling strategies within a single-level structure. This constraint makes it challenging to model diverse scheduling strategies across multiple processes in large organizations.

To overcome these limitations, future enhancements will focus on integrating ontology-based modeling with event queuing theory and cooperative scheduling strategies. Leveraging multi-agent technology, this approach will facilitate process ontology-based simulations, allowing different scheduling strategies to be applied to distinct processes. Additionally, multi-agent cooperative simulation will be introduced, enabling improved synchronization between subprocess models and agent-based simulations within each subprocess. This will create a more adaptable and scalable enterprise process management system, better suited for complex, large-scale organizations.

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