https://doi.org/10.5392/JKCA.2017.17.07.044

지속적 프로세스 개선을 위한 성과 중심의 생애 주기 기반 비즈니스 프로세스 관리 프레임워크

A Life Cycle-Based Performance-Centric Business Process Management Framework For Continuous Process Improvement

한관희
경상대학교 산업시스템공학부/공학연구원

Kwan Hee Han(hankh@gnu.ac.kr)

요약

최근에 많은 기업들이 기업 목표를 달성하기 위해 프로세스 혁신이나 개선을 지속적으로 꾀하고 있으며, 이를 지원하는 도구로 BPM (Business Process Management)이 많이 도입되고 있다. BPM의 생애 주기는 프로세스 진단, (재)설계 및 실행으로 이루어지는데, 모든 BPM 활동들은 성과 척도와 밀접한 관련을 갖고 운영되어야 한다. 본 논문의 목적은 프로세스 기반 성과 측정 모델과 통합된 생애 주기 기반 BPM 프레임워크를 제안하는 것이다. 제안 프레임워크에서는 BPM 전 생애 주기 동안 비즈니스 프로세스와 성과 척도가 체계적인 상관관계를 가지고 밀접하게 운영된다. 기업의 혁신이나 개선 담당자들은 제안 프레임워크를 사용하여 프로세스 진단 단계에서는 기업 성과에 가장 영향을 주는 프로세스를 용이하게 확인할 수 있고, 프로세스 (재)설계 단계에서는 새롭게 설계된 프로세스의 성과를 측정할 수 있으며, 프로세스 실행 단계에서는 성과 척도를 모니터하여 비즈니스 활동 들을 조정할 수 있게 된다.

■ 중심어 : | 비즈니스 프로세스 관리 | 프로세스 시뮬레이션 | 프로세스 마이닝 | 비즈니스 성과 관리 | 프로세스 개선 |

Abstract

Many enterprises have recently been pursuing process innovation or improvement to attain their performance goal. To comprehensively support business process execution, the concept of business process management (BPM) has been widely adopted. A life cycle of BPM is composed of process diagnosis, (re)design, and enactment. For aligning with enterprise strategies, all BPM activities must be closely related to performance metrics because the metrics are the drivers and evaluators of business process operations. The objective of this paper is to propose a life cycle-based BPM framework integrated with the process-based performance measurement model, in which business processes are systematically interrelated with key performance indicators (KPIs) during an entire BPM life cycle. By using the proposed BPM framework, company practitioners involved in process innovation projects can easily and efficiently find the most influencing processes upon enterprise performance in the process diagnosis phase, evaluate the performance of newly designed process in the process (re)design phase, monitor the KPIs of new business process, and adjust business process activities in the process execution phase through the BPM life cycle.

■ keyword : | Business Process Management | Business Process Simulation | Process Improvement | Process Mining | Business Performance Management |

접수일자 : 2017년 05월 08일
수정일자 : 2017년 05월 23일
심사완료일 : 2017년 05월 23일
교신저자 : 한관희, e-mail : hankh@gnu.ac.kr

I. Introduction

Most enterprises are struggling to change their existing business processes into agile, product- and customer-oriented structures to survive in the competitive and global business environment. In today's dynamic business environment, the ability to improve performance is a critical requirement for business organizations. Therefore, many enterprises have recently been pursuing business process innovation or reengineering to attain their performance goals[1][2].

A business process is defined as a sequence of activities to achieve a complete business goal. To comprehensively support business process execution, the concept of business process management (BPM) has been widely adopted in most enterprises.

BPM is defined as the identification, understanding, and management of business processes linked with people and systems and across organizations.

Over the last decade BPM has become a mature discipline, with a well-established set of principles, methods and tools that combine knowledge from information technology, management sciences and industrial engineering with the purpose of improving business processes[3][4].

The BPM life cycle is composed of process diagnosis, (re)design, and execution/monitoring phase. In the diagnosis phase, the operational processes are analysed for identifying problems and finding bottlenecks for improvement. In the process (re)design phase, to-be processes are newly designed and their performance is evaluated. In the execution phase, business activities are monitored, coordinated and controlled continuously for better performance.

For aligning with enterprise strategies, BPM activities must be closely related to performance metrics because the metrics are the drivers and evaluators of business processes. Since the metrics indicate how well the business is doing relative to a defined strategy, they help managers to derive better business decisions.

Therefore, for effective BPM, it is imperative to establish the relationship between business processes and performance metrics, before deploying the BPM system.

However, current measurement practices have not clearly defined and managed the relationships between business processes and key performance indicators (KPIs). Therefore, a process-based performance measurement model is needed to provide a systematic link between organizational strategy, resources, and business processes.

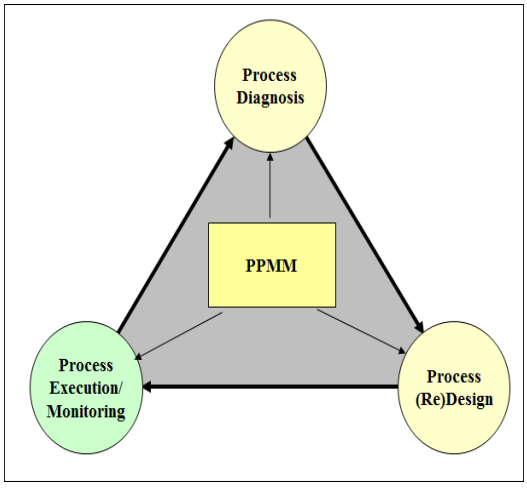

Figure 1. Life cycle-based Performance- centric BPM framework

The objective of this paper is to propose a life cycle-based BPM framework, as shown in [Figure 1], which is integrated with the process-based performance measurement model (PPMM), in which all BPM activities are closely related and linked with KPIs during an entire BPM cycle for better performance management.

Proposed framework is the integrated results of our previous research[5-10].

The rest of this paper is organized as follows. Section 2 describes related works. Section 3 reviews the PPMM, which is an underlying scheme of performance-centric BPM. Section 4 describes procedure and method for implementing BPM system based on PPMM. Finally, the last section summarizes the results and suggests directions for further research.

II. Related Works

Of the research related to the performance measurement of an enterprise, Munehira *et al.* suggested that it is necessary to specify which processes should be improved or created to achieve the business performance goals described in BSC (Balanced Score Card). For this purpose, they defined the relations between BSC structure and business model elements. Yet they did not implement their proposed method to a real business case[11].

Ariyachandraa and Frolick presented a framework for BPM, and suggested the major critical success factors that will influence the success of a BPM initiative[12]. Kim and Shin proposed ISO 9001 Quality Management System based on BPM, and implemented quality management system called KQMS (KISTI Quality Management System)[13].

In the previous research, author of this paper proposed the performance measurement framework called PPMF (Process-based Performance Measurement Framework) comprised of three sub-models as follows: a process model, a KPI model and a K-P (KPI-Process) model[5]. By using above proposed framework, the influencing impacts of process/sub-process upon KPIs can be traced to, and the contribution of tactical/ operational level KPIs on strategic level KPIs can be easily calculated.

Author of this paper also proposed two-stage business process analysis for the process improvement, which covers diagnosis and (re)design phase of BPM life cycle, based on PPMF and business process simulation (BPS)[7].

In the diagnosis phase of BPM life cycle, for discovering unknown process model and identifying bottlenecks in an existing processes based on process mining approach, Van der Aalst *et al.* made a case study which describes the application of process mining, in order to evaluate the performance of process and to identify opportunities for improvement[14]. They applied process mining approach using ProM software[15].

Garg and Agarwal applied some of the process mining techniques with the help of Petri net on the real time data of a private community hospital to get meaningful information and knowledge about these flow, for example discover paths followed by particular groups of patients[16]. Choi *et al.* analyzed repair processes of electronic devices using process mining approach. In this research, the method for finding major failure patterns is proposed by multi-dimensional data analysis[17].

One of the key areas for applying simulation is BPM in which the simulation method is applied to analyze, improve, and redesign the processes and increase productivity[18][19]. April *et al.* suggested the usefulness of simulation for the business process re-engineering (BPR) by presenting the case study of a personal claims process at an insurance company[20]. the simulation method is applied to analyze, improve, and redesign the processes and increase productivity. Safari discussed and provided a practical end-to-end process for business process modeling and simulation in service industries on a

detailed level[21].

Sahraeidolatkhaneh and Han proposed the BPM framework to integrate the diagnosis and (re)design phase of BPM life cycle by sharing automatically generated process model and basic statistics in the diagnosis phase based on the process mining method[10].

In the area of business activity monitoring (BAM), Broda *et al.* proposed key steps and critical success factors to BAM implementation. The key steps are as follows: define a vision, establish the data model, build real-time data streams, and roll out operational dash boards. They suggested that the critical success factors are performance, heterogeneous data access, and usability[22].

Jiang *et al.* developed a statistical process control (SPC) framework to identify important changes deserved in business activity monitoring. To model and track thousands of diversified customer behaviors, the proposed SPC system consists of efficient and robust profiling methods to accommodate different behavior patterns including business changes, structural breakdowns, and unnecessary errors[23].

Han and Kang identified critical success factors for BAM system implementation, and developed BAM system prototype for global automotive company[6]. Our previous research proposed BAM system design framework integrated with the process-based performance measurement model (PPMM), in which KPIs are closely related with business processes[8].

For efficient BAM, author proposed an ECA rule pattern to remedy current limitations of the ECA rule for CEP (Complex Event Processing) and develop a prototype system based on the proposed ECA rule pattern[9].

As reviewed in the above, most research deal with methods and approaches suitable for each phase of BPM life cycle. So, in the BPM area, the integrated approaches dealing with whole BPM life cycle focused on performance have not been proposed.

III. Process-Based Performance Measurement Model

The general objectives of enterprise performance management system are as follows: measure performance against key customer requirements, make strategic objectives clear, focus on core processes, focus on critical variables, signal where performance is headed, identify which critical factors require attention, and provide an unambiguous basis for assessing and rewarding performance[24].

Especially, in terms of focus on the business processes, the need for systematic performance measurement based on business processes has been steadily increasing. However, the proper correlation scheme between business processes and KPIs (Key Performance Indicators) is not clearly established in the current measurement practices.

As a result, in the diagnosis phase of BPM, it is difficult to decide which process should be improved to achieve a specific performance goal, or which performance index is influenced when a specific business process is executed successfully. In the execution phase, it is also difficult to decide which KPIs or business processes are monitored and to define the relationships between monitored KPI and other KPIs. Consequently, a performance measurement model that is closely correlated to business processes should be established to achieve the goal of an enterprise.

The proposed PPMM (Process-based Performance Measurement Model) consists of three sub-models, as shown in [Figure 2]: KPI model, process model, and

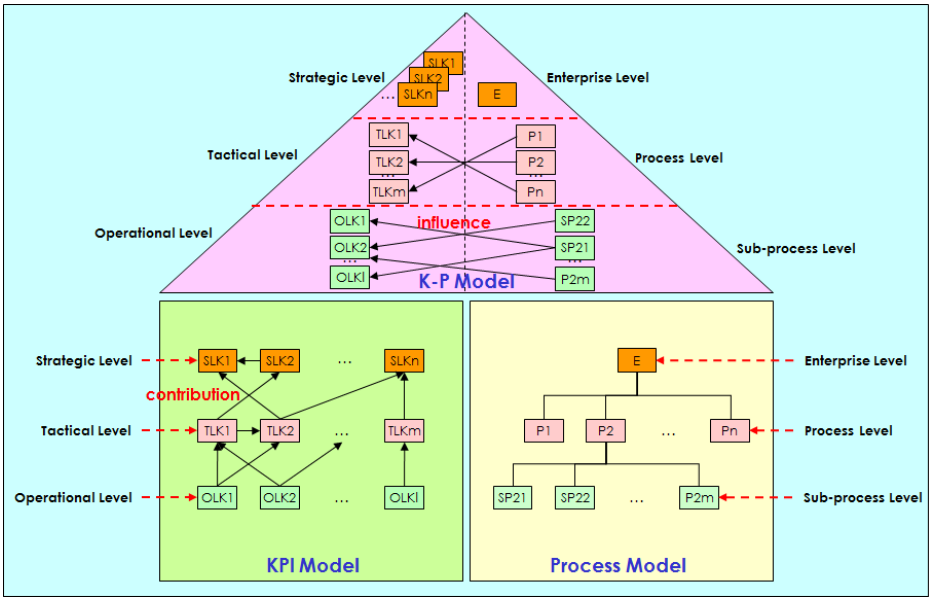

Figure 2. Process-based Performance Measurement Model

K-P model.

Firstly, KPIs are hierarchically classified into three levels in the KPI model according to the following management decision level: strategic level KPI (SLK), tactical level KPI (TLK), and operational level KPI (OLK). The contribution index having a 3-point scale, which is a measure of the contribution of a specific KPI to other same level or higher level KPI, is determined in the KPI model.

Secondly, business processes are classified into three levels in the process model in accordance with the size of the process span as follows: enterprise level, process level, and sub-process level. Each sub-process has a network composed of unit activities.

The definition of process, sub-process and activity in this paper is compliant with the definition of workflow management coalition (WfMC)[25]. For example, process model of Case Company S consists of 14 main processes as follows: understand market and customers, develop vision and strategy, research and development, engineering, marketing and sales, purchasing, production, customer satisfaction, manage information, manage human resource, finance, execute environmental management program, manage external relationships, and manage changes. And total number of sub-processes is 84.

Finally, the K-P model represents the relation between KPI and business process. Enterprise, process, and sub-process levels in the process model correspond to SLK, TLK, and OLK in the KPI model, respectively. The influence index having a 3-point scale, which is a measure of the influence of a business process on a specific KPI, is determined in the K-P model.

[Figure 3] shows the integrated view of PPMM of the Case Company S. In the left side of [Figure 3] (K-P model), influence index of 'production' process upon the 'output quantity' TLK (numbered as ②) is marked as 3, which means major influence. The detailed systematic procedure to develop a PPMM in an organization was previously addressed by author

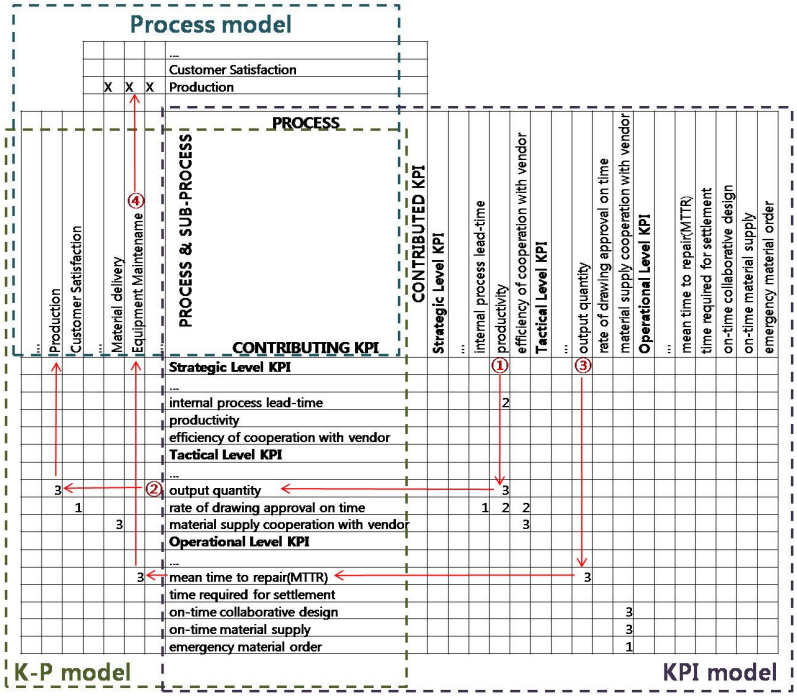

Figure 3.Integrated view of PPMM (simplified)

of this paper[5].

IV. Performance-Centric BPM Framework

1. Diagnosis Phase

The diagnosis of business processes conventionally was conducted by interviews with users, questionnaires, and direct observation of business processes.

If the event data exists within the application system, the above tasks can be done efficiently and rapidly. The application system of enterprises usually records event data such as tasks that have been executed, their order of execution, and the process instance they belong to.

These event data can be used to extract knowledge about the process, and therefore they are especially useful for the purpose of business process diagnosis.

Event data are analyzed using process mining approaches such as the process discovery for discovering control flow, the organizational perspective to find relationships between performers, and the data perspective and performance perspective to find bottlenecks[26-28].

Process mining as a bottom-up approach is recently used in the diagnosis stage to find weak points for making improvements in the business processes[1][10][17].

In parallel with the process mining approach, what-if analysis as a top-down perspective is performed based on PPMM during the diagnosis phase to determine which processes should be executed successfully to achieve a target SLK.

First of all, the TLKs with the greatest contribution to the target SLK in the KPI model are identified, and then the business processes that directly influence the target TLK in the K-P model can be selected as candidate business processes. If no process directly influences the target TLK, we alternatively use a target OLK with the greatest contribution to the target TLK in the KPI model, and then identify a sub-process that directly influences the selected target OLK in the K-P model. Then the higher level process of the identified sub-process can be selected as a candidate process in the process model.

The use of PPMM enables another problem to be addressed: determining which SLKs are influenced if a target process or sub-process is innovated or improved. To solve this problem, the TLK that is influenced by the target process in the K-P model should be identified, after which the SLKs that are contributed by the selected TLK in the KPI model can be determined.

At the sub-process level, we can also determine firstly the OLK that is influenced by the target sub-process in the K-P model, secondly the TLK that is contributed by the selected OLK, and thirdly the SLKs that are affected by the selected TLK in the KPI model.

For example, in the Case company S, the problem is to select process and sub-process we need to improve for enhancing the 'productivity' SLK of internal process perspective. By using the PPMM, we identify that the major contributing TLK to the 'productivity' SLK is 'output quantity' in the KPI model (arrow number ①), as shown in Figure 3. Then we determine that the major influencing process on 'output quantity' TLK is 'production' process in the K-P model (arrow number ②).

To find the major influencing sub-process, we see that the major contributing OLK to the 'output quantity' TLK is 'Mean time to repair (MTTR) in the KPI model (arrow number ③). This result indicates that the major influencing sub-process on 'MTTR' OLK is 'equipment maintenance' sub-process in the K-P model. Finally, we find that 'equipment maintenance' is the sub-process of 'Production' process in the process model (arrow number ④).

2. (Re)design Phase

In the (re)design phase, business performance is measured for newly designed processes with respect to metrics established in PPMM. Simulation method is usually used for detailed business process analysis, due to its ability to evaluate the impact of process changes and new processes in a model environment.

After the what-if macro analysis in the diagnosis phase, micro process analysis is performed. Micro process analysis, which is a kind of quantitative business process analysis using a simulation tool, focuses on evaluating the ability to meet performance requirements with respect to throughput time, service level, and resource utilization, etc. OLKs are used as metrics for (re)design phase, whereas SLKs and TLKs are major concerns of the diagnosis phase.

After the target business process is selected for innovation or improvement in the diagnosis phase, the performance of the as-is process is reviewed, after which a to-be process is newly designed.

At the re(design) phase, the process simulation for performance prediction of the newly designed process is conducted as follows. Firstly, a process model is built by using simulation software. Next, simulation parameters such as processing time and other experimental data for each activity of the business process are prepared.

In this step, the statistics such as inter-arrival time of cases and probability distribution of processing time of each activity and discovered process model

which represents the activity sequence and control flow already built in the diagnosis phase based on the process mining method is directly used.

During the simulation execution, various performance metrics are measured and compared with the actual performances of existing process for evaluating the to-be process.

As an example in the Case company S, we addressed the problem of process improvement of 'equipment maintenance' sub-process for reducing MTTR OLK identified in the diagnosis phase.

After reviewing the current performances of the existing 'equipment maintenance' sub-process, the to-be process is redesigned in a form of UML (Unified Modelling Language) activity diagram as shown in [Figure 4]. In the as-is sub-process, repair man records each repair result after the task of "test" and "replace". These are duplicate tasks with "record results" activity of clerk. Therefore, these activities are omitted in the re-designed sub-process.

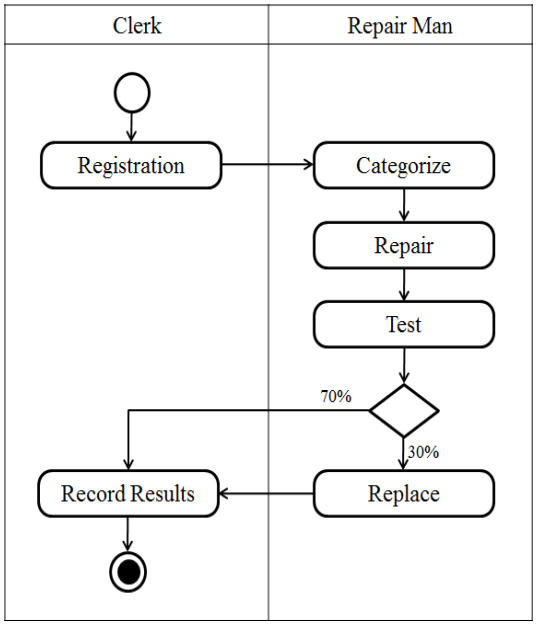

Figure 4. New 'equipment maintenance' sub-process

This sub-process consists of six activities. 1) register maintenance request, 2) categorize failure, 3) repair, 4) test, 5) replace, 6) record results. The role of clerk is performed by a single worker, and repair operations are executed by a labour pool comprised of 8 workers.

For the performance prediction of the new process, a simulation model is built using ExtendSim tool[29].

One month period, which has 160 hours with additional 40 hours warming-up time, is simulated and several performance metrics are measured. Core performance indicator of equipment maintenance sub-process is average throughput time from the start of maintenance request registration to the end of result recording.

The predicted average throughput time for new process is 7.27 hours by simulation experiment. The trend of throughput time is plotted versus simulation time in [Figure 5], which shows stabilization of average throughput time as simulation time proceeds. The results indicate that the average throughput time of new process is reduced by 12 %.

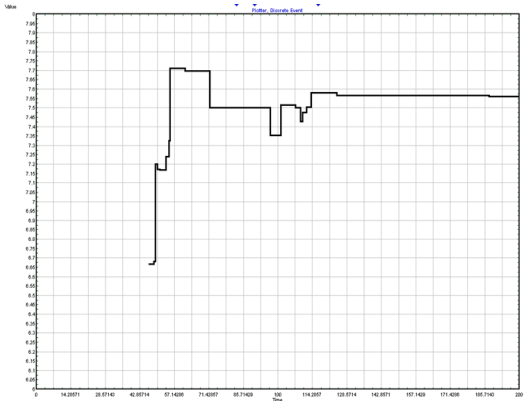

Figure 5. Average throughput time trends

3. Execution Phase

During the execution phase, a BAM (Business

Activity Monitoring), which is closely linked to KPIs through the PPMM, is conducted for providing real-time access to critical business performance indicators to improve the speed and effectiveness of business operations[8].

The goal of BAM is to provide real-time information about the status and results of various business operations, processes, and transactions. Representative feature of BAM is that it monitors many enterprise information systems simultaneously and displays exceptional situation on the dashboard if symptoms of problem are identified by pre-defined rules[6].

During the execution phase of business process, the impact of each unit task's performance on the enterprise-level performance can be monitored and measured in real-time, and the analysis result of monitoring activities can be reflected to the business process operations by integrating proposed PPMM and the BAM system function.

For the successful BAM, first of all, monitoring objects of which performance should be measured in real-time are selected. Candidates for real-time performance measurement in an enterprise are categorized into two groups: One group is such KPIs that are significant to attain an enterprise goal through the real-time performance measurement. Target KPIs for monitoring can be selected based on KPI model of PPMM at any KPI level. The other group is such business processes that should be controlled and executed by the enterprise BPM system. PPMM in this paper is used for determining which processes should be executed without error to achieve a target SLK.

For example, in the Case company S, 'efficiency of cooperation with venders' of customer perspective is selected as a target SLK for BAM.

Since SLK is enterprise level, it is too broad in scope and difficult to calculate and monitor comprehensively. Therefore, most contributing TLK to selected SLK is the candidate KPI for monitoring.

Based on the PPMM, we identify that the most contributing TLK to this SLK is 'material supply cooperation with vendor (MSC)' in the KPI model. The contributing OLKs for this TLK can be found in the KPI model. These are on-time collaborative design (OTCD), on-time supply (OTS) and emergency material order rate (EMO).

As a result, 'material supply cooperation with vendor' is selected as a monitoring object, and is calculated by weighted average of 3 contributing OLKs as mentioned above. Its formula is as follows:

$$MSC=3/7*OTCD+3/7*OTS+ 1/7*(100-EMO) \quad (1)$$

In the equation (1), the weight of each OLK is the amount of contributions to TLK, which is specified in PPMM.

[Table 1] explains meaning of terms used in the above equation

Table 1. Meaning of terms used in the equation(1)

Term	Meaning	calculation
OTCD	on-time collaborative design	(monthly # of on-time collaborative design completion) / (monthly completed total # of collaborative design) * 100
OTS	on-time supply	(monthly # of on-time supply / monthly total # of supply) * 100
EMO	emergency material order rate	monthly # of issued emergency order) / (monthly total # of purchase order)* 100

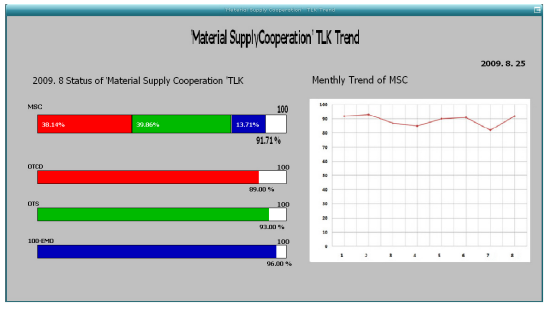

Figure 6. Display of KPI monitoring

[Figure 6] shows dashboard for the monitoring of 'material supply cooperation with vendor' TLK trend. The left part shows the status of certain month as a bar chart: The upper bar represent current status of 'material supply cooperation' index by weighted average of other three indexes as formulated above. Lower three bars describe the current status of three OLKs contributing to MSC SLK. The right part of [Figure 6] shows monthly trend of MSC index as a graph of broken line.

V. Conclusions

Whether the enterprise focuses on profitability, earning per share or market share growth, hitting such goals is becoming ever more challenging. To cope with these challenges, companies must analyze, (re)design, monitor and manage their processes to align with business performance.

The paper proposes life cycle-based BPM framework integrated with the process-based performance measurement model, in which all BPM activities are closely related and linked with KPIs through the entire BPM life cycle for better performance management.

By using the proposed performance-centric BPM framework, company practitioners involved in the process innovation projects can easily and efficiently find the most influencing processes upon enterprise performance in the process diagnosis phase, evaluate the performance of newly designed process in the process design phase, and monitor the KPIs of new business process and the process itself during the process enactment phase.

Currently, the implementation of BPM framework in this paper is a stand-alone system since it is built on an Excel sheet. In the near future, further research will be required to develop an integrated information system supporting the PPMM.

Moreover, as well as the importance of business process to an enterprise performance, knowledge is also treated as a critical driving force for attaining enterprise performance goals because knowledge facilitates the better business decision makings in a timely fashion.

Therefore, as a further research, development of process-centered enterprise structure integrating process, performance and knowledge in a value chain context is needed.

참 고 문 헌

[1] 한관희, 최상현, *비즈니스 프로세스 관리,* 한경사, 2013.

[2] K. Kasemsap, "Chapter 10. Mastering Business Process Management and Business Intelligence in Global Business, Organizational Productivity and Performance Measurements Using Predictive Modeling and Analytics," IGI Global, 2017.

[3] W. M. P. van der Aalst, "Business Process Management: A Comprehensive Survey," ISRN Software Engineering, pp.1-37, 2013. doi:10.1155/2013/507984.

[4] M. Dumas, M. La Rosa, J. Mendling, and H. Reijers, *Fundamentals of Business Process Management,* Springer-Verlag, Berlin, 2013.

[5] K. H. Han and J. G. Kang, "A Process-Based Performance Measurement Framework for Continuous Process Improvement," International Journal of Industrial Engineering - Theory, Application and Practice, Vol.14, No.3, pp.220-228, 2007.

[6] 한관희, 강진구, "실시간 기업을 위한 비즈니스 활

동 모니터링 시스템의 설계 및 구현," Entrue Journal of Information Technology, Vol.7, No.2, pp.115-123, Jul. 2008.

[7] K. H. Han, J. G. Kang, and M. Song, "Two-Stage Process Analysis Using the Process-Based Performance Measurement Framework and Business Process Simulation," Expert Systems with Applications, Vol.36, No.3-2, pp.7080-7086, 2009.

[8] K. H. Han, S. H. Choi, J. G. Kang, and G. Lee, "Business Activity Monitoring System Design Framework Integrated with Process-based Performance Measurement Model," WSEAS Transactions on Information Science and Applications, Vol.7, No.3, pp.443-452, 2010.

[9] 한관희, 이준우, "복합 이벤트 처리 시스템 개발을 위한 ECA 규칙 기반 이벤트 중심 아키텍처 설계," Entrue Journal of Information Technology, Vol.11, No.3, pp.88-99, 2012.

[10] 아체 사레이도렛하니, 한관희, "효율적인 비즈니스 프로세스 진단 및 설계를 위한 프로세스 마이닝과 시뮬레이션 통합 프레임워크," 한국콘텐츠학회논문지, 제17권, 제5호, pp.221-233, 2017.

[11] T. Munehira and M. Mori, "The New Business Model Designing Method to Implement the Strategy in the To-Be Business Model," Proceeding of the 11th Annual International Conference on Industrial Engineering Theory, Applications and Practice, Nagoya Japan, pp.732-737, 2006.

[12] T. R. Ariyachandraa and M. N. Frolick, "Critical Success Factors in Business Performance Management-Striving for Success," Information Systems Management, Vol.25, No.2, pp.113-150, 2008.

[13] 김상국, 신성호, "BPM을 기반으로 한 ISO 9001 품질 경영 시스템 구축," 한국콘텐츠학회논문지, 제6권, 제4호, pp.38-45, 2006.

[14] W. M. P. van der Aalst et al., "Business Process Mining: An Industrial Application," Information Systems, Vol.32, No.5, pp.713-732, 2007.

[15] http://www.processmining.org

[16] N. Garg and S. Agarwal, "Process Mining for Clinical Workflows," Proceedings of the International Conference on Advances in Information Communication Technology & Computing, Bikaner, India, 2016.

[17] 최상현, 한관희, 임건훈, "프로세스 마이닝 기법을 활용한 고장 프로세스 분석," 한국콘텐츠학회논문지, 제13권, 제4호, pp.399-406, 2013.

[18] M. Laguna and J. Marklund, *Business Process Modeling, Simulation and Design*, CRC Press, Boca Raton, FL, USA, 2013.

[19] W. M. P. Van der Aalst, *Business Process Simulation Survival Guide*, Handbook on Business Process Management, Springer, Berlin, Heidelberg, Vol.1, pp.337-370, 2015.

[20] J. April, M. Better, F. Glover, J. P. Kelly, and M. Laguna, "Enhancing Business Process Management with Simulation Optimization," BP Trends, pp.1-11, 2005.

[21] A. Safari, "An Effective Practical Approach for Business Process Modeling and Simulation in Service Industries," Knowledge and Process Management, Vol.23, No.1, pp.31-45, 2016.

[22] T. Broda and K. Clugage, "Improving Business Operations With Real-Time Information: How to Successfully Implement a BAM Solution," Business Integration Journal, Jul/Aug. 2006.

[23] W. Jiang, T. Au, and K. L. Tsui, "A statistical process control approach to business activity monitoring," IIE Transactions, Vol.39, No.3, pp.235-249, 2007.

[24] Institute of Management Accountants, *Tools and Techniques for Implementing Integrated*

Performance Management Systems, IMA Publication Number 98332, 1998.

[25] http://www.wfmc.org

[26] M. Song and W. M. P. van der Aalst, "Towards comprehensive support for organizational mining," Decision support systems, Vol.46, No.1, pp.300-317, 2008

[27] W. M. P. Van der Aalst, M. H. Schonenberg, and M. Song, "Time Prediction Based on Process Mining," Information Systems, Vol.36, No.2, pp.450-475, 2011.

[28] W. M. P. van der Aalst, *Process Mining*, Springer, 2016.

[29] Imagine that Inc., *ExtendSim User's Guide*. Imagine That Inc., San Jose, CA, USA, 2017.

저 자 소 개

한 관 희(Kwan Hee Han) 정회원

- 1982년 2월 : 아주대학교 산업공학과(공학사)
- 1984년 2월 : 한국과학기술원 산업공학과(공학석사)
- 1996년 8월 : 한국과학기술원 자동화및설계공학과(공학박사)
- 2000년 3월 ~ 현재 : 경상대학교 산업시스템공학부 교수

<관심분야> : BPM, Process Mining, Digital Manufacturing, Modeling & Simulation