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Evaluation models for service oriented process in spare parts management

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Abstract Maintenance, repair, operation (MRO) and spare parts supply is a critical issue for expensive repairable items such as cutting tool in the metal cutting industry. A new type of servicization model in the cutting tool supply chain reveals that most research has focused on local optimization of operational issues such as tool monitoring, spare parts management, logistics, and scheduling problems in isolation. The innovation in technologies, such as radio frequency identification and web services, for information sharing provides the ability to plan and schedule the tool requirement cross different layers in the MRO supply chain. However, their impact on the, technology complexity and performance is uncertain. In order to provide evaluation approach at the design phase, this paper analyzes the service oriented process from two dimensions that evaluate technology complexity, and system performance. Implementation of these evaluation models helps organizations analyze the business processes and further improve them through the analysis.

Keywords Service oriented architecture (SOA) · Maintenance, Repair, Operation (MRO) · Supply chain management (SCM) · Performance measurement

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Introduction

Manufacturers, such as aeronautical and defense, automotive, high-tech or electronic makers, and petroleum industry spend about $41 billion annually for maintenance, repair, operation (MRO) and spare parts supply (Jackman 2007). Of this, the actual price of a spare is about 39% where as procurement process represents 25% and managing the inventories represents 36% of the overall cost (Lynn 2004). Clearly, reducing the cost of procuring and managing spare parts inventories can have a significant impact in many industries. In order to reduce high inventory and procurement related costs, innovative business model are being developed for servicization in MRO supply chain, which do more than just stock and ship products. Servicization charges a customer for the service instead of selling them the products (Oldham et al. 2003). The cutting tool provider, pursuing to be a total MRO solutions supplier, is a typical example of this servicization model (Vurva 2002). For example, Blueswarf Inc. remotely monitors the machining process, schedules frequency analysis, and notifies operators of tool changes, speed tuning, potential maintenance issues, and further automatic replenishment. Based on aligning the incentives of manufacturers and tool suppliers, the improved operation efficiency and extended tool life drops tooling cost dramatically. To provide the service, distributors/suppliers have to manage manufacturers' tool from operation status to plan a replenishment schedule.

Enhancement of operation efficiency requires application of emerging information technology, such as sensors, radio frequency identification (RFID), and web services. Oliveira et al. (2008) have suggested an open CNC with sensors to collect information about the machining process and production. Industry applications use a sensor-driven technology on acoustic emission, force sensing, and torque for machining process monitoring and control to estimate tool life or classify certain wear parameters (Shi and Gindy 2007). However, the signals obtained from the sensors are dependent on various factors, including disturbances from outbreaks at cutting edges, chatters, and machining conditions, that can increase the difficulty of tool wear monitoring (Sick 2002).

Other researches address the prediction and prevention of the tool degradation rather than detecting the faults in traditional maintenance practices. Optimizing asset utilization may involve tuning up machine parameters such as feed, speed, and depth of cut to maximize usage of a worn tool or minimize failure risks (Kwon and Fischer 2003; Lee et al. 2006). In this scenario, integrating RFID technology—a sensor-driven maintenance system—can be effective for tool management. The RFID tag attached to the cutting tool records operation status, remaining tool life, and calibration data, along with data from other physical sensors such as accelerometers and acoustic sensors. These records would then suggest for tool replacement to eliminate the potential problem of tool wear (Cheng and Prabhu 2007a).

Moreover, Web services establish the communication infrastructure of the overall system to resolve the problem of information integration among distributed, cross-platforms, and heterogeneous systems. The web services technology helps in seamless integration of the inner business process as well as the business-to-business (B2B) process in the supply chain. Although such integration approach can significantly enhance the efficiency of the MRO supply chain, its impact on the complexity of processes, usability, and performance is still uncertain.

Although business to business (B2B) transaction or supply chain collaboration can be achieved by different technology such as agent-based approach or workflow protocol (Feng 2005; Park 2002), it also may increase process complexity. This paper proposes two analysis models that evaluate technology complexity and performance measurement to determine the success of a project. The analysis also suggests sufficient hardware resources for the new technology to execute smoothly and increase user experience. The dimensions considered in these analysis models address service processes from a different viewpoint to analyze the business processes thoroughly and improve their performance. Implementation of these evaluation models provides a concrete business process analysis for the cutting tool supply chain while deciding whether to adopt the new technology at the design phase.

Therefore, this paper focuses on solving tool management using RFID and web services technology and develops two analysis models for evaluating technology complexity, and performance measurement. According, the organization of this study is: "Spare parts supply chain management" presents a framework for the spare parts supply chain with the aid of RFID and web services technology as well as a unified tool procurement planning. "Complexity study" evaluates the technology complexity measurement in an exploratory project on cutting tool procurement. "System performance study" formulates an analytical model based on the queuing theory to predict the service duration time within the web services environment. The last section concludes the paper with prospective future work.

Spare parts supply chain management

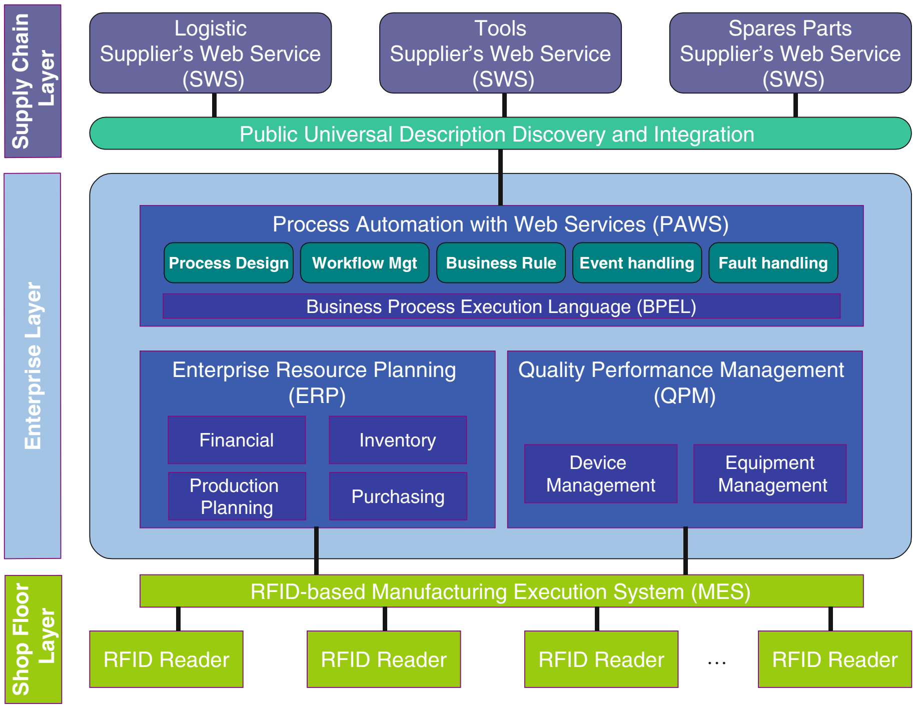
Framework of service oriented spare parts supply chain

The shop floor layer triggers the demand for cutting tools. Each Computer Numerical Control (CNC) tool has an RFID tag that records the tool's preset data (projection, edge radius, and effective diameter), operation data (speeds, feeds and depth of cut) and the usage time. With the tool attached to the spindle, configuration of the RFID reader on the CNC machine allows reading the data from the RFID tags. This avoids most common sources of potential data entry errors, tool-offsetting errors and possible tool crashes. After completion of each operation, the programmed RFID encoder on the CNC machine writes the usage time of the tool onto the RFID tag and further updates the Quality Performance Management (QPM) system. Based on the demand for tool replacement, as scheduled by QPM, a purchase order can be created from ERP in advance to avoid shortages and reduce downtime. Process Automation with Web Services (PAWS) is an automatic workflow system for the tool quotation process within and between the supply chains. In PAWS, ERP broadcasts the tool requirements to the web services of certificated suppliers, registered with the Universal Description Discovery and Integration (UDDI) server. Suppliers Web Services (SWS), located in each supplier's server, verifies the inventory and price in its own database and responds to the quotation based on its current status. The business logic of the Request for Quotation (RFQ) process in PAWS choosesthe candidate supplier and starts another RFQ process for the logistics provider. This automation workflow system not only integrates the inner-business process including QPM, ERP, and mailing system, but also combines the business-to-business (B2B) process in the supply chain. The following sections discuss, individual layers with prototype systems. Figure 1 shows the framework of the spare part supply chain.

Supply chain layer

In this layer, RFID enables a tool replenishment process and response to request for quotation (RFQ). The RFID information, providing tool specifications, is the bases for procuring replacement cutting tools from among several vendors. An illustration of the variation of supply chains uses emulation of

Fig. 1 Framework of applying RFID in cutting tool supply chain management



external actors, including tools vendors, spare parts vendors and logistic vendors. SWS in each supplier's server verifies the inventory and price in its own database and responds to the quotation based on its current status. On the procurement side, the main business process will be supplier selection, based on responses to RFQ.

Enterprise layer

The main software components in this layer include ERP, QPM, and PAWS.

ERP: The core system for enterprise operation includes foundation data (customer profile, supplier profile, and product profile), and production information (material requirement planning, bill of material, and routing). According to the production planning and inventory, ERP create shop orders to produce the product, purchase order to buy raw material, and spare parts. The financial module supports the purchasing transaction. The proof-of-concept implementation, in this study uses the TEAM (Total Enterprise Application Manager) as the ERP system.

QPM: A critical business system which captures data, processing data, and reporting information required for ISO/QS9000, fills the gaps of ERP systems. This study adopts the solution provided by IQS, Inc. as the implementation platform. The QPM system accumulates the tool usage time for cutting tools and CNC machines and triggers the demand for the tool replacement in the device management module, and preventive maintenance time for the CNC machine in the equipment management module. Based on the demand for tool replacement scheduled by the QPM system, the ERP system creates the purchase order for the spare parts vendors, in advance, to avoid shortages and reduce downtime.

PAWS: Process Automation Web Services (PAWS) is an automatic workflow system for the tool quotation process, within and between the supply chains. The detail of PAWS is explained in the following section.

Process automation web services (PAWS)

The business logic of the RFQ process in PAWS chooses the candidate supplier and initiates another RFQ process for the logistics provider. Based on one kind of process description languages, BPEL, PAWS constructs the automatic business process mechanism. BPEL is a combination of graph-oriented and procedure workflow language to describe the business process. It specifies the business process and interaction protocols (Akram et al. 2006). In BPEL, each task unit is defined as an activity. The basic activities include messaging (receive, invoke, and reply), data handing (assign) as well as many other kinds of control element: branch, iteration, event handling, fault handling, and compensation (canceling of committed actions). The advantage of BPEL is that business processes can incorporate different functions provided by web service partners which also solves the business integration implicitly. By representing a workflow that coordinates activities among other web services, BPEL allows the web services to invoke other web services, manipulate data and handle exceptions.

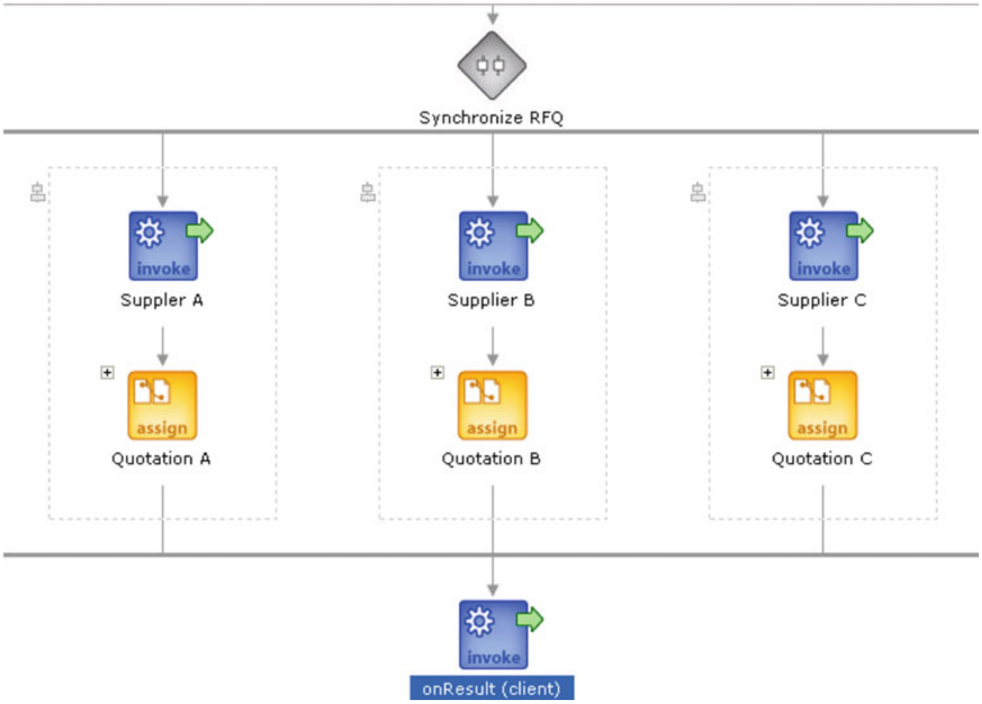


Fig. 2 Broadcast RFQ to each supplier in PAWS

Business analysts and managers are able to easily compose business processes graphically with tools such as Oracle BPEL Manager. These development tools allow the logic of the business process to be specified by graphically linking together desired activities. It is a graphic representation of the BPEL process implementing the RFQ process. Thus, PAWS demonstrates the use of workflow systems with the accuracy of RFID data collection to automate a transaction process to reduce the lead-time for the RFQ process. Figure 9 shows the quotation process which broadcasts the RFQ synchronous to each supplier. Figure 2 demonstrates the use of PAWS to automate a transaction process to shrink time consuming RFQ process.

RFID in spare parts supply chain

Shop floor layer

RFID-based MES: Combining RFID control, required development of the RFID-based MES system. Based on real-time shop floor status, material, capacity, and due date of orders, RFID-based MES creates detailed scheduling for each workstation and responds the available-to-promise date (ATP), work in progress (WIP), and material usage to ERP system. After the manufacturing process, the remaining tool life estimates can occur by machining parameters. Although there are many ways to evaluate the remaining tool life such as sound frequency analysis, here this paper applied the basic tool life evaluation approach according to the Taylor tool life equation.

CNC Machine: The main workstation contains toolholder which has to replace/calibrate when usage exceeds a period of time. Toolholder carries on a cutting tool and RFID tag. This paper focuses on monitoring and tracking the status of this tool. Interfacing with live CNC controller hardware will occur at a future stage.

RFID devices: This paper adopts the RFID device and RFID tag provided by Balluff, Inc. for the proof-of-concept implementation. The RFID device can function as RFID reader, as well as RFID encoder. The RFID tag attached to the cutting tool records the tool information and production parameters. The RFID device functions as reader and detects the tag and transfers data into RFID-based MES system. The RFID device functions as an encoder and writes operation status, remaining tool life, and calibration data into the RFID tag. The tool usage time for cutting tools and CNC machines in the RFID tag triggers the demand for tool replacement and preventive maintenance time for the CNC machine. The tool usage time accumulation process executes automatically by RFID technology, eliminating potential data entry errors and lost data. Figure 3 depicts the RFID tag's data structure, which may be divided into two kinds of data: pre-allocated data and flexible data. Pre-allocated data includes tool id, calibration data, production parameters, job id, and check-in/out time.

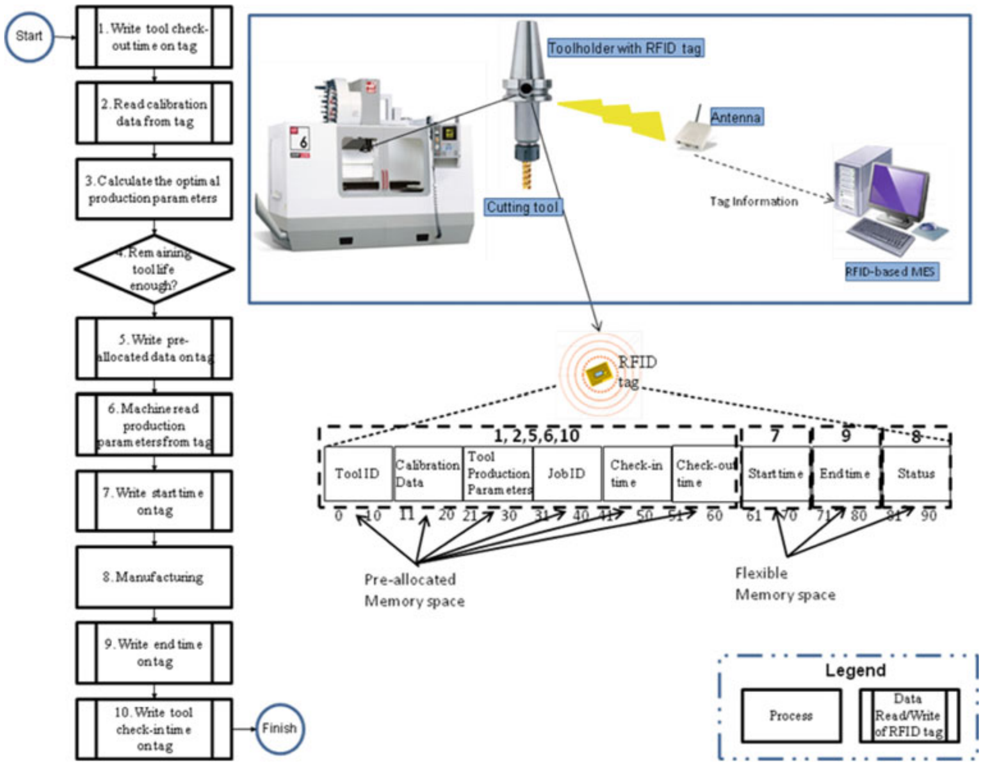


Fig. 3 The data structure of RFID tag in the manufacturing process

Complexity study

Although this supply chain framework provides the functionality and doable solution, there are still hiding costs which cannot be discovered before the implementation. The section will discuss the framework in usability, and complexity viewpoints.

Technology complexity metrics in software implementation

The technology complexity metric in process and system evaluation has been studied (Cheng 2008; Cheng et al. 2008). The resulting model, Business Process Analysis in Goal, Operations Methodology, and Selections (BPA-GOMS), is composed of two attributes—the internal complexity of an activity and the interaction complexity. The internal complexity models user-level behaviors and how to perform the business process using cognitive theory. Interaction complexity is identified through a business process analysis that examines interactions with other resources, including employees, customers and computer programs. Usability and interaction complexity provide insights into node level and information exchange in business process analysis. Figure 4 shows an example of information flow between components. Thus, inter-activity complexity can be measured using a sequence, as follows:

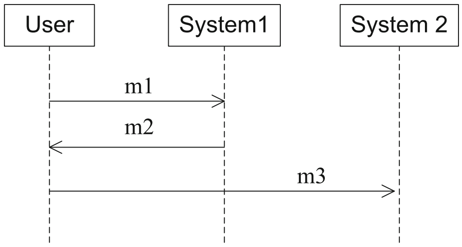


Fig. 4 Information exchange among components

Table 1 Inter activity complexity of Fig. 4

Elements	Fan-in	Fan-out	Inter-activity complexity
User	1	2	3
System 1	1	1	2
System 2	1	0	1

$$\begin{aligned}&\text{Inter-activity complexity}\\&\quad = \text{Total number of information flows}\\&\quad = (\text{Fan-in} + \text{Fan-out})\end{aligned}$$

The user's inter-activity complexity of Fig. 4 is 3. Table 1 shows the inter-activity of all elements. A relatively high information exchange indicates stress points in the business process. This means that a change in this component would tend to affect many other components, making implementation or modification of such a component difficult.

In this research, the complexity of intra-activity is measured by number of statements or operators. Thus:

$$\begin{aligned}&\text{Intra-activity complexity}\\&\quad = a^{*}(\#\text{ of external operators})\\&\qquad + b * (\#\text{ of internal operators})\end{aligned}$$

And, a and b are weighted parameters.

The fundamental principle behind the metrics is that the complexity of a business process is composed of two attributes—the internal complexity of an activity and the complexity of its interaction with the environment—and is expressed as follows:

$$\begin{aligned}&\text{Complexity} = \text{Intra-activity complexity}\\&\qquad \times (\text{inter-activity complexity})^{2}\end{aligned}$$

Raising the equation to the power of 2 is done to express the complexity as a nonlinear function, which means that the information flows contribute to the complexity of the business process in a nonlinear relationship with intra-activity complexity (Sheppard, 1993). It also reflects the fact that it is more difficult to perform the interactions among the entities than the individual activity. This evaluation approach has also applied in software complexity (Henry and Kafura 1981) and manufacturing complexity estimation (Phukan et al. 2005).

Figure 5 shows an example of the BPA-GOMS (Business Process Analysis-GOMS) model, which involves three-two systems. Each block contains the operation name, number of operators, and spending time. In this case, the assumptions of weight parameter are equal to one. Table 2 expresses the total complexity of this example and estimated time to complete the business process. These complexity metrics are intended to provide a basis for comparing design alternatives rather than to establish an absolute quantification. The inter-module metrics can evaluate interactions between systems and alleviate stress points, and uncover the reasons for those stress points. In the next section, we apply the complexity metric in the case study.

Steady-state of the intra-activity

Intra-activity complexity considers interactions between elements, and the inter-activity complexity take each node cognitive loading into account. But the real complexity of inter-activity strongly depends on activities performing frequency. The inter-activity complexity should consider the probability of each routing performed. This is quite true in the real life that each process path has its own probability. The higher probability of the path means the users spend more efforts on these frequently activities. Business can also more focus on improving these activities. It also provides an insight for business to perform the Business Process Reengineering (BPR). On the software point of view, developers need to emphasize on testing these high frequency process paths to reduce the major error probability. Therefore, the inter-activity complexity evaluates the routing transition and find out the long-run probability on all activities. These high probability activities and their structures represent the operational complexity.

For example, Fig. 6 shows two BPA-GOMS processes in nodes and arcs representation with the same structure and different transition probability. Figure 6a has the higher probability performing in a linear process activity, and Fig. 6b has almost equally probability for each routes. In this case, the inter-activity complexity for these two business process are different and strongly depending on the transition probability. Therefore, this section discusses a dynamic business process analysis in examining routing transition. Based on the transition matrix, the probability of each process activity occurring can be achieve.

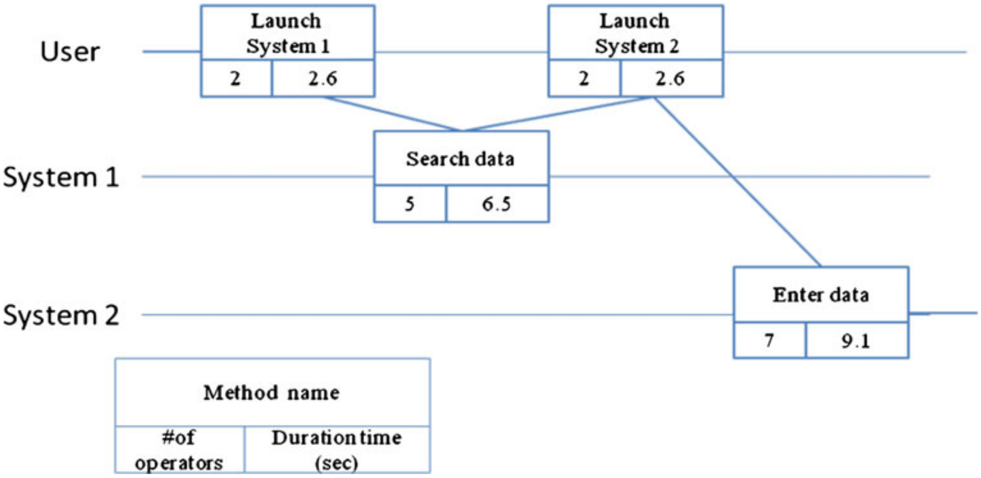


Fig. 5 Example of BPA-GOMS model

Table 2 Total complexity in an example of a BPA-GOMS model

Elements	Intra-activity	Inter-activity		Total complexity	Total time (s)
		Fan-in	Fan-out		
User	4	1	2	36	5.2
System 1	5	1	1	20	6.5
System 2	7	1	0	7	9.1
Total	16	3	3	63	20.8

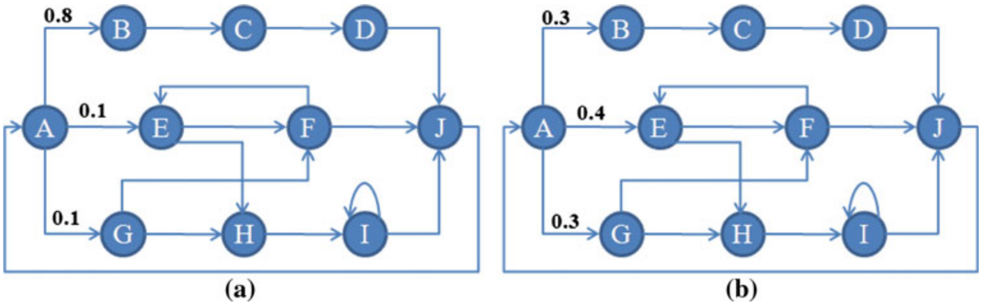


Fig. 6 The same structure with different transition probability

A business process with n nodes can be represented as an $n \times n$ matrix P. Where P_{ij} means there is a probability from node i to node j and 0 otherwise. Because every node has at least one link to another link in the business process, then each row sum of P is equal to 1, and P is called a transition matrix.

$$\sum_{i=1}^{n} p_{ij} = 1 \tag{1}$$

To find the long-term behavior of the business process, a stable equilibrium can be achieved using Markov Chain. A finite Markov chain defined by the stochastic matrix P has a unique stationary probability distribution if P is irreducible and aperiodic (Bolch et al. 2006; Liebler 2003).

If the Markov Chain M is stochastic matrix, irreducible and aperiodic, then it converges to a unique stationary probability, π (Bolch et al. 2006).

- Stochastic: a nonnegative matrix P is called stochastic if each row sum is equal to one.
- Irreducible: P means that the process is strongly connected. For each pair of nodes, there is a path between them.
- Aperiodic: P is said to be aperiodic if there is no integer k such that $P_k = P$. In other words, there is no directed cycle that the chain has to traverse.

The stationary probability distribution means that after a series of transactions P will converge to a steady-state probability vector π regardless of the choice of the initial probability vector. That is

$$\lim_{k\to\infty} p_k = \pi \tag{2}$$

The steady-state is presented as

$$p_k = p_{k+1} = \pi \tag{3}$$

And thus

$$\pi = p^T \pi \tag{4}$$

Using the stationary probability distribution $\boldsymbol{p}$ as the entropy vector is reasonable and quite intuitive because it reflects the long-run probabilities that a random instance will pass the activity. In other words, an activity is the key process component if the probability is high.

However, business process is not necessary to have the strongly connected. In this research, the PageRank approach is adopted (Page et al. 1998). To solve the irreducible and aperiodic problem in transition matrix, adding a link from each node to every node and give each link a small transition probability controlled by a parameter d.

The improved transition matrix becomes

$$p' = \left((1-d)\,\frac{E}{n} + dA^T\right) P \tag{5}$$

Table 3 Attributes of transition variants

Path transition variable	Probability (a)	Probability (b)
p_{ab}	0.8	0.3
p_{ae}	0.1	0.4
p_{ag}	0.1	0.3
p_{bc}	1	1
p_{cd}	1	1
p_{dj}	1	1
p_{ef}	0.7	0.7
p_{eh}	0.3	0.3
p_{fj}	0.5	0.5
p_{fe}	0.5	0.5
p_{gh}	0.6	0.6
p_{gf}	0.4	0.4
p_{hi}	1	1
p_{ij}	0.9	0.9
p_{ii}	0.1	0.1
p_{ja}	1	1

where E is ee^T, and is a column vector of all 1's. and thus E is a $n \times n$ square matrix of all1's.

Thus, $(1-d)\,\frac{E}{n} + dA^T$ is a stochastic matrix with irreducible and aperiodic.

If the equation is scaled so that $e^T P = n$,

$$P' = (1-d)\,e + dA^T P \tag{6}$$

The parameter d is called the damping factor which can be set between 0 and 1. $d = 0.85$ was used in the Google PageRank.

Using the power iteration method, here is the pseudo code

```
Process flow-Iterate (G)
    $P_0 \leftarrow en$
    $k = 1$
repeat
        $P_{k+1} \leftarrow (1-d)\,e + dA^T P_k;$
        $k = k + 1;$
until  $\|P_{k+1} - P_k\| < \varepsilon$
return  $P_{k+1}$
```

Table 3 shows the transition variants for each in two models. The only difference is the routing transition variable p_{ab}, p_{ae} *and* p_{ag}. Using the pageRanking algorithm and manipulate with the transition matrix, the steady probability can be achieved. In this example, $d = 0.9$

The single-step transition probability matrix for model (a) is represented as

$$P_1^{(a)} = \begin{bmatrix} 0.01 & 0.73 & 0.01 & 0.01 & 0.1 & 0.01 & 0.1 & 0.01 & 0.01 & 0.01 \\ 0.01 & 0.01 & 0.91 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 \\ 0.01 & 0.01 & 0.01 & 0.91 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 \\ 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.91 \\ 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.64 & 0.01 & 0.28 & 0.01 & 0.01 \\ 0.01 & 0.01 & 0.01 & 0.01 & 0.46 & 0.01 & 0.01 & 0.01 & 0.01 & 0.5 \\ 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.37 & 0.01 & 0.55 & 0.01 & 0.01 \\ 0.01 & 0.01 & 0.01 & 0.9 & 0.01 & 0.01 & 0.01 & 0.01 & 0.91 & 0.01 \\ 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.1 & 0.82 \\ 0.91 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 \end{bmatrix}$$

The steady probability

$$\pi_\infty^{(a)} = [0.19\ 0.15\ 0.14\ 0.14\ 0.04\ 0.05\ 0.02\ 0.03\ 0.04\ 0.20]$$

The steady probability

$$\pi_\infty^{(b)} = [0.19\ 0.05\ 0.05\ 0.06\ 0.13\ 0.11\ 0.05\ 0.07\ 0.08\ 0.20]$$

Technology complexity evaluation in tool replenishment process

Tool replenishment process

Manual process: Fig. 7 shows the process flow of the manual tool replenishment process. In the replenishment process, there are three events which may cause different scenarios. The first one is in OP6 that an operator may have 0.7 probabilities to reject using the tool after evaluating the tool condition, and request a new one. The 0.3 probability for an operator uses the cutting tool and causes the tool failure during the manufacturing. The other two events occur in OP15 and OP 20 that purchasing manager has 5% to miss the purchasing information from vendors. The detail description of process is explained in Table 4. The numbers of operators for each operation are assumed in this research.

RFID-based automated process: Fig. 8 shows the process flow of the RFID-aided tool replenishment process. With the advantage of recording processing time to estimate remaining tool life, the QPM sends an alert for the operator to evaluate the remaining tool life. Therefore, an operator may have less chance (such as 1%) to use the cutting tool and causes the tool failure during the manufacturing. In addition, the web services technology enables the autonomous responding to purchase requests. This can reduce information exchange lost problems. The detail description of process is explained in Table 5.

The resulting network models are depicted in Figs. 9 and 10. The total complexity have been translated in the transiton matrix and the computation explains above have been applied to quantify the intra-activity complexity, and inter-activity

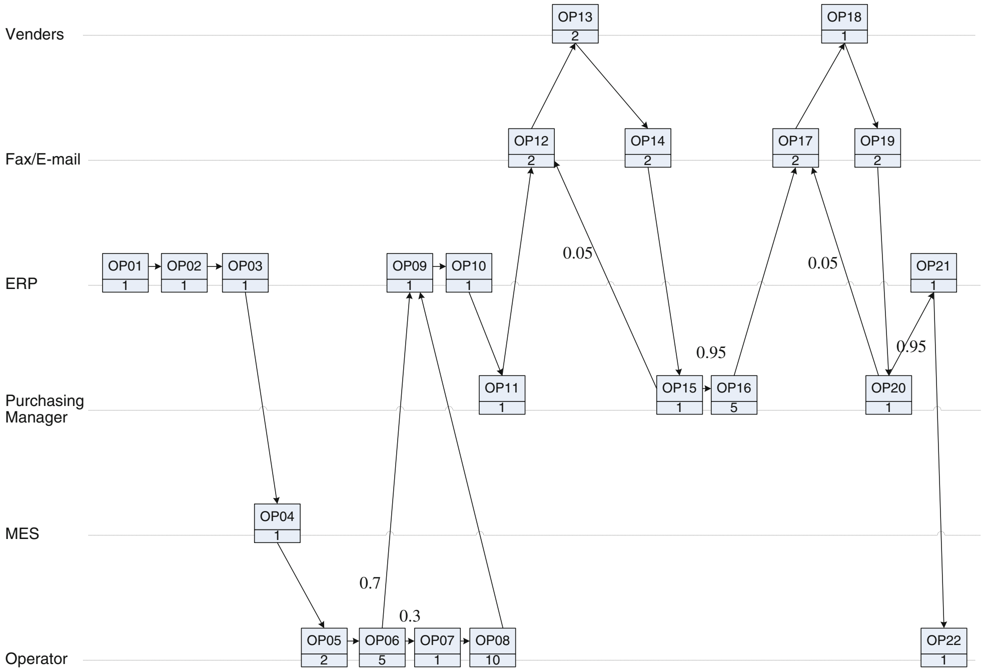


Fig. 7 BPA-GOMS model of manual tool replenishment process

Table 4 Description of manual tool replenishment process

OP No.	Description	# Of operators
OP01	ERP receives orders from customer	1
OP02	ERP creates work orders based on the production schedule	1
OP03	ERP releases work orders to MES in the shop floor	1
OP04	MES creates detail schedules considering resources, materials, machines, and tools	1
OP05	Operators check the remaining tool life visually	2
OP06	Operators evaluate whether the job can be completed with the remaining tool life or not. It not, feedbacks to ERP. Otherwise, proceeding to produce	5
OP07	Manufacturing	1
OP08	Tool failure. The tool cannot complete the job, and the production has to be stopped. Feedback to ERP	10
OP09	ERP adjusts a new production plan based on tool status from shop floor feedback	1
OP10	ERP starts a new purchasing plan, and informs to a purchasing manager	1
OP11	A Purchasing manager gets the certified tool vendors from ERP	1
OP12	The purchasing manager sends out a RFQ to vendors via e-mail or fax	2
OP13	Vendors receive the RFQ and respond price and available date	2
OP14	Vendors respond a price and available date via e-mail or fax	2
OP15	The purchasing manager confirms receiving all responses. If not, inform to vendors again (go to OP11)	1
OP16	The purchasing manager compares the price and chooses an appropriate vendor	5
OP17	The purchasing manager sends out the RFP to the selected vendor via e-mail or Fax	2
OP18	The selected vendor accepts the offer	1
OP19	The selected vendor sends out the acknowledgment of the RFF via e-mail or Fax	2
OP20	The purchasing manager confirms receiving the acknowledgement. If not, inform the selected vendor again (go to OP17)	1
OP21	The purchasing manager updates the new tool purchasing into ERP	1
OP22	The operator receives the new tool	1

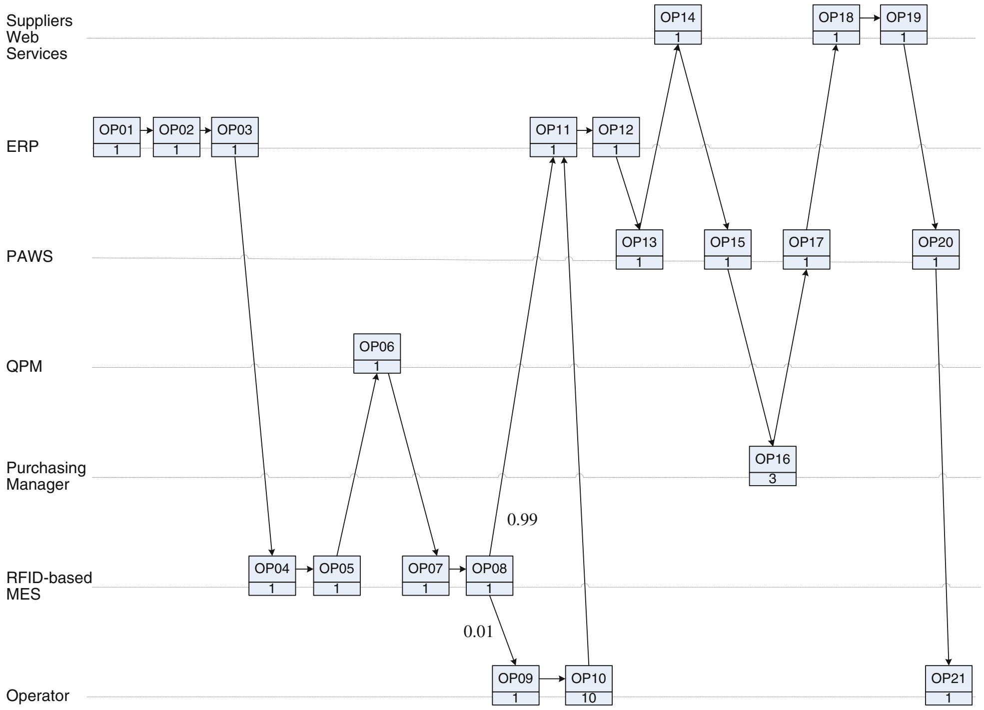


Fig. 8 BPA-GOMS model of RFID-aided tool replenishment process

Table 5 Description of RFID-aided tool replenishment process

OP No.	Description	# Of operators
OP01	ERP receives orders from customer	1
OP02	ERP creates work orders based on the production schedule	1
OP03	ERP releases work orders to RFID-based MES in the shop floor	1
OP04	MES creates detail schedules considering resources, materials, machines, and tools	1
OP05	RFID-based MES requests remaining tool life from QPM	1
OP06	QPM retrieve the individual tool life	1
OP07	RFID-based MES adaptively adjust production parameter to fit production scheduling	1
OP08	If the job can be completed with the remaining tool life or not. It not, feedbacks to ERP. Otherwise, proceeding to produce	1
OP09	Manufacturing	1
OP10	Tool failure. The tool cannot complete the job, and the production has to be stopped. Feedback to ERP	10
OP11	ERP adjusts a new production plan based on tool status from shop floor feedback	1
OP12	ERP starts a new purchasing plan using PAWS, and informs to a purchasing manager	1
OP13	PAWS broadcasts RFQ to certified tool vendors web services	1
OP14	Vendors' web services receive RFQ and send the price back using web services automatically	1
OP15	PAWS selects the appropriate vendor based on defined business rules, and informs a purchasing management	1
OP16	The purchasing manager accepts the suggested vendor	3
OP17	PAWS sends out the RFP to the selected vendors using web services	1
OP18	The selected vendor web service receive the RFP, and accept the offer	1
OP19	The selected vendor web service confirms the RFP using web services	1
OP20	PAWS receives the confirmation, and updates with ERP, QPM, and RFID-based MES	1
OP21	The operator receives the new tool	1

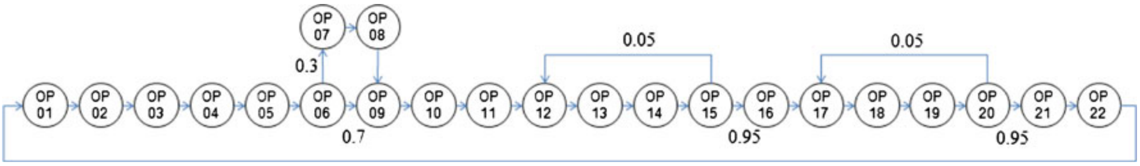


Fig. 9 Network model of manual process

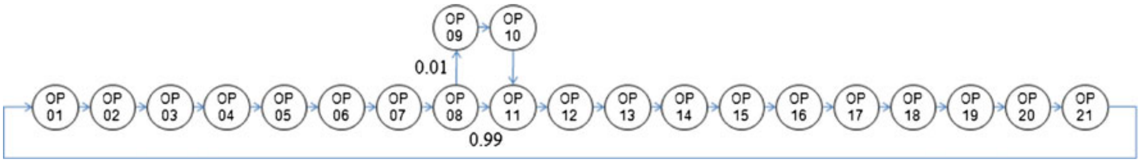


Fig. 10 Network model of RFID-based process

Table 6 Results of description of RFID-aided tool replenishment process

OP No.	Manual tool replenishment process			RFID-aided tool replenishment process		
	Steady-state probability	# Of operators	Intra-activity complexity	Steady-state probability	# Of operators	Intra-activity complexity
OP01	0.0458	1	0.0458	0.0505	1	0.0505
OP02	0.0457	1	0.0457	0.0503	1	0.0503
OP03	0.0457	1	0.0457	0.05	1	0.05
OP04	0.0457	1	0.0457	0.0498	1	0.0498
OP05	0.0457	2	0.0914	0.0495	1	0.0495
OP06	0.0456	5	0.228	0.0493	1	0.0493
OP07	0.0169	1	0.0169	0.0492	1	0.0492
OP08	0.0197	10	0.197	0.049	1	0.049
OP09	0.051	1	0.051	0.0052	1	0.0052
OP10	0.0505	1	0.0505	0.0094	10	0.094
OP11	0.05	1	0.05	0.0569	1	0.0569
OP12	0.0518	2	0.1036	0.056	1	0.056
OP13	0.0512	2	0.1024	0.0552	1	0.0552
OP14	0.0506	2	0.1012	0.0544	1	0.0544
OP15	0.0501	1	0.0501	0.0537	1	0.0537
OP16	0.0474	5	0.237	0.0531	3	0.1593
OP17	0.0493	2	0.0986	0.0526	1	0.0526
OP18	0.0489	1	0.0489	0.0521	1	0.0521
OP19	0.0486	2	0.0972	0.0516	1	0.0516
OP20	0.0483	1	0.0483	0.0512	1	0.0512
OP21	0.0458	1	0.0458	0.0509	1	0.0509
OP22	0.0458	1	0.0458			
Total	1	45	1.84661	1	32	1.1907

Table 7 Complexity analysis of manual process

Elements	Intra-activity	Inter-activity		Total complexity
		Fan-in	Fan-out	
Vendors	0.1513	2	2	4208
Fax/E-mail operations	0.4006	6	4	40.06
ERP	0.2845	3	3	10.242
Purchasing manager	0.3854	3	5	24.6656
MES	0.0457	1	1	0.1828
Shop floor operators	0.5791	2	2	9.2656
Total	1.8466	17	17	86.8368

Table 8 Complexity analysis of RFID-aided process

Elements	Intra-activity	Inter-activity		Total complexity
		Fan-in	Fan-out	
Suppliers' web services	0.1581	2	2	2.5296
ERP	0.2637	2	2	4.2192
PAWS	0.2127	4	4	13.6128
QPM	0.0493	1	1	0.1972
Purchasing manager	0.1593	1	1	0.6372
RFID-based MES	0.1975	2	3	4.9375
Shop floor operators	0.0992	2	1	0.8928
Total	1.1398	14	14	27.0263

complexity before and after applying RFID and web services in cutting tool replenishment process. Table 6 shows the transition variants for each in two models. Using the pageRanking algorithm and manipulate with the transition matrix, the steady probability can be achieved. In this example, $d = 0.9$.

Based on these BPA-GOMS models, the results of the analysis of the complexity of each business process are shown in Tables 7 and 8, respectively. Each element has its intra-activity and inter-activity complexity with other elements. The total complexity is calculated based on "Technology complexity metrics in software implementation" and "Steady-state of the intra-activity". It shows that the manual process needs more operators (including external and internal operators) to complete the entire procurement process. The result shows that the RFID-aided process has a lower score (27.03) than the manual process (86.84). This indicates that the new process is easy to use because there is less complexity.

In this case, because suppliers, ERP, and purchasing managers all use the web services as a single platform to input and communicate information, the effort to verify information lost can be eliminated, thereby reducing the probability of communication and information exchange error. Using RFID in the cutting tool management, operators obtain enough information in evaluating cutting tool conditions to complete a job. The example also shows a decrease of 68% in the total complexity, suggesting that the RFID integrated process has higher usability.

System performance study

Performance modeling for web services environment

In this cutting tool supply chain framework, varieties of messages exchange between different systems via web-services. A message from a client, issued to request web service, may have to wait in a queue if the web services cannot serve multiple messages at the same time, and the web services processing time is greater than the arrival time between new web services requests. The end-to-end response time, the time from when a request enters the web services system until it leaves is the most important performance measure to end users. From a system provider's point-of-view, the rate of the web services processing and the number of requests served per unit time is more important.

Therefore, the study uses a queuing network model to estimate the performance index of the process service time. The details of the assessment technique depend on the type of request—open or closed. In open queuing networks, the

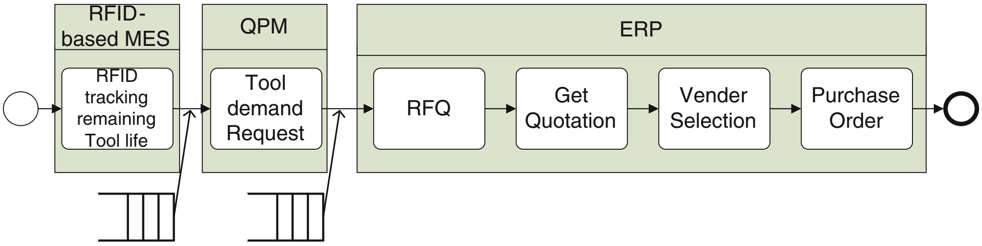


Fig. 11 Tool replenishment process flow

Fig. 12 The estimated value

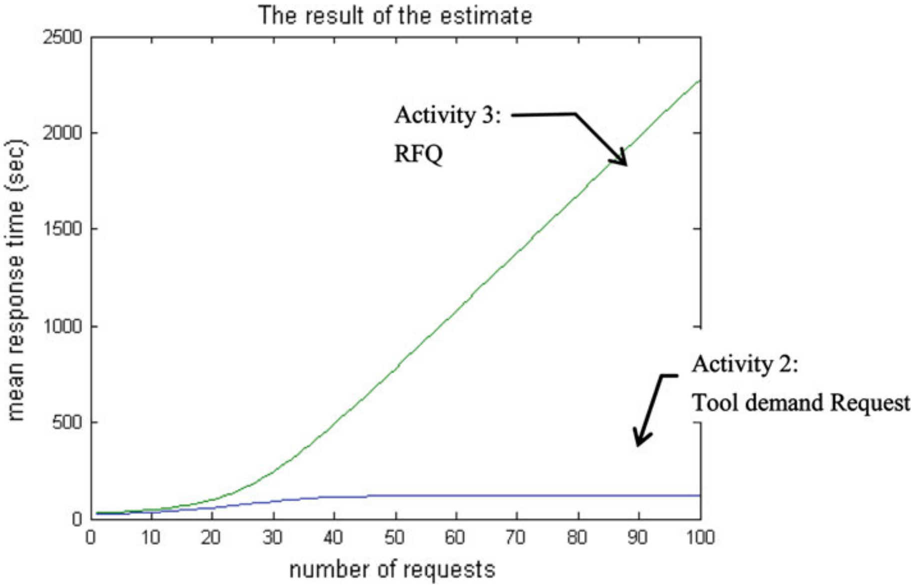


Table 9 The average processing time for each activity

No	Activity	Mean (s)
1	RFID tracking remaining tool life	20
2	Tool demand request	24
3	RFQ	30
4	Get quotation	180
5	Vender selection	25
6	Purchase order	20

arrival rate of requests characterizes the workload. Therefore, the total number of requests in the system can vary over time. On the other hand, in closed queuing networks, the number of clients and the amount of time spent by a web service between receiving a request and submitting a response governs the rate of requests. Since the number of clients in the cutting tool supply chain framework determines the number of requests, appropriate system model is a closed queuing network. The solution technique used is the mean value analysis (MVA) algorithm (Stuck and Arthurs 1985) that relies on three equations:

1. Little's formula:

$$Q_m = X R_m, \tag{7}$$

   where Q_m is the queue length of request at the queue, m. X is the throughput rate. R_m is the response time for the request at the queue m.

2. Mean waiting time:

$$R_m = D_m(1 + Q_m), \tag{8}$$

   where D_m is the mean of processing time for the web services.

3. Throughput rate

$$X = \frac{n}{\sum_{m=1}^{M} R_m + Z} \tag{9}$$

   where X is the throughput of the request with n requests. z is the time spent by a tool before submitting a request.

Comparing the predicted response time with the actual response time, measured experimentally verifies the accuracy of the baseline queuing model is verified. The result

Table 10 The comparison of estimated value and experimental results (average from 10 experiments)

Number of requests	Evaluation process	Average time (min)	Difference (min)
Requests = 5	Estimated service time	5.15	1.02
	Experimental result	6.17	
Requests = 50	Estimated service time	19.08	1.92
	Experimental result	17.16	
Requests = 100	Estimated service time	43.75	17.54
	Experimental result	61.29	

Table 11 Hardware specification

CPU	Pentium III
CRU frequency (MHz)	886
RAM (M)	384
HDD rpm	7200
HDD buffer (M)	2
Netcard	10/100 Mbps

of the queuing model shows the relationship between mean response time and number of requests. The assessment model yields values for performance measures such as utilization, throughput, response time, and queue length.

Performance evaluation in tool replenishment process

Within this proposed model, queues occur in two of the activities of the whole process. Figure 11 shows the whole process with two queues. The first queue occurs when the QPM receives an alert message from RFID-based MES; the server is occupied and starts to make a purchase decision. Other entering messages have to be queued until the current message transmits to the ERP system and release the port for the next alert message.

The second queue occurs when the message enters the ERP system. The ERP system integrates tool orders and requests quotations from vendors. Since ERP is also a web services based structure, information, whether to be received or passed forward, can only complete through one port. Whenever orders arrive to ERP at an occupied port, the sequent orders must to queue before processing to allow considering vendor quotations and placing the final order by ERP. The main activity in ERP when dealing with spare parts procurement is to send demands and receive quotations from vendors. This process occupies most of the time of the whole procurement process.

A developed estimation model analyzes the queuing model with the mean value analysis approach. Since queues occur during two activities of the whole process, the remaining activities are estimated using the average processing time. To illustrate reasonable shop floor demands, the study analyzes different scenarios: small-sized shops (5–10 requests), medium-sized industrial units (10–50 requests), and large-sized plants (50–100 requests), where the various numbers of demands occur simultaneously.

An estimation model is built to analyze the queuing model with mean value analysis approach. Since queues happen only in two activities in whole process, the rest activities is estimated using average processing time shown in Table 9. According to the performance model, the estimated total process service time with five requests is 5.15 min. Table 10 shows the result obtained from analytical model and compares it with observed results in average from the 10 times actual experiments. The simulation experiment was tested in the Penn State Laboratory. The experiment results are obtained from a simulation model, based on 5, 50, and 100 requests triggered at the same time.

Figure 12 illustrates the relationship between the numbers of requests and mean response time. When requests increase, the response time will increase also. With the requests received increasing, the response time increases in both simulation results and analytical model. However, the lack of accuracy in the 100 requests experimental result shows the analytical results cannot reflect the increased impact due to insufficient hardware capability (Cheng and Prabhu 2007b). To show the capability of web server, we list the hardware specification as Table 11.

Conclusions and future work

The adoption of RFID and web services for real-time sensing and communication provides strong capabilities for real-time service. The proposed two measurements provide the ability to analyze the business process at the design phase. The complexity study shows the RFID-based automatic process has the higher usability and accuracy than the manual process. The RFID-based procurement process has less complexity score than the original process based on our complexity model. The analysis of the performance model helps to estimate the service duration time for the web services environment. Future research can focus on refining the complexity metrics and performance model as well as apply them on the different industry.

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