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ANALYZING BOTTLENECK RESOURCE POOLS OF OPERATIONAL PROCESS USING PROCESS MINING

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Abstract. *Resource management is crucial in operational process management because it directly affects the performance of the operational process. However, resource models are generally very complicated and variable in real world process management. Therefore, process mining techniques based on the real log data can be utilized to scrutinize resource utilization and bottleneck detection. In this paper, a method for detecting the bottleneck is proposed in the viewpoint of the resource pool that was involved in the process execution. In addition, the method is combined with the critical path analysis in order to detect the bottleneck resource pools of the decomposed process models of the whole process.*
Keywords: Bottleneck, Resource pool, Critical path, Process mining

1. **Introduction.** Recently, most enterprises accumulate meaningful operation event data in their information systems to keep the track of conducted tasks. The stored event data is called an event log, which typically contains information about events referring to activities and cases. Process mining takes those event logs to discover process models, check conformance and enhance performance of the processes [1]. It also enables enterprises to analyze and improve activities based on operational process models. One can find a point to improve the performance of business process in manufacturing and service industries by identifying constraints such as a critical path or bottleneck phenomenon. A critical path is the sequence of activities that takes the most time among all paths in the process model [2,3], and a bottleneck is the congestion point of the systems which slows down the whole operation system [4].

There have been many studies of managing operational process by identifying the critical path and bottleneck phenomenon, especially in the project management field [5-7]. Project management focuses on managing the process performed one-time. In addition, all tasks in the process are performed determinatively. However, operational process in real world is more complicated and performed recursively. In addition, a sequence of tasks in the process is diverse and tasks are performed selectively. For example, a particular activity cannot be conducted while other activities are conducted in one case. Therefore, a new technique to identify critical path and bottleneck phenomenon reflecting this uncertainty issue is needed to manage operational process. In this paper, we introduce a new technique to identify those constraints in business process and analyze the impacts of them. In particular, we first present the concept of a resource pool and the capacity of resource pool. Then we introduce the technique to identify bottleneck in operational process.

2. Related Work. There have been many researches to manage a process. In traditional project management, PERT/CPM has been widely used in many areas to plan and control a schedule. PERT (Program Evaluation and Review Technique) was developed by the US Navy for the planning and control of the Polaris missile program and the emphasis was on completing the program in the shortest possible time. CPM (Critical Path Method) was developed by DuPont and the emphasis was on the trade-off between the cost of the project and its overall completion time [8].

Chang et al. introduced the technique to identify critical path in a workflow [9]. The critical path analysis in a workflow allows companies to utilize it in many workflow issues, especially workflow resource management and workflow time management. They proposed a method to systematically determine the critical path under the workflow model.

van der Aalst identified a bottleneck as the point where the execution time of activity takes the most time [1]. They calculated the execution time of all activities in business process and highlighted the activity with the most execution time. It is a traditional and straightforward technique to identify bottleneck in process management.

Damji and Damji introduced a technique to identify a bottleneck resource pool in simple process [10]. However, they did not assume complicated process models with gateways and critical path analysis. In their research, they calculated the capacity of resource pool in business process. The resource pool with the minimum capacity is recognized as the bottleneck resource pool, which causes the bottleneck phenomenon in the business process. This research identifies the bottleneck phenomenon in the aspects of resources in process.

3. Capacity of a Resource Pool. There are a number of resources involving in business activities. Each resource may have different capacities, which represents the resource's maximum flow rate if it is fully utilized. In a simple process, the capacity of each resource is calculated; however, there are a number of resources in business process and a group of resources tend to perform similar activities. A group of resources that perform similar kinds of activities is called a resource pool. A number of resources may be involved in performing an activity and it is also true that one resource may be involved in carrying out several activities. Since there are a number of resources in real world business, each resource's capacity implies important meaning in business process. Therefore, it is more suitable to calculate the capacity of a resource pool, which represents the sum of the capacities of all resource units in that pool. A resource pool is defined by considering the activities that the resources have performed as Definition 3.1.

Definition 3.1. (Resource pool) *A resource pool r_i is defined as a set of resources that can be assigned to the same activity in a process. $a(r_i)$ is a function that maps r_i to the activity set that the resource has been assigned in the process. The set of resource pools of process P is denoted by R_p.*

Generally, event log and database of information systems contain information that is necessary to calculate the capacities of resource pools, for instance, who performed each activity, how long they perform the activity, and how often the activity performed for every process execution. Based on the useful information, we can calculate the capacity of a resource pool as Definition 3.2.

Definition 3.2. (Capacity of a resource pool) *The capacity of resource pool r_i is calculated as:*

$$C_{r_i} = \frac{|r_i|}{T_{r_i}} = \frac{|r_i|}{\sum_{a_k \in a(r_i)} t(a_k) \cdot \Pr(a_k)}$$

where T_{r_i}: the sum of average execution times of the activities that have ever performed by r_i in the process; $t(a_k)$: the sum of average execution times of activity a_k in the process; $\Pr(a_k)$: the expected execution probability of activity a_k for a single execution of the process.

4. **Bottleneck Identification of Business Process.** Since a sequence of activities in a process is variable and activities are performed selectively, a process may have different bottleneck resources according to the sequence of process activities. To identify bottleneck resources accordingly, one should decompose the business process into multiple processes and identify each decomposed process's bottleneck resource.

Therefore, one or more different resource pools may exist in a process. Different resource pools generally have different capacities and calculating their capacities leads to determining the pool with the minimum capacity, which represents the bottleneck resource pool of the decomposed process.

Definition 4.1. (Bottleneck of a process) *The bottleneck of a process is the resource pool that has the minimum capacity among all the resource pools that have been involved in the process.*

$$BN_P = \arg\min_{r_i \in R_p} C_{r_i}$$

Let us consider a simple example in Figure 1. Tables 1 and 2 provide the information of its resource pools and the execution time of the activities with the resource pools in charge.

FIGURE 1. A simple example process P_1

TABLE 1. The resource pools and their resources of process P_1

Resource pool r	r_1	r_2
Resource w	w_1, w_2	w_3, w_4

TABLE 2. The activities and their information of process P_1

Activity a	a_1	a_2	a_3
Execution time $t(a_k)$	1	1	1
Resource pool in charge r	r_1	r_2	r_1

In this simple example process, the capacities of resource pool r_1 and r_2 are $C_{r_1} = |r_1|/T_{r_1} = 2/2 = 1$ and $C_{r_2} = |r_2|/T_{r_2} = 2/1 = 2$, respectively. It means the resource pool r_1 can perform one case in a unit time while the resource pool r_2 can perform two cases in a unit time. Therefore, the resource pool with the minimum capacity, resource pool r_1, is the bottleneck resource pool in this simple process.

5. **Example.** In this section, we illustrate this formula with a more realistic process example in Figure 2. The process model was presented with BPMN (Business Process Model and Notation) [11], which is often used to draw process models in many business operations. There are four resource pools, performing ten activities in the example process. Tables 3 and 4 show the execution time of each activity and resource pools in the example process. The percentage in the process model represents the execution rate of each path. For example, a_4 is conducted 30% while a_5 is conducted 70% in the exclusive gateway just after a_2.

The capacities of four resource pools are calculated as: $C_{r_1} = |r_1|/T_{r_1} = 2/(8+2+3) = 0.154$, $C_{r_2} = |r_2|/T_{r_2} = 2/(4+4+2) = 0.2$, $C_{r_3} = |r_3|/T_{r_3} = 2/(3+6\times 0.3+3) = 0.256$, and $C_{r_4} = |r_4|/T_{r_4} = 1/(12\times 0.7) = 0.119$, respectively.

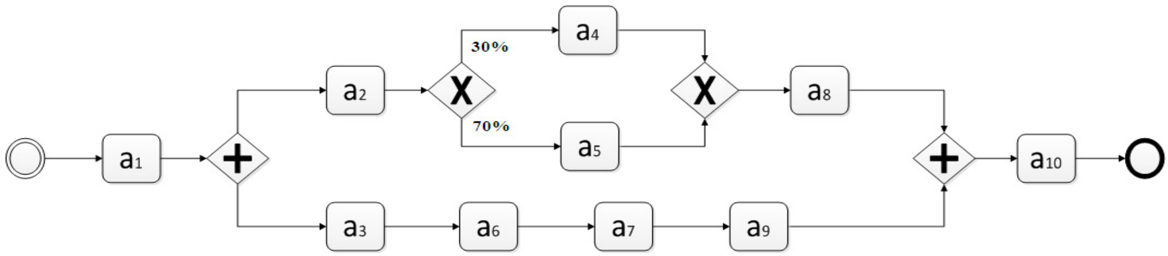


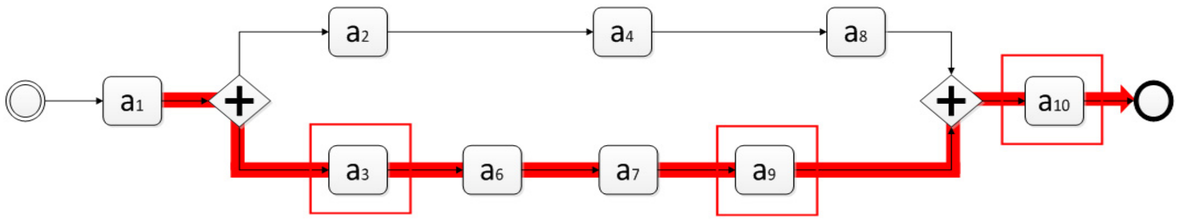
FIGURE 2. An example process P_2

TABLE 3. Execution times and resource pools of activities of process P_2

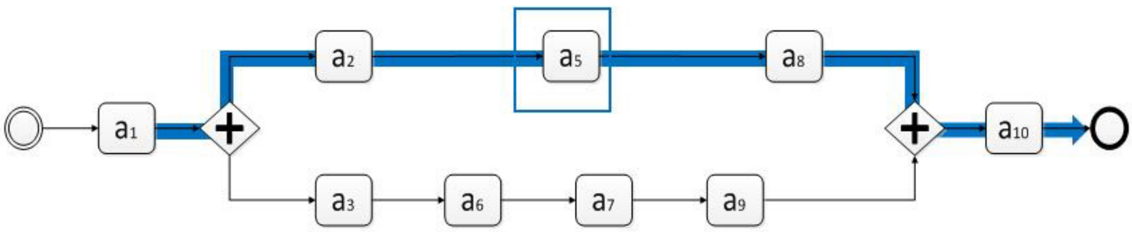
Activities	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
Execution time $t(a_k)$	3	4	8	6	12	4	3	2	2	3
Assigned resource pool r	r_3	r_2	r_1	r_3	r_4	r_2	r_3	r_2	r_1	r_1

TABLE 4. The resource pools and their resources of process P_2

Resource pool r	r_1	r_2	r_3	r_4
Resource w	w_1, w_2	w_3, w_4	w_5, w_6	w_7



(a) Bottleneck activities of DP_1



(b) Bottleneck activities of DP_2

FIGURE 3. Bottleneck identification from decomposed processes of process P_2. Bold lined paths are the critical paths of decomposed processes and the marked activities are the activities of the bottleneck resource pools.

In order to find the proper bottleneck resource of the process, the process model needs to be decomposed into two process models as shown in Figure 3, because each decomposed process model may have their different bottleneck resource pool(s). Among resource pools involved in decomposed process DP_1, resource pool r_1, whose resources perform activities a_3, a_9 and a_{10}, has the lowest capacity. Therefore, resource pool r_1 is considered as the bottleneck resource pool of DP_1. The activities that resource pool r_1 performs are marked in Figure 3(a). On the other hand, among resource pools involved in decomposed process DP_2, resource pool r_4, whose resources perform activities a_5, has the lowest capacity.

Therefore, resource pool r_4 is the bottleneck resource pool. The activities that resource pool r_4 performs are marked in Figure 3(b).

Finally, the two resource pools r_1 and r_4 are the bottleneck resource pools of the decomposed process DP_1 and DP_2 accordingly. Therefore, the resource pool of process P_2 is the union of the bottleneck resource pools of the two decomposed processes, is $BN_P = \{BN_{DP_1}, BN_{DP_2}\} = \{r_1, r_4\}$.

6. **Conclusions and Future Research.** In this paper, we presented an approach to identifying bottleneck resource pools in operational process. We first identified the bottleneck resource pools of each decomposed process and then analyzed the impacts of resource pools on the decomposed process based on their capacities on the critical paths of the decomposed process. To solve the problem, we specifically proposed the technique of calculating the capacity of resource pools in business process. The resource pool with the minimum capacity is recognized as the bottleneck resource pool in this research.

As future work, the systematic methods of decomposing process models and the verification techniques of deriving theoretical bottleneck resource pools can be further investigated with real-life process models and be analyzed through discrete-event simulation [12].

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