Simulation-based Evaluation of Resource Allocation Strategies for Archival Management Workflow: the Macau Case

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***Abstract*—Workflow management systems are widely adopted for implementing business processes. Archival workflow [3] is a precise representation of the archival process, reflecting the formal coordination mechanisms between archival activities and manual processes with respect to the specific requirements of the local governing body. Understanding key performance indicators of archival processes is considered as one of the crucial factors for the government organizations. Process Simulation enables detailed analysis of such performance indicators without actually deploying the processes. In this paper, we analyze a number of resource allocation strategies for the existing workflow model from Macau Historical Archives using Colored Petri Nets models. Based on these models, the strengths and the weaknesses of each resource assignment schemes are evaluated against a number of performance indicators.**

Keywords- archival management workflow; process simulation; resource assignment.

I. INTRODUCTION

A business process [1] consists of a group of logically related tasks that utilize the resources of the organization to provide defined results in support of the objectives of an organization. Process simulation [2] is a technique that pictorially models or represents processes, resources, products and services in a dynamic computer model. It focuses on emulating the logical sequences of each activity within a system. Process simulation can reveal the behavior of the processes and can assist in gathering vital statistics, without the risk of executing a real process or having to interrupt ongoing operations. Basically, process simulation is performed when new processes are going to be deployed or when the performance of existing processes are needed to be evaluated. Due to its potential benefits, process simulation is widely accepted as an important method for analyzing and projecting resource usage in both manufacturing and service industries.

Each task in a process is associated to a resource pool. A resource pool contains a number of resources (e.g. staff members, machines) that may perform the task. However, the problem of choosing a suitable resource allocation strategy for a particular context has received little attention. In this paper, we show how simulation technology can be effectively used to evaluate resource allocation strategies in a workflow from Macau Historical Archives. Archive [3] is a collection of records and documents which need to be kept and conserved as an invaluable asset. Although archival management systems are more tailored toward preserving digitized data, a manual archival process [3] by experienced technicians is still needed for handling of traditional paper-based records. In addition, performing such archival management process often requires understanding of historical information, government policies, local custom, and tradition. As a result, archival management processes are usually different from one country to another and these systems are usually tailored for specific needs of a local government. Operations in an archival process are performed within the archival lifecycle [3]. Archival lifecycle includes tasks such as appraisal, accession, removing contaminants, measuring, initial repair, arrangement and descriptions, digitization, preservation, and utilization by end users.

Archival management processes are best suited for being designed as workflow models [4]. Workflow is a depiction of a sequence of operations, defined as composite tasks that comprise both human and computational subtasks. Workflow management systems are widely adopted for implementing business processes. Archival workflow [5] is a precise representation of the archival process, reflecting the formal coordination mechanisms between archival activities and manual processes with respect to the specific requirements of the local governing body. Integration of workflow modeling concept into archival management problem allows efficient handling of complex and sometime tedious tasks in preservation procedure. It also allows better control over retraceability, accountability, and separation of logic (process definition) from archival data.

There are subtle differences between archival processes and enterprise workflows models. For instance, archival processes are required to follow the international/local archival management standard and cannot be changed arbitrarily. In addition, it is crucial to preserve the records' integrity, originality, and authenticity. Most importantly, archived records are mostly deposited by various government departments and therefore the entire archival process must be accountable for legal reasons. Such differences can severely limit the number of available process improvement options for the process engineers. For instance, during process reengineering, control flow of the

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archival processes cannot be arbitrarily modified due to legal reasons. As a result, rigorous evaluation is needed before changes are permanently applied to existing archival processes. Process simulation is best suited for analyzing the resource allocation problems in archival workflows since effectiveness of proposed changes can be studied in detail without causing any interruption to the existing systems.

According to the recent statistics from Macau Historical Archives, approximately 14% of processing for microfilm pages is delayed and bottlenecks are located at a number of tasks within the existing workflow. As a result, a large number of assigned records cannot be processed on time. In this paper, we consider four resource allocation strategies for Macau Historical Archives and we show how to set up simulation experiments to evaluate these strategies. Based on the results of these experiments, we evaluate the impact of various strategies on a number of performance indicators. In addition, we demonstrate the importance of balanced decision making in selecting appropriate allocation strategies.

The paper is structured as follows. In Section 2, we discuss related work on business process simulation and resource allocation in workflows. In section 3, we detail the archival management process for Macau. In Section 4 we introduce the proposed simulation method considered in this study. In section 5 and 6 we describe the resource allocation strategies and experimental results. Finally, we draw conclusions in Section 7.

II. BACKGROUND AND RELATED WORK

Integration of workflow technology into archival management systems are reported in [6] and [7]. In [6], Integrated Digital Special Collection (IDIN) prototype was developed with the aim of improving the management of archival and manuscripts at the Brigham Young University. In their approach, sierra-php [8] was used to develop IDIN system along with workflow management functions. In [7], a conceptual framework for using service-oriented architecture (SOA) for archival management is proposed and a SOA-compliant digital preservation system was built based on SCA-BPEL service composition approach. In [7], the architecture of the system is specified in SCA model whereas the behavior of each service is defined in BPEL model.

Although simulation experiments are widely used in evaluating business processes, performance evaluation of archival management system has been rarely reported in literature. To the best of authors' knowledge, no work has been reported on simulation-based evaluation of resource allocation strategies for archival workflows.

Workflow model analysis can be performed at logical, temporal, and performance levels [9]. Performance related theoretical analysis of a workflow model based on Petri Nets is proposed in [9]. In their work, Li et al. [9] proposed a formal framework for modeling and analyzing workflows. Li et al. also propose a multidimensional workflow net (MWF-net) which includes multiple timing workflow nets (TWF-nets) as well as the organization and resource information. TWF-net containing iteration structures are then used to compute resource availability and workload. On the contrary, the work by Son et al. [10] address the issue of determining the (minimum) amount of resources needed in a workflow in order to ensure that temporal constraints are met with a certain probability. The difference between approaches proposed in [9], [10] and ours is that, in our approach, simulation experiments are used to evaluate the alternative resource allocation strategies, whereas in their approaches, theoretical analysis based on Petri Nets and critical paths are used for performance evaluation.

Simulation based analysis of business processes were reported in [11], [12]. In [11], a discrete-event simulation model was used to analyze the business process at the Center for Social Work in Slovenia for predicting the effects of the new organizational scheme, the duration of the processes, and potential bottlenecks. The difference between the experiments performed in [11] and our approach is that, in [11], simulation analysis is performed for reengineered business processes with revised control flow models, whereas in our approach, control flow of the workflow is kept unchanged for simulation. Similar experiment based on ARENA™ simulation system [12] was also conducted for the custody-of-prisoner process at a police force.

Escalation strategies for business processes are evaluated using simulation models in [13]. Escalation actions are used to reduce the deadline violations, or to negotiate an extended deadline with the customer. In [13], Paganos et al. proposed two strategies to minimize the number of escalations needed during workflow execution and to mitigate their associated costs. The first strategy aims at minimizing the number of escalations calculating a slack time variable. In the second strategy, an algorithm is used to predict whether a case is going to miss a deadline. When a potential deadline violation is detected, the case is escalated. The difference between our approach and the strategies proposed in [13] is that, in our approach, we focus on the strategies for increasing various types of resources, whereas in [13], strategies are designed using temporal aspects of the workflow only.

Simulation experiment for an insurance claim process from an Australian Company is also conducted by van der Aalst et al. [14] to analyze various deadline escalation strategies. In their approach, potential deadline violations are first detected. Then, suitable escalation strategies are selected and applied. In their work, escalation strategies are evaluated from three perspectives: the process perspective, the data perspective, and the resource perspective. A number of strategies are investigated in this study, which include alternative path selection (performing an alternative task when the execution is delayed), resource redeployment (bringing in more resources into the workflow execution) and data degradation (requiring less data input in order to move faster). In [15], four escalation strategies from [13], [14] are evaluated from temporal (workflow time) and cost (execution, resource, compensation) perspectives. The difference between the experiments performed in [13],[14],[15], and our approach is that, in [13],[14],[15], the control flow as well as resource assignment of the base model is revised for escalating, whereas in our approach, resource assignment and average completion time of the tasks are only considered for the simulation.

III. ARCHIVAL MANAGEMENT WORKFLOW

Archival management task in Macau was set up in 1952 under the name of "Macau General Archives". Later, it was renamed as "Macau Historical Archives" and incorporated into Cultural Affairs Bureau of Macau in 1986. The facilities currently offer safe storage for valuable historical records. Macau Historical Archives plays a key role for managing information for the Government of Macau Special Administrative Region (Macau SAR). Macau Historical Archives comprises of several working groups including archive, conservation, surrogating and public service. In total, approximately 50000 records are preserved in the archive. These records include articles, books, slides, microfilms, maps, photos and electronic files. Some of the records are acquired from legislatures, government departments and private organizations. The overview of the system is depicted in Figure 1.

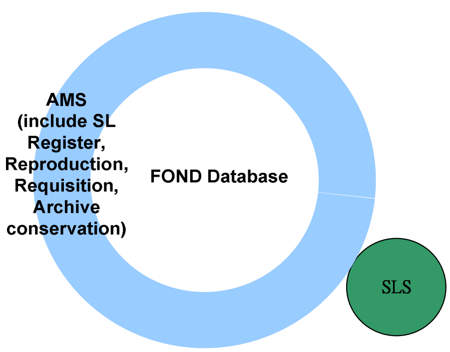

Figure 1. Overview of the system

AMS stands for archival management system. The main function of AMS is to manage the operations in an archival process with are performed in accordance with the archival lifecycle. FOND is a centralized database for storing archival records. SLS is a library management system which supports international standards, including MARC21 [16], ISO2709 [17], Unicode [18], XML [19] and SOAP [20].

Processes within archival workflow are complex and can only be handled by archival specialists. Degree of automation may differ from one area of the workflow to another. For instance, digital records can be archived in more automated way compared to paper-based records. Archived records are mostly deposited by various government departments and therefore the entire archival process must be accountable for legal reasons. Archives are invaluable assets and therefore it is essential to maintain highest level of security for these records.

We conceptualize the workflow model of Macau Historical Archives in Figure 2. First, records for archiving are evaluated in the "Appraisal" (T1) process. Appraisal is the process of assessing whether these records have sufficient value to warrant acquisition by an archival institution. After the appraisal task, these records are formally accepted by the archive institute in "Receive record transfer" (T2) process. Next, in "Initial conservation" (T3) process, basic cleaning of the records is performed before they are grouped in certain order in "Arrangement" (T4) process. Then "Description" (T5) process is carried out to analyze, organize and record details of the archive based on international description standards.

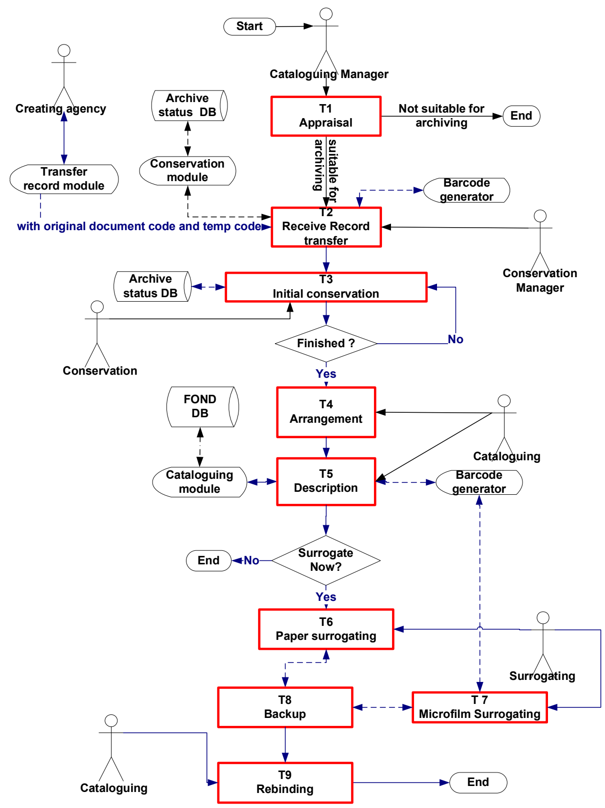

Figure 2. Archival management workflow (Level 0)

After descriptions are added, "Paper surrogating" (T6) process is carried out to create digital archives from the physical format. The next steps in the process involve creating backups and rebinding archives. In "Backup" (T8) process, the original files are copied into storage media so that it can be restored if the original data is deleted or damaged. "Rebinding" (T9) process is performed for repackaging as well as for associating the related meta-information with the specific archival record for permanent storage. "Microfilm surrogating" (T7) process captures and stores images of the archives in microfilm formats. Finally these records are stored at the permanent storage. Depending of the nature of the archived material, periodic maintenance tasks (i.e. preservation) are also scheduled at the end of the process. Due to the space limitation, we select two of the sub-workflow models ("Receive record transfer" (T2) and "Initial conservation" process (T3)) for further illustration.

In "Receive record transfer" process (T2) (see Figure 3), the deposit manager selects a temporary location for incoming archive. Next a checking list and a temporary code for the record are printed. Then, the record is checked by the conservation manager, cataloguing manager and the creating agency. Based on the result of the checking, the record is either signed for registering in the archival management system (AMS) or sent back to the creating agency.

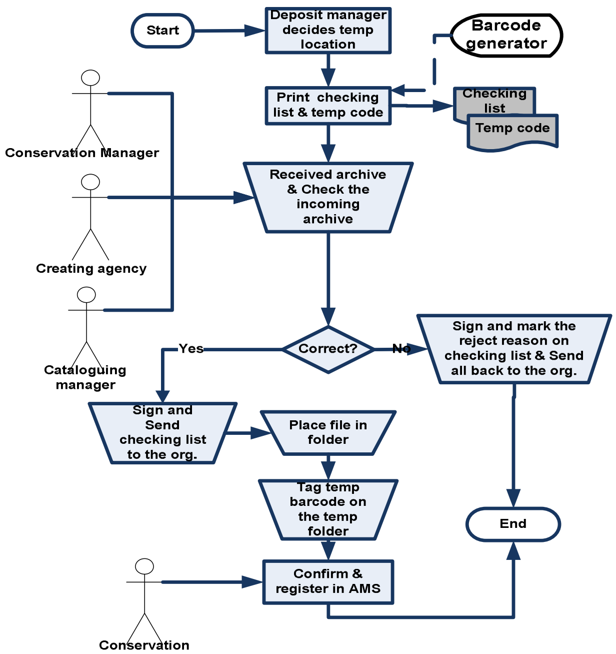

Figure 3. Receive record transfer process (T2) (Level 1)

The workflow model of "Initial conservation" (T3) process is shown In Figure 4. In T3, the condition of the records is approved by a conservation manager at several stages of the workflow. First, disinfection is performed for the record. If it satisfies the basic cleaning plan which is made at the beginning of each year, staples and dust from the record are removed. Then, the record is assessed for its condition. Next, the record is placed in an archival folder and tagged with a temporary code. If the record is in poor condition, it is labeled with a special code for future reference. Finally, an approval is sought from the conservation manager before it is passed on to another process.

IV. SIMULATION METHOD

A number of simulation models are considered for our experiment; (a) original as-is model based on existing resource allocations in Macau Historical Archives; (b) a revised model with additional human resources, (c) a revised model with additional equipments, (d) a revised model with both additional human resources and equipments, and (e) a revised model with reduced processing time for each task. We then encode these process models and associated attributes using a discrete-event simulation technique. In this paper, we use Colored Petri Nets (CPN) [21], but other techniques/tools could be used instead (e.g. Arena).

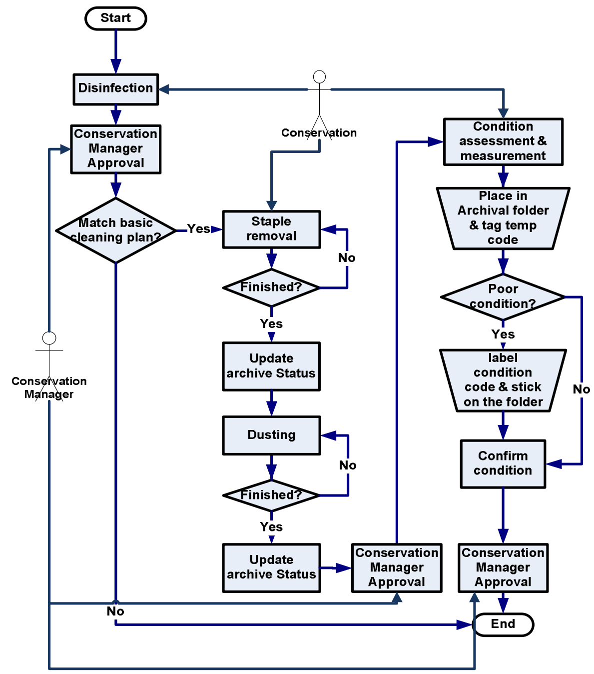

Figure 4. Initial conservation process (T3) (Level 1)

In the CPN models, each task is assigned with an "estimated average completion time" for processing job and an "estimated average task cost" (see Table I). These values are calculated from the recent statistical data from Macau Historical Archives.

TABLE I. AVERAGE TASK COST AND COMPLETION TIME OF EACH TASK IN THE WORKFLOW

Task	Task description	Estimated average task cost (per record)	Estimated average completion time (per record)
T1	Appraisal	$5.28	2 minutes
T2	Received record transfer	$9.5	4 minutes 25 seconds
T3	Initial conservation	$182.83	85 minutes
T4	Arrangement	$4.3	2 minutes
T5	Description	$3810.15	24 Hours
T6	Paper surrogating	$37.23	19 Minutes 30 seconds
T7	Microfilm surrogating	$12.84	6 Minutes
T8	Backup	$17.83	8 Minutes 20 seconds
T9	Rebinding	$18.43	10 Minutes
Total (per record)		**$4098.39**	**1577 Minutes 15 seconds**

We consider human resources and equipments in our experiments. There are 4 managers (senior technician level) at each department. There are also a number of deposit, conservation, surrogating, and cataloguing managers. Total cost for each type of resources is shown Table II.

TABLE II. HUMAN RESOURCES IN MACAU HISTORICAL ARCHIVES

Position	Conservation dept	Cataloguing dept	Surrogating dept	Deposit dept
Senior technician $25370/month	1	1	1	1
Professional technician $20650/month	8	6	4	--
Part-time worker $35/Hour	--	--	7	--
Total cost per month($)	$190570	$149270	$118470	$25370

Two scanners ($106,000 & $40,000 per each.) and one eclipse scanner ($680,000) are used for scanning microfilm to images. One DSV 300 scanner ($270,000) is used for editing microfilms and one DAW writer ($430,000) is used for writing microfilms. Two disinfection machines ($170,000) and two dusting disposal machines ($150,000) are also considered for simulation.

V. STRATEGIES

At the beginning of each year, transfer lists are sent to the Macau Historical Archives by various organizations. A transfer list contains approximately 225 records for archiving. In normal condition, approximately two transfer lists and a box of microfilm are received per year. Each box of microfilm contains approximately 2000 images. According to the recent statistics in Macau Historical Archives, approximately 14% microfilm pages are delayed and the bottleneck was located at T4, T5 and T6 since relatively high number of assigned records cannot be processed on time.

We also find that delays in these tasks have a ripple effect on the whole workflow process. For instance, delay in T4, T5, and T6 often causes accumulation of a large number of unprocessed records at several locations in the archival workflow. However, Macau Historical Archives only has limited physical storage capacity for incoming new records and records which are being processed. As a result, new records for appraisal are often rejected or postponed. To alleviate these problems, four resource assignment strategies are designed for evaluation.

Detailed descriptions of these strategies are depicted in Table III. In original as-is case, the total cost of resource is $2,649,680. In strategy S1, the number of conservation, cataloguing, and full-time and part-time surrogating staff are increased. In strategy S2, the number of equipments are increased. In strategy S3, both staff number and equipments are increased. In strategy S4, we decrease the average completion time of each task by 10% to speed up the entire workflow process. For better accuracy, simulation experiments are run for 4 years period.

TABLE III. FOUR TYPES OF RESOURCE ALLOCATION STRATEGY

Strategy	Resource allocation				Total cost for resource
	Staff	Manager	Equip.	Avg. Completion time	
Original (as-is model)	CVS[a]: 8 CTS[b]: 6 SGS[c]: 4 SGP[d]: 7	CVM[e]: 1 CTM[f]: 1 SGM[g]: 1 DPM[h]: 1	PS[i]: 2 ES[j]: 1 DSV[k]: 1 DAW[l]: 1 DF[m]: 2 DUS[n]: 2	See Table I	$2649680
S1	CVS[a]: 12 CTS[b]: 10 SGS[c]: 8 SGP[d]: 11	CVM[e]: 1 CTM[f]: 1 SGM[g]: 1 DPM[h]: 1	PS[i]: 2 ES[j]: 1 DSV[k]: 1 DAW[l]: 1 DF[m]: 2 DUS[n]: 2	See Table I	$2903480
S2	CVS[a]: 8 CTS[b]: 6 SGS[c]: 4 SGP[d]: 7	CVM[e]: 1 CTM[f]: 1 SGM[g]: 1 DPM[h]: 1	PS[i]: 4 ES[j]: 2 DSV[k]: 2 DAW[l]: 2 DF[m]: 2 DUS[n]: 2	See Table I	$4175680
S3	CVS[a]:12 CTS[b]:10 SGS[c]:8 SGP[d]:11	CVM[e]: 1 CTM[f]: 1 SGM[g]: 1 DPM[h]: 1	PS[i]: 4 ES[j]: 2 DSV[k]: 2 DAW[l]: 2 DF[m]: 2 DUS[n]: 2	See Table I	$4429480
S4	CVS[a]: 8 CTS[b]: 6 SGS[c]: 4 SGP[d]: 7	CVM[e]: 1 CTM[f]: 1 SGM[g]: 1 DPM[h]: 1	PS[i]: 2 ES[j]: 1 DSV[k]: 1 DAW[l]: 1 DF[m]: 2 DUS[n]: 2	-10%	$2649680

Table footnote:
a: Conservation staff
b: Cataloguing staff
c: Surrogating staff
d: Surrogating part time
e: Conservation manager
f: Cataloguing manager
g: Surrogating manager
h: Deposit manager
i: Paper scanner
j: Eclipse scanner
k: Microfilm reader
l: Digital archive writer
m: Disinfection machine
n: Dusting machine

VI. EXPERIMENTAL RESULT

The final step in the experiment is to analyze the simulation results in terms of time and cost. We take into account three types of temporal properties in this experiment: (1) average waiting time at each task, (2) average workflow completion time of each task, and (3) total workflow time for processing a case from start to completion. Two types of costs are considered in this experiment: (1) average task cost and (2) total workflow cost for processing each record.

From the experiment result (Figure 5, 6, 7, and 8), we can see that the original as-is model has relatively long average waiting time for each task. It also has the longest workflow time among all experimental models.

After applying S1 strategy (with additional staff members and 9% increase in the budget), the simulation result shows that the average waiting time of T4, T5, T6, T8 and T9 are reduced by approximately 70~90%. The average workflow completion time of T5, T8 and T9 is also reduced by approximately 4~10%. The total workflow time is reduced by 12%. Average task cost and total workflow cost is reduced by approximately 5~20% and 35%.

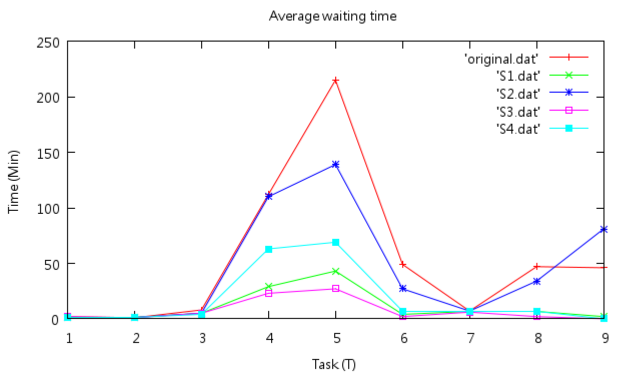

Figure 5. Average waiting time

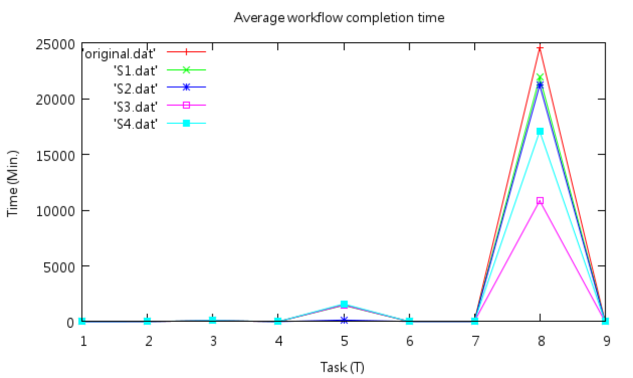

Figure 6. Average workflow completion time

After applying S2 strategy (with additional equipments and 57% increase in budget), the average waiting time of T5, T6 and T8 are reduced by approximately 30~40%. The average workflow completion time of T5 is also reduced by approximately 90% leading to 14% decrease in the total workflow time. In this strategy, average task cost is reduced by approximately 5~10 % and total workflow cost is reduced by 25%.

After applying S3 strategy (with additional staff/equipments and 67% increase in the budget), the average waiting time of T4, T5, T6, T8 and T9 are reduced by approximately 80~95%. The average workflow completion time of T8 and T9 are also reduced by approximately 15% and 50%, leading to 15% reduction in total workflow time. However, average task cost and total workflow cost are increased by approximately 40% and 18%.

After applying S4 strategy (by decreasing the processing time of each task by 10%, and the same budget as existing as-is model), the average waiting time of T3, T4, T5, T6, T8 and T9 are reduced by approximately 50~95%. The average workflow completion time of T8 is reduced by approximately 30% leading to 30% reduction in total workflow time. Average task cost and total workflow cost are also reduced by approximately 8% and 33%.

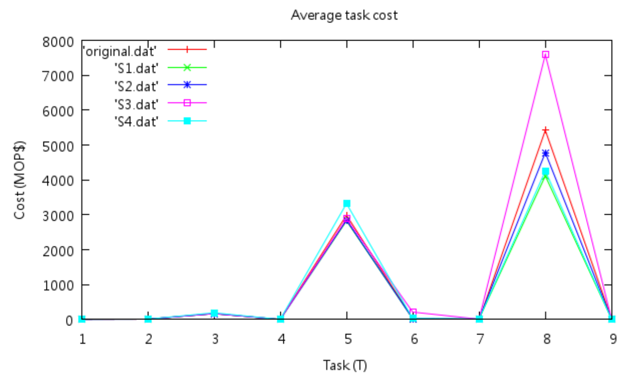

Figure 7. Average task cost

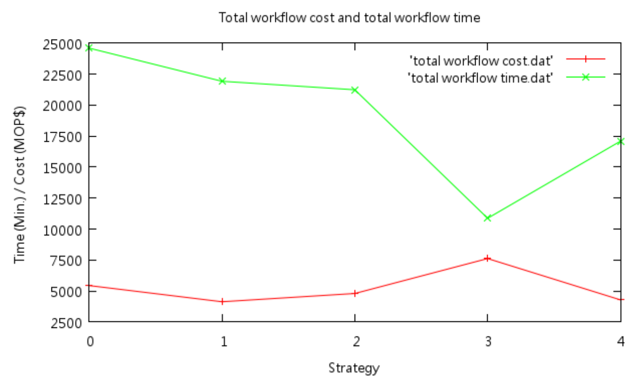

Figure 8. Total workflow time and workflow cost

From the above results, we find that S4 and S1 are more favorable than other strategies for improving the performance of original workflow model. In S4 strategy, 10% reduction in processing time of each task significantly reduces the total flow time and total cost to 30% and 33% without requiring extra budget for resources. In S1 strategy, 9% increase on resource cost results 12% and 35% reduction in the total flow time and total cost. The experiment also reveals that increasing the number of equipments is less effective since extra investment in expensive equipments outweighs the reduction in the workflow time.

VII. CONCLUSION

Performance evaluation on archival workflows has relatively little coverage in literature. In this paper, we show how Color Petri Nets simulation models can be effectively used to analyze resource allocation strategies for Macau Historical Archives. Based on these models, the strengths and the weaknesses of each resource assignment schemes are evaluated against a number of performance indicators. The results from the simulation experiments also reveal several bottlenecks of the existing processes, which are caused by a number of factors. The analysis results from this study can be used to improve the existing workflow model in Macau Historical Archives.

As for the future work, we are planning to apply genetic algorithm (GA) to find the most suitable resource allocation strategy. Macau Historical Archives is also planning to improve digital preservation process. Preservation of digital information is still subject to intense ongoing research. Ensuring the longevity of digital information faces a number of challenging issues such as short media life, obsolete hardware and software, and defunct Web sites [22].

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