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A SITUATIONAL METHOD FOR HEALTHCARE BUSINESS PROCESS IMPROVEMENT

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Abstract

Healthcare business processes are complex due to the many decisions and procedures captured, are highly dynamic, increasingly multidisciplinary and ad hoc which makes it difficult to achieve any meaningful improvement through control flow improvement. This study aims at developing and validating a method for healthcare business process improvement with extensions of process mining and visual analytics. Situational method engineering is used to develop a method for healthcare business process improvement and validated through simulations using synthetic event-logs. The results show that the throughput for all resource combinations gravitates to 1 hour after a simulation period of two hours in the original KPI. A new KPI with the lower upper bounds at 0.091 hours and medium upper bound 0.132 hours posts an average throughput of 0.94387hours (56.63 minutes) compared to the original 1.11hours (66.6 minutes) when two testers and one Solver (Complex) are added. This demonstrates the effectiveness of the method. It is also proven that deployment of resources on the most common trace has the highest impact on throughput reduction. Further testing of the method using real life or field data is to be carried out in future.

Keywords: *Process Mining, Visual Analytics, Method, Simulation, Improvement, Throughput, Healthcare*

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1. INTRODUCTION

A business process is a sequence of activities that focus on fulfilling an organizational task, while improvement in the business process context is the advancement of effectiveness and efficiency with respect to time, quality, cost or flexibility [1]. In most cases process improvement enables transitions from as-is situation to a to-be situation. The ever competitive environments have made it necessary for most organizations to make changes to their operational processes so as to attain higher efficiency and/or improve customer satisfaction, among other survival strategies. Process improvement often involves addressing key performance indicators (KPI) such as time, cost, quality and compliance which have variously featured in research. However, it is often not clear how actual improvement is achieved. Most of the research outputs have focused on artefacts; hence resulting in improved control flow rather than improved processes [2][3]. Control flow address just one aspect of a process: leaving out data and resources.

In the healthcare environment the improvement focus is on organization and structure of the involved processes and not on the medical practice itself [4]. Out of the four performance indicators (quality, time, cost, and flexibility), the most important measure is how fast patients are served and the resources deployed in the treatment. This research uses throughput time as the Key Performance Indicator (KPI) of improvement in a business Process. Shortening of the throughput time translates to cost cutting and customer satisfaction [1]. Healthcare business processes are complex due to the many decisions and procedures captured, are highly dynamic, increasingly multidisciplinary and ad hoc [5]. These make it difficult to achieve any meaningful improvement through control flow improvement which only works well in processes that are not highly dynamic or complex. The option for improvement in this case is best effected through resource variation using a combination of process mining and visual analytics

The aim of this study was to develop and validate a method for healthcare business process improvement with extensions of process mining and visual analytics. The study focuses on organizational aspects of the involved processes and not on the medical/clinical practice itself.

To facilitate structured improvement of the healthcare processes a method can be used. Though defined variously [6] [7][8], a method can be simply defined as a structured way of moving from what-is to what-to-be. A method is based on a specific way of thinking that involves directions and rules, structured in a systematic way in development activities with corresponding development products. It consists of procedure, techniques, results or products and a scheme of who does what [9]. A process that deals with the design, construction and adaptation of methods, techniques and tools for the development of information systems is called Method Engineering. Method engineering (ME) is the discipline to design, construct, and adapt methods, techniques and tools for the development of information

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systems [10]. Situational method engineering has since emerged from the general method engineering. In healthcare, a situation is equivalent to aim or objective, such as improvement about cost, throughput flexibility and quality [11].

Historical electronic health records in form of event-logs are mined using process mining to create accurate and evidence based process models that reflect reality in petri-net form. The petri-nets are annotated with organizational information and simulated according to various resource configurations. The output data from the simulations is used to plot various throughput graphs on a common axis for comparison and selection of best performing alternatives.

The rest of this paper is organized as follows: Section 2 presents related work, section 3 the mandatory elements of a method, section 4 the situational method for healthcare business process improvement and section 5 is the validation of the method. Finally section 6 presents the conclusion and further directions.

2. RELATED WORKS

There is lack of a supporting methodology for process improvement. In the few cases where attempts towards this venture have been made, the proposed methodologies have turned out to be largely unstructured [12] [2]. These claims are supported by [1], who however, went ahead to describe a matrix which can be used as an instrument in a business process improvement project. [13] present a methodology for process improvement that is however very general and either uses redesign and is control flow based. An attempt by [14] only ended up generating improvement ideas as opposed to the improvement itself. These lead to the call "Don't forget to improve the process!" [2].

The method artifact has been applied in a number of computing researches [15][16][17][18][19]. Most of the studies focused on the development of method engineering rather than its application [16][18][19]. Most of the existing approaches do not describe the act of improvement itself e.g. how to get from as-is to the to-be states or lack methodological structure that can be reused. An exception is the case of [17] who presented a method for Governance risk compliance. The method was however limited in terms of evaluation since it was not applied to a real Governance risk compliance environment. Other than the difference in environment, the research also used different technologies. In a study by [12], it was indeed established that among the improvement approaches of Business Process Reengineering and Business Process Redesign, none supports the act of improvement.

3. MANDATORY ELEMENTS OF A METHOD

Numerous researchers including [10][12][21], concur that a method artifact must meet the following mandatory elements:
(1) Procedure model: order of activities to be fulfilled when employing the method.
(2) Technique: way of generating results; supports an activity.
(3) Results: an artifact (e.g. a document, et cetera.) created by an activity.
(4) Role: the one who carries out the activity and is responsible for it.
(5) Information model: consists of the above-described elements and their relationships.
These elements are used in the building of the SM-HBPI method.

4. CHARACTERIZATION OF THE SM-HBPI METHOD

SM-HBPI method is not part of the organizational business process, but rather, operates outside the organizational business process [22]. Event logs from the business process are used as input for the method, and the method output is used to configure the business process for improved performance.

The method utilizes a combined tools approach that is either been proposed or adopted in a number of researches [23][24][25][26]. A number of tools and techniques are used including: ProM, Eventflow, CPN tools and Gnuplot among others. The tools and techniques employed at any one stage depend on the goal of that activity. Generally the method determines the bottlenecks in the workflow; reveals the most followed paths in the workflow; supports resource variation to remove bottlenecks and finally presents the extent of improvement.

4.1 SM-HBPI Method Fragments

Method fragments are defined as coherent pieces of Information Systems development methods [18]. These fragments act as building blocks of a method, and are normally stored in a method base and called when needed. The following method fragments built using statechart diagrams are used in SM-HBPI.

4.1.1 Data Preparation Fragment Model

This preliminary process, otherwise the so called data wrangling involves data cleaning and ensuring consistency in timestamps in terms of format. The original data format has to be converted to mxml for ProM and txt for Eventflow. The two files are saved for future processing as depicted in Figure 1.

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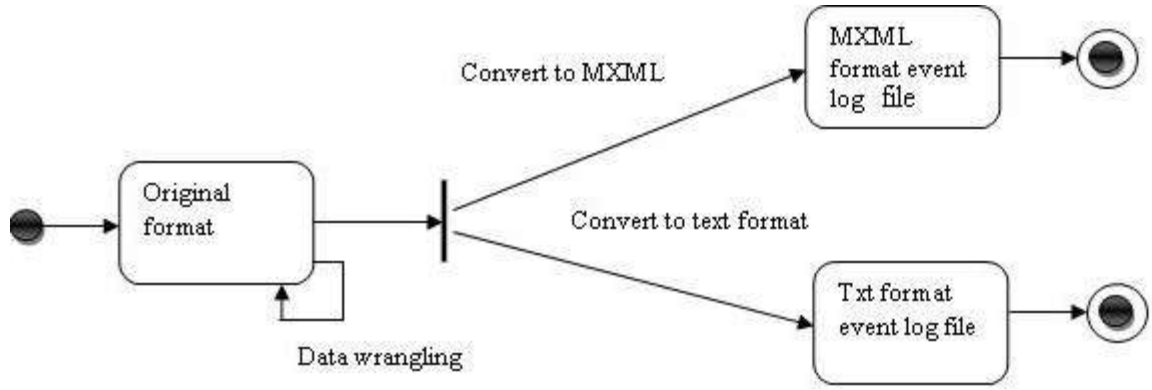

Fig 1: Data preparation fragment model

Subsequently the text file will be used for generating the most common trace in Eventflow, while the *mxml* file is used to generate the process net in ProM.

4.1.2 Workflow Analysis Fragment Model

Workflow analysis consists of a number of steps including loading of the necessary files, mining the organizational file and saving it, filtering so as to remove incomplete traces then mining the process net using a particular plug-in. Some plug-ins such as the heuristic miner yield process nets that require conversion into petri nets for analysis while some such as the Alpha class do not. Petri nets are an invention of Carl Adam Petri [27] and are widely used to analyze distributed systems as well as process models. The classical Petri net consists of nodes that are either places or transitions. Arcs are used to connect nodes of different types e.g. connection of a place to a place or transition to another transition is not allowed. Graphically, places are represented by circles, transitions by rectangles and arcs by directed lines. Petri nets have three advantages that make them the best choice for workflow analysis. They use formal semantics despite their graphical nature, state-based instead of (just) event-based and have a variety of analysis techniques [28].

The resultant petri-net is analyzed using the performance petri-net analysis to reveal bottlenecks and other performance information. At this stage, the KPIs (such as average waiting time before a patient can see a doctor) can be changed as required. Different KPIs present different bottleneck activities as well as performance statistics. The fragment showing these activities is depicted in Figure 2.

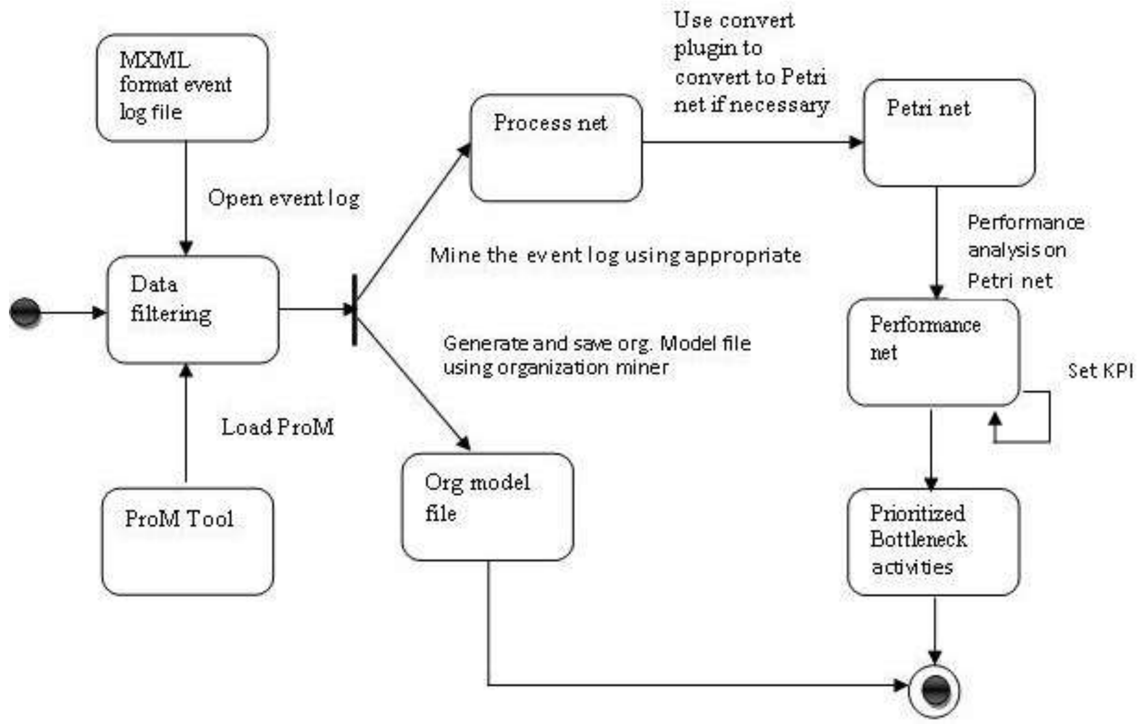

Fig 2: Workflow analysis fragment model

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Almost all processes can be decomposed into sub activities, a concept applied across redesign projects [29]. A number of mining plugins are available in ProM. Their selection depends on the aspect of interest and environment. Some of the candidate include: (1) the alpha (α) algorithm and alpha++ algorithm plugin that produce petri net models (hence conversion is not necessary) for simulation at performance stage. The alpha algorithm miner is good and ideal for noisy data [23]. Information that is extracted from process mining includes overall throughput time, individual activity times and bottleneck activities. (2) The heuristic miner's main advantage is in presentation. The heuristic net does not include petri net notation (difficult for people such as doctors and management to understand) as is the case in alpha algorithm plugin. However, the heuristic miner cannot on its basic form handle abstraction though it can be converted to a petri net. The heuristic miner has better results if the setting for the and-threshold is changed to 10 and the setting for the length-one-loops is changed to 0.999 [30].

Performance indicators are agreed and set between the medical specialists/managers and the analyst. The time settings are agreed and effected through the performance interface then the performance is simulated again automatically to reveal those nodes with high (yellow), medium (pink), and low (blue) waiting time.

When executing a process, earlier activities hand over work to the later ones. This makes them more crucial in that in case of a bottleneck, the later events/activities remain idle. By working backwards from the end, idle activities need to be accounted for e.g. which earlier activity is holding them from executing. Earlier activities and events that feed a bottleneck activity may be the reason for delay and not the perceived bottleneck itself especially if the bottleneck has more than one feed.

Reasons for a feed causing delay to subsequent activities whereby it is not a bottleneck itself could be attributed to challenges in organizational positioning. In case there is only one feed, or it is determined that the feeds are not responsible for the delay, then the bottleneck activity needs to be investigated. Options of speeding it up include resource numerical involvement (parallelism), automation, and re-sequencing of the activity.

In the selection of the process to improve, the heuristic suggested for determining which process to change are 'dysfunction', 'importance' and 'redesign feasibility' [31][32]. Dysfunction can be equated to bottlenecks in process mining, while the importance of a process can be gauged from the flows through it, which is revealed using Eventflow. Process mining in particular is able to filter the occasional and irregular flows only presenting a business process that is fairly stable with clear work activities, therefore meeting the redesign feasibility requirement as well.

4.1.3 Configure Simulation File to Remove Bottlenecks

In ProM, the organization model file is opened and merged with the prioritized bottleneck activities file using a merge simulation models option under analysis. This results in a process model that is annotated with performance information. Configuration at the high level refers to the high level Petri nets. High level Petri nets allow use of individual tokens instead of indistinguishable tokens of place/transition nets, resulting in a much more compact representation of systems [33]. On the same screen, distribution and arrival rates, plus resources can be changed. Next, the model is prepared for exporting to CPN tools 2.0 through the analysis option. This gives the user the option of selecting the desired perspectives of time and resources. Extras required are the MXML logging, throughput time monitor and resource availability monitor. The file is then finally exported as a CPN tools 2.0 file. The Configuration simulation fragment is shown in Figure 3.

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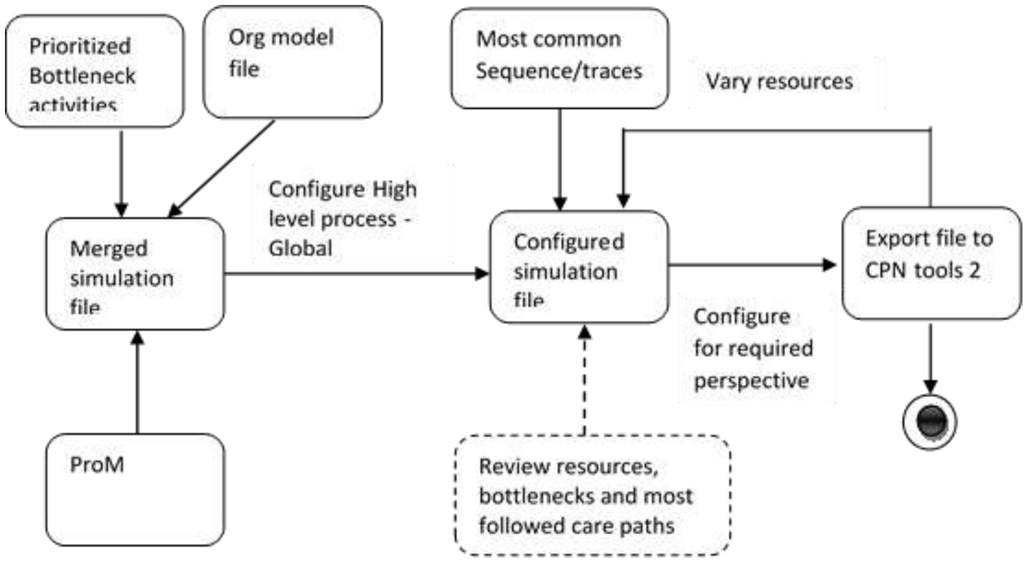

Fig 3: Configure simulation file to remove bottlenecks

Expert and management input are very necessary in decisions regarding resources. The resources can be people, machines or laboratories.

4.1.4 Simulation of the Process Model

In order to tackle limitations associated with simple petri nets, one of the solutions extending the initial approach is the colored Petri Net (CPN). In CPNs every token has a value i.e., they are "colored" and can be distinguished and used in computations [34].

A simulation toolkit known as CPN tools developed by CPN Group, University of Aarhus, Denmark) is freely available at http://cpntools.org/. The CPN 2 Tools is loaded followed by the simulation file. Once the simulation file is loaded, configuration information automatically configures the environment. In some cases editing can be done in ML language. The interface can display the process model at different levels, the highest being the environment. Likewise, execution progress can be monitored at different levels of abstraction. The timer, step replication function has to be set before starting the simulation. The simulation fragment is depicted in Figure 4.

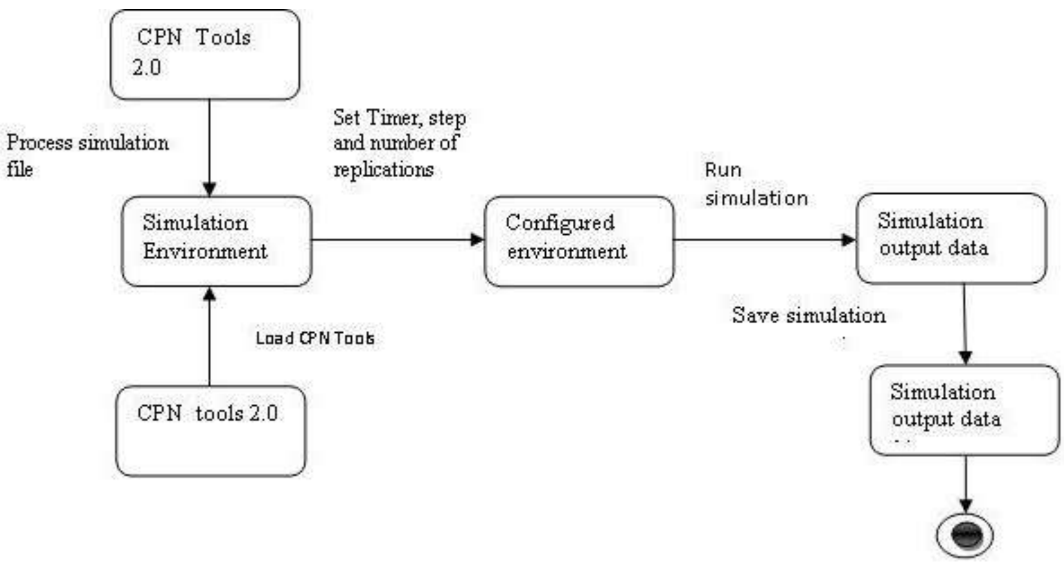

Fig 4: Simulation fragment model

4.1.5 Plot Output Graph

From the simulation data, various scenarios are generated in graphical form on a common axis using Gnuplot. For each scenario, the throughput can be read just after steady state. This clearly reveals the performance of each configuration with regard to Key performance Indicator (KPI), arrival time and resources resource levels committed. A diagram depicting the plot fragment is shown in Figure 5.

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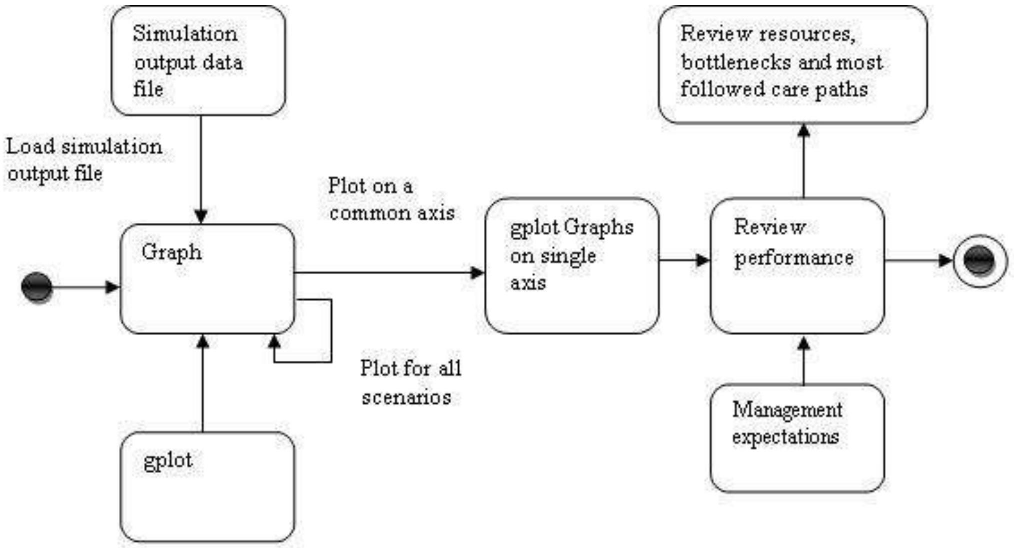

Fig 5: Plot throughput fragment model

4.1.6 Most Followed Path/Trace

The highest impact of a deployed resource is realized when it is deployed on activities that have the highest weight in the processes net e.g. the most followed/common path [35]. On loading the event file into Eventflow, all records are displayed. The view presented is not informative given the unstructured organization and that too many variations overwhelm the eye.

In order to realize better presentation, the categories that do not add value and do not affect the accuracy of the desired information are abstracted by un-checking them. Other features such as alignment on specific activities/categories, sorting, and aggregation, help reveal most followed path. This could be at the top or bottom depending on the sorting option in place. A diagram depicting the generation of the most common trace is shown in Figure 6.

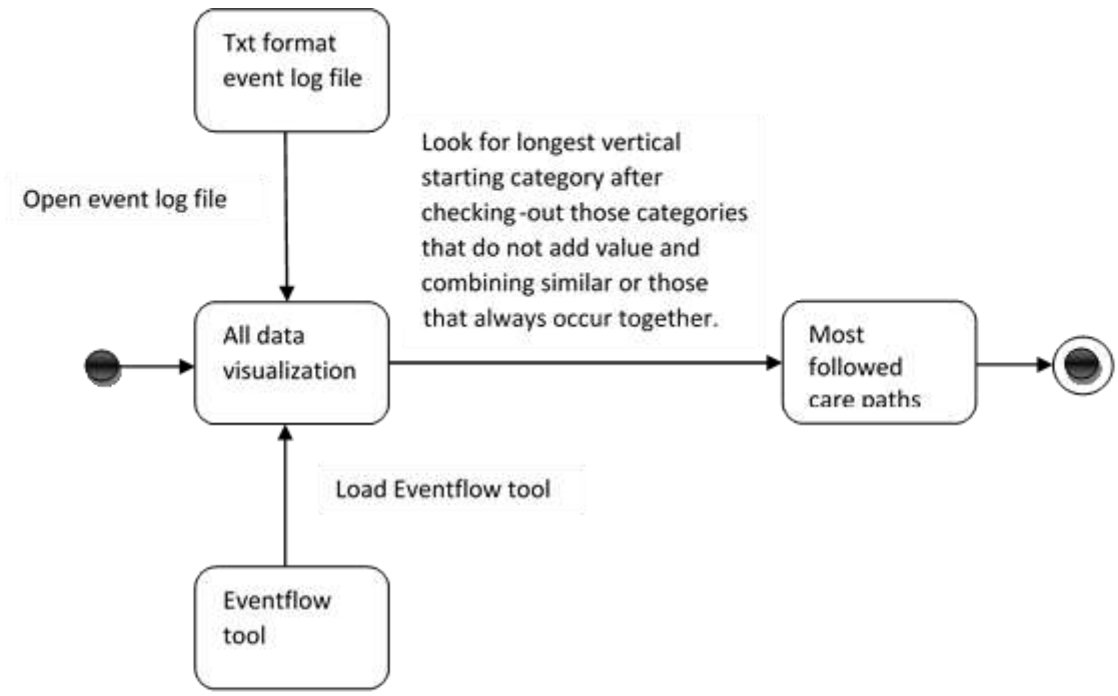

Fig 6: Most followed trace fragment

4.1.7 Compare and Select Best Performance

Once the various alternatives have been plotted on a graph with a common axis, the management are allowed to decide the final option for implementation. A number of factors may have to be considered for example working space and necessary infrastructure. The compare and select performance fragment is shown in Figure 7.

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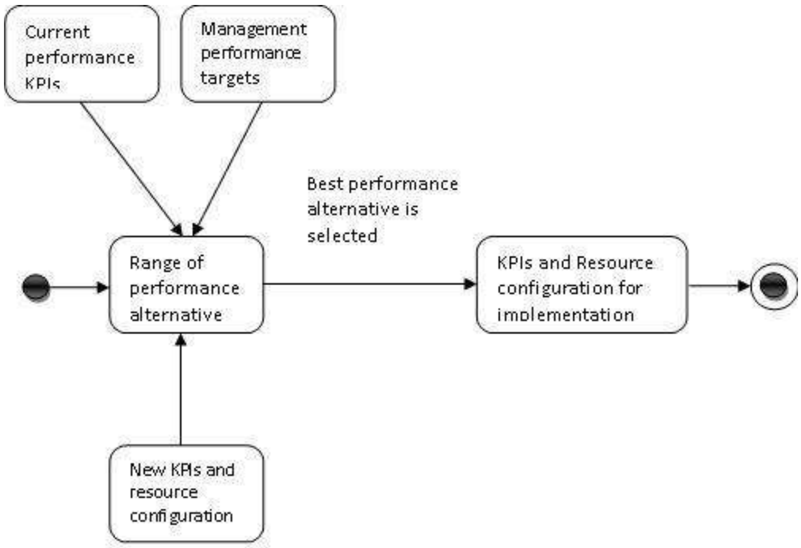

Fig 7: Selection of performance alternative

4.2 SM-HBPI Information Model

The final requirement is that of an information model. The information model presents an integrated document according to method requirements e.g. procedure, techniques, role and results of the method as required [12]. A description of the procedure is hierarchically presented in steps, with the method fragments that implement them. The information model also shows the roles of stakeholders that must interact with the various fragments in order to fulfill the step. Finally, the outcome expected from each step is set out as results. The SM-HBPI information model is shown in Table 1.

Table 1: SMHBPI information model

	Description	Fragment	Role			Results
			Expert	Mgt	ICT Dept	
PROCEDURE	1) Data preparation	[1]			√	Event log file in MXML and txt formats
	2) Mine and save organizational model	[2]		√	√	Organizational model file
	3) Generate Process Model	[2]			√	Process workflow
	4) Convert Process model to petri net	[2]			√	Petrinet of the workflow
	5) Generate Performance Petri net	[2]	√	√	√	Annotated petri net with performance information
	6) Determine most followed path(s) by abstracting unnecessary detail and aligning on particular category	[6]	√	√	√	A clear view of information of interest relative to other categories in sequence whereby the most followed path is at the top
	7) Determine bottlenecks in the performance model	[2]		√	√	Different colors depicting state of the nodes
	8) Merge organization and performance files	[3]			√	Simulation model with both performance and organizational information
	9) Export to CPN tools after configuring resources to remove bottlenecks	[3]		√	√	Simulation file in CPN format with new resource configuration
	10) Simulation to determine improvement	[4]			√	Simulation output file with performance information
	11) Plot performance graphs	[5]	√	√	√	Throughput graphs
	12) Repeat steps 3-5, then set new KPI and iterate steps 6-11.	[2]	√	√	√	A record of acceptable KPI
	13) Compare and select best performance alternative.	[7]	√	√	√	Resource configuration for improved performance with known KPI

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Key

Figure 5: Data preparation fragment model – (1) Figure 6: Workflow Analysis - (2)
Figure 7: Configure simulation file to remove bottlenecks – (3) Figure 8: Simulation - (4)
Figure 9: Plot output graph – (5) Figure 10: Most followed paths – (6) Figure 11: Selection of best alternative – (7)

5. VALIDATION OF SM-HBPI METHOD

Simulation is widely used as a tool for analyzing business processes [34][36][37][38][39]. Likewise it is a preferred method for validation of petri-nets [40][41][42]. Simulation was also used to validate methods developed by [43][44].

Simulation is rarely used for operational support or decision making because it hardly represents the real process or accuracy [45]. However, by using event log information captured in Process aware information Systems (PAIS) that accurately represent the events and timing of a process, the challenge of accuracy in resulting process net is surmounted. Healthcare processes are huge and an authentic accurate process net can only be built from systems that automatically use historical data as input to generate models. While simulation model and information can be built from scratch, - a tedious undertaking, ProM has a facility for directly exporting the data using an option called “Export to CPN Tools 2.0”.

5.1 Simulation Approach

This study adopts an approach similar to [34], however, with limited aspects of state information. The information contained in the workflow system contains design, historical and state information.

Historical data was used to set simulation model parameters such as arrival rate and processing time. Likewise the probability distribution was calculated as a weighted average consisting of the last 100 cases. These parameters are not sensitive to individual changes in the short term, and can be assumed to be constant in the simulation period in consideration.

A change in resources on the simulation model is possible despite it being based on historical information. This results in a different state of processing time or throughput. However, such change has to be incorporated into the initial configuration before the simulation run. This allowed investigation of various “what-if” scenarios with regard to resource configurations. Starting from a historical state requires, a large replication period so that data of the transient (warm-up) are insignificant relative to the steady-state condition [4].

It is assumed that time expended is inversely proportional to the resources committed in a task or group of tasks. However, time cannot be reduced to less than that required to complete the longest task in a business process, even if the others can be accomplished in parallel, eliminated or sequenced. The assumed availability of unlimited resources may also not be applicable some tasks such as those that cannot be carried out by more than one resource. Expert and management opinions are necessary when varying resources.

5.2 Simulation Procedure

The simulation involves pre-preparation in ProM, followed by the actual simulation in CPN Tools 2.0. The output is presented in Gnuplot. In ProM, the original process net is taken as the benchmark as the distribution and arrival rate is determined automatically. Likewise, resources are retained as automatically determined. In the panel, the perspectives of time and resources are selected, and on extras, throughput time monitor and resource availability monitor are selected. The configured process net is exported through the analysis option as a CPN Tools 2.0 file.

In order to analyze the effect of resource variation, distribution and arrival rate as automatically generated in the benchmark are maintained. The resources are edited, while the perspectives and extras are retained as in the benchmark. The model is then exported through the analysis option as a CPN Tools 2.0 file. This is repeated until all options are over

The CPN tools 2.0 simulation file is loaded by double clicking it. It is necessary to manually set the performance statistics and the throughput monitor options. Under Overview, a number of nets at different levels are listed. They can be clicked and dragged to the screen area. Normally, environment level displays as you open the file. In case it does not; it can also be dragged to the screen area. In the tool box, the simulation binder is dragged out and the simulations options that include: the number of steps, total steps; amount of time and total time is set. The replication function must be within the environment area. The simulation output is automatically saved in an output file that is in the same directory as the simulation file.

The number of resources is the independent variable, while the arrival rate, and probability distribution are the dependent variables in the simulation. While time cannot be varied e.g. held constant, however, its variation is measured in throughput time per resource alternative.

Five steps are essential for a simulation experiment and have to be determined before the actual runs. First the variations to use are selected. Other important parameters include warm-up time, run lengths and number of replications. The experiment design adopted in this paper is similar to the one used by [46] [47]. As a rule of thumb, [48] proposes three to five replications. This study adopted five replications for higher accuracy.

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5.3 Results

This study used a synthetic event log, Repair Example, that is freely available from http://www.processmining.org/logs/start for training. The event log is about a telephone repair shop operations. The event log of 1000 records has already been cleaned for ProM, though it presented some challenges when applied to Eventflow with regard to some records. ProM allows instantaneous activities but not Eventflow. Instantaneous activities have the same start and end times.

ProM also automatically ignores records in which the end time is earlier than the start time, while in Eventflow they have to be checked out. An interesting feature of this event log is that the resources include people and the system.

Once the *mxml* file has been loaded into ProM, the organizational miner is used to mine the organizational model that is saved under an appropriate name. The file is automatically loaded later when required for merging with the performance model to realize a high level net.

To get the process model, the data is first filtered, in this case using the simple filter. The advanced filter can be used to enforce more advanced features in the log. In the process of filtering, a start point and End point for the net have to be decided. It is important that the start and end point activities encompass most of the activities in the log else the mined log has poor fitness such that the model realized has poor reflection of reality.

The event log was mined using Alpha ++ algorithm with Registration as the start event and Archive repair as the end activity. Petri nets have one start and one End point hence meeting the requirements of a workflow net. Only event logs that are not noisy can be mined using Alpha ++ algorithm.

To generate a performance Petri net, the petri net is analyzed using “Performance analysis with Petri net” to realize performance net that shows bottlenecks and other performance information.

The automatically generated performance metrics or KPIs are adopted first e.g. the low level upper bound at 0.1250 and the medium level upper bound at 0.1661 while the arrival rate is 1.93 cases per hour. Since there are bottlenecks already in the model, an attempt is made to alleviate them before setting a new KPI.

Three colors are used in a performance network to indicate the performance at particular nodes relative to the set performance indicators. They include blue (low delay/waiting), yellow (medium delay/waiting) and pink (high delay/waiting).

Most Followed Path

To reduce complexity of the view in RepairExample, registration and analyze defect activities are combined and called start. The two activities almost affect all cases hence can be combined. If throughput is improved on the sequence shown in Figure 8, e.g. <Start, repair (complex), test repair> the improvement impact on the overall process is highest.

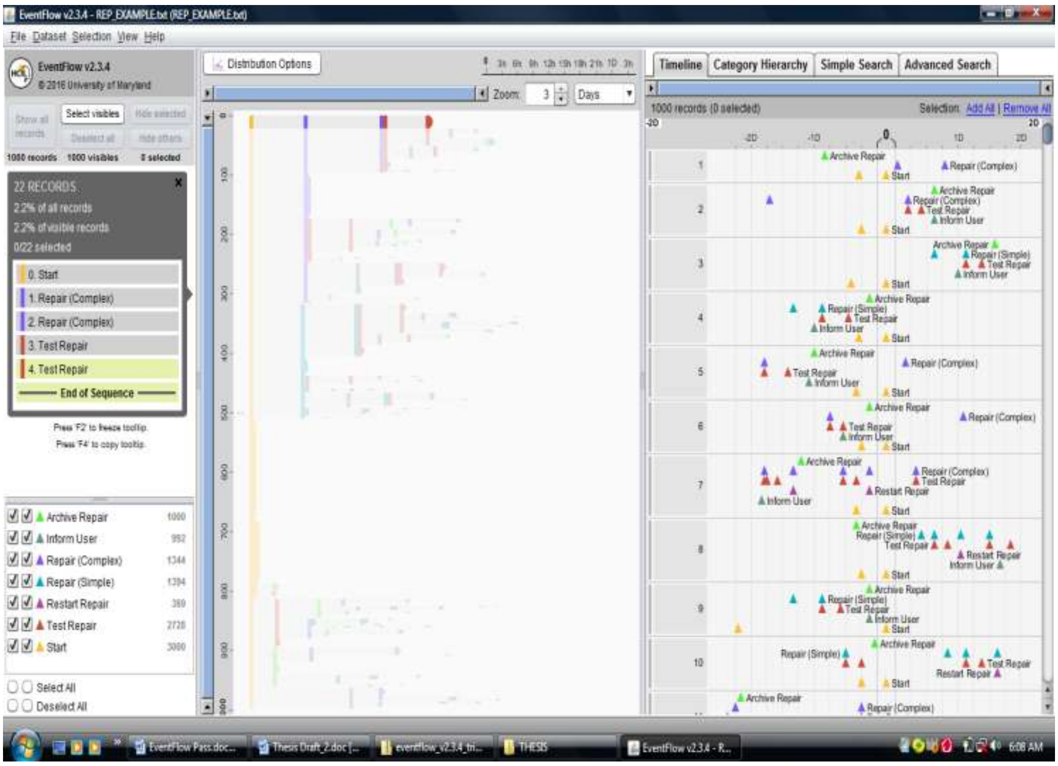

Fig -8: View of the most followed path

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Though the numbers of cases that follow this sequence to the end are only 2.2%, those that follow the same sequence part of the way are much more. For example, those that follow the sequence to the start of test repair are 5.2%, to the start of repair (complex) - 31.7%. The most followed sequence/trace is therefore <registration, Analyze repair, Repair (complex), test repair>.

Activities that feature in the most followed path and have substantial delay (yellow and pink) are: Analyze defect (yellow), Repair (complex)- both uptake and within. Comparative to the low of 0.1250 hours detected by the system, the delay in Analyze defect is 0.13 hours and 0.38 at repair (complex). Waiting time for repair (complex) is 0.19.

In ProM, the organization model file is opened and merged with the prioritized bottleneck activities file using a merge simulation models option under analysis. This results in a process net that is annotated with performance information. Configuration at the high level refers to the high level Petri nets. High level Petri nets allow use of individual tokens (colored) instead of indistinguishable tokens of place/transition nets, resulting in a much more compact representation of systems [33].

In resource variation, only one extra resource was added for analyze defect (Tester5) given the difference in time, however the delay at repair complex is about three times the low set time. It was also noted that the same resource is able to resolve both the waiting and delay in repair (complex). A decision was made to investigate the effect of gradual increase of resources at repair (complex) e.g SolverC as in Table 2.

Table - 2: Extra resource deployment scheme

	Alt 1	Alt2	Alt3
Tester	1	1	1
SolverC	1	2	3

The resources are then added in the high level process net before exporting to CPN tools 2.0.

Simulating the Model in CPN tools

The CPN simulation environment panel is an aggregated view of the process only summarizing the simulation model in terms of input, resources and output. The environment panel for RepiarExample baseline is shown in Figure 9.

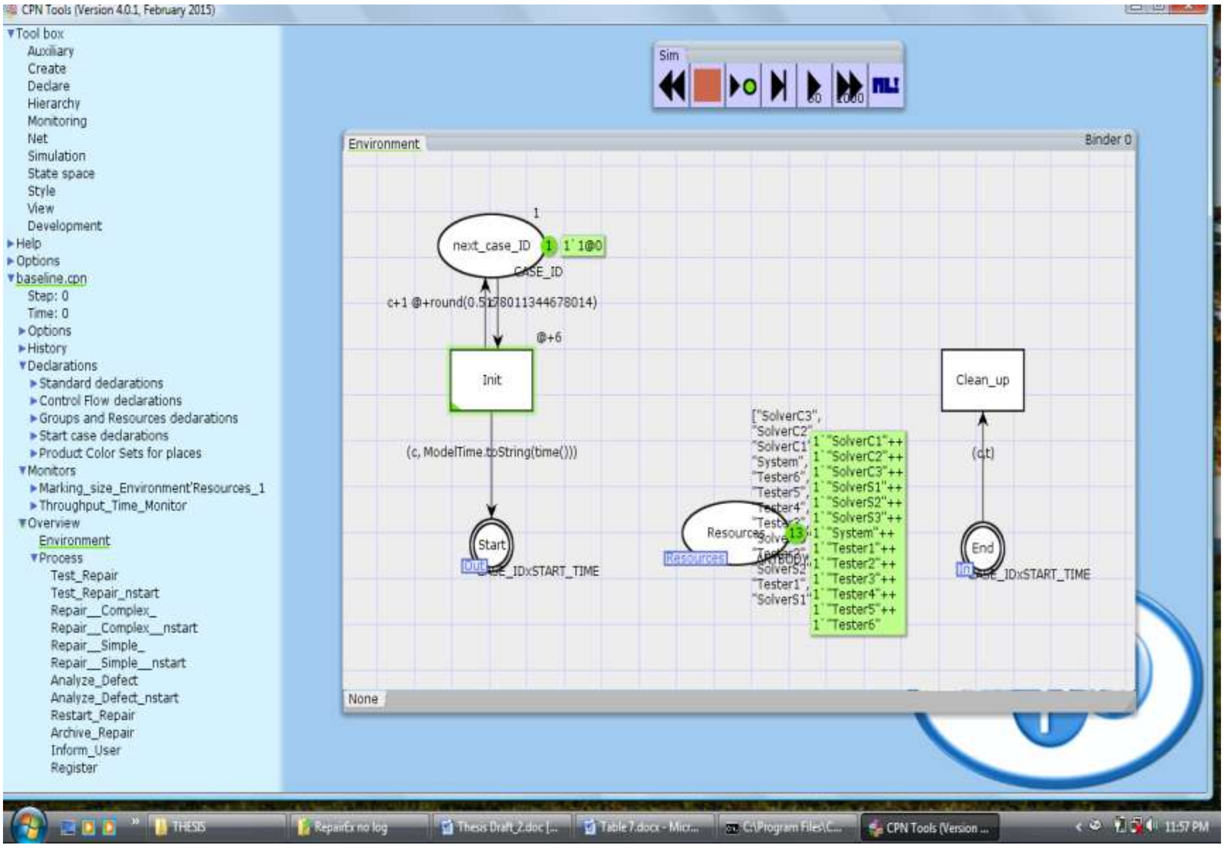

Fig -9: Baseline CPN configuration

A delay of +6 is introduced at transition Init (initialization) to make the process more sensitive to small variations. The throughput time monitor is set to time both timed such as delay and waiting and untimed events such as step and case counts.

The simulation data is captured in a log in text form from where it is imported into excel worksheet for formatting before saving it as a .dat file that can be read by Gnuplot.

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Plot Performance Graphs

A determination of the warm-up period and run length had to be made first, by plotting an initial graph using the baseline data. A time of 0.5 hours or 30 minutes and was adopted as the warm-up time. The run length is five times the warm up period e.g. at 2.5 hours.

For the three alternative resource combinations in Table 2, a plot in Figure 10 was generated.

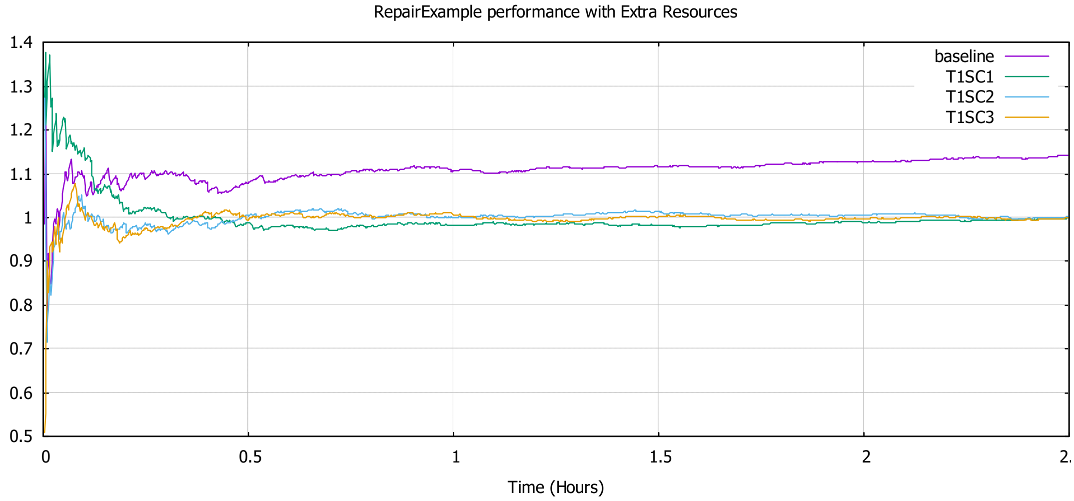

Fig 10: Throughput for various resource configurations

The most interesting feature is that other than all combinations delivering a throughput lower than the baseline, they all gravitate to about 1 hour after 2.5 hours. The explanation is that after 2.5 hours all work that had been delayed in process is cleared. After the pending work is cleared, some resources become idle or only perform as Alt1 would. It is therefore prudent for management to opt for Alt1, since it is a cheaper option. The on average improvement is approximately 0.11 hours or 6 .6 minutes.

New KPI for RepairExample

To investigate the effect of a new KPI, the SM-HBPI information model is iterated from step six to step 12. However, the steps 1 to 5 have to be repeated without any change because ProM does not store intermediate models.

The average throughput as per the performance net is 1.11 hours with the automatic generated low level upper bound at 0.125 hours (7.5 minutes) and the medium level upper bound at 0.166 hours (9.96 minutes) as depicted earlier. A new KPI in which the upper bounds are lowered by two minutes was set at 0.091 (lower upper bound) and 0.1327 (medium upper bound) as in Figure 11.

To reduce complexity some alternatives that were considered not viable because they had a throughput higher than or equal to the baseline were abstracted so as to reveal the best two alternatives of one Tester, three Solver Complex (T1SC3); and two Testers and one Solver Complex (T2SC1) shown in Figure 11.

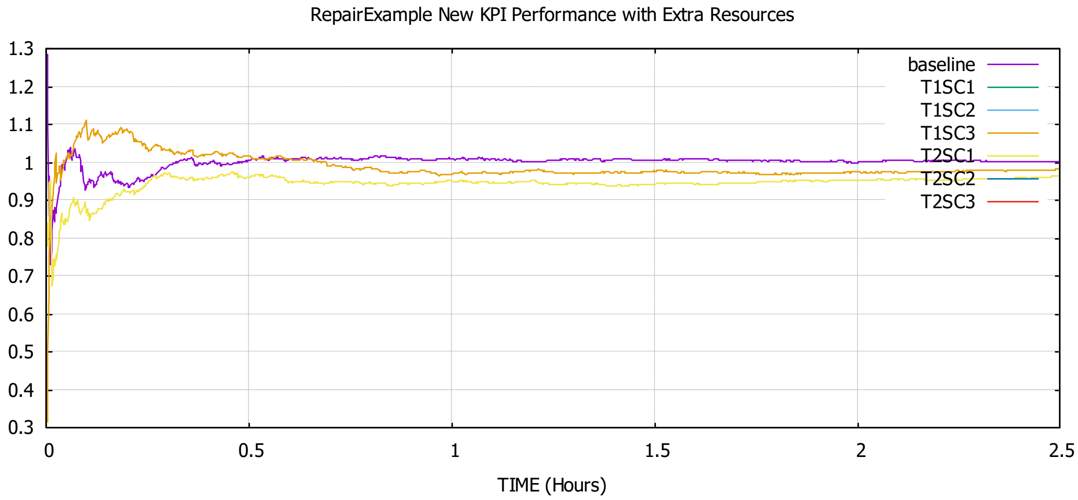

Fig 11: Best two alternatives with new KPI

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Comparatively, best performance is that of Alt4 or T2SC1 (two testers and one Solver (Complex). The throughput is on average 0.94387 (56.6322 minutes) compared to the original 1.11 (66.6 minutes). By just resolving the bottlenecks without a new KPI the average throughput was 1.00 though at a lesser cost of one Tester and one repair (complex). The comparative resources against throughputs are shown in Table 3.

Table 3: Improvement alternatives

	Throughput (hrs)	Improvement (hrs/minutes)	Resources required
Current	1.11		
After resolving bottlenecks on current performance	1.0	0.11 hours or 6.6 minutes	Testers -1 SolverC - 1
New KPI	0.944	0.166 hours or 9.96 minutes	Testers -2 SolverC - 1

6. CONCLUSION

In this paper, the SM-HBPI method has been presented and validated. It is formally proven that deployment of resources on the most common trace has the highest impact on throughput reduction. This is a proof of effectiveness of the method. The method is useful in improving healthcare business processes in both public and private settings resulting in a better satisfied clientele.

The validation carried out in this study used synthetic event logs that may not capture the actual environment in the field. It is therefore recommended that in future, the method be validated using real life data and in the field.

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REFERENCES

[1] P. Griesberger, S. Leist, G. Zellner, "Analysis of techniques for business process improvement", In *ECIS 2011Proceedings*. Helsinki, Finland, 2011.

[2] W. M. van der Aalst, M. La Rosa, F.M. Santoro, Don't forget to improve the process!, 2016, Berlin, Springer.

[3] M. Dumas, "From Models to Data and Back: The Journey of the BPM Discipline and the Tangled Road to BPM 2020", *In Proceedings of the 13th International Conference on Business Process Management*, LNCS 9253, Springer, 2015.

[4] M. Netjes, R. S. Mans, H.A. Reijers, W.M. van der Aalst, R.J. Vanwersch, "Bpr best practices for the healthcare domain", In *Business Process Management Workshops, Springer*, Berlin, Heidelberg, 2010, pp. 605-616.

[5] A. Rebuge, D.R. Ferreira, (2012). "Business process analysis in healthcare environments: A methodology based on process mining", *Information systems*, Vol. 37, No.2, pp. 99-116, 2012.

[6] J. Becker, M. Kugeler, M. Rosemann, (Eds.). Process management: a guide for the design of business processes, 2013, Springer Science & Business Media.

[7] T. Bucher, M. Klesse, Contextual method engineering, Institute of Information Management, University of St. Gallen, St. Gallen, 2006.

[8] S. Greiffenberg, Method engineering in business and administration, German Edition, Verlag Dr. Kovac, Hamburg, 2004.

[9] T.J. Burns, F.P. Deek, "A Practitioner Based Method Tailoring Model for Information Systems Development", *Situational Method Engineering: Fundamentals and Experiences, 15*, 2007.

[10] S. Leist, G. Zellner, "Evaluation of current architecture frameworks", In *Proceedings of the 2006 ACM symposium on Applied computing*, ACM, 2006, pp. 1546-1553.

[11] A. Gericke, R. Winter, "Situational change engineering in healthcare", In *ECEH*, H. Stormer, A. Meier, M. Schumacher, Eds. Bonn, 2006, pp. 227–238.

[12] G. Zellner, "A structured evaluation of business process improvement approaches", *Business Process Management Journal*, Vol. 17, No. 2, pp. 203-237, 2011.

[13] S. Adesola, T. Baines,"Developing and evaluating a methodology for business process improvement", *Business Process Management Journal*, Vol. 11, No. 1, 2005, pp. 37-46.

[14] R.J.B. Vanwersch, "Rethinking care processes: does anybody have an idea?", PhD Thesis, School of operations management and logistics, Technical University of Eindhoven, Eindhoven, The Netherlands, 2016.

[15] N.Bouillard, P. Montarnal, R. Herbin, "Development of numerical methods for the reactive transport of chemical species in a porous media: a nonlinear conjugate gradient method", In *Coupled Problems*, CIMNE, 2005 pp. 16.

[16] J.P. Comet, H. Klaudel, S. Liauzu, "Modeling multi-valued genetic regulatory networks using high-level Petri nets", In *International Conference on Application and Theory of Petri Nets*, Springer, Berlin, Heidelberg, 2005 June, pp. 208-227.

[17] A. Gericke, H.G. Fill, D. Karagiannis, R. Winter, "Situational method engineering for governance, risk and compliance information systems", In *Proceedings of the 4th international conference on*

https://doi.org/10.15623/ijret.2018.0710012 Received: 22-08-2018, Accepted: 04-10-2018, Published: 25-10-2018

design science research in information systems and technology, ACM, 2009 May, pp. 24.

[18] B. Henderson-Sellers, C. Gonzalez-Perez, J. Ralyté,"Comparison of method chunks and method fragments for situational method engineering", In *Software Engineering, 2008. ASWEC 2008. 19th Australian Conference on*, IEEE. 2008 March, pp. 479-488.

[19] B. Henderson-Sellers, J. Ralyté, "Situational method engineering: state-of-the-art review", *Journal of Universal Computer Science*, Vol. 16, No.3, pp. 424–478, 2010.

[20] S. Christensen, L.M. Kristensen, T. Mailund, A sweep-line method for state space exploration. In *International Conference on Tools and Algorithms for the Construction and Analysis of Systems*, Springer, Berlin, Heidelberg, 2001, April, pp. 450-464.

[21] R. Winter, J. Schelp, "Reference modeling and method construction: a design science perspective", In *Proceedings of the 2006 ACM symposium on Applied computing*, ACM, 2006, pp. 1561-1562.

[22] D. Truex, D. Avison, "Method engineering: reflections on the past and ways forward", *AMCIS 2003 Proceedings*, 64, 2003, Pp. 507-514.

[23] P. Riemers, "Process improvement in Healthcare: a data-based method using a combination of process mining and visual analytics", MSc thesis, Technology Management, Eindhoven University of Technology, Eindhoven The Netherlands, 2009.

[24] W.M.P. van der Aalst, "Process Mining: Discovery, Conformance and Enhancement of Business Processes", Springer Publishing Company, Incorporated, 2011.

[25] G. M. Nugteren, "Process Model Simplification", MSC thesis, Business Information systems, Eindhoven University of Technology, Eindhoven, The Netherlands, 2010.

[26] T. Gschwandtner, "Visual Analytics Meets Process Mining: Challenges and Opportunities", In *International Symposium on Data-Driven Process Discovery and Analysis*, Springer, Cham, 2015, pp. 142-154.

[27] C.A. Petri, "Kommunikation mit Automaten ,", PhD thesis, Institut f¨ur instrumentelle Mathematik, Bonn, 1962.

[28] K. Barkaoui, R. Ben Ayed, Z. Sbai, "Workflow soundness verification based on structure theory of Petri nets", *International Journal of Computing and Information Sciences*, Vol. 5, No.1, pp. 51-61, 2007.

[29] A. Bernstein, M. Klein, T.W. Malone, "The Process Recombinator: A Tool for Generating New Business Process Ideas" In *Organizing Business Knowledge: The MIT Process Handbook,* T.W. Malone, K. Crowston G.A. Herman Eds, MIT Press, Massachusetts, 2003, pp. 403-422.

[30] J.Y. Zhou, "*Process mining: acquiring objective process information for healthcare process management with the CRISP-DM framework"* MSc Thesis, School of operations management and logistics, Technical University of Eindhoven, Eindhoven, The Netherlands, 2009.

[31] M. Hammer, J. Champy, "*Reengineering the Corporation: Manifesto for Business Revolution", A*. Zondervan, 2009.

[32] H.A. Reijers, "Design and control of workflow processes: business process management for the service industry", Springer-Verlag. 2003.

[33] J. Desel, "Validation of process models by construction of process nets", In *Business Process Management*, Springer, Berlin, Heidelberg, 2000, pp. 110-128.

[34] A. Rozinat, R.S. Mans, M. Song, W.M. van der Aalst, "Discovering simulation models", *Information Systems*, Vol. 34, No.3, pp. 305-327, 2009.

[35] D.M. Schunselaar, H.M.W. Verbeek, H.A. Reijers, W.M. van der Aalst, "A structural model comparison for finding the best performing models in a collection", In *International Conference on Business Process Management*, Springer, Cham, 2015 August, pp. 180-188.

[36] Y. Liu, H. Zhang, C. Li, R.J. Jiao, "Workflow simulation for operational decision support using event graph through process mining", *Decision Support Systems*, Vol. 52, No. 3, pp. 685-697, 2012.

[37] S. L. Mansar, H.A. Reijers, "Best practices in business process redesign: validation of a redesign framework", Computers *in Industry*, Vol. 56, No. 5, pp. 457-471, 2005.

[38] J.G. van der Vorst, S.O. Tromp, D.J.V.D. Zee, "Simulation modelling for food supply chain redesign; integrated decision making on product quality, sustainability and logistics", *International Journal of Production Research*, Vol. 47, No. 23, pp. 6611-6631, 2009.

[39] M. van der Aalst, M. Netjes, H.A. Reijers, "Supporting the full BPM life-cycle using process mining and intelligent redesign", *Contemporary Issues in Database Design and Information Systems Development*, IGI Global, pp. 100-132, 2007.

[40] K. Jensen, L.M. Kristensen, L. Wells, "Coloured Petri Nets and CPN Tools for modelling and validation of concurrent systems", *International Journal on Software Tools for Technology Transfer*, Vol. 9, No. 3-4, pp. 213-254, 2007.

[41] J. Becker, P. Bergener, D. Breuker, M. Räckers, "An Empirical Assessment of the Usefulness of Weakness Patterns in Business Process Redesign", In *20th ECIS* Vol. 2012.

[42] E. Verbeek, M. van Hattem, H. Reijers, W. de Munk, "Protos 7.0: Simulation made accessible. In *Applications and Theory of Petri Nets 2005"*, Springer, Berlin, Heidelberg, 2005, pp. 465-474.

[43] A.R. Hevner, S.T. March, J. Park, "Design research in information systems research, *MIS Quarterly*" Vol. 28, No. 1, pp. 75–105, 2004.

[44] K. Peffers, T. Tuunanen, M.A. Rotenberger, S. Chatterjee, "A design science research

https://doi.org/10.15623/ijret.2018.0710012 Received: 22-08-2018, Accepted: 04-10-2018, Published: 25-10-2018

methodology for information systems research", *Journal of Management Information Systems*, Vol. 24, No. 3, pp. 45–77, 2007.

[45] W.M.P. van der Aalst, J. Nakatumba,A. Rozinat, N. Russell, "Business Process Simulation: How to get it right?", *BPM Center Report BPM-08-07*, BPMcenter.org, 2008.

[46] M. W. N. C. Loosschilder, M.H. Jansen-Vullers, "Quantification of the implementation of the parallel heuristic", Beta, Research School for Operations Management and Logistics, 2007.

[47] M.H. Jansen-Vullers, P.A.M. Kleingeld, M. W. N. C. Loosschilder, M. Netjes, H.A. Reijers, "Trade-Offs in the Performance of Workflows–Quantifying the Impact of Best Practices", In *Business Process Management Workshops*, Springer Berlin Heidelberg, 2008, January, pp. 108-119.

[48] A. Mehta, "Smart modeling: Basic methodology and advanced tools", *Proceedings of the winter simulation conference*, J.A. Joines, R.R. Barton, K. Kang, K., A. Fishwick, Eds., 2000, pp. 241-245.

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