

Workflow Management in Clinical Engineering Department

^[1]Sukanya Sudarsanan, ^[2]Aravinth J

Department of Electronics Communication and Engineering
Amrita School of Engineering, Coimbatore
Amrita Vishwa Vidyapeetham, India

Article Info

Volume 83

Page Number: 6203 - 6211

Publication Issue:

May-June 2020

Abstract:

Quality assurance is very significant in healthcare to provide quality service. The clinical engineering department in a hospital plays a key role to bring medical innovations for people care. This paper provides an insight to the process management of the clinical engineering department. The preliminary phase of process improvement is to analyse the existing workflow and identify the process variants. This is more relevant in a clinical engineering department in a hospital which directly affect the reduced down time of machine thereby process improvement. This paper suggests a process mining technique to evaluate the existing model, identifying process variants as well as the prediction of throughput time to complete a task which is an add-on towards six sigma analysis. The study relies on fuzzy miner algorithm which provides efficient insight of process model. The results help to understand the value added and non-value-added activities also it helps in business process reengineering.

Keywords: BPMN, CMMS, process model, heuristic and fuzzy miner

Article History

Article Received: 19 November 2019

Revised: 27 January 2020

Accepted: 24 February 2020

Publication: 18 May 2020

I. INTRODUCTION

The Healthcare industry is fast growing sector with advances in medical technology as per studies conducted by India Brand Equity Foundation [1]. About 25-40 percent of total fixed asset cost in a hospital is utilized for medical equipment [2,3]. The biomedical engineering department is an integral part to choose efficient technology for hospitals and thereby providing the best services to patients. The primary function of the biomedical engineering department is asset management, maintain a perfect service strategy and procurement of equipment. The rise in the number of medical equipment in recent years is huge. So proper maintenance is a necessity considering the total number of assets, the number of break down calls, recalls of equipment, and also criticality of equipment. Primarily hospitals run by corporate the medical equipment maintenance management (MEMP) is a prominent issue since

they have to deal with large number of equipment from different locations.

According to WHO, "medical device is an instrument that is used in the prevention, diagnosis or treatment or detecting, measuring, restoring, correcting or modifying the function of the body and medical equipment is defined as medical device require calibration, maintenance, repair, training and decommissioning" [4]. There is various maintenance method followed by the department to reduce the downtime of equipment. The maintenance can be scheduled such as preventive maintenance, quality assurance. Unplanned maintenance such as a breakdown of equipment which is described as emergency maintenance based on equipment criticality. The higher investment, as well as maintenance cost shows that it requires a well-organized management plan abide by the standards of Joint commission for accreditation of Healthcare Organization (JCAHO). Based on the standards each

hospital formulates a workflow map suitable for departments. Implementation of a software tool which helps in providing favorable business process improvement plans. CMMS has been assisting maintenance management as well as help managers in decision making based on key performance indicators. This indicator can be the number of breakdowns, time requirements for both scheduled and unscheduled maintenance, inventory management and manpower requirement. Thus, CMMS provides a framework for well-organized business process monitoring and analysis. An efficient data management and data analytics incorporated with this framework plays a big role in the organization to manage the implementation of different process in the department as well as quality assessment [5]. To design the ideal workflow, several methods are available such as traditional technique like interviewing employees and create a BPMN model which can be utilized for business process analysis. The main issues relay on business process flow are the identification of skipped events, delayed events etc.

Quality assurance test methods available in maintenance management are Total Productive Maintenance (TPM), Reliability-centered maintenance, Six sigma analysis, etc. The latter is the most prominent technique at this time. The process mining method will make six sigma (DMAIC) analysis effortless in each step of an investigation. This method provides data-based insight towards each process that happens in the department. The contribution of this paper is to add process mining [6] tool in the framework which effectively analyse data and identify process variants in biomedical engineering department focusing mainly on purchase section. The goal is maximum reliability, economic efficiency, improves time delay and thereby improves the performance sight be deviation from exact process flow. The paper is organized as follows, second section deals with the applicability of this method and several studies went up this date in workflow process management. Section 3 describes different methods utilized to understand the

case study. Section 4 discusses the observations in the study. Section 5 is the conclusion.

II. BACKGROUND

Applying the process mining technique to a data set helps in executing business process analysis more efficiently. Every analysis for workflow mining can be broadly divided into data-driven model and expert knowledge-based model. Data-driven model depends on past data that is stored in the information system. There are plethora of methods for process discovery and conformance checking. The alpha algorithm is basic and simple algorithm for process discovery. Cook and Alexander L. Wolf [7] set the basic idea of process mining by reviewing the logical dependency between each activity. They presented a technique to identify patterns and a probabilistic view of process behavior. The several attributes towards the activity are the time of occurrence, resource (the person who handle a particular activity), etc. and extraction of sequence instances using Markov model. The significant variables like entropy, event count, periodicity and causality from frequency table were formed. The ranking was done to both forward and reverse entropy. Rediscovery of a large class of workflow nets using alpha algorithm is possible. Van der Aalsta, H.A. Reijersa (Et al) [8] analyzed different perspective when evaluating an event log like case perspective, organizational perspective, performance perspective, and process perspective. An event log records each event to activity forms trace and it has case Id for identifying process instance and another major attribute is timestamp, also performer for each event. They demonstrated social network analysis in the ProM framework. But there was limitation for alpha algorithm. Later Wil van der Aalst (Et al) [9] evaluated the causality between each activity and if there exists a causality, they turned to be in a sequence by inspecting event log. It is easy to build the workflow nets by initially identifying the starting transition and all possible final transition. They addressed the challenge of short loops. But the limitation of the alpha algorithm was that it is not possible to identify the repeated

task and hidden task. A.J.M.M. Weijters, J.T.S. Ribeiro [10] introduced a flexible heuristic miner and tackled some problems considering noise in event log. They implemented algorithm in ProM framework. Causal net process model is utilized for FHM approach. They initially created a dependency graph (DG) and extended it to augmented causal nets. The last step in FHM approach is that to find long distance dependency. Only simple long-distance relation was mined using this algorithm and Diogo R. Ferreira [11] illustrated how process mining methodology efficiently works in finding process behavior, deviation points in clinical workflow. They demonstrated a case study in a hospital emergency department. The developed a process mining tool called Medtrix Process Mining Studio. The event log collected from the database of hospital is inspected using SQL queries and pre-processing of log is essential to obtain efficient process model. Clustering similar type of activities. Different types of algorithms are available k means algorithm, self-organizing map, Tree cluster plugin, sequence clustering etc. They used sequence clustering approach which uses markov chain method made this method to handle noises in an event log and to create healthcare process model and their performance by forming a sociogram. Ronny Mans, Hajo Reijers (Et al) [12] evaluated dental process using both process mining and discrete event simulation in order to examine impact of digitization. They use Prom and CPN tool for process modelling. For performance analysis average through put is evaluated from past and compared to new input. Yair Meidan (Et al) [13] used data driven approach to identify key performance indicator to reduce cycle time. Selective naive Bayesian classifier (SNBC) approach was used for cycle time prediction [14,15]. They concluded that uncertainty in waiting time can be decreased by using machine learning and data mining methods. Sebastian J. van Zelst (Et al) [16] proposed an online conformance checking method to identify whenever a deviation from ideal flow is notified by using past dataset. They used two search algorithms to successful online

conformance checking. Joyce Pebesma and co-authors [17] studied risk of cardiovascular patient with diabetes 2 using process mining technique. Algorithm calculating cardiovascular diseases consider risk factors such as age, gender etc. and applied k means clustering technique and visualized similarity of clusters this can be used to customized therapeutic plans. Onur Dogan (Et al) [18] examine the pathway of customer in major shopping malls. The location of customer is extracted from the camera available in shopping malls for dataset and fuzzy c means clustering is utilized to classify dataset. This effectively clustered pathway of customers. This paper demonstrates a case study on discovering a process model and evaluates the bottleneck points using the dataset from purchase department under clinical engineering department.

III. METHOD

The paper illustrates two visualizing models in the paper for designing a process management model, BPMN model and process mining model. The BPMN model is obtained from a number of interviews with the employees. The event log is created using the data extracted from CMMS. A Django framework is suggested to notify the management total turnaround time if occurred using the regression model. Fig. 1 represents a block diagram for the steps involved to evaluate a process flow management.

A. Workflow model

The clinical engineering department has well-defined work flow which leads to reduce downtime of an equipment. As the number of assets under the department increases the process modeling become a complex task to be accomplished. In the case of hospitals under corporate, workflow management of the clinical engineering department is a high-end priority. Here in this paper we have demonstrated a case study about the workflow of clinical engineering department in a hospital. The biomedical department mainly contains sub departments such as a call center where medical

device complaints from different hospitals are being registered. Another division under clinical engineering department is a purchase department where procurement of each device is happening and the biomedical engineering department where the engineers communicate directly with the end users such as nurses, doctors, radiology department, etc. The Business Process Management and Notation (BPMN), a diagrammatic representation of business process to communicate effectively the workflow with the staff and stake holders. Initially by interviewing employees and investigations a BPMN model was developed.

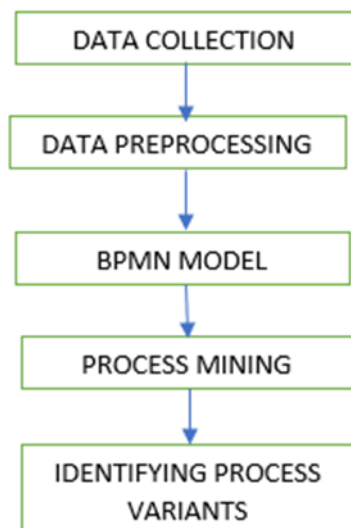


Fig. 1 Block Diagram

Clinical Engineering department relies on different factors while purchasing equipment for the hospital. The quality, quantity, cost, technology used, reliability, availability of service and parts, the requirement of contracts like original equipment manufacturer (OEM) and independent service organization (ISOs), applicability, customer satisfaction and end of life (EOF) are key elements in procurement. The purchase part can be classified as consumables, accessories, spare parts, contracts, services, etc. A team consisting of members from biomedical department, administrative level and from customer side prefix a budget for next financial year. An efficient quality management improves the

service of the department and also can quantify the efficiency. The time required for approval of purchase order is significant because time delay may increase downtime of equipment. So, by predicting the time requirement to complete a purchase order for a particular part from past history is useful while defining bottleneck points

B. Process Mining

Process mining is a methodology that fills the gap between data mining and process mining. The data-driven approach reduces the time delay for generating a process model. The technique can be broadly classified as process discovery, conformation checking. The preliminary phase is process discover where modelling a process model from the data obtained. The process variants for example, a case of skipping an event is discovered, thus easily identification of bottleneck points is key for this methodology. The log file is created for discovering workflow using process mining technique. The event log contains case ID is an identifier of activity. Here case ID, is a workorder number given to each end-user after registering a complaint in call center it shows the beginning of the activity. Each workorder consist of number of activities called events. This event are steps in a process flow in the department. The timestamp is another column in a log file. It shows how much time is required to complete task. The log file is converted to XES file [19] using software like disco, ProM.

C. Heuristics Miner Algorithm

To discover the basic model of workflow a heuristic miner was utilized. The event log was imported to ProM software and applied a built-in heuristic miner. Petri net is a conventional process modeling language for identifying process model. It consists of places and transition. By using the firing rule, tokens can flow through petrinet. A transition is visualized as square and it is connected through places that model attainable states. When firing is activated transition accept a token from input and

produce an output. In the beginning of process discovery, one should evaluate the causal dependency between each activity. The causal dependency can be illustrated in dependency graph (DG). For dependency measure in a matrix, Let X be an event log over T and $a, b \in T$ $|a > b_X|$ is the number of times b precedes a

$$|a \rightarrow b| = \begin{cases} \frac{a > a}{|a > a| + 1} & a = b \\ \frac{(|a > b| - |b > a|)}{(|a > b| + |b > a| + 1)} & a \neq b \end{cases} \quad (1)$$

D. Fuzzy Miner

Fuzzy model [20,21] creates a process model instead of petrinet model. This approach is easy to handle complex business process models. Both ProM software as well as disco software used in this project has built-in fuzzy miner tool. The correlation between each event was calculated and the causal activity matrix is obtained from this correlation. Fuzzy miner calculates with weight to each element and an additional correlation weight for each edge.

E. Linear Regression

Once the process is discovered and performance is evaluated using process miner model, the total time taken to approval of purchase order can be predicted for future comparison while procuring similar parts. This will be an additional support for quality improvement. The noise in the dataset is filtered and dataset is trained using linear regression algorithm. The timestamp for each process as input to the technique and one can predict turnaround time.

$$y = \theta_1 + \theta_2.t \quad (2)$$

t = input training data

θ_1 = intercept

To predict cost function (4) in order to update θ_1 and θ_2 values, root mean square error is utilized

$$\text{minimize } \frac{1}{n} \sum_{i=1}^n (\text{pred}_i - y_i)^2 \quad (3)$$

$$\text{cost function} = \frac{1}{n} \sum_{i=1}^n (\text{pred}_i - y_i)^2 \quad (4)$$

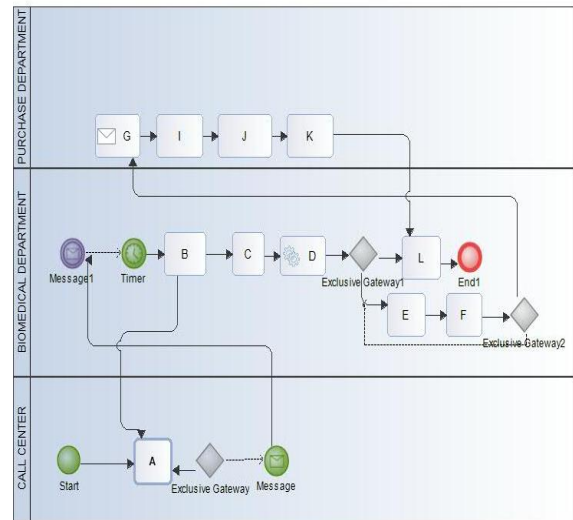


Fig. 2 BPMN Model

TABLE I Casual Activity Matrix

	A	B	C	D	E	F	G	H	I	J	K	L
A	0.0	0.92	-1.0	-1.0	-1.0	0.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
B	-1.0	0.0	0.92	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
C	-1.0	-1.0	0.0	0.92	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
D	0.66	-1.0	-1.0	0.0	-1.0	0.90	-1.0	-1.0	0.5	-1.0	-1.0	-1.0
E	0.5	-1.0	-1.0	-1.0	0.0	0.0	-0.4	0.75	-1.0	0.5	-1.0	-1.0
F	0.0	-1.0	-1.0	-1.0	0.0	0.0	0.91	-1.0	-1.0	-1.0	-1.0	-1.0
G	0.5	-1.0	-1.0	-1.0	0.4	-1.0	0.0	0.88	-1.0	0.5	-1.0	-1.0
H	0.5	0.5	-1.0	-1.0	-1.0	-1.0	-1.0	0.0	0.92	-1.0	-1.0	-1.0
I	0.5	-1.0	-1.0	-1.0	-1.0	-1.0	0.5	-1.0	0.0	0.91	-1.0	-1.0
J	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	0.5	-1.0	0.0	0.92	-1.0
K	0.5	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	0.0	0.8
L	0.8	-1.0	-1.0	-1.0	0.8	0.5	-1.0	0.66	-1.0	0.5	-0.8	0.0

IV. RESULTS AND DISCUSSION

The clinical engineering department holds a well-defined equipment inventory management. The complete details of a device are verified while a purchase order was approved by the department. When the vendor obtains the site readiness from the hospital, the transportation and installation process of equipment get started. The clinical engineer enters the equipment to asset management software to create an identification number. Each equipment has accessories like ECG cable, SpO2 probes, NIBP cuff, etc. in a physiological monitor. Training should

be given for end-users once the installation process is completed. An appropriate service methodology is a significant part of the biomedical engineering department. Different service models are daily rounds, preventive maintenance, quality assurance, breakdown maintenance, etc. Daily round conducted by clinical engineer in the assigned departments. It verifies the functionality of equipment and probability of failures. The scheduled inspections for full functionality of medical equipment to eliminate the failure

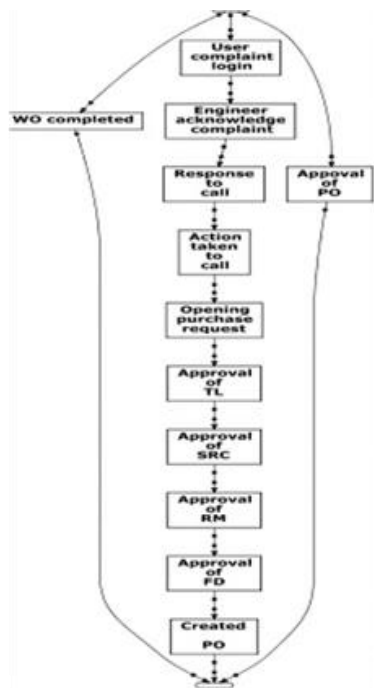
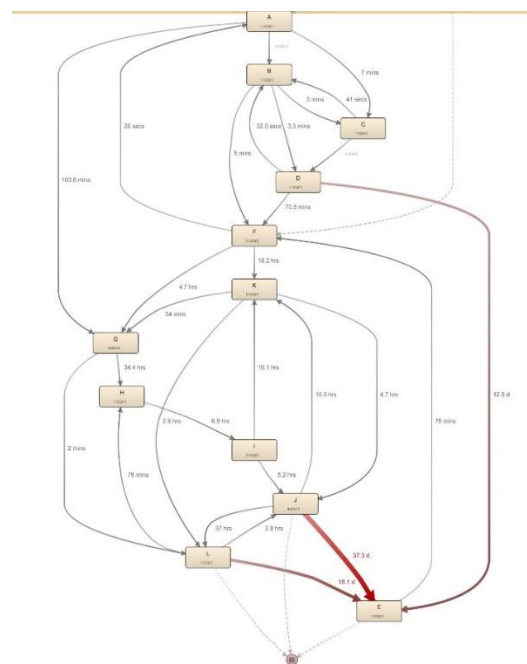


Fig. 3 Process Model using C-Net Heuristic Miner

Preventive maintenance frequency is fixed as per international guidelines. Breakdown maintenance calls from end users is the starting event in the workflow. Breakdown maintenance is a corrective activity when the device does not deliver the advised output. Once the call center provides a complaint number to end-user, A message has sent to the engineer to acknowledge the complaint from the call center. The immediate action should be taken by engineers to verify the problem occurred in the field and if necessary, a purchase request should be sent within a day to the purchase department. Also details

of breakdown should be documented in software. On initiation of request for quotation and approval of purchase order from purchase department begins an event of inventory alert. The completion of the workorder marks the end of the traces after the parts received. The BPMN model of the above activity is depicted in Fig. 2.

For process discovery the causal relation between each activity was visualized using casual activity matrix. The output $M[A \times A]$ ranges from $[-1,1]$. In Table. 1 illustrates the possible relation of events to each other. Based on which process flow map was obtained. Process mining from transactional log obtained from software demonstrates the performance of process in an organization. Here a dataset from the purchase division of clinical engineering department is utilized for process model evaluation. Fig 3 demonstrates the causal net model of visualization which improves the traditional modeling languages in process mining [22]. In the model the nodes represent activity. Causal dependency also displays as arch in the graph. This shows a basic model of workflow in the department. But identification process variables and performance analysis are obtained from fuzzy miner algorithm which is a built-in tool in disco software



In Fig. 4 the process model using fuzzy miner is illustrated. using fuzzy miner about process are evaluated. Most cases are skipped events which may not recorded software. The performance analysis shows maximum 37 days to complete workorders which has requirement of spare parts. There are lot of factors affecting delay in time. Primarily cost, availability of part, quality, delays from negotiation, delay from vendor side, availability of service engineers, transportation delay for offsite service, etc.



Fig. 5 Heat Map of the data

A Django framework with regression model predicts total turnaround time require for the process to complete, this helps the management team to evaluate the existing process model

Fig 5 shows the correlation of dataset which contains 6000. It evaluates any dependency of cost in time turnaround time. It shows it is relative to a less percent. The linear regression evaluates the total turnaround time for each workorder and predicts the time for particular purchase in future. Regression model fits to the dataset which shows about 99% accuracy.



Fig. 6 Django Framework

Fig. 6 display working Django framework to notify the engineer and manager incase of any delay happens in the process model. This notification can

reduce the downtime of equipment in future

V. CONCLUSION

The work shows the three-visualization model for process management of biomedical engineering department in hospital. The paper focus on the purchase department under the clinical engineering department. BPMN model is conducted by investigating employees, causal net model shows the basic process model. Fuzzy miner helps to evaluate process variants in the system. This data driven approach helps performance analysis and six sigma analysis in maintenance management. In future reengineering models can be evaluated and online conformance checking using process mining technique helps in real time discovery in case of any bottleneck divisions occurred.

Acknowledgment

This paper would not have been possible without exceptional support of Narayana Health. The authors would extend thanks to whole clinical Engineering department of Narayana Health for their immense support and finally Dr.Nitin Yadav General manager, south zone for his support throughout project.

REFERENCES

1. India and H. India, "Healthcare Industry in India, Indian Healthcare Sector, Services", Ibef.org, 2020. [Online]. Available: <https://www.ibef.org/industry/healthcare-india.aspx>. [Accessed: 07- Feb- 2020].
2. B. Tabshouri, "Medical Equipment Maintenance: Management and Oversight", Biomedical Instrumentation & Technology, vol. 47, no. 4, pp. 339-339, 2013. Available: 10.2345/0899-8205-47.4.
3. B. Wang, E. Furst, T. Cohen, O. Keil, M. Ridgway and R. Stiefel, "Medical Equipment Management Strategies", Biomedical Instrumentation & Technology, vol. 40, no. 3, pp. 233-237, 2006. Available: 10.2345/i0899-8205-40-3-233.1.
4. "Medical devices", World Health Organization,

2020. [Online]. Available: https://www.who.int/medical_devices/en/. [Accessed: 01- Apr- 2020].
5. Wienker, K. Henderson and J. Volkerts, "The Computerized Maintenance Management System an Essential Tool for World Class Maintenance", *Procedia Engineering*, vol. 138, pp. 413-420, 2016. Available: 10.1016/j.proeng.2016.02.100.
6. S. Park and Y. Kang, "A Study of Process Mining-based Business Process Innovation", *Procedia Computer Science*, vol. 91, pp. 734-743, 2016. Available:(<http://www.sciencedirect.com/science/article/pii/S1877050916312492>). [Accessed 8 February 2020].
7. J. Cook and A. Wolf, "Event-based detection of concurrency", *ACM SIGSOFT Software Engineering Notes*, vol. 23, no. 6, pp. 35-45, 1998. Available: 10.1145/291252.288214..
8. W. van der Aalst et al., "Business process mining: An industrial application", *Information Systems*, vol. 32, no. 5, pp. 713-732, 2007. Available: 10.1016/j.is.2006.05.003 [Accessed 9 February 2020].
9. W. van der Aalst, T. Weijters and L. Maruster, "Workflow mining: discovering process models from event logs", *IEEE Transactions on Knowledge and Data Engineering*, vol. 16, no. 9, pp. 1128-1142, 2004. Available: <https://ieeexplore.ieee.org/document/1316839>. [Accessed 8 February 2020].
10. A. Weijters and J. Ribeiro, "Flexible Heuristics Miner (FHM)", 2011 IEEE Symposium on Computational Intelligence and Data Mining (CIDM), 2011. Available: 10.1109/cidm.2011.5949453 [Accessed 9 February 2020].
11. Machine Learning and Data Mining", *IEEE Transactions on Semiconductor Manufacturing*, vol. 24, no. 2, pp. 237-248, 2011. Available: 10.1109/tsm.2011.2118775 [Accessed 9 February 2020].
12. Á. Rebugue and D. Ferreira, "Business process analysis in healthcare environments: A methodology based on process mining", *Information Systems*, vol. 37, no. 2, pp. 99-116, 2012. Available: 10.1016/j.is.2011.01.003 [Accessed 9 February 2020].
13. R. Mans, H. Reijers, D. Wismeijer and M. van Genuchten, "A process-oriented methodology for evaluating the impact of IT: A proposal and an application in healthcare", *Information Systems*, vol. 38, no. 8, pp. 1097-1115, 2013. Available: 10.1016/j.is.2013.06.005 [Accessed 9 February 2020].
14. Y. Meidan, B. Lerner, G. Rabinowitz and M. Hassoun, "Cycle-Time Key Factor Identification and Prediction in Semiconductor Manufacturing Using Machine Learning and Data Mining", *IEEE Transactions on Semiconductor Manufacturing*, vol. 24, no. 2, pp. 237-248, 2011. Available: 10.1109/tsm.2011.2118775 [Accessed 9 February 2020].
15. Aravinth, J and Valarmathy S 2015, "Multi Classifier Based Score Level Fusion of Multi-Modal Biometric Recognition and its Application to Remote Biometrics Authentication", *The Imaging Science Journal*, vol. 64, no. 1, pp. 1-14, December 2015.
16. S. Veni and S. Thushara, "Multimodal Approach to Emotion Recognition for Enhancing Human Machine Interaction - A Survey," *International Journal on Advanced Science, Engineering and Information Technology*, Volume 7, No.4, Pages 1428-1433, 2017
17. S. van Zelst, A. Bolt, M. Hassani, B. van Dongen and W. van der Aalst, "Online conformance checking: relating event streams to process models using prefix-alignments", *International Journal of Data Science and Analytics*, vol. 8, no. 3, pp. 269-284, 2017. Available: 10.1007/s41060-017-0078-6 [Accessed 9 February 2020].
18. J. Pebesma et al., "Clustering Cardiovascular Risk Trajectories of Patients with Type 2 Diabetes Using Process Mining", 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2019. Available: 10.1109/embc.2019.8856507 [Accessed 9 February 2020].
19. [18] O. Dogan, B. Oztaysi and C. Fernandez-Llatas, "Segmentation of indoor customer paths using intuitionistic fuzzy clustering: Process mining visualization", *Journal of Intelligent & Fuzzy Systems*, vol. 38, no. 1, pp. 675-684, 2020.

- Available: 10.3233/jifs-179440 [Accessed 9 February 2020].
20. C. W. Günther and E. Verbeek, "xesstandarddefinition | XES", Xes-standard.org, 2020. [Online]. Available: <http://www.xes-standard.org/xesstandarddefinition>. [Accessed: 10- Feb- 2020].
 21. B. van Dongen and A. Adriansyah, "Process Mining: Fuzzy Clustering and Performance Visualization", Business Process Management Workshops, pp. 158-169, 2010. Available: 10.1007/978-3-642-12186-9_15 [Accessed 10 February 2020].
 22. Processmining.org, 2020. [Online]. Available: http://www.processmining.org/_media/blogs/pub2014/on_decomposed_process_discovery.pdf. [Accessed: 01- Apr- 2020].
 23. W. van der Aalst, A. Adriansyah and B. van Dongen, "Causal Nets: A Modeling Language Tailored towards Process Discovery", CONCUR 2011 – Concurrency Theory, pp. 28-42, 2011. Available: 10.1007/978-3-642-23217-6_3 [Accessed 3 April 2020].