Process Inspection and Data Collection for Manufacturing

Antoniy Petrov
Control Systems Department,
Technical University of Sofia, Plovdiv branch
Plovdiv, Bulgaria
antoniy.petrov@gmail.com

Albena Taneva
Control Systems Department,
Technical University of Sofia, Plovdiv branch
Plovdiv, Bulgaria
altaneva@tu-plovdiv.bg

***Abstract*—Manufacturing systems of the future will be characterized by the individualization of products, early detection, diagnosis of faults, forecast of equipment damage, loss of performance and profits and even more. Nowadays, based on informatics evolution and its application in industrial area, the so-called Smart Manufacturing (SM) has promised to ensure self-optimizing manufacturing in industry by its potential such as maintaining reliability of equipment. For this purpose, in this article the benefits and challenges of self-optimizing manufacturing concept regarding its capability and responsibility are presented describing the adaptation to changing manufacturing environment. The idea of the work is to obtain data, needed for Key Performance Indicators (KPIs) calculation, then to apply IIoT solutions for collecting, visualizing and store the information for further analysis. The major and desired effects are: the time decrease for decision taking, product quality improvement, delivery on time and product cost.**

Keywords—data collection, quality management, production control, fault detection

I. INTRODUCTION

Some of the most important topics in mass production in terms of world supply chain crisis are **product quality**, **delivery on time** and **product cost**. In times of material supplying crisis most of the factories are impacted and their deliveries to customers are quite delayed. One of the reasons for this is not enough information on time to take decisions fast. From other side the manufacturers have been carrying out predictive maintenance long ago. They divide in different levels of maintenance depending of the company's maturity. Four maintenance classes can be drawing out: Reactive, Preventive, Rule-based predictive and Machine learning-based predictive. More definitions, terminology in fault detection and diagnosis are coordinated within the IFAC Technical Committee SAFEPROCESS and International Federation for Information Processing [4], [5] and [6]. Approaches of SM theory show the systematic use of mathematical process and their models, identification and estimation methods and methods of computational intelligence. In this way it is possible to develop adaptive methods of fault detection and diagnosis modules embedding in Programmable Logic Controller (PLC). Some advantages of this solution are:

- small problems and early detection
- fault tolerant and management approach
- monitoring of the process variables and better data representation
- transient responses data and processes
- diagnosis of faults in components, sensors, actuators, distributors
- instant notification regarding the predefined event

To treat these advantages some theoretical basements are assumed about industrial process. The general steps in fault detection and diagnosis methods can be observing fundamentals, process observation, choosing the fault detection and fault diagnosis methods to apply in recent case, designing and developing the fault tolerant system, testing and commissioning, [4], [7]. In this work the data gathering of production process is main benefit. The supervision is made, includes and is focused at present state, indicating undesired or unpermitted states, taking relevant actions to avoid damages. From theoretical point of view the deviations from normal process behavior result faults, following to many causes. In next section a kind of model and description for assembly system is given. Hence the observation of the process is conducted. This work will help in development of a module or algorithm for predictive maintenance of equipment in assembly manufacturing processes. The Miniature Circuit Breakers (MCB) is the manufacturing process and a target in fault detection research area. Fruitful results can be applied as a typical solution for many other assembling processes.

.

II. PROCESS INSPECTION

Product quality depends mainly from components quality and well-adjusted process. The term: Non-quality costs (NQC) is important not only in economic area. It can be viewed as a kind of criteria and can describe the manufacturing quality level. For example, the costs for design, development, maintenance, and other activities, that can be measured and analyzed in the product's life cycle, as well as in all the operational phases of the company.

Delivery on time depends from machines capacity, product quality, material availability, "Mean Time To Repair" (MTTR) and "Mean Time Between Failure" (MTBF).

In this work is taken an automatic assembly process and well-illustrated using Value Stream Mapping (VSM) tool. This approach in production cycle allows to identify where it can be improved the process. An example of automatic assembly process is given on fig. 1.

VSM shows different steps of manufacturing process:

- components delivery (Upstream) flow with frequency and inventory (I)

978-1-6654-7625-6/22/$31.00 ©2022 IEEE

- assembly process - automatic assembly process
- finishing process - mixed automatic and manual processes
- Quality Control (QC)
- expedition to the customers (Downstream) frequency

Bellow the process steps there is timeline shows:

- inventory (I) in days between each process
- "Takt time" (TT) of the process for manufacturing one product in seconds

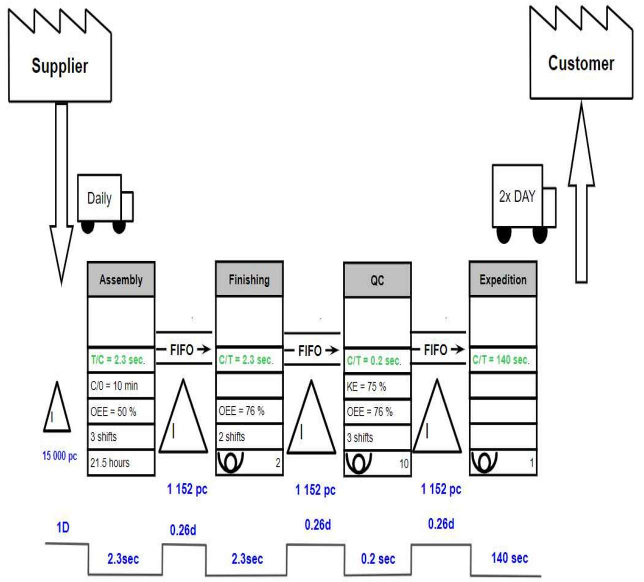

Fig. 1. VSM of assembly process

With a closer look and analyzing present VSM is evident that **assembly** process has been designed to be faster than **finishing**. Obviously, it is with worse Overall Equipment Efficiency (OEE). This is an indication that focus must be on this process to find the reason for the unwanted performance.

The manufacturing process improvement could be done by dealing on automatic or manual activities. The fruitful approach is first to focus on automatic process. In this way the final product costs may decrease and does not depend of human factor. As to the manual processes improvement it is achievable only with automatization, where it is possible. Fig. 2 shows the automatic process with its parameters:

- T/C (takt time / cycle time) = 2 seconds/product
- C/O (Changeover time, time to switch to another reference) = 10 min
- OEE = 50%
- Working shifts = 3 shifts
- Working hours per day = 21.5 hours (for all shift without regular breaks)

The main goal and importance are to keep KPIs in acceptable ranges. This is ensuring that all customer orders will be produced with sufficient quality and shipped on time. The known and widely used term is Production Lead Time (PLT).

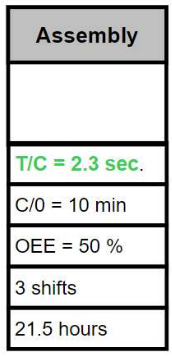

Fig.2 VSM process description

If there is no enough information all decisions will be taken late and this will impact PLT. Thus, in this work, the idea is to define data needed for KPIs calculation and to apply Industrial Internet of Things (IIoT) solutions for collection, visualization and store the information for further analysis. The major and desired effects are:

- the time decrease for decision taking
- product quality improvement
- delivery on time
- product cost

In general point of view all of the above can be viewed as a process inspection. The main effort is to collect the proper data for the assembly process is needed to obtain and arrange data on-time [24]. The best and common way is to be used the PLC from the assembly machine. In the next section is presented the real data collection for process inspection.

III. Data Collection

There are varieties of ways to collect information from manufacturing processes. The one of the most efficient is to gather directly from the PLC. Fig. 3 illustrates the data collection scheme with local Human-Machine Interface (HMI) visualization of the machine. In this way operator can monitor the process and regarding to the response and escalation, to intervene. This approach is very simple for implementation and does not require the complex communications and network structures. Nowadays almost all automatic machines are equipped with PLC and HMI. In present work there are required elements as follows:

- data structure definition;
- data calculation block;
- data visualization HMI screens:

The main purpose of the PLC is to manage and control the process without unnecessary tasks performing. Hence, there are disadvantages of this approach: the PLC memory has limitations and the device is not good enough to be used for data history storing.

On the next fig.4 is given the block scheme of the network architecture for gather data with local visualization and storage in database. It illustrates different approach using additional communication for data history collection. An advantage here is that the data can be stored and analyzed for longer period ago. It depends of the SQL server volume limit.

The disadvantage of this method is overloading of communication and SQL server if is recording data very often for remote monitoring by client's devices on-time. The operator reaction impacts to the workability as well. From the practical point of view, experience, analyzes of process performance and losses, is acceptable the each working shift data to be stored. This means that at the end of the working shift, collected information recorded by the PLC and is forwarded to the SQL server.

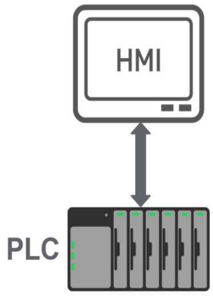

Fig. 3. Data collection with local visualization

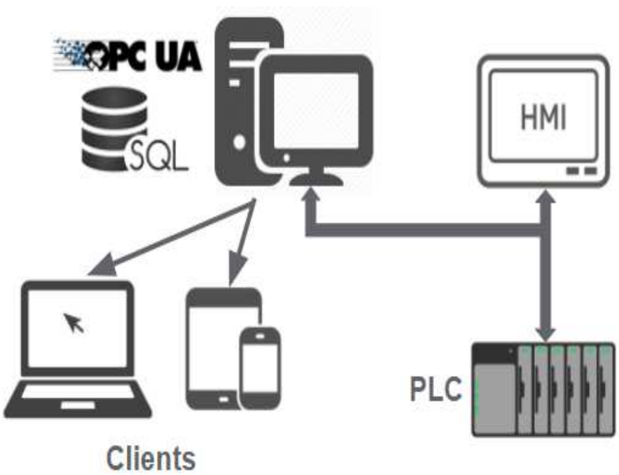

Fig. 4. Block scheme of the network architecture for Data collection

There is an option to decrease dependency of the local SQL server from the data storage to replace it with Cloud storage from fig. 5.

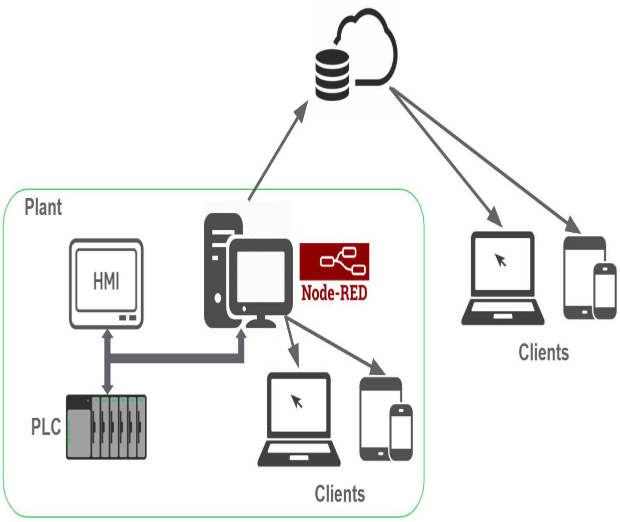

Fig. 5. Data collection with local HMI and cloud storage

Data period limitation is by subscription to the cloud service. Also keeping a lot of data on cloud has other risks:

- Subscription costs are proportional to the amount of the data and number of users;
- Service contract with cloud provider;
- Internet connection stability;

To have best process data access with minimum loss of information, a method that combines all positives of the above is shown on fig. 6. It's visualized process information to local machine operator, plant management and support function using NodeRed and remote clients, store data in local plant database server for long-term analyzes and allows key users outside the plant also to be able to access process data on-time using remote connection to the cloud storage.

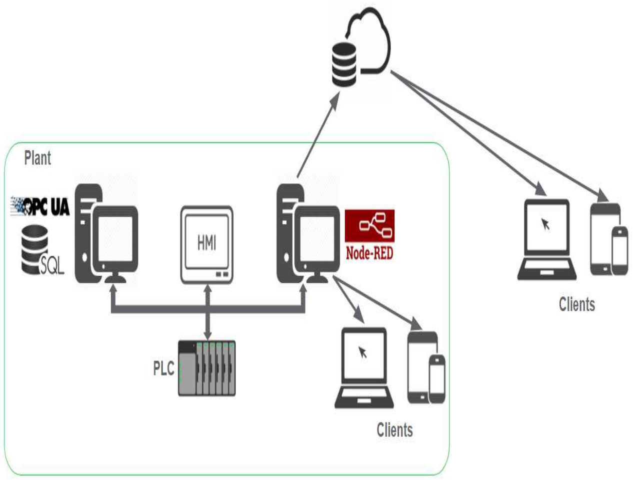

Fig. 6. Data collection with local HMI, storage in database and cloud

The widely used Object linked and Embedded System for Process Control Unified Architecture technology (OPC UA) is used to read the PLC data remotely and saved in SQL server. Hence to achieve better process monitoring with on-time data visualization method from fig. 5 is more reliable. It allows a local process monitoring by operator on HMI and local server with NodeRed has following advantages:

- Support and compatible with almost all known PLCs;
- Read data and send it to cloud servers;
- Local dashboards creation for data visualization on key places in manufacturing area;
- Faster escalation if support needed;
- Remote clients from anywhere (inside or outside plant). Only requirement is internet connection;
- Cloud storage allows to record data for defined period of time;

This method is most efficient and most complex for implementation in the same time. Its disadvantages are:

- Complex for implementation;
- High competent specialists knowing all of the technologies;
- More devices for maintenance;

No matter which method is selected it is necessary to be prepared data format and data collection in PLC to speed up decisions of machine operator and production leader. Fig. 7 and fig.8 show current OEE and MDR (Manufacturing Defect Rate) in percentage and is it in green or red zone. This is first indication that something of the process is not in target.

Fig. 9 is Time loss diagram showing on-time analyzes of each machine statement. Different machine statements are separated as Value Added (VA) and Non-Value Added (NVA) or Losses.

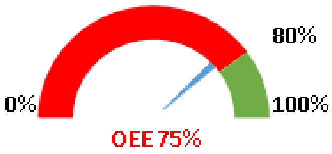

Fig. 7. OEE chart

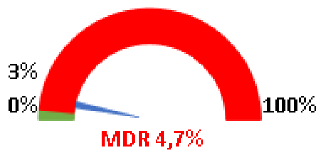

Fig. 8. MDR chart

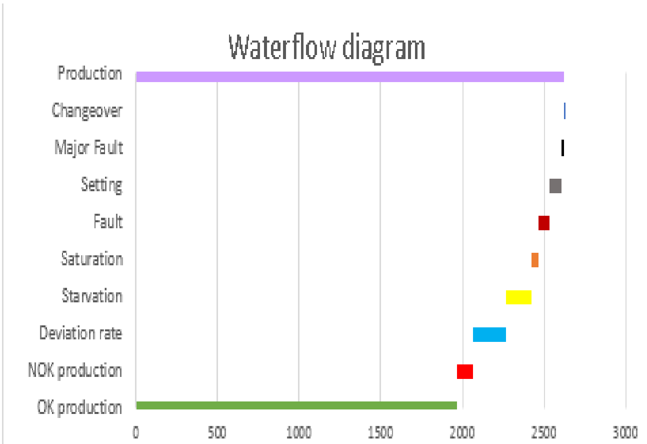

Fig. 9. Time loss diagram

The Pareto diagram of station stoppages by time shows how long machines has not been in production mode due to different station.

The Root-Cause analyzes (RCA) of these diagrams can focus the attention to most problematic station. Depending of the station purpose (assembly or inspection/control) this could lead actions for station settings improvement or product/components quality improvement.

A. Data Format

To prepare the visualization and storage for further analyses we need following information energy consumption especially: electrical and compressed air

- OK quantity: counter of produced good products
- NOK quantity: counter of produced bad products
- Theoretical quantity: counter of theoretical products that have to be produced for machine opened time
- OEE: calculated overall equipment efficiency
- MDR: calculated manufacturing defect rate
- Counter for each rejection (Code + Number)
- Counter of stoppages for each machine station
- Time counter of stoppages for each machine station
- Time counters for each machine state:
- Changeover: time for changing between two references
- Major fault: machine is in stoppages for more than 15 minutes
- Setting: time that machine is in manual operation for adjustments
- Fault: machine is in stop due fault by some equipment
- Starvation: machine has no parts to produce of some feeding system is jammed and cannot feed components to the assembly process
- Saturation: machine output for evacuation of good or bad parts is full and assembly operation is blocked
- Production: total time scheduled for production

All of this data is stored in PLC for real-time visualization and stored in database for each shift for further analyses. This approach in production cycle allows us to identify where it can be improved the process.

IV. Results

The Value Stream Mapping is presented 4 steps of the industrial assembly process of MCBs. The automatic assembly process with 30 stations is investigated and monitored remotely.

The specialized software environment Minitab was used for results representation. Widely used Graphic representation, not only for quality control area for analysis, is the Pareto diagram. In this investigation for data processing was applied the tool. It is a type of bar chart with horizontal axis, representing categories of interest. Usually these are so called "defects". Hence by ordering the data from largest to smallest, it can be used to determine which of the defects are “important”. Pareto chart can draw one chart for all gathered data, or separately for groups by different mean.

In this work is used Pareto charts for data representation of the industrial process. The type of bar chart in which the horizontal axis represents our stations categories of interest, rather than a continuous scale.

The obtain results are useful and promising for the prediction maintenance and smart manufacturing in the further steps.

The data collection for industrial assembly process of MCBs was made. An automatic assembly machine with 30 stations was observed for more than a year. Few Pareto charts are made and presented. The results are given on the figures bellow.

Pareto chart of rejections shown on fig.10. The conclusion of that diagram makes the attention to the top 3 or 5 most frequent product rejection codes for selected period. Root-Cause analyzes (RCA) of these rejections can lead:

- Product or components improvement;
- Product or component quality improvement;
- Machine adjustments improvement;

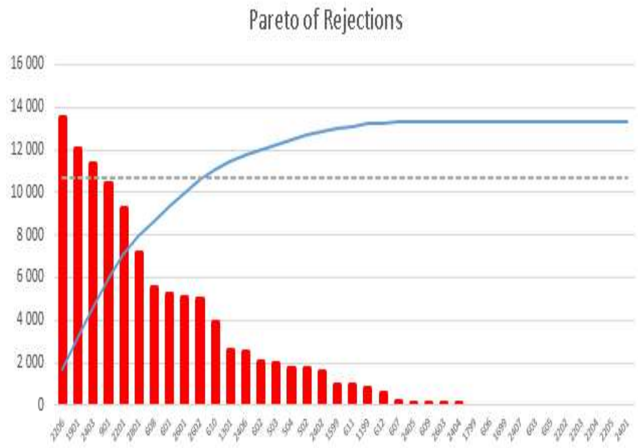

Fig. 10. The Pareto chart of rejections

With the collected data another Pareto diagrams are shown on fig. 11 and fig.12.

Following the Pareto rule or so called 80/20 rule we can focus on 20% of categories of interest which leads to 80% of the rejections or stoppages. Data presentation by Pareto chart is useful in repeatable cycle of continuous improvement process.

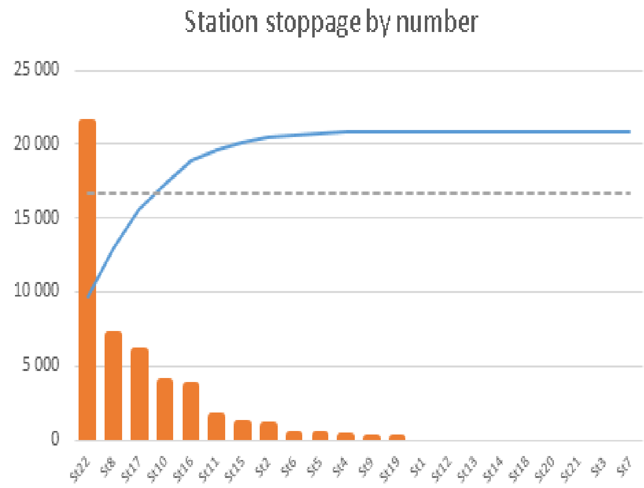

Fig. 11. The Pareto chart of station stoppages by number

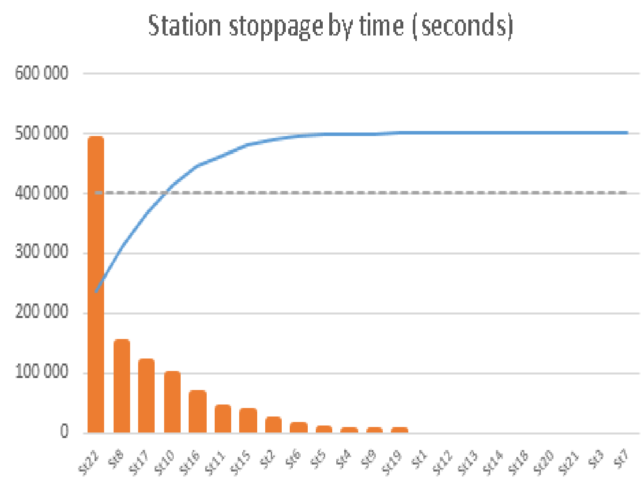

Fig. 12. The Pareto chart of station stoppages by time

The result is obtained from another Pareto chart of station stoppages by number. It shows how often machine has not been in production mode due to different station.

V Conclusion

In this work the data gathering and monitoring, for MCB manufacturing, are main benefits. The Value Stream Mapping is first tool in continuous improvement process showing where to focus the resources. Having correct data with proper presentation is the key for taking right decisions on time. The advantages of Pareto rule are used and based on it the decision is made.

The obtained results can represent process performance, problems and losses for different period of time. The manufacturing process of MCB is presented as a real problem in the SM area. The inspection is time consuming procedure but important. In addition, the representation of the gathered data is fruitful for future work. It can be developpe a case study solution and then to be adapted to another assembling processes. The used and presented Pareto tool in this paper is widely used in different assembly processes and automatic systems.

The results will be used to adaptive algorithm development for maintenance in the frame of fault diagnosis as a next step in the manufacturing system

Acknowledgment

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support

References

The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use "Ref. [3]" or "reference [3]" except at the beginning of a sentence: "Reference [3] was the first ..."

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished" [4]. Papers that have been accepted for publication should be cited as "in press" [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

References

[1] Al. Ichtev, "Hardware Versus Analytical Redundancy for Fault Detection. Application for a Servo System", *Proceedings of the Technical University of Sofia,* ISSN: 2738-8549, vol.71, No. 2, 2021, https://doi.org/10.47978/TUS.2021.71.02.015

[2] Sl. Dimitrov, L. Dimitrov, R. Dimitrova, St Nikolov, "Examination of the Process of Automated Closure of Containers with Screw Caps", Recent Research in *Control Engineering and Decision Making*, Volume 199, Springer Nature Switzerland AG 2019, ISBN 978-3-030-12071-9, ISBN 978-3-030-12072-6 (eBook), https://doi.org/10.1007/978-3-030-12072-6, 2019, pp. 502-514

[3] R. Kosturkov, V. Nachev, T. Titova “Diagnosis of Pneumatic Systems on Basis of Time Series and Generalized Feature for Comparison with Standards for Normal Working Condition”, *TEM Journal.* Volume 10, Issue 1, Pages 183-191, ISSN 2217-8309, DOI: 10.18421/TEM101-23, February 2021.

[4] R.Isermann, Balle, P.”Tredns in the application of model-base fault dectection and diagnosis in technical processes.” *Control Engineering Practice – CEP,* vol 5, pp.638-652, 1997

[5] IFIP, Proc. of the IFIP 9th *World Computer Congress*, Paris, France, September 19-23, Elsevier, 1983

[6] T., Omdahl, editor. ’Reliability, availability and maintainability (RAM) dictionary.”, *ASQC Quality Press,* Milwaukee, 1988

[7] R. Isermann “Fault-Diagnosis Systems”, Springer 2006, https://doi.org/10.1007/3-540-30368-5

[8] R. Isermann “Fault-Diagnosis Applications”, Springer 2011, https://doi.org/10.1007/978-3-642-12767-0

[9] J. Gertler, “Fault Detection and Diagnosis in engineering systems”, *Marcel Dekker, Inc*., USA, 1998

[10] L.S. Nelson, "The Shewhart Control Chart − Tests for Special Causes," *Journal of Quality Technology*, 16, pp 237−239, 1984

[11] C.H. Ng and K.E. Case, "Development and Evaluation of Control Charts Using Exponentially Weighted Moving Averages," *Journal of Quality Technology*, 21, pp.242−250, 1989

[12] E.S. Page, "Cumulative Sum Charts," *Technometrics*, 3, 1−9, 1961

[13] J. Prins and D. Mader, "Multivariate Control Charts for Grouped and Individual Observations," *Quality Engineering*, 10,pp 49-57, 1998

[14] T.P. Ryan, *Statistical Methods for Quality Improvement*, 2nd edition, John Wiley & Sons, 2000

[15] Z. Stoumbos, M.R. Reynolds, T.P. Ryan, and W.H. Woodall (2000). "The State of Statistical Process Control as We Proceed into the 21st Century," *Journal of the American Statistical Association*, 95, pp. 992-998, 2000

[16] H.M. Wadsworth, K.S. Stephens, and A.B. Godfrey, *Modern Methods for Quality Control and Improvement*, 2nd edition, John Wiley & Sons, 2001

[17] Western Electric, *Statistical Quality Control Handbook*, Western Electric Corporation, Indianapolis, Indiana, 1956

[18] D. J. Wheeler and D. S. Chambers, *Understanding Statistical Process Control*, Second Edition, SPC Press Inc.,1992

[19] D. J. Wheeler, Advanced Topics in Statistical Process Control: The Power of Shewhart Charts, SPC Press, Inc., 1995

[20] W.H. Woodal, "Controversies and Contradictions in Statistical Process Control," *Journal of Quality Technology*, 32, pp. 341-378.

[21] Zhang, K., Kao, I., Kambli, S., & Boehm, C.. Experimental studies on intelligent fault detection and diagnosis using sensor networks on mechanical pneumatic systems. In *Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2008,* Vol. 6932, p. 693247, 2008

[22] De Amorim, R. C., & Mirkin, B, Minkowski metric, feature weighting and anomalous cluster initializing in K-Means clustering. *Pattern Recognition*, *45*(3), 1061-1075, 2012

[23] Emran, S. M., & Ye, N., Robustness of canberra metric in computer intrusion detection. In *Proc. IEEE Workshop on Information Assurance and Security, West Point, NY, USA,* pp. 80-84, 2001

[24] Jain, A. K., Murty, M. N., & Flynn, P. J., Data clustering: a review. *ACM computing surveys (CSUR)*, *31*(3), pp.264-323, 1999