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STATISTICAL ANALYSIS OF THE DATA, WHICH RECEIVED FROM AN ASSEMBLY LINE AND THE USE OF THE RESULTS TO DO LINE BALANCING

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ABSTRACT

Automated data acquisition from machines, assembly and test lines become easier and more common with the widespread use of automation in production factories. Automatically collected data gives more accurate and simultaneous information than manually collected data, but automatically collected and stored data does not efficiently converted into knowledge. This study done in a factory, which works in the industrial technology area, belongs to an international company. The purpose of this study is, to determine the station occupancy in the assembly line by using automatically collected data from the assembly line, by using process capability analysis which is one of the statistical analysis method to compare the capability of the station occupancies on the line according to MTM results and define the difference between MTM results and 6 months realized data. If the difference is not acceptable, needed improvement percentage will be advised to reach the MTM result as reference. Line balancing is done according to MTM results. If the difference between realized process times and MTM results are not acceptable, the line balancing, which is done according to MTM results, will be updated.

Method and time measurements implemented, after the assembly line set up and serial production were begin. Method and time measurements implemented on sample selected product types, due to wide range of the product type variety to reduce possible costs and time waste in case of using all the product types as inputs of the same method-time studies. Automatically collected data analyzed and the station occupancy revealed, method-time measurement results compared to realized station occupancy by using process capability analysis, results presented to the decision maker to decide for the changes of line balancing.

Keywords: *Automated Data Acquisition, Line Balancing, Assembly Line, Process Capability Analysis, OEE*

JEL Codes: *O14, O30, O39*

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Research Article

1. INTRODUCTION

The digitization of production systems provides the possibility of automated data acquisition in the industry. The digitization along the value streams proof itself necessary for the industrial future, e.g. to support flexibility, modularity and adaptability in automated assembly systems (Koch, 2014). The real time data, which collected from the machines or the lines used in the companies to increase transparency and the derivation of short-term production control as well as process optimization. The manual data acquisition and developing variants, which range from 41 % to 74 % (medium 58 %) more of the overall time consumption an approach for multimodal data acquisition in production systems (Pawellek, 2014).

Automatically collected and stored data can be used for searching, analyzing and optimizing several topics like production efficiency, high work in process (WIP) inventories, production schedule shuffling, time and quality losses, and line balancing etc.

Line Balancing is leveling the workload across all processes in a production and assembly lines. The aim of the line balancing is remove bottlenecks and utilize the capacity efficiently. In spite of enormous academic effort in assembly line balancing, there are still considerable gap between requirements of real problems on the assembly line and the results of academic research.

When a new assembly or production line set up in a factory, it brings always some difficulties and questions together. First of all we need to decide how many operator should be allocated to the line, which and how many processes should be assigned to the operators, what we should do to minimize the waiting times in the line. On the other hand, we need weekly, daily and shift base production target to give input for capacity, cost and production planning. For all these calculations, method and time measurements (MTM analysis) is a first and important step to get information related to the new assembly line. MTM analysis are repeated due to the reason of changes such as technical improvements, physical changes of the line, process changes in the production and assembly lines. When the lines are settled down technically and the operator skills are in an acceptable level, the deviation between each repeated MTM results are expected low. Despite that, in the new production or assembly lines, deviation between results of MTM analysis can be surprisingly high due to the non-ergonomic movements of the operators in the line, technical deficiency or unexpected breakdowns/problems during the production.

In this case study, method and time measurement (MTM analysis) done for each station in the assembly line as the preparation of line balancing in the beginning of the serial production and repeated in every 3 months. MTM analysis is a basic but significant data to give input to all calculations while managing the production. On the other hand, there is always risk to get the real information when operator feels that an authority measures his work. Purpose of the study is comparing the capability of realized automatically collected data of the assembly line with the method and time measurement results (MTM analysis) as reference to define the difference between both of them. If the deviation is higher than the upper and lower control limits, which are defined by taking the time measurement result as reference point, all calculations need to be revised which take reference the time measurement results. The aim of the comparison, to make visible the possible waiting times or waste in the line and not to face with the non-expected bottlenecks and identify the potential improvements of the processes.

2. METHOD & DATA

An assembly line take place on (work) stations K=1,…,m usually arranged along a conveyor belt or similar mechanical material handling equipment. The work pieces (jobs) consecutively moved from station to station on the line. At each station, certain operations repeatedly executed regarding the cycle time (maximum or average time available for each work cycle) (Boysen, Fliedner, Scholl, 2007).

The assembly line balancing problem can explained as the requirement to assign task elements according to priority and some other constraints (i.e., the relevance relation between tasks and a workstation). Each workstation on the production line in order to achieve specific objectives, such as maximizing the production efficiency, output and minimizing the number of workstations, cycle time, slack time and ergonomic risks (Gökçen, Ağpak, 2006). Furthermore, line balancing will reduce the workload differences between the operators; decrease the work in process (WIP) stocks between the stations.

The tasks and duration of the tasks are defined as a first step to do line balancing. Accurate definition of tasks' duration make possible to allocate correct work load for each operator. When the tasks are well balanced in each station or for each operator, waiting times and stock level decrease between operations. Time measurement is a way to define the task durations in a line. It is independent from the operator, which means measurements are repeated with different operators and in different shifts and calculated as an average value at the end. The significant point is to find out the real duration of each defined tasks. On the other hand, human factor should be taken into consideration, while doing the time measurements to find out the defined tasks duration in the production or assembly lines. When people are realized that they are under observation while working by an authority, they may not always show their normal performance. Time measurement results are used as an important input to manage the production. Due to the deviation possibility between time measurement results and realized task durations, that would be better to analyze the data to ensure the measurements.

In this study, the realized data collected from a new assembly line in a factory, which works in the industrial technology area, belongs to an international company. Process times of the tasks are received from the database via SQL queries as station based between October 2018 and May 2019. During 30 weeks, samples are collected from 10 stations in an assembly line weekly for each station. All calculations and the statistical analysis done with 300 randomly selected samples for each week. As a statistical analysis "process capability analysis" is used for the topics generally related quality of the product or the process. However, the method, process capability analysis is used in this case to compare the capability of the realized process time of the tasks with the time measurement results as a reference. In the literature, Newmark (2003) used process capability analysis to analyze task durations in the line and optimize the assembly line.

Capability analysis is one of the traditional techniques, which have been used for assembly line optimization. Using capability analysis for assembly line improvement should not be overlooked (Newmark, 2003).

Determining takt time (task duration) is an important first step to analyze an assembly line. Takt time is the rate in time that a plant must maintain to meet customer demand (Suzaki, 1987). Control steps generally implemented to maintain continuous improvement (CIP) in the assembly lines.

Typically, in assembly lines the techniques, which based on takt time used to balance the work level of the single operations and thus optimize the whole flow and efficiency of the assembly line. However relying only on the average values can occur missed opportunities for improvements in the manufacturing process or assembly line. Because of that, it would be requested to get efficiently information on the variability and process capability of these operations. Hereby, missed improvement opportunities can be catched and to process improvements can be successfully optimized (Newmark, 2003).

Process capability analysis is a method of combining the statistical tools developed from the normal curve and control charts with good engineering judgment to interpret and analyze the data representing a process. The purpose of the process capability analysis is to determine the variation spread and to find the effect of time on both the average and the spread (Wooluru, Swamy, Nagesh, 2014).

Statistical process control (SPC) is a large class of techniques, which target evaluating, monitoring and possibly reducing variability in production processes in the industry. Two different approaches can be tracked in the definition of process variability: the first considers variability per se, which is, in terms of the variance of the measured data; the second way considers some information about the acceptable level of variability for the process. Such an acceptable variability often expressed in terms of specification limits for the measured quantities of interest; process capability can be defined as a measure of the ability of the production process to meet the specifications (El-Awady, Schaper, Kailath, 1996).

Definitions of process control used to specify qualified measurements for potential and performance of process in the industry, which are elements of capacity (Pearn, Chen, 2002). Capability analysis made by using a data set in statistical calculations for defining the system's capability. In order to define the system capability, the values compared. If the product is approximately percentage 100 in tolerance limits, it can said that the system is "capable". The tolerance limits are determined by customers, engineers and management and they are classified as requirements, aims, specifications and standards. There should be lower and upper limits of specification restrictions for the definition of the system (Motorcu, Güllü, 2006).

Process Capability refers to the evaluation of how well a process meets specifications or the ability of the process to produce parts that conform to engineering specifications, Process Control refers to the evaluation of process stability over time or the ability of the process to maintain a state of good statistical control. These are two separate but vitally important issues that we must address when considering the performance of a process and so the assessment of process capability is inappropriate and statistically invalid to assess with respect to conformance to specifications without being reasonably assured of having good statistical control (Wooluru, Swamy, Nagesh, 2014).

Process capability index is outline insights, which quantify the real, or the potential execution of procedure attributes with respect to the objective and particular confinement. It has been the most regularly utilized index (Saha, Majumder, 2018).

Process capability analysis defines as all statistical techniques that used for determination on process variability, to analyze this variability according to product requirements and specifications and significant reduction or elimination of this variability (Işığıçok, 2012).

The six-sigma range considered as a measure of process capability. Natural tolerance range (control limits) is the result of natural variability of production. However, specification limits are set according to compliance between quality and design. Process capability analysis is a technique that used for the topics as decision of rejected products, product and process design, sales, production planning and production (Işığıçok, 2012).

The aim of a process capability analysis is to estimate, monitor, and possibly reduce variability in industrial production processes. Capability analyzes are based on critical and important assumption that the process itself is in control. Suppose that a (measured) process parameter is a stationary stochastic time series: it will characterized by a (constant) mean and a (constant) standard deviation. We can usually think that due to a generic random noise, its variability, represented by its variance (Bittanti, Lovera, Moiraghi, 1998).

The most natural way to express the information about process variability and specifications by means of a synthetic index is to define some measure of the variability and compare it with the width of the specification interval (Bittanti, Lovera, Moiraghi, 1998). As an essential part of statistical process control, process capability analysis is commonly measured by process capability indices (PCIs) and widely used to determine whether a process is capable of producing items with required specifications limits or not (Wang, Yang, Hao, 2016). One of the most commonly used PCIs is Cp, which is defined by following equation:

$$C_p = \frac{USL - LSL}{6\sigma} \tag{5}$$

Clearly, the aim of process control is to make as large as possible. The definition given above for the process capability ratio does not account for any location parameter of the distribution (e.g., its mean or its median); in order to obviate this problem the more general index was proposed (Bittanti, Lovera, Moiraghi, 1998), which is defined as;

$$C_{pk} = Min\left(\frac{USL-\mu}{3\sigma}, \frac{\mu-LSL}{3\sigma}\right) \quad (6)$$

This definition clearly serves the purpose of avoiding the kind of ambiguity described above for the case of off-center processes, as the two specification limits treated separately and the process mean duly taken into account (Bittanti, Lovera, Moiraghi, 1998). The LSL and USL abbreviations in the formula refer respectively to the lower specification limit and upper specification limits.

Cp and Cpk are often estimated based on three basic assumption (Jose, Luke, 2013):

- The process is statistically in control.
- The collected process data are independent and identically distributed.
- The collected process data follow a normal distribution.

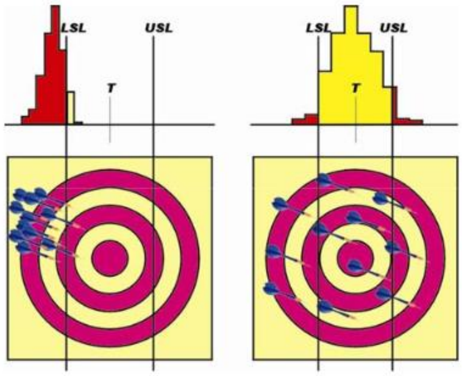
Process capability is the long-term performance level of a process brought under statistical control. Process capability indices are effective tools for the continuous improvement of quality, productivity and managerial decisions. The indices form complementary system of measurement of process performance (Erameh, Raji, Durojaye, Yussouff, 2016).

In the industry, since it is not possible to centralize strictly all processes, both Cp and Cpk values should be used together for process capability analysis. The comments of indices Cp and Cpk are as follows in Table-1. However, mean shift and variability problems in a process are as follows in Figure-1..

Table 1. Comments of Cp and Cpk Indices (Işığıçok E., 2012)

Cp -Cpk	Interpretation
Cp<=1	Process is not capable, there should be process improvements
1<Cp<=1,33	Process does not meet the specification limits, process control should keep up
Cp>1,33	Process meets the specification limits
Cpk=1	Some of the data approximates the specification limits
Cpk>1	All data is within the specification limits
0<Cpk<1	Process mean is within the specification limits, but process is not capable
Cpk=0	Process mean is equal with one of the specification limits
Cpk<0	Process mean is out of the specification limits, and process is not capable

Figure 1. Mean Shift and Variability Problems in a Process (Işığıçok, 2008 and 2012)



3. APPLICATION

In a company, that uses MTM or its derivatives for production planning and/or business offers, a large amount of work is performed to define the expected time needed for a certain task to be done by the operator. (Laring, Forsman, Kadefors, Örtengren, 2002). MTM system and its modern versions are in widespread use in many companies, and used to calculate production times for line balancing, line pacemaker setting and in calculation of business offers.

Automated collection of the process time for each station and accurately measuring operation durations in an assembly line were the first bundle steps of this study. The assembly line has software and hardware infrastructure like SQL server, barcode readers and sensors due to the need of digital transformation in industry. Whenever a task is began and accomplished in the station of the assembly line, the operator scan the barcode, in this way the beginning and the end time stamps saved in the SQL server as year, month, day, hour, minute and second. The tasks durations are calculated as seconds with a basic SQL query, which takes the difference between the finishing time stamp and beginning time stamp of the tasks for each order. For 30 weeks from 10 station one sample is randomly selected for each station, from the largest pool to define the sample pool with total 300 samples. Time measurement (TM) results are our reference values for each task to identify the upper and lower control limits to do process capability analysis. Afterwards, capability analysis of the collected data conducted to identify opportunities for improving operations in the mentioned assembly line. Missed possible improvements might be catched like Newmark mentioned also in his study in 2003.

When the assembly line begin to the serial production, to calculate total production time for each product, to give a production target to the line and to do the production plan accordingly, method and time measurements implemented on sample selected product types. Line balancing is done according to the method and time measurement results.

Table 2. Line Balancing in Line A

<table>
<tr><th></th><th>Station1</th><th>Station2</th><th>Station3</th><th>Station4</th><th>Station5</th><th>Station6</th><th>Station7</th><th>Station8</th><th>Station9</th><th>Station10</th></tr>
<tr><td>MTM Result (cumulative seconds)</td><td colspan="3">636</td><td>404</td><td>644</td><td colspan="3">634</td><td colspan="2">629</td></tr>
<tr><td>Operator Quantity</td><td colspan="3">1</td><td>1</td><td>1</td><td colspan="3">1</td><td colspan="2">1</td></tr>
</table>

After rump-up phase finalized, technological opportunities of the assembly line used to collect the process times of each task which performed in each station simultaneously, used to do statistical analysis to find out the possibility of difference between realized process times of the tasks and the time measurement result. Application steps implemented as followed:

- Understanding the basic concepts of process capability analysis and its measures.
- Process data collection.
- Calculate required statistics.
- Validate the critical assumptions.
- Estimate the confidence intervals.
- Estimation of Cp and Cpk.
- Analysis of process capability results.

Line A has been chosen since being a new project in the company, which has approximately 10 assembly stations. This study will be extended to other lines after improvements in this line have been achieved. Line A has 10 stations. Three separated process capability six pack reports will be generated for each station, corresponding to different OEE levels, 1-OEE values for 15%, 20% and 25%.

OEE (Overall Equipment Effectiveness) needs to be considered after MTM analysis and using the results to do line balancing in an assembly line. During the MTM analysis, the task of each operator is measured for a while. When we consider that tasks are repeated during the shift and 6 days per week, there can occur some performance losses. We can give an actual target to the assembly line by taking into account the OEE.

OEE measures how effectively time is used to produce a quality product. The formulas to do OEE calculation are below (Vorne Industries Inc., 2002-208):

OEE = Availability * Performance * Quality (1)

Availability = Operated Time/ Planned Production Time (2)

Performance = Ideal Cycle Time/ (Operating Time/Total Pieces) (3)

Quality=Good Pieces/Total Pieces (4)

For this purpose, firstly, descriptive statistics, 95% confidence interval on mean and process capability six pack report for 15%, 20%, 25% below and above the time measurement result of each station was created to define an interval between upper control limit and lower control limit. This was calculated separately for station 1 as follows. Table 1 shows us the confidence intervals for the mean, descriptive statistics for 15%, 20%, 25% overall equipment inefficiency values for station 1 and indicates whether the TM result is within the confidence interval. When the results were examined, it was concluded that the TM result was outside the confidence interval for 15%, 20% and 25% equipment inefficiency values.

Descriptive statistics for Station 1 and 95% confidence limits were found as follows in Table-3. Similarly, since the TM result for station1 is 328 seconds, this value is outside the confidence interval.

Table 3. Confidence interval for the first station and comparison of the MTM result and 95% confidence interval

OEE	1-OEE	n	Mean	Standart Deviation	95% Confidence Interval	Station	MTM Result	Comment
85%	15%	30	288,7	35,82	275,88 - 301,52	Station 1	328 seconds	Out of confidence interval

After this analysis, 15%, 20%, 25% 1-OEE values for station1 were obtained as process capability six pack, as shown in Figure 1-Figure 2 and Figure 3. When the process capability six pack report is examined, it is seen that the results are presented in six statistical packages. The first chart from the left shows the I-chart for individual values, the second chart from the left shows the moving range values, the third chart from the left shows the distribution of the last 25 observation values. The first graph from the right shows the graph of the capability histogram with the specification limits, the second graph from the right shows whether the data is normally distributed, and the third graph from the right shows the process capability indices.

It can be said that the data of Station1 is normally distributed, individual values and variability are under control, and the last 25 values are randomly distributed around the mean value. On the other hand, when the capability histogram was examined, it was observed that, there are measurement results below the lower specification limit of 277.8sn, which is 15% lower than the MTM result, 328 seconds, but there are no measurement result above the upper specification limit. Finally, in addition to the excess of measurements below the LSL, it can be said that the process is not sufficient since the Cp and Cpk indices are less than 1 and the standard deviation is quite large.

Figure 2. Process capability analysis for the first station according to %85

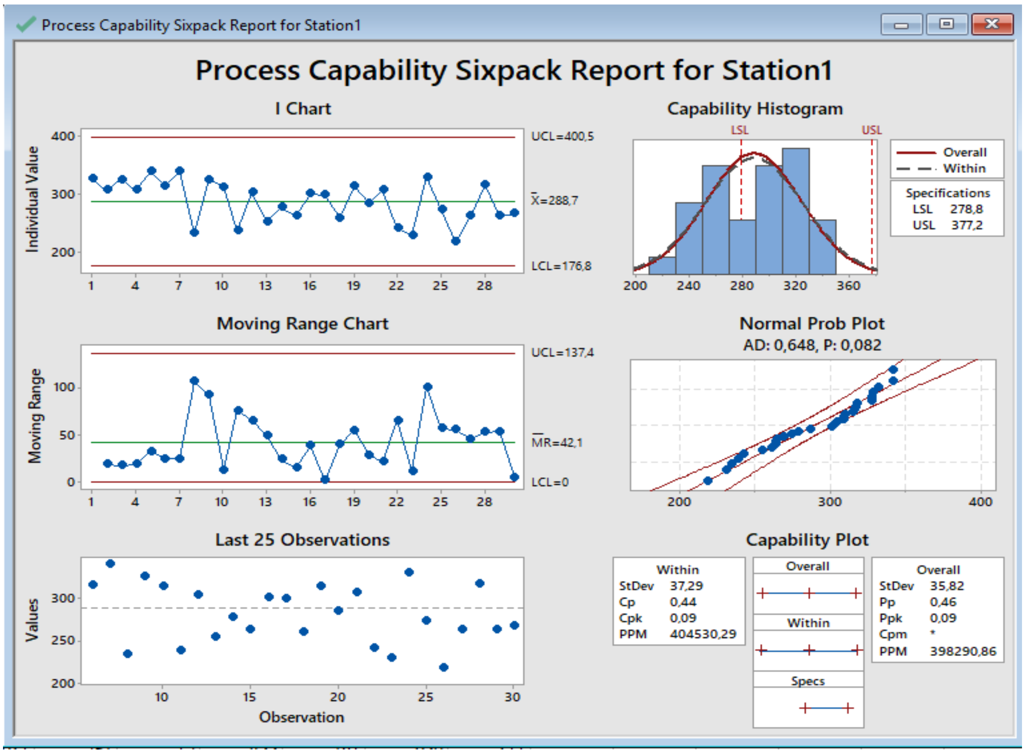


Figure 3. Process capability analysis for the first station according to %80

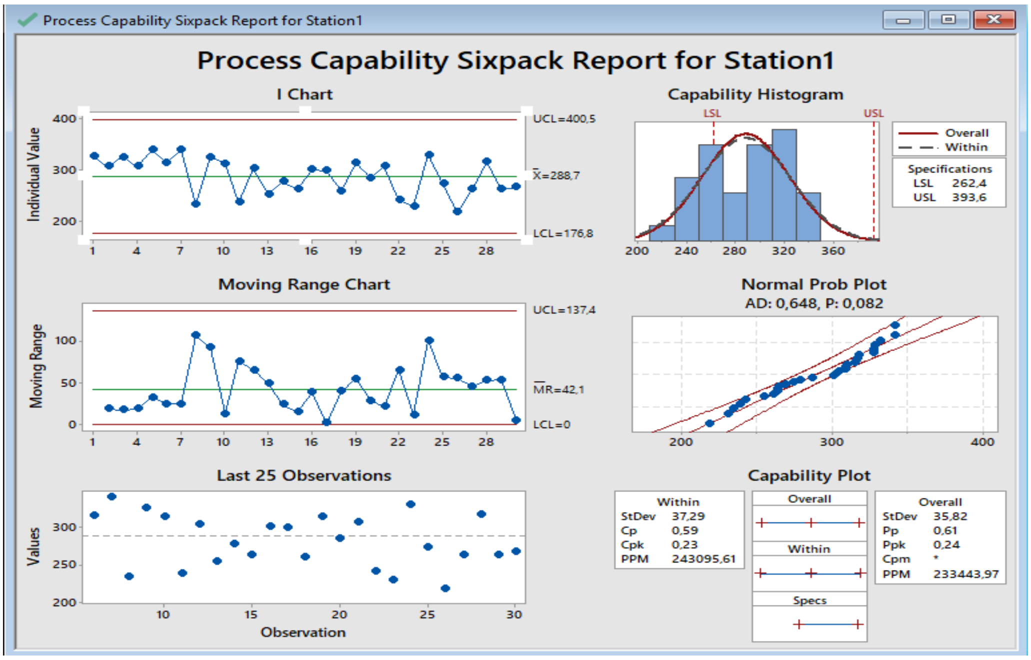


Figure 4. Process capability analysis for the first station according to %75

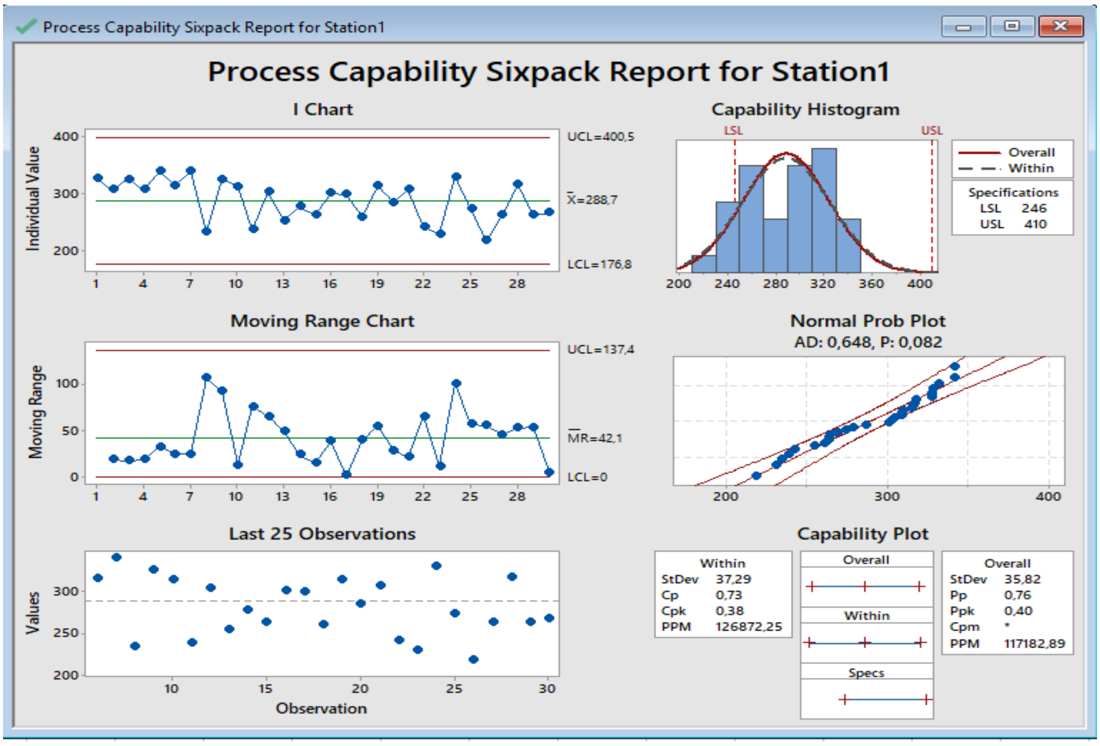


Table 4. Some important statistical results for 10 station

Statistics/Criteria	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station 10
MTM Result	**328**	**108**	**200**	**404**	**644**	**135**	**278**	**221**	**423**	**206**
n	30	30	30	30	30	30	30	30	30	30
Mean	288.7	308.6	259.1	628.0	637.7	176.8	370.5	248.2	532.8	275.9
Standart Deviation	35.82	59.11	72.70	92.92	126.20	55,00	94.70	72.83	66.57	48.77
Anderson-Darling Normality Test p value	0.082	0.178	0.026	0.420	0.419	0.247	0.024	<0.005	0.114	0.316
Distribution Shape	Normal	Normal	Loglogistic	Normal	Normal	Normal	Weibull	Weibull	Normal	Normal
Confidence Interval (CI 95%)	275.9 - 301.5	287.4 - 329.8	233.1 - 285.1	594.7 - 661.3	592.5 - 682.9	157.1 - 196.5	336.6 - 404.4	222.1 - 274.3	509.0 - 556.6	258.4 - 293.4
Does the CI involve MTM?	No	No	No	No	Yes	No	No	No	No	No
I chart center line (Mean)	288.7	308.6	259.1	628.0	637.7	176.8	370.5	248.2	532.8	275.9
I chart control limits (LCL - UCL)	176.8 - 400.5	169.6 - 447.6	80.5 - 437.7	405.4 - 850.6	304.2 - 971.2	1.6 - 352.0	160.8 - 580.2	96.0 - 400.5	341.5 - 724.1	135.6 - 416.2
Is I chart in control or under control?	in control	out of control	out of control	out of control	out of control	in control	out of control	out of control	out of control	in control
Does I chart control limits involve MTM?	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
MR chart center line (Mean)	42.1	52.3	67.2	83.7	125.4	65.9	78.9	57.2	71.9	52.8
MR chart control limits (LCL - UCL)	0 - 137.4	0 - 170.8	0 - 219.4	0 - 273.5	0 - 409.7	0 - 215.2	0 - 257.6	0 - 187.0	0 - 235.0	0 - 172.4
Is I chart in control or under control?	in control	out of control	in control	out of control	out of control	in control	in control	out of control	out of control	in control
Process Capability (LSL - USL) (%25)	246 - 410	81 - 135	150 - 250	303 - 505	498 - 830	101.25 - 168.75	208.5 -347.5	165.75 - 276.25	317.25 - 528.75	154.5 - 257.5
C_p	0.73	0.19	0.31	0.45	0.50	0.19	*	0.37	0.55	0.37
C_{pk}	0.38	-1.25	-0.01	-0.55	0.42	-0.05	-0.02	0.19	-0.02	-0.13
Is the proses capability sufficient or not?	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient
Process Capability (LSL - USL) (%20)	262.4 - 393.6	86.4 - 129.6	160 - 240	323.2 - 484.8	531.2 - 796.8	108 -162	222.4 - 333.6	176.8 - 265.2	338.4 - 507.6	164.8 - 247.2
C_p	0.59	0.16	0.25	0.36	0.40	0.15	*	0.26	0.44	0.29
C_{pk}	0.23	-1.29	-0.07	-0.64	0.32	-0.08	-0.07	0.15	-0.13	-0.20
Is the proses capability sufficient or not?	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient
Process Capability (LSL - USL) (%15)	278.8 - 377.2	91.8 - 124.2	170 - 230	343.4 - 464.6	547.4 - 740.6	114.75 - 155.25	263.3 - 319.7	187.85 - 254.15	359.55 - 486.45	175.1 - 236.9
C_p	0.44	0.12	0.19	0.27	0.29	0.12	0.37	0.19	0.33	0.22
C_{pk}	0.09	-1.33	-0.12	-0.73	0.27	-0.12	-0.13	0.11	-0.24	-0.28
Is the proses capability sufficient or not?	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient	insufficient

4. CONCLUSION & FUTURE WORK

The sectors and areas like banking, marketing and sales have more possibility to collect and store the data. Therefore, there are many use cases of data analyzing and data mining topics in banking, marketing or sales areas in the literature. However, it has been a limited chance to find stored data related technical areas in the industry to work on it. Nowadays, it is increasing to collect data related technical areas such as production, quality and maintenance with the automation of the factories. Companies began to invest huge servers to collect and save the data, which are related with the technical areas.

We recognized the importance of the conversion knowledge from real time data in the industry by this study. The application is basic but significant in point of avoiding business blindness. When mass production started, it brings its own systematic, rules and formulas for managing the production, continuous improvements, problem solving. In addition to this, engineers are working according to this systematic for several years. We can easily collect simultaneous data from the technical areas and store to analyze them by the automation systems of the factories. Engineers should combine the old methods with the new chances. MTM analysis method was not used by itself in this study as a difference from literature. Furthermore, the real time data which was collected from the assembly line, was used to compare the results of the MTM method and give a hint regarding sufficiency of previous line balancing study.

When the new assembly line set up and begin the serial production, to give the daily production target to the assembly line, to do the production plan accordingly and to track the performance of the assembly line, MTM analysis is done and used as a first step. However, the actual daily output and performance may be different due to unexpected reasons. In this case automated data acquisition of the process time and analysis make it possible to compare and determine the differences between MTM results and collected realized process time of the assembly line.

Operator workload and need calculated according to MTM results in the previous line balancing study. MTM results and the process times which collected automatically from the assembly line, do not fit together according to process capability analysis. According to process capability analysis, the processes are not capable for each station, even the OEE is 75%. Due to high deviation between MTM result and collected data, MTM analysis will performed again. The results of the MTM analysis will be used as an input data to revise the line balancing calculation. Possible waiting times between processes will be decreased, operators workloads will be levelled, stock level between processes will be balanced and with these actions OEE will increased from 75% to 80% in mid-term period and from 80% to 85% in long-term period in the assembly line and catch the 85% OEE target..

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