Integrating Performance Indicators to Track the Production Development of Manufacturing Lines

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Abstract

Lean concepts that many companies use to pursue business goals are based on key performance indicators coming directly from the manufacturing floor. These KPI's such as availability, efficiency, productivity, throughput, capacities, and changeovers are essential in determining the performance of support and fundamental areas. Moreover, engineering management techniques should be applied to educate people to focus their work on these KPI's. This will definitively ensure positive results to meet the companies goals. Once employees are engaged in the specific steps that occur between the process and result, it allows for a better understanding on how to deal with the production bottlenecks that can affect these key indicators. This research intends to provide detailed data about how KPI's can increase after these key principles are integrated on the manufacturing lines and gain support from management and employees alike. This increase in performance will directly impact the organization and can assist in providing transparency to the areas that need improvement allowing for continuous operations as deemed necessary. Following this action plan, with the support from the management team, the manufacturing personnel could benefit from these key performance indicators thus assisting these employees with achieving the organizations goals.

Keywords
Key performance indicators, process development, improve, engineering management, production, manufacturing.

1. Introduction
A vast number of manufacturing companies expand their business, especially those affiliated with the bioprocess, pharmaceutical, and medical device industries. In general, when a company plans to develop an expansion, it is due to the organizations volume of production, dwarfing the organizations maximum capacity, or they are launching a new product line with a forecasted high demand. These numbers must possess the capability of validation via the use of analytics that pertain to the market and productions performance. This is where lean concepts and key performance indicators take place, to ensure that the actual production behaves as expected and no waste is impacting the current capacity. Metrics such as downtimes, OEE, headcount, bottlenecks, and productivity should be measured to determine if the actual process is clean, and more capacity is required or if there are any opportunities to improve and capacity could me increase with simple action items.

Manufacturing companies should focus the production process on achieving the optimal functioning of systems in production regarding the set goals, and above all, it is a matter of material, spatial and temporal harmonization, or coordination of resources involved in production processes (Rylková et al. 2021). To achieve that optimal functioning, many of these performance indicators should be measured, informed, and controlled. Some KPIs are connected one to the other because a continuous process depends on previous stations. For example, measuring downtimes will provide information about the total amount of time that a line was down, not performing as scheduled with unplanned stops and reduced capacity. Also, this number is directly correlated with available time which is one of the Overall Equipment Effectiveness (OEE) factors to measure with this KPI. Having your process running efficiently and without any unplanned stops, will avoid increase unnecessary headcount and eliminate overtime work to deliver a planning schedule.

The metric of tracking headcount is directly associated with the productivity system of measurement. Moreover, the process of hiring more personnel to achieve staffing requirements to expand the production area. Productivity measures how people perform based on output in units versus man worked hours. However, hiring personnel without any experience in the area would result in a lowered productivity due to many sidelines effect, such as the learning process. Key performance indicators like productivity will be able to track the learning curve and show a metric for training developments, to ensure OEE factors are not being affected. On the other hand, bottlenecks in the process should be measured to be used in the calculation of maximum capacity analytics before the comparison of projected volume. Those bottleneck numbers are needed to provide the current capacity before approving expansion plans. Measuring capacity as a key performance indicator provides an overview of the production state and linked to the reasons for downtimes previously describe, demonstrates how the process performs. A previous report from Performance Measurement Systems (PMS) states that data obtained through these systems bring knowledge about an organization's operations and must be interpreted to support decision makings such as expansions plans and capacity improvements (Duarte et al. 2018).

1.1 Objectives

The general objective of this paper is focused on developing those key performance indicators to the manufacturing floor and inform the persons that have direct impacts on those metrics. Measuring availability, productivity, and capacity provide a clear picture of the level of performance from manufacturing and supporting areas. Implementing tools that work as an aid for the manufacturing floor to keep track of KPI's will be the main outcome for this analysis. Even though, analyzing data, and developing actions items may results in business benefits, encouraging employees to be aware of those metrics with structured daily meetings gives a sense of ownership while achieving the businesses goals. With the intention of applying some of the topics from engineering management, analytics, and economics, the production indicators must be evaluated in comparison to company performance targets.

2. Literature Review

Due to the increased demand for products from biopharma industries, the manufacturing sector has been identified as one of the most important businesses worldwide. The traditional metrics' that were measured before to track Key Performance Indicators are no longer useful because technology improvements have been implemented to simplify the data analysis. Most of the methods developed have focused on determining the production efficiency of a machine for a particular time frame but fail to consider the machine efficiency history (Muthumanickam et al. 2020). The concept of OEE is the Overall Equipment Effectiveness and it is used as a measurement metric of a production process. This technique involves other factors such as availability, downtimes, outputs measured in units, and quality yields. Tracking KPI's gives quantitative data for decision-making and support the business in achieving their strategic goals. When determining capacity and actual good count, there are two ways to calculate the number, theoretical and practical capacity. Theoretical capacity assumes that nothing in your production ever goes wrong.

Accountants describe this capacity as working at full efficiency all the time. Practical capacity is the level of capacity that includes unavoidable operating interruptions. Another description is unavoidable losses of operating time. (Boyd 2021). These capacity models are needed before analyzing the current production on the manufacturing process due to the relation between each one. Productivity, on the manufacturing floor, is based on the total quantity of goods manufactured units by the total hours spent on the product. This is one of the most important KPI's evaluated to achieve company budget and economic savings. Directly link to productivity and how people are performing comes the headcount for your business and the distribution between direct and indirect labor costs. Headcount must be considered to assure the process is developed with the required people and no excess of headcount is impacting productivity goals nor the volume of production. Identifying the potential root causes for not achieving the metrics' goals requires actions items which are the driving results for improvement. To implement key performance indicators to manufacturing lines, a structured approach must include planning, execution, and results. The greatest way to present those results is using visual managements techniques to inform all production floor and supporting departments of their performance.

3. Methods

The methodology used for this paper follows the SMART matrix tool in which the implementation of a plan's task will be analyzed to understand what is needed to develop the sequence of actions. While objectives were already discussed, a matrix for communicating and setting a timeframe for execution is required. The SMART tool consists of 5 attributes – Specific, Measurable, Attainable, Resources, and Time. Table 1 shows a table summarizing the project task and indicating the area of attention as well, the KPI that will be measured, resources needed to achieve the objective and the expected time to complete the actions. In general, this assessment is expected to improve and drive positive results to the business, also providing recommendations for improvements in terms of operational cost.

Table 1. Methodology to develop a SMART matrix tool for Key Performance Indicators

KPI's	Production output	Manufacturing Headcount	Productivity
Specific	Increase production output by a 15% with the reduction of lines downtimes.	Add a 100 people in headcount to boost 24/7 operations reducing overtime by a 20%.	Improve productivity by a 10% after removing waste in process flow.
Measurable	Measuring lines downtimes and tracking the good unit count at the end of the mfg. line will give the baseline for the improvement.	Manufacturing headcounts shift by shift with the required employees per line achieve targeted production.	Performing time study between station and units through the process.
Attainable	Since the bottleneck of the line is the final station, a data collection tool will provide hour by hour the line output.	While mfg. floor is expanding operations and requires more people, an intense recruitment is needed.	With the analysis of cycle times and takt times, Engineering should be able to improve bottleneck times.
Resources	By having the line leaders collecting the data and reporting down times, the top 5 reasons for waste time will be given.	After staffing goal is requested from operations to Human Resources, the goal of 25 people per month should be started.	The evaluation of technical data from equipment that could be adjusted to reduce waste time.
Time-bound	At the end of Q3.	4 months after the request is placed.	By the end of current year.

4. Data Collection

Once the key performance indicators were successfully identified and measured, the purpose of this matrix tool can be achievable by the people accountable for the actions, at the time-bound given. The selection of appropriate tools for manufacturing improvement, together with their applicability, incorporation, and acceptance within operations is a major problem for many companies (Herron et al. 2006) Since this may be a different method than companies used to apply their KPI's tracking tools, the results can vary from what was previously measured without today's lean concepts developments.

5. Results and Discussion

As a means of measuring and tracking key performance indicators, all methodologies discussed are important for the continuous operation of the manufacturing floor. However, these metrics need to be shared with employees to guide them through business objectives and goals by the end of the year. Employees must know how they are performing, the metrics that are being tracked, and the opportunities identified. Implementation of SQDC boards on production is the best approach to communicate metrics and to be compared month to month with their previous performances. SQDC acronym consolidates Safety, Quality, Delivery, and Cost. Production outputs are considered as delivery metrics and bottlenecks as cost metrics. Integrating these key performance indicators into the manufacturing line and discussing them with employees are part of the visual management concepts of Lean manufacturing. Conducting daily meetings to inform employees of any abnormal events is crucial when attempting to accomplish the organizations goals and to maintain effective communication between line operators, line leaders, and mid-level management. Figure 1 shows a simple four-blocker often used for leading monthly performance reviews on the manufacturing floor.

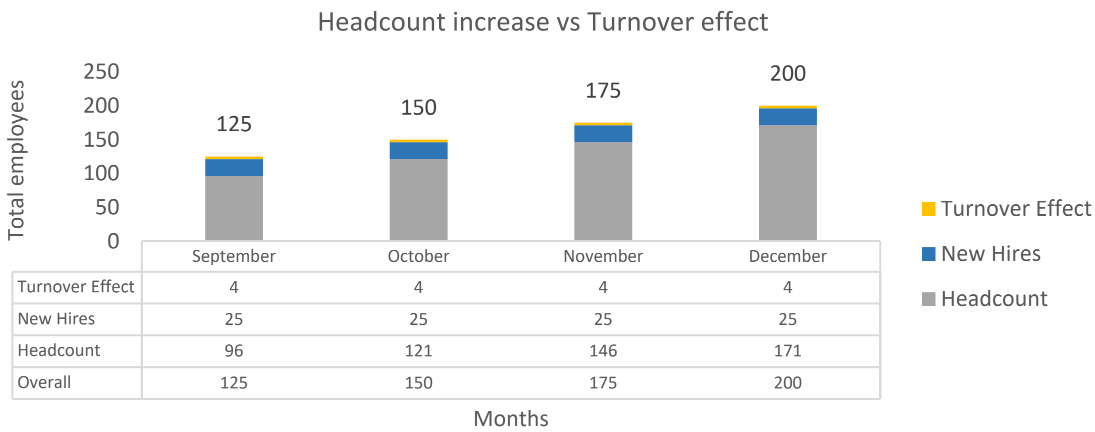
Figure 1. Dashboard with SQDC metrics used in monthly performance review meeting

5.1 Numerical Results

Adding 100 people into the headcount to boost 24/7 operations reducing overtime by 20% is a challenge, even more, when the time frame is too short. If the manufacturing floor needs to operate 24 hours, 7 days a week, having the required headcount is essential. To track this indicator and evaluate the benefit of reducing overtime, an employee turnover rate must be estimated. The employee turnover rate is the measurement of the total employees that enter and leave the business in a specific period. Organizations need a practical procedure for measuring and analyzing the cost of employee turnover, especially because top managers view the cost of hiring, training, and developing employees as investments that must be evaluated just like other corporate resources. The objective is costing human resources is not just to measure the relevant cost but also to develop methods and programs to reduce the cost of human resources by managing the more controllable aspect of those costs (Cascio 2019). To calculate the turnover rate, divide the sum of total employees that leave the company within a specific time, can be a month, a year, or a quarter by the total average of employees in headcount, then multiply by 100 as shown in equation (1).

$$Turnover\ rate = \frac{[\sum Employees\ leave]}{[\,Total\ employees\,]} * 100 \tag{1}$$

After giving the employee turnover rate, the KPI has been successfully measured, but now needs to be applied to the target goal of hiring employees by month. If the goal plan is to hire 100 people after 4 months of the request and 25 is the target per month, then the turnover rate must be applied to determine the additional employees that need to be hired. This is to balance the turnover effect and operations requirements does not result impacted. With this hiring the overtime reduces and instead of charging doubles hours to operate 24/7, will be consuming straight time regular hours. Figure 2 shows a graph assuming that the turnover rate is 16% and the expected quantity of employees that must be hired is 25, then to balance the turnover effect 4 more employees should be hired per month.



	September	October	November	December
Turnover Effect	4	4	4	4
New Hires	25	25	25	25
Headcount	96	121	146	171
Overall	125	150	175	200

Figure 2. Example of employee turnover rate applied to monthly hires

Achieving productivity goals by removing waste in process flow and improving a 10% can be helpful for the business, principally if the previous two goals are accomplished. Increasing the production output and keeping the straight time hours even, would increase productivity, because there is a 1:1 relation between those two KPI. The following equation (2) shows the calculation for productivity using good unit count and total charged hours.

$$Productivity = \frac{[\sum Good\ Count\ Units]}{[\sum Total\ charged\ hours\ ]} \quad (2)$$

However, increasing headcount will reduce productivity due to the learning curve and training development for new hires, at least for the first 3 to 6 months depending on the type of manufacturing process. To stabilize this possible effect of decreasing productivity with the addition of new employees, an analysis of the equipment, process, and flow must be performed. In most of the companies, this action belongs to the Continuous Improvement team, to develop a time study of the process overall to determine the opportunities for improvement. Time study is the analysis of cycle times and takt times that helps to identify the station with the highest bottleneck that limits the line flow. By analyzing data from time studies, one action could be adding more equipment in line to increase capacity and split bottleneck with two different stations. Another action could be to focus on reducing line spacing and make it shorter to reduce walk waste time between locations. Figure 3 shows an example of how adding second equipment identified as the bottleneck, splits the cycle time when is scheduled non simultaneously and the bottleneck roll to other station, because every 6 minutes, station D will be receiving one unit.

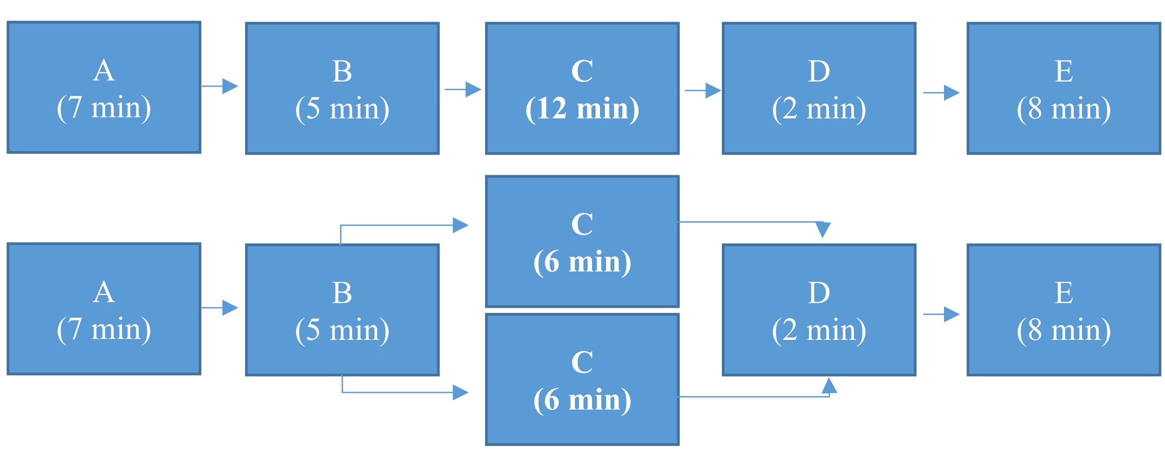


Figure 3. Example of adding a second equipment identified as the bottleneck split cycle time.

Reducing cycle times and performing these time studies are also required when determining capacity using line bottlenecks and total available time. There are many companies that commit to productivity with a reduction in bottlenecks and are added to their budget's commitments. As budgets are negotiated, mid-level managers in this more optimistic and supportive environment are willing to discuss openly the problems and opportunities facing the operation; they are confident that top management seeks realistic budgets (Riggs 2004) Management often discuss proposals and negotiates capital expenditures for new equipment by an agreement with improvements in productivity. The following equation shows steps to calculate the capacity of one line assuming the bottleneck 2.5 minutes as a result of times study. The available time is determined by an average, used in many industries of 7 hours per shift, 3 shifts a day, 7 days a week, and 50 weeks a calendar year.

$$Capacity = \frac{[\,7hr * 3shift * 7days * 50\ weeks]}{[\,2.50\ min\,]} \tag{3}$$

As part of lean concepts, there are different methods to calculate capacity, but for this simulation the KPI measured is the bottleneck of the line. Lean manufacturing is a management approach focused on incremental improvements in operations. Different lean strategies are being utilized by the manufacturing industry to improve the performance of current manufacturing system processes (Singh et al. 2018).

5.2 Graphical Results

As a means of increasing the production output by 15% with reductions in line downtimes as stated, a few tools must be implemented to track the values and variables. A simple spreadsheet can be used to track the output at the end of a production line. This data collection can be supplied to the line leaders, which can include a full day of production broken down into an hour-by-hour analysis. Per this table, a metric of count per shift, per line, and per day can be measured and analyzed for the setting of realistic goals. Another factor that this table must possess is the accurate tracking of downtimes or abnormal events that affect the production lines run time. This information must be documented and analyzed to decipher the production lines bottlenecks and/or downtimes. With the downtime section, the top 3 to 5 events that effected the days production can be identified and reviewed by the line leaders and the management team. Manufacturing supervisors and engineers should be accountable for the analysis and reduction of line downtimes to remove roadblocks and produce units to reach the increment of 15% as the established goal. This specific KPI of produced units is the numerator at the productivity calculation formula. Table 2 shows an example of a manual tracking tool with production in units and a record of line downtimes for an 8-hour shift. This sheet becomes useful when tracking all those downtimes that prevent lines to meet output goals and once are identified actions may be settled.

Table 2. Example of tracking tool table to measure production output by hour

Shift: _3rd__	**Tracking Tool (Production output)**			**Date: _10/05/2021_**
Hour	**Actual Good Count**	**Downtime (min)**	**Reason**	**Remarks**
12:00 ■ AM □ PM	15	-	-	-
1:00 ■ AM □ PM	5	-	-	Lunch (30 min)
2:00 ■ AM □ PM	11	-	-	-
3:00 ■ AM □ PM	12	-	-	-
4:00 ■ AM □ PM	8	8 (min)	Rework	Incorrect assembly
5:00 ■ AM □ PM	10	-	-	Shift end
6:00 □ AM □ PM				
7:00 □ AM □ PM				
8:00 □ AM □ PM				
9:00 □ AM ■ PM	5	35 (min)	Raw material issue	Accelerate delivery
10:00 □ AM ■ PM	12	-	-	-
11:00 □ AM ■ PM	7	10 (min)	Equipment repair	Follow equipment PM

5.3 Proposed Improvements

For those industries that are expanding production and plan to manufacture new goods, this information about KPI must be tracked since the first batch of production. Controlling the headcount is very important to avoid hiring extra personnel and the turnover rate could be estimated with the business actual data. Once the production starts, the productivity should be measured, and a learning percentage should be applied because people will be performing without the projected experience. However, those hours might be taken out of the equation when calculating productivity and charged to a training center. Also, mid-level management needs to discuss with the new employees their expectations of the new line, product, or area that is under the expansion process to ensure they are aware of the company goals and objectives. After that, it is highly recommended to develop daily meetings with visual management tools that assure people know how they are performing and their continuous development as they are getting experienced with the new tasks. In general, this paper recommends specific information about how key performance indicators add value to meet company goals and how sharing this information with all employees engages them to meet those objectives as well.

6. Conclusion

The paper has focused on integrating key performance indicators as a new approach to understand manufacturing metrics, accomplish business goals, and inform direct and indirect employees about the performance tracking tools. By using these concepts and the examples shown previously, a new method to analyze business commitments for future projections and forecasts can be achieved based on the existing data collected. Looking for improvements in the manufacturing floor is always required for continuous operation and monitoring consistency. Once targeted goals are achieved, new goals must be established to always look for opportunities and boost production aspects. Using visual management boards provides an excellent alternative to describe the monthly performance and present a structured design of metrics. Further research on how implementing other factors or metrics to the process can be developed. Additional usage of these of these guidelines by different audiences can assist in the development of additional metrics' and baselines. The strategic model of the SMART matrix gives a quick reference on what is the specific metric that should be tracked, if it is measurable or quantified, how the measurement will be attainable or achievable, the resources or requirements to focus on those goals, and the time-bound that the action will be implemented as a due date. Also, SQDC metrics and dashboards with monthly meetings influence positively the environment with employees because they can communicate with mid-level managers and make them feels like part of the decision-making process. For a company that is expanding their business and wants to guide step by step the new hires employees to drive them through the metrics tracking process, this level of understanding is required to ensure constructive behavior. Integrating key performance indicators into the manufacturing line is an investment with short-term benefits.

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