Derivation of a 3-degree Breakdown of Overall Operational Efficiency (OOE) to Identify the Main Factor of Non-Efficiency in the RMG/Footwear Industry

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Abstract

Overall Operational Efficiency (OOE) is the key lever in the Apparel/Footwear Manufacturing industry today which drives the costing, productivity, and optimization of resources. Consequently, it is significant to determine the reasons for low OOE to mitigate the risk of higher cost, low productivity, and excess use of resources. In most of the cases, the common practice is to use the 1st Degree formula only to calculate OOE which is challenging in case of detecting the root cause for low efficiency. This study deals with this challenge by outlining the Three (3) degrees of Breakdown of OOE in a manufacturing unit that finally drives to decide which main factor to pull down the Efficiency is. The analytical approach formulates the 2nd & 3rd degree of OOE measurements by correlating all the possible parameters by using the conventional theory of OOE (1sr Degree) and introduces the four possible factors of OOE: Availability Rate, Level of Performance, Quality Rate & Direct-Indirect labor Ratio. The correlation was proved later on by the data collection, data plotting on the derived formulas, and further analysis from a manufacturing unit. Finally, the macro level to micro level derivation illustrates how an Apparel/ Footwear manufacturing factory can identify the factors related to low Efficiency & take faster decisions on those factors to take the right actions to improve Efficiency.

Keywords
Efficiency, Availability Rate, Performance degree, Quality Rate, Direct-Indirect Labor Ratio

1. Introduction
The Apparel & Footwear manufacturing industry has witnessed a massive growth in consumption of these products over the last few decades. American Apparel and Footwear Association (AAFA 2023) published a report that states: In 2022, the average American spent a record-breaking high of $1,143.29 for 68.5 pieces of clothing and $330.62 to buy 8.3 pairs of shoes. The report also highlights that The U.S. apparel and footwear industry contributed more than $490 billion in retail sales to the U.S. economy in 2022. The total market value was 1,102.57 Billion in 2021 and by 2030, the projection is to reach USD 4,965.5 Billion growing at a CAGR of 18.2% from 2023 to 2030. (Verified Market Research 2023). These statistics show how rapidly the consumption of apparel and footwear is growing year by year. With the increase in market demand, the production rate should also be increased at the same pace. However, the challenge is production rate is still lower than the market needs for apparel & footwear (Jayawardena 2020). Overall Operational Efficiency is the proper focal point to deal with this type of crisis.

The production sector of the Apparel and Footwear industry has large numbers of problems every day, even every hour. So it is almost impossible to find every problem on the surface. Therefore, it is important to know the easiest method to dig down the problem to find the root cause. Like other measures, almost all the manufacturing units of Apparel and Footwear currently use the conventional formula for OOE, defined as 1st Degree of the Formula to measure OOE. The factors used in this formula can only measure the current level of Efficiency of a manufacturing unit. But, in the case of low efficiency, it hardly drives to the root cause because of the limitations of the parameters. This research helps to give this overview of the root causes of problems by giving more insight into the OOE formulas.

This research is beneficial for all the Apparel and Footwear Manufacturing units, where the challenge of finding out the main problems with lower efficiency exists. Also, this research will help them to take analytical but quick actions on the main points to improve regarding lower efficiency. At last, the theory from this study can be implemented to make any tools to take a quicker decision on the problem for fast reactivity.

1.1 Objectives

The objectives of this research are: Firstly, to derive the 2nd and 3rd Degree of Formula for OOE. Then, to validate the derived formula with a set of data collection and by plotting the data on the derivations. Also, to give the micro details of OOE to evaluate the factors behind low efficiency. Finally, the objective is to correctly identify the root cause so that there would not be any delay in taking the right actions to improve operational efficiency.

2. Literature Review

This study engaged with an extensive literature review using Twenty-four (24) research articles. This section covers various scholarly studies to define the common terms used for Overall Operational Efficiency (OOE) in the Apparel & Footwear sectors and connect them to develop further analytical studies.

2.1. Overall Operational Efficiency

Johnson & Lee (2012) defined Operational Efficiency as the ratio of Output produced to the Input or Resources given for production. According to Tareque et al. (2020), Efficiency is the ratio of the qualityful output that is performed by a man, machine or in process to the total input or resources given for production. An efficient process is to produce a good or provide a service by using the minimum input of resources (Jacobs et al. 2014). Sudarshan & Rao (2015) calculated Overall Efficiency by operators' total minutes produced divided by the total minutes attended. Efficiency (%) = [Total minute produced by an operator/Total minute attended by him x 100] (Sudarshan & Rao 2015) Overall Operational Efficiency is the ratio of Output Minutes generated from the Input or Resources minutes given to the system.

OOE = Output Minutes / Input Minutes

2.2. Importance of Overall Operational Efficiency

Organizational strategies depend on efficient processes. This efficient process design finally drives to minimize the cost (Kalluru & Bhat, 2009). Operational Efficiency is a deciding factor for maximizing the quality of products or services while minimizing the resources utilized by the process. Overall Operational Efficiency (OOE) plays a vital role in maximizing the profitability of any manufacturing industry. Sufian (2006) showed how Operational Efficiency can play an important role in improving the financial performances in the financial sector like Banking. Rajput et al. (2018) analyzed how Efficiency is related to Productivity and better quality rates in the garments manufacturing industry. Manufacturing units are now focusing more on improving process performance to compete with the fast-growing world and efficiency is one of the main factors to be more competitive in this fast-growing world (Araújo et al. 2017).

Overall Operational Efficiency is a significant term used in apparel or footwear factories. Tareque et al. (2020) described that Efficiency is the main factor to improve the lead time & cost of manufacturing. So, it is necessary to focus on Operational Efficiency to be competitive with the global world by having a less costly and shorter lead time.

2.3. 3-Degrees of OOE

In this article, we can see the evolution of the Generic Efficiency formula that is widely used and defined as the 1st degree of Overall Operational Efficiency here.

2.3.1. 1st Degree OOE

$$\text{OOE} = \frac{\text{Output Minutes}}{\text{Input Minutes}}$$

$$\textbf{1}^{\textbf{st}}\textbf{ Degree OOE} = \frac{\text{Right Output x SMV}}{\text{Working Minutes x Manpower}}$$

2.3.1.1. Factors of 1st Degree OOE

Output Minutes

Output minutes means the total standard times (minutes) produced by the production.
So, Output Minutes = Right Output x SMV
For example: A manufacturing unit produced 100 pieces of desired quality output. Each piece requires 10 minutes time to produce from input to output.
So, the output minutes will be = 100 x 10 = 1000 minutes

SMV

SMV or Standard Minute Value or SAM is the measure of Total time required to manufacture or produce a product or output in Apparel or Footwear Factory. Abtew et al. (2020) defines SMV as a numerical value which is the standard time to make a product by a standard worker in a standard environment. Rahman et al. (2014) calculated SMV by Basic Time added with the Bundle allowance, machine allowance & personal allowance. Basic time is the average time taken by a machine operator to complete a full cycle considering a performance rating.
SMV= (Basic Time + Bundle allowance, machine allowance & personal allowance %)
= (Average Cycle Time x Performance Rating%+ Bundle allowance, machine allowance & personal Allowance %)
For example, if a machine operator's average cycle time complete an operation is 30 seconds with a performance rating of 90% and for that operation, if the total allowance is 12% then,
The SMV for that particular operation is = (30 x 90%) + (30 x 90%*12%)
= (30 X 90%) x (1+12%)
= 30.24 seconds

Right Output

Production with the desired quality is significant not only because, it's impact on Efficiency but also, the Right Quality is one of the important factors that can optimize the overall cost. Alauddin & Mita (2013) portrays the importance of the Total Quality management system to ensure the Right quality product which has the positive impact on productivity & efficiency. Juran et al. (1999) describes Quality as the factor for which customers or consumers are satisfied and willing to pay. So, if the quality is not the desired one, the demand will be less and the cost will be high. Sahoo (2020) defines the Right quality products are free from the defects and rejects or reworks.
Right Output = Produced Quantity - Defective Quantity - Rejected Quantity

Input Minutes

Input minutes is the total minutes attended by the given resource into the production.
Input Minutes = Working Minutes x Total Number of Manpower

Working Minutes

Lisa Hult (2016) compares the normal working hours from different countries in garment industries and calculates the maximum working hour's limits for an individual from a variety of countries. Sikdar et al. (2014) found that average working hours for female garment workers is 11.21 hours. Total working minutes is the remaining time of Planned Production minutes after excluding the break times.

Total Manpower

The most important resource in a garment manufacturing line is the manpower or laborers who are directly or indirectly involved in the production of the goods.
Chiang (2013) stated that Direct labor are those who are involved in the production or directly related to the products and the rest others who play the supporting role to the direct labors without being directly involved with the products are Indirect labors.
Total Manpower = Direct labor + Indirect Labor

2.3.2. 2nd Degree OOE

The 2nd degree of Overall Operational Efficiency (OOE) follows the same theory of Overall Equipment Effectiveness (OEE) except the fact that, OEE is about the machine efficiency whereas OOE is about measuring the man-machines combined efficiency. Therefore, we include one parameter (Direct-Indirect Manpower Ratio) with the OOE formula.
Patel & Deshpande (2016) defined OEE = Availability Rate x Level of Performance x Quality Rate

Considering the Manpower, We can derive,
2nd Degree of OOE = Availability Rate x Level of Performance x Quality Rate x Direct-Indirect Ratio

2.3.2.1. Factors of 2nd Degree OOE

The 2nd Degree of OOE identifies a deeper version of the factors defined in 1st Degree OOE. It consists of Four (4) Factors.
Relkar & Nandurkar (2012), Dewi et al. (2020) & Solaiman (2020) described the First Three factors in their study.
We can define our parameters from that study like below:
Availability Rate is the ratio of Factory Actual Running or Operating Time to Total Factory Opening Time.
Availability Rate = Operating Time / Opening Time
Here, Operating Time= Opening Time - Down or Stoppage Time
Level of Performance is the measure of how well a production line is converting the inputs into the desired outputs comparing the running time with the standard time.
Level of Performance = Standard Time / Running Time
Running time means Time to produce per piece
Running Time= Operating time x Direct worker / Total pieces produced

Quality Rate is the Total Right output produced among the Total produced outputs in a line within a certain time.
Quality Rate = Right Output / Total Number of Outputs
Ambika & Regy (2014) gave an overview of the Man to Machine Ratio from where the concept of our Fourth parameter Direct-Indirect Ratio of Manpower has stated.

Direct-Indirect Ratio is the ratio of Direct Labor to the Total Manpower working in a line.

$$\text{Direct-Indirect Ratio} = \frac{\text{Direct Labor}}{\text{Direct + Indirect Labor}}$$

2nd Degree of OOE: Availability Rate x Level of Performance x Quality Rate x Direct-Indirect Ratio

$$= \frac{\text{Operating Time}}{\text{Opening Time or Working Minutes}} \mathbf{x} \frac{\text{Standard Time}}{\text{Running Time}} \mathbf{x} \frac{\text{Right Output}}{\text{Total Outputs}} \mathbf{x} \frac{\text{Direct Labor}}{\text{Direct + Indirect Labor}}$$

$$= \frac{\text{Operating Time}}{\text{Opening Time or Working Minutes}} \mathbf{x} \frac{\text{Standard Time (SMV) x Total pieces produce}}{\text{Direct Labor x Operating Time}} \mathbf{x} \frac{\text{Right Output}}{\text{Total Outputs}} \mathbf{x} \frac{\text{Direct Labor}}{\text{Direct + Indirect Labor}}$$

Opening Time is the total paid working minute of the manpower to produce goods. For example, If a Factory opens the production shift at 8.00 am and closes at 5.00 pm where there is a lunch break of 1 hour which is unpaid, then the total opening time is Eight (8) hours or working minutes is 480 mins.

Operating Time is the total actual operational time for which the total line or manufacturing unit runs to produce goods. All the unplanned breaks need to be excluded from the Opening time to get the Operating time. For example, If there is a changeover going into the line for any day, the operating time for that day is : Opening time - changeover stoppage times.

2.3.3. 3rd Degree OOE

The 3rd Degree of OOE remains the same as the 2nd Degree formula.
3rd Degree of OOE = Availability Rate **x** Level of Performance **x** Quality Rate **x** Direct-Indirect Ratio

2.3.3.1. Factors of 3rd Degree OOE

The 2nd degree and 3rd Degree factors are the same in the base formula except the fact that 3rd degree focuses on another level breakdown of the only parameter "Level of Performance".
In 3rd Degree OOE:
Level of Performance = SMV Performance% e x Line Balancing Ratio % x Bottleneck Performance %

3rd Degree of OOE: Availability Rate **x** Level of Performance **x** Quality Rate **x** Direct-Indirect Ratio

$$= \frac{\text{Operating Time}}{\text{Opening Time or Working Minutes}} \mathbf{x}(\text{ SMV Performance\% e x Line Balancing Ratio \% x Bottleneck Performance \%}) \mathbf{x} \frac{\text{Right Output}}{\text{Total Outputs}} \mathbf{x} \frac{\text{Direct Labor}}{\text{Direct + Indirect Labor}}$$

Nabi et al. (2015) demonstrated the Individual worker performance by Standard Time and Rating which is SMV Performance in our study. This is the ratio of Standard time or SMV to the Actual Cycle Time measured. For example, if one operator taking 50 seconds for any specific operation where the standard time for that operation is 1.5 mins, then the Operators SMV performance or Rating is = $\frac{50}{90}$ = 55.56%.

Ahmed (2021) illustrated that Line Balancing is a production smoothing technique that creates the balances between machine operators and machine time to match the productivity to the takt time. Line Balancing Ratio is the numeric measure to understand how balanced the production line is and what are the bottleneck points for low productivity.

Urban & Rogowska (2018) highlighted how Bottleneck operations impacted the profitability & productivity of the entire value chain of a production system. Bottleneck operation refers to the measured highest cycle time of any operation or lowest production rate for that operation. Bottleneck Performance is the measurement of how well the bottleneck operator is doing the job. In other words, it identifies if there is any gap between the theoretical Bottleneck output and actual Bottleneck output.

3. Methods

Derivation from 1st degree to 2nd & 3rd Degree OOE

$$1^{st}\text{ Degree OOE} = \frac{\text{Right Output x SMV}}{\text{Working Minutes x Manpower}}$$

Multiplying all other possible parameters i.e. Operating Time, Direct Labor and Total Output in both Denominator & Numerator; we conclude that

$$\text{OOE} = \frac{\text{Right Output x SMV x Operating Time x Direct Labor x Total Output}}{\text{Working Minutes x Manpower x Operating Time x Direct Labor x Total Output}}$$

Rearranging the Denominator and Numerator:

$$= \frac{\text{Operating TIme}}{\text{Working Minutes}} \mathbf{x} \frac{\text{SMV x Total Outputs}}{\text{Direct Labor x Operating TIme}} \mathbf{x} \frac{\text{Right Output}}{\text{Total Outputs}} \mathbf{x} \frac{\text{Direct Labor}}{\text{Total Manpowers}} \text{ (OOE } 2^{nd}\text{ Degree)}$$

$$= \frac{\text{Operating TIme}}{\text{Working Minutes}} \mathbf{x} \frac{\text{SMV x Total Outputs}}{\text{Direct Labor x Operating TIme}} \mathbf{x} \frac{\text{Right Output}}{\text{Total Outputs}} \mathbf{x} \frac{\text{Direct Labor}}{\text{Total Manpowers}}$$

$$= \frac{\text{Operating TIme}}{\text{Working Minutes}} \mathbf{x} \frac{\text{SMV x Total Outputs}}{\text{Direct Labor x Operating TIme}} \mathbf{x} \frac{\text{Total measured Cycle Time x Bottleneck Cycle Time}}{\text{Total Measured Cycle Time x Bottleneck Cycle Time}} \mathbf{x} \frac{\text{Right Output}}{\text{Total Outputs}} \mathbf{x} \frac{\text{Direct Labor}}{\text{Total Manpowers}}$$

$$= \frac{\text{Operating TIme}}{\text{Working Minutes}} \mathbf{x} \left(\frac{\text{SMV}}{\text{Total Cycle Time Measured}} \mathbf{x} \frac{\text{Total measured Cycle Time}}{\text{Direct Labor x Bottleneck Cycle Time}} \mathbf{x} \frac{\text{Bottleneck Cycle Time x Total Outputs}}{\text{Operating Time}} \right) \mathbf{x} \frac{\text{Right Output}}{\text{Total Outputs}} \mathbf{x} \frac{\text{Direct Labor}}{\text{Total Manpowers}}$$

$$= \frac{\text{Operating Time}}{\text{Opening Time or Working Minutes}} \mathbf{x} \text{ (SMV Performance\% e x Line Balancing Ratio \% x Bottleneck Performance \%) } \mathbf{x} \frac{\text{Right Output}}{\text{Total Outputs}} \mathbf{x} \frac{\text{Direct Labor}}{\text{Direct + Indirect Labor}} \text{ (OOE } 3^{rd}\text{ Degree)}$$

4. Data Collection

The data highlighted from the Stitching Section: Line No: 3 of XYZ Apparel Factory for a running model **A.** The factory opens at 8.00 AM and Closes at 5.00 PM. The total good output after 5.00 PM is 650 Pieces. The Industrial Engineering team defined the Standard Time to make one piece as 10.84 minutes. There are 35 machine operators, 2 online quality controllers, 2 helpers and 1 supervisor allocated for that line. From the observation, the break times are noted like below table:

Table 1. TABLE Break Times During Production

Duration	Break Type / Reason
9.00 - 9.05	Production Target Set-up Meeting

9.05 - 9.07	Stoppage Time
10.00 - 10.15	Refreshment Break
10.30 - 10.40	W/S 1 to W/S 4 off due to material shortage
1.00 - 2.00	Lunch Break
2.00 - 2.10	Color Changeover
4.00 - 4.15	Snacks Break

During the Production, 10 pieces were rejected for the wrong placement of components and 10 pieces were rejected by the Quality inspector for thread color mismatch issue. Quality inspector sent back 30 pieces for repair and at the end of the day, all of these were repaired by the line operators. The Total Line Cycle Time was 15 minutes measured by stopwatch. The Bottleneck operation was Collar Join Seam Stitch and time was 36 seconds. The Target of Efficiency was 80% on that specific day.

5. Results and Discussion

5.1 Numerical Results

1st Degree OOE:

Table 2. Parameters of Degree-1 OOE

SMV	10.84 min
Right Output	650 pc
Unpaid Lunch Break	60 mins
Working Minutes or Opening Time	540-60 = 480 mins
Direct Manpower	35
Indirect Manpower	5
Total Manpower	40

Table 3. Result of Degree-1 OOE

Output Minutes	=10.84 x 650 = 7046
Input Minutes	= 480 x 40 = 19200
OOE	$=\frac{7046}{19200}$ = **36.7%**

Table 2 and Table 3 shows that only four factors can drive us to measure the OOE. But, the limitation of the 1st degree formula is that we can't identify which parameter is the main reason for the low OOE.

2nd Degree OOE:

Table 4. Parameters of Degree-2 OOE

Total Break Time	=5+2+15+10+15= 47	Opening Time	480	Operating Time	=480-47 = 433
SMV	10.84	Right Output	650	Rejects	=10+10=20
Total Outputs	=650+20=670	Direct Labor	35	Indirect Labor	5
Total Manpower	40	Running Time	$=\frac{433 \times 35}{670}$ = 22.61		

Table 5. Results of Degree-2 OOE

Availability Rate	$=\frac{433}{480}$ = 90.20%
Level of Performance	$=\frac{10.84}{22.61}$ = 47.94%
Quality Rate	$= \frac{650}{670}$ = =97.01%
Direct-Indirect Ratio	$=\frac{35}{40}$ = 87.5%
OOE	= 90.2% x 47.94% x 97.01% x 87.5% = **36.7%**

From Table 4 and Table 5 derived the 2nd degree OOE 36.7% as 1st degree but with more parameters involved. It finally helps to identify which factor is the reason for this low OOE. Here, we can see among the four factors, the lowest is Level of Performance which is 47.94%. If we break the Level of Performance, then we can find the Running time (22.61) is responsible for the low value of Performance.

3rd Degree OOE:

Table 6. Parameters of Degree-3 OOE

Total Break Time	=5+2+15+10+15= 47	Opening Time	480
Operating Time	=480-47 = 433	SMV	10.84
Right Output	650	Rejects	=10+10=20
Total Outputs	=650+20=670	Direct Labor	35
Indirect Labor	5	Total Manpower	40
Total Measured Cycle Time	15	Bottleneck Cycle Time	= 36/60 = 0.60
SMV Performance	$=\frac{10.84}{15} = 72.27\%$	Line Balancing Ratio	$=\frac{15}{0.60x\ 35} = 71.428\%$
Bottleneck Performance	$=\frac{0.60\ x\ 670}{433} = 92.84\%$		

Table 7. Results of Degree-3 OOE

Availability Rate	$=\frac{433}{480} = 90.20\%$
Level of Performance	= 72.27% x 71.428 % x 92.84% = 47.93%
Quality Rate	$= \frac{650}{670} = =97.01\%$
Direct-Indirect Ratio	$=\frac{35}{40} = 87.5\%$
OOE	= 90.2% x 47.93% x 97.01% x 87.5% = **36.7%**

In the 2nd Degree OOE, we identified Level of Performance as the main factor to pull down the efficiency. But, we can identify which factors of Level of Performance are the main reasons for it. Considering the result from Table 6 and Table 7, we can understand that Level of Performance of that line consists of three other factors. And here the result shows that, Line Balancing Ratio and SMV Performance are the root causes behind the low efficiency 36.7%. Also, the minimum standard value of Bottleneck performance is 100%.

6. Conclusion

This research comes to an end with the formulation of two unique ways of calculating Operational Efficiency along with the conventional 1st degree formula. This 1st degree formula is widely used in almost all of the apparel or footwear factories today. Due to this, most of the manufacturing units are unable to identify the root cause of having low efficiency which makes over utilization of resources thus the costing of the overall operations faces higher and higher levels. This research creates the scope to identify the root cause of low efficiency processes with a quick and logical approach that finally could save the apparel or footwear manufacturing industry from waste of resources and creates cost effectiveness. From the result we can sum up that from the 1st degree OOE, we can only measure the Operational performance by calculating the efficiency. But, when the result indicates the value is too low, it also highlights there are some problems going on with the production. But, from the 1st degree formula, it is difficult to know the real reason behind the problem. So, we finally derived the 2nd degree and after data plotting on the 2nd degree, we found the same Efficiency value as 1st degree. Firstly, this validates the 2nd degree OOE derivation and then, from the parameters, we found the problem is in the Level of Performance since, this value among the four parameters was the lowest. Breaking down the Level of Performance into Three more factors, we finally arrived at our 3rd degree of OOE. The 3rd degree also provides the same OOE which validates the 3rd degree derivation finally. And also, after plotting required data into the breakdown of the Level of Performance formula, we see that the results are the same in Degree-2 and Degree-3 of OOE. Finally, from the result, we successfully identified that Line Balancing Ratio, SMV Performance and Bottleneck performance are the main reasons behind the low efficiency we found on the 1st step of measuring OOE.

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Acknowledgements

This research was carried out from the observation and analysis for a project regarding Efficiency Improvement during the time of the author's job in an apparel Factory. This research would not have been completed without the data collection and analysis taken from the factories. I would like to appreciate all those factories, my mentor and my colleagues during the journey for their direct and indirect inputs to this research.

Biography

Md Muhibur Rahman is an Industrial & Production Engineering graduate from Shahjalal University of Science and Technology, Sylhet. After completing the BSc Engineering Degree, He joined YKK BGD Pte Ltd. as a Manufacturing Engineer in 2018. Besides this, He has also experiences in Industrial Engineering Professional Career at Ever Smart Bangladesh Ltd. After this, He moved to grow his career to join one of the Top Retail Brands in the Industrial and Production Management Sector. He has a total of 5.5 years of experience in Production management, Chemical Manufacturing, Ready Made Garments Manufacturing, Industrial Engineering, Efficiency Improvement, Lean Management, Cost Optimization, Process Improvement, Real-Time Data Management & Operational Excellence.