Redesign Glass Cut Process to Increase Production Capacity at Window Manufacturing Company (WMC), Puerto Rico

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Abstract

Window Manufacturing Company (WMC) in Puerto Rico is a prestigious and visionary brand in the manufacturing industry of doors, windows, and architectural solutions, which over 55 years of experience. Glass and aluminum are two of the materials used in their production operations to deliver high quality doors and windows. In the critical areas of the glass-cutting process, there are no existing metrics or standardizations evaluate the state of operations. This research aims to improve the glass cut process output from 4,500 to 6,500 square feet daily. To achieve this objective, the entire process must be analyzed and observed from beginning to end to identify the root causes of the deficiencies in the maximization of capacity and production of glass cutting. Since the glass cutting line is the most demanded and has much variability in products, styles, sizes, and measurements, we can cut 6,500 square feet daily with 3.4 hours of overtime, which means an annual loss near $60,000. We use different empirical methods to analyze data, such as Lean Six Sigma, DMAIC methodology, and production optimization. By implementing several design alternatives, the objectives set for the project were reached and exceeded.

Keywords
Lean Six Sigma, Glass Manufacturing, Senior Design Project, Process Improvement

1. Introduction
WMC is the leading corporation in designing and manufacturing aluminum and glass goods. They specialize in custom doors and windows designing, manufacturing, distributing, and installing them for homes and businesses. This project will be based on the specific area of Glass, which has several phases in creating the final product. Glass cutting production is currently 4,500 square feet per day over 7.5 hours. This is a problem since the glass cutting line's capacity needs to be utilized to its full potential without incurring in overtime. To enhance the production output, management wants to enhance capacity by increasing glass cuts to 6,500 square feet in the same period. This project aimed to redesign the glass-cutting process to increase production capacity, including more planning and communication in the area, optimizing warehouse carts during production hours, equipment downtime, and a gantry layout design that can respond quickly to dynamic production requirements.

1.1 Objectives
Two objectives were established: increase capacity and production in the glass cut process from 4,500 SQFT to 6,500 SQFT daily and optimize the organization of the carts and glass gantry and reduce management downtime by 35%. Achieving these objectives will result in 100% reduction of the current overtime costs.

2. Literature Review
The project was organized following the process improvement DMAIC principles, with phases of historical data analysis, root cause analysis and implementation of alternatives. Several industrial engineering methods were used to facilitate evaluating causalities between the response and independent variables, with statistical validation of results provided, like Perez et al. (2021). Statistical inference tools can facilitate these analyses, with methods like those in Montgomery and Runger, (2010). The tools for the historical data analysis include a stopwatch time study to determine standard time

according to, Korkmaz at all (2020). With the standard time, the daily throughput was determined. In these and other applications of time studies, an initial sample is collected and used to compute the final number of observations required for the study considering the margin of error and significance level (Meyers & Stewart, 2002). For the alternatives, some of the tools used were Kanban, Man Machine Diagram, and facility layout. With these tools, the operators' tasks were re-organized and standardized, while the work methods were simplified. The man-machine diagram is a process modeling tool to compute the idle and productive times. Similar applications in literature from Montoya-Reyes et al. (2020), use the diagram to model a lathe and a grinding process. The results show improvement on the productivity of the line operators. One of the tools used to improve the process was facility layout. It is described by Pérez-Gosende et al (2020), as the process of setting up all factors necessary for production to optimize performance measures, in this case, maximize productivity. Some challenges for using facility layout are the variable material flow in a productive facility.

Additionally, the inventory management system was updated by recommended the required number of Kanban cards (Hunglin & Hsu-Pin, 1990) to operate in an optimal fashion. Kanban systems serve to control material flow in productive processes. There are several applications and mathematical methods, to compute the number of cards required in systems of this kind. One interesting application from Braglia, Gabbrielli & Marrazzini (2020) is using a Kanban system considering variable changeover times, which is applicable to our process, and we recommend the application of a similar rolling Kanban in future improvements. The tools applied from the project will result in the proposition of several design alternatives, which are then evaluated with a weighted decision analysis. The selected alternatives are then selected for implementation, and the values of the objectives are re-calculated, Cabrera et. al (2021).

3. Methods

Diverse lean and industrial engineering tools were combined to achieve the maximum impact on the company. For the historical data analysis, it was desired to understand the current process areas of opportunity. Standard times were computed using a stopwatch and work sampling studies, and several non-value-added tasks were detected. These were input in the workforce capacity analysis to determine the current production vs. the expected monthly production. To determine the root causes of the problems mentioned, tools like fishbone and the five whys were applied. It is faster to give solutions for resolving problems after conducting a root cause analysis. A decision matrix with a scale of one to three was used to help in determining the best option once the alternatives were presented. After implementing the improvements and standardizing them, the glass cut production target and the anticipated monthly production target were compared to confirm that the goals had been accomplished. Finally, Man Machine diagrams and a Gantt chart were used to show how long the suggested processes would take as well as the time savings.

4. Data Collection

For the historical data analysis, we saw the average demand vary monthly. The fluctuations in demand were evaluated with a One-Way Anova test, seen in table 1, where it can be concluded that the mean demand is not uniform each month since the p-value is less than the significance level α. If the project objectives are achieved, the company would be able to comply with the maximum requirements for any month of the year, as the production capacity will exceed the largest production requirements.

Table 1. Glass Cut Production Analysis of Variance (ANOVA) test results

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
NOVEMBER	19	54859.6	2887.35	1774708.273		
DECEMBER	25	79147.2	3165.89	1407098.034		
JANUARY	21	95311.1	4538.62	1601646.282		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	32524977.71	2	16262488.86	10.31503485	0.00013579	3.14525838
Within Groups	97748027.37	62	1576581.087			
Total	130273005.1	64				

Next, we will describe the operation sequences and traveling distances.
Based on the operator's tasks, the distances are evaluated considering the functions illustrated in Figure 1:

Operator A selects orders on the first computer
Operator A examines the gantry to determine the rack number
Operator A goes to the second computer to print labels
Operator A place the labels on each cut glass
Operators B, C, and D split the cut glass panel
Operators B, C, and D dispose of the waste material 7. Operators B, C, and D put the final products on the carts.

Considering the rectilinear distances and frequency of these tasks, the time spent on walking tasks consumes 120 shift days annually when computed using the Maynard Operation Sequence Technique by Zandin, (2002).

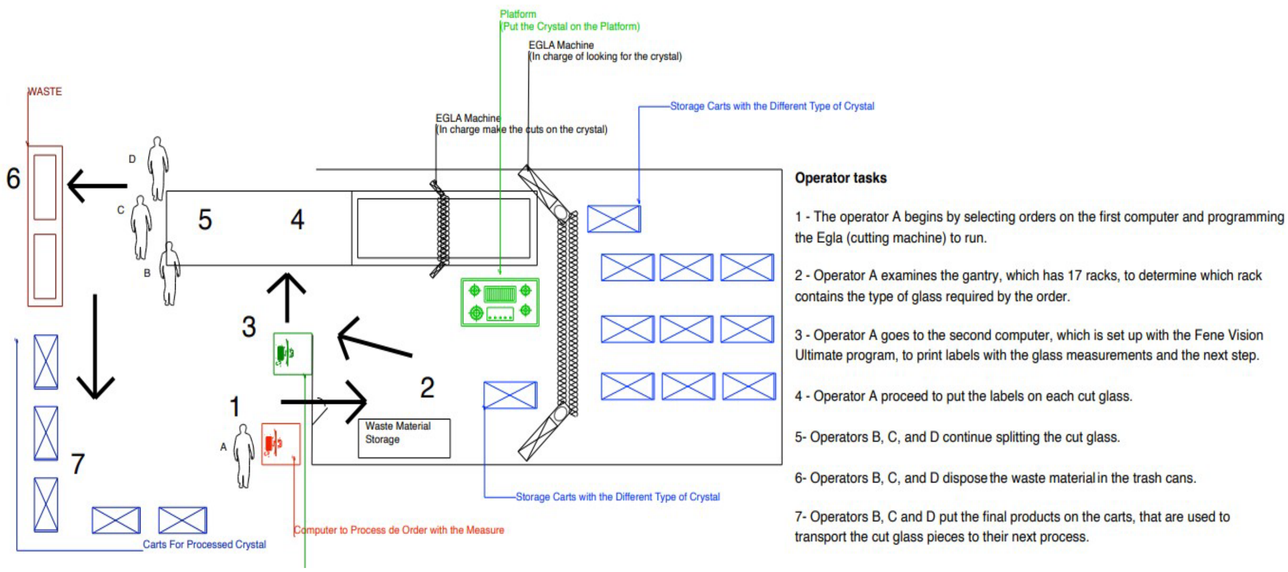

Figure 1. Spaghetti diagram showing process flow

A time study using a stopwatch to establish tasks standard times was conducted. It is divided into three standard calculations for: 1) operators. 2) Hegla machine with the best-case glass scenario - glass panel is located on the racks in front of the gantry, and 3) Hegla machine with the worst-case glass scenario - glass panel is in the back racks of the gantry. Worst and best scenarios will consider the longest and shortest glass location times.

The time study (Groover, 2007) assumptions considered a 5% margin of error, thirty preliminary observations were made for the operator time study, and five initial observations for the two machine time studies. The formula for calculating the n is then applied (sample size). The value n determines the number of additional observations obtained from the procedure after conducting the preliminary observations.

A 5S audit was conducted to observe the order of the area, the process of systematizing, shining, standardizing, and maintaining. During the process, it was observed that there was not much organization within the area, lack of cleaning, absence of labeling identification, disorganized glass gantry, limited carts space, have all been identified as deficiencies. According to this 5s checklist, the area of standardization, S4, is a significant area of opportunity. After conducted all the observations, it is obtained a total exist nineteen with score 67.8% and rating 1.4 and score 34.8% as seen in Figure 2.

WMC

5S Checklist - Manufacturing VALCOR

Area: HEGLA
Auditor: Julio E. Rodriguez & Adiary Vicéns
Date: 22-Feb-22

	Checklist item	Criteria	Exist? (Y / N)	Rating (0,1,2,3 or 4)	Comments
S1	**Sort - SEIRI**				
1	Cabinets and shelves	No irrelevant reference materials, documents, drawings, etc.	N	0	
2	Desks and tables	No irrelevant reference materials, documents, etc.	N	0	
3	Drawers	No excess pieces of equipment, documents, etc.	Y	2	
4	Other storage area	Storage area is defined to store unneeded items and out-dated documents	N	0	
5	Standards for disposal	Standards for eliminating unnecessary items exist and are being followed	Y	2	
S2	**Set in order - SEITON**				
6	Tools and equipment	Locations of tools and equipment are clear and well organized	Y	1	
7	Materials and products	Locations of materials and products are clear and well organized	Y	1	
8	Labeling	Labels exist to indicate locations, containers, boxes, shelves & stored items	Y	2	
9	Inventory control	Evidence of inventory control exists (i.e. Kanban cards, FIFO, min & max)	N	0	
10	Outlining / dividing lines	Dividing lines are clearly identified and clean as per standard	N	0	
11	Safety	Safety equipment and supplies are clear and in good condition	Y	4	
S3	**Shine - SEISO**				
12	Building structure	Floors, walls, ceilings & pipework are in good condition & free from dirt/dust	Y	1	
13	Racks and cabinets	Racks, cabinets and shelves are kept clean	Y	2	
14	Machines and tools	Machines, equipment and tools are kept clean	Y	3	
15	Stored items	Stored items, materials and products are kept clean	Y	3	
16	Lighting	Lighting is enough and all lighting is free from dust	Y	2	
17	Ventilation	Good movement of air exists through the room (limits the spread of viruses)	Y	1	
18	Pest control	Pest control exists and effective	Y	3	
19	Cleaning tools	Cleaning tools and materials are easily accessible	Y	2	
20	Cleaning responsibilities	Cleaning assignments are defined and are being followed	Y	1	
S4	**Standardize - SEIKETSU**				
21	Visual controls	Information displays, signs, color coding & other markings are established	Y	2	
22	Procedures	Procedures for maintaining the first three S's are being displayed	N	0	
23	5S documentation	5S checklists, schedules and routines are defined and being used	N	0	
24	Responsibilities	Everyone knows his responsibilities, when and how	Y	2	
25	Regular Audits	Regular audits are carried out using checklists and measures	N	0	
S5	**Sustain - SHITSUKE**				
26	5S System	5S seems to be the way of life rather than just a routine	N	0	
27	Success stories	Success stories are being displayed (i.e. before and after pictures)	y	2	
28	Rewards and recognition	Rewards and recognition is part of the 5S system	y	3	

Comments
Exist a lack of cleaning tools, they only have a regular broom. The operators only sweep the crystal and nothing else.
The tools are not at the same place every day
Lack of 5S audits

	Exist?	Rating	
	19	1.4	

Figure 2. Waste Walk for Production Operations

5. Results and Discussion

The variables included are the duration of manual and automated operations, and the nonvalue added activities at its effects on the process cycle time (Y). Further analysis performed in this section includes:

- Measurement and classification of downtimes.
- Breakdown of idle and productive times for machine and operators
- Root cause analysis

5.1 Numerical Results

A downtime study was performed where it can be observed the major problems encountered were idle time and the organization and management area. This is shown in a Pareto chart in Figure 3 where the highest Muda are 16% on low production short on carts, 15% on exceed break time, 10% on preparation to start operations, 10% on production stop missing carts, and 9% on regular orders stop for recuts.

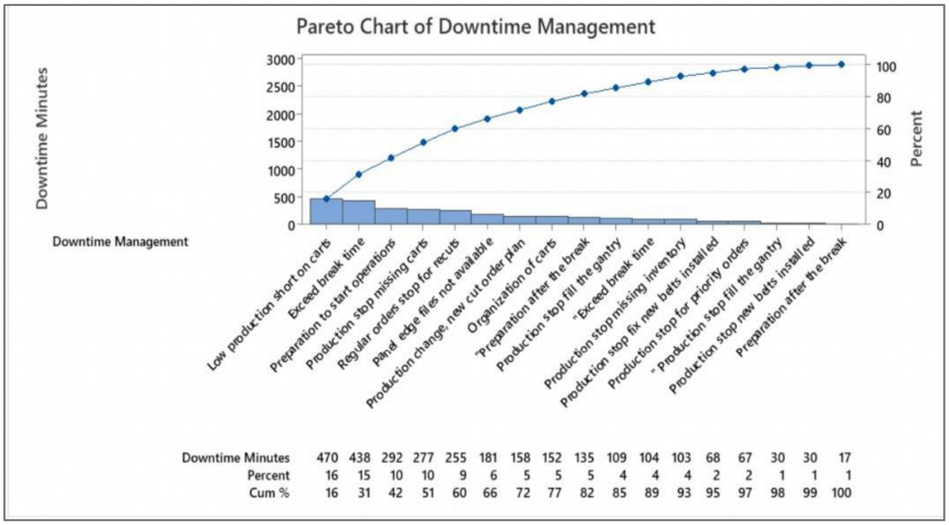

Figure 3. Management Downtime Pareto Chart

A man machine diagram modeled the tasks of the Operators A, B, C and D, which reveals that 60 SQFT can be produced in 6 minutes. WMC must produce 87 SQFT in six minutes to meet its daily production goal of 6,500 square feet. Table 2 reveals that the machine's idle time and productive time are approximately 50 percent and 50 percent, respectively, indicating a large portion of the shift is not productive time.

Table 2. Man Machine Diagram - Baseline

Total Cycle (Sec)	376

Resource	Productive Time (sec)	% Productive	Idle Time (sec)	% Idle
Hegla	190	51%	186	49%
Op. A	192	51%	184	49%
Op. B, C and D	188	50%	188	50%

It was discovered that task #2, which is to go to the gantry and check the rack number where the glass panel is located before each order, is redundant and wastes a lot of time, because the gantry changes the glass location order daily to be filled by inventory. This is how WMC first set up the gantry layout. Because the most demanded glass must be positioned in front so that the Hegla can locate them faster and create less waiting time for operators, it can be concluded that this order is not optimized according to the use of each glass panel, which creates machine idle time.

5.2 Graphical Results

The historical data analysis showed that the main identified problems were:

1. Management downtime, related to personnel, materials, and workload management. The focus will be in personnel, considering that they create the major downtime.
2. Production downtime, considering method, layout, and environment. The focus will be in layout, considering waiting for carts take too much time.
3. Equipment downtime, considering waiting for the operator to verify the gantry order take too much time

A root cause analysis was performed for each of the three subproblems. In Figure 4, we proceeded to further explore the reasons for production downtime. One of the primary areas of concern was the facility layout, as it was not possible to park the quantity of production carts required to satisfy daily demand. The solutions for these issues are presented in the next section.

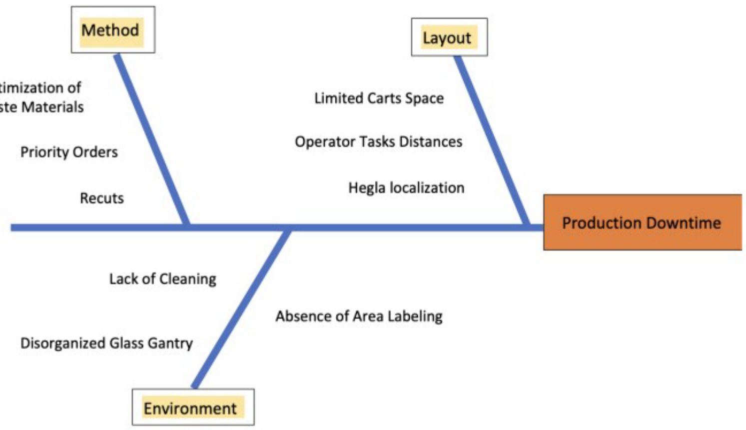

Figure 4 . Production Downtime Pareto Chart

5.3 Proposed Improvements

After performing the root cause analysis, the following changes were made to the process: • Rebalance manual operations and eliminate nonvalue added activities
Gantry Re-layout
Inventory Management System Improvement: Kanban Storage Carts Additional details for each improvement are discussed next.

For the rebalancing of manual operations and elimination of nonvalue added activities tasks were reassigned. Three new Man-Machine configurations were proposed were Man-Machine Option #3 is based on deleting task number two of the glass-cutting process, that is, Operator A examines the gantry to determine which rack has the type of glass required by the order and reassigns task 4, applying labels to each final cut glass to operators B, C, and D instead of operator A. It is possible to produce 120 square feet in the same 6-minute period with this man-machine diagram option #3. This equates to a 100% increase in production and the best option for optimizing Hegla and Operators B, C and D. This option, shown in table 3, reduces the idle time of the Hegla machine by 25% and the idle time of the operators B, C, and D by 19%, resulting in the best option for both. Operator A's idle time increases by 5%, but by reducing both the idle time of the machine and the idle time of the other operators, it is possible to reach a production of 120 squared feet, which exceeds the objective. WMC needed eighty-seven square feet in 6 minutes to reach its goal of 6,500 sqft, according to the analysis. With this diagram shown in table 3b., it is possible to reach a daily production of 9,000 squared feet.

Table 3. (a) Man-Machine Best Option b) Man machine diagram

Total Cycle (Sec)	373

Resource	Productive Time (sec)	% Productive	Idle Time (sec)	% Idle
Hegla	285	76%	88	24%
Op. A	168	45%	205	55%
Op. B, C and D	256	69%	117	31%

Man-Machine Diagram					
Time (S)	**Hegla Machine**	**Time (S)**	**Operator A**	**Time (S)**	**Operators B,C and D**
22	Inactive	22	Begins by selecting orders on the first computer	22	Wait
28	Starts by locating the rack with the type of glass that the order requires and transporting it	20	Goes to the second computer to print labels	28	Wait
		8	Wait		
14	The glass panel is placed on the second platform, which is responsible for placing the glass on the cutting table	14	Wait	14	Wait
53	Hegla's second bar makes the cuts to the glass panel	22	Begins by selecting orders on the first computer	53	Wait
22	Inactive	20	Goes to the second computer to print labels	30	Put the labels on each cut glass
28	Starts by locating the rack with the type of glass that the order requires and transporting it	106	Wait	108	Start to split the cut glass and dispose the waste material
14	The glass panel is placed on the second platform, which is responsible for placing the glass on the cutting table				
53	Hegla's second bar makes the cuts to the glass panel	22	Begins by selecting orders on the first computer		
22	Inactive	20	Goes to the second computer to print labels	118	Put the labels on each cut glass and put the final products on the carts
28	Starts by locating the rack with the type of glass that the order requires and transporting it	77	Wait		
14	The glass panel is placed on the second platform, which is responsible for placing the glass on the cutting table				
53	Hegla's second bar makes the cuts to the glass panel	22	Begins by selecting orders on the first computer		
22	Inactive	20	Goes to the second computer to print labels		

Another corrective action was to improve the organization of the glass gantry, since it had been demonstrated that this solution would reduce downtime and save time and resources in the area. As already stated with the gantry arranged differently every day and the glass panels in different numbers of racks each day, it created an unnecessary task for operator A, which was to go and check the rack number after each order, number two, it increased the distance between the operators' tasks, resulting in more consumption time on business days, and number three, it increased the idle time of the operators and the Hegla machine in the man machine. This is a new order, shown in table 4 where each glass panel was placed according to its use, since having an optimized gantry order is the best alternative in all senses. Reorganizing and cleaning the glass gantry can take up to 3 hours of overtime on three working days. Since this reorganization will consume three days of overtime, that means a cost of implementation of $600.00 to the company. Distances between operator's tasks consume now consume sixty-four shift days per year, representing a 46.7% percent reduction from the original 120 shift days.

Table 4. Optimized Gantry Order

Initial Order	Recommended Order	Glass	Freq	% Freq
16	1	5C	2727	20.12%

9	2	1/4 C	2059	15.19%
17	3	1/8 C	1532	11.30%
15	4	1/4 G	983	7.25%
1	5	MIX	936	6.91%
13	6	1/8 G	890	6.57%

For the inventory management system improvements, a Kanban Storage Cart was recommended. The number of required Kanban was established using the following equation:

$$k = \frac{DL\,(1+S)}{C}$$

Where the variables are defined as:
D = demand
LT = lead time
S = safety stock
C = container size
k = number of Kanban

Assuming the glass cuts area reaches the goal of 6,500 sqft in a 7.5-hour shift, the variables in the formula are shown in Table 5. The Kanban analysis suggests that six (6) carts must be available for a continuous flow, resulting in zero pauses in production for lack of carts.

Table 5 Kanban formulas assumptions and results

Variable	Value	Units
Monthly production	149500	sqft/month
Shift duration	7.5	hrs./day
Working Days	23	days/month
Daily Production	6500	sqft/day
Hourly Production	867	sqft/hr.
Demand	867	sqft/hr.
Lead time	7	hr.
Container size	1152	sqft

5 Conclusions

The project aimed to redesign the glass-cutting process to increase production capacity. To obtain the improvement, the main problem was divided in subproblems that considered task execution, inventory management system and layout. Following a root cause analysis, a weighted decision process was performed and three solutions, were identified. For the two objectives:

Increase capacity and production in the glass cut process from 4,500 SQFT to 6,500 SQFT daily – with the recommendations provided, the production increased to 9000 SQFT daily. Since there are seventy-five periods of 6 minutes on working days, multiplied by the production that these man-machine diagrams can do in the period of 6 minutes, which is 120 square feet, the total daily production is 9,000 square feet. This means that it has been demonstrated that in addition to the expected production capacity, an additional 2,500 square feet per day can be produced.

Optimize the organization of the carts and glass gantry and reduce management downtime by 35% - with the recommendations, the management downtime is reduced by 79%. This percentage of decrease is proven in the 8-waste checklist, where it was cut from 3 months of annual loss to only one month. Transportation was high in waste and was reduced to low, motion and extra processing were also from high reduced to medium, overproduction and waiting, were type medium reduced to low, resulting in reducing non value added activities.

The project achievements are summarized in table 6. Both objectives were exceeded, allowing the company to duplicate its daily output while reducing process downtimes. By achieving both objectives a 100% reduction of overtime costs was achieved, since production can be performed during regular work hours.

Table 6. Project objectives achievement

Alternatives	Before	Implemented Alternative	Project Objective Accomplished
ManMachine Diagram Option #3	• Glass Cut Production of **4,500** SQFT • Daily **3.4** hours of overtime • Overtime annual loss of **$59,670**	• Glass Cut Production of **9,000** SQFT • There's **no** overtime and **no** annual loss	Yes
Plannings and Operations Flowchart	• **High** management downtime • Annual loss of **three months** approximately	• Reduced management downtime by **79%** • Annual loss of **one month** approximately	Yes

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