Engineering and Technology Journal e-ISSN: 2456-3358
Volume 04 Issue 03 March- 2019, Page No.-545-551
DOI:10.31142/etj/v4i3.01, I.F. - 4.449

Inventory Cost Analysis Work in Process (WIP) Under Focus of Lean Accounting, Simulation and Optimization Scenarios

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ABSTRACT: In this research, we present a cost analysis of the materials that are in a queue to be processed, better known as work-in-process inventory (WIP, for its acronym in English).

The inventory in process will be analyzed with three models: 1. A system of waiting lines, 2. Lean Accounting and 3. Simulation of discrete events that helps measure the benefits of Lean Accounting, applying an objective function to determine the minimum cost of WIP. This was obtained by applying a key tool called Simrunner. A cost breakdown structure was also established at each stage of the process. The present work is of interest to the administrators and managers of the Lean team and useful for short-term decision making.

KEYWORDS: value stream costs, simulation, work in process inventory, waiting for lines, promodel

I. INTRODUCTION

In the 21st century, global competition is forcing all companies to be much more efficient to stay in the market. This is how the reduction of costs and waste becomes a critical element for organizations that seek to stay and follow the vanguard [1]. The philosophies to reduce waste and costs is Lean Manufacturing which, together with Lean Accounting, will allow managing challenges related to costs and delivery level with great success. Within these wastes are inventories of work in process (WIP) that increase costs per area, can become obsolete and process flexibility is lost. Within these wastes are WIP that increase costs per area, can become obsolete and process flexibility is lost.

[2] mentions that estimated costs are relevant inputs for decision-making models and therefore it is important that they are estimated appropriately. In the case of WIP and waiting times, the Lean Accounting methodology is applied. Despite the great potential of the Lean strategies, many studies report flaws in the final results [3], which is why an interaction of Lean tools, optimization, and simulation is proposed.

In this research, it is proposed to develop scenarios of discrete events simulation created in Promodel in which the processes and effects of these are identified in detail by calculating performance measures. Value stream costing analysis is applied, a lean accounting tool to analyze the WIP related costs. Optimization is also applied through simulated models in Promodel. Simrunner will provide scenarios that minimize costs, both the cost of waiting time for entities in the locations and the inventory of work in process.

II. METHODOLOGY

Figure 1 shows the steps developed to analyze the behavior and costs of the WIP. Under the assumption that their Lean manufacturing methods have reached a state of sufficient maturity. The methodology proposed by the author.

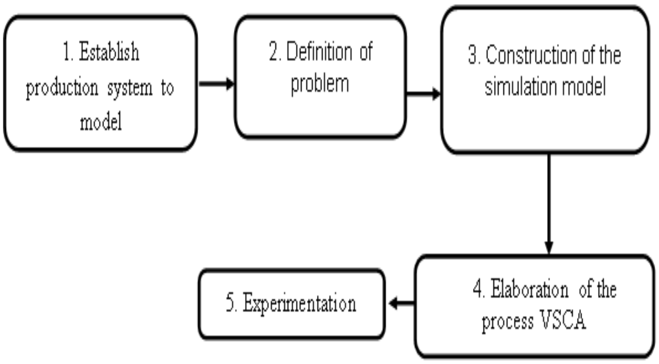

Figure 1. Steps for the development of the investigation.

III.RESULTS

1.Establish production system to model

The production system to be modeled is extracted from the thesis of [4] entitled manual of practices of simulation of discrete systems with Promodel. The problem is an open Jackson network with 4 nodes (A, B, C, and D) shown in Figure 2. The main objective of this thesis is to develop practical simulation cases that are based on the reality of the production systems. As a complement to this research work, the costs of work in process inventory under the Lean Accounting approach, and optimization are analyzed.

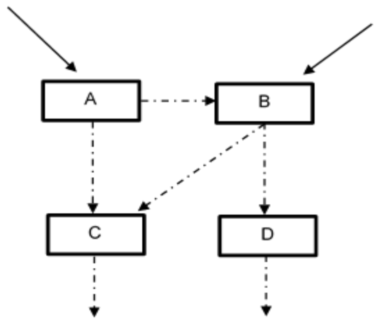

Figure 2. Systemnetwork.

A production system is selected where metal parts are manufactured, which are classified into 5 categories, each category with a different monthly demand. The production process consists of 4 stations (A, B, C and D. Station A works with 3 machines, B 3 machines, C 1 machine and D with 3 machines.

The production rate per hour in a type A machine is 2 units. Type B of 2 units.Type C of 4 units and D of 2 units per hour. One month of 20 days and 8 daily hours of work, exponential times are assumed.

2. Definition of the problem

The problem is to measure the financial and operational aspects in the simulated system to determine the level of service that minimizes the total cost of the system without affecting the outputs of the finished product. The measurement is based on:

1. Jackson's open network.
2. Lean Accounting tool.
3. Optimization with Simrunner.

3. Construction of the simulation model

The basic stages for the development of a simulation model are described, describing in detail what must be done in each of these steps to warrant the success of a simulation project.

For this purpose, the suggestions of [5], [6] and [7] are considered.

A. Data collection

For the development of this stage, data are obtained from [8], [9] and [4] for the construction of the simulated model. Jackson's open network in Promodel, which according to the system represented in Figure 2 above, defines the following data in Table 1 and 2, also defining the process routes:

TABLE 1. SIMULATED SYSTEM DATA

Node	λ (number of arrivals per unit of time)	µ (number of services per unit of time)	S (number of servers)	ρ (condition of non-saturation)
A	4.68	2	3	0.78
B	5.55	2	3	0.95
C	3.01	4	1	0.75
D	4.21	2	3	0.7

TABLE 2. MONTHLY DEMAND BY TYPE OF PIECE AND ROUTES OF THE PROCESS.

	Type piece a	Type piece b	Type piece c	Type piece d	Type piece e
Demand	68	409	272	272	136
Routes	A,B,C	A,B,D	B,D	A,C	B,C

B. Verification of the model

Verification of the simulation model. The behavior of the input variables was visually inspected to verify their proper functioning and to validate that the parameters used in the system description work correctly.

C. Validation of the model

This process consists of carrying out a series of tests with the actual input information described in the data collection to ratify their behavior and analyze their results. In this case, the behavior of the arrivals to the real system is analyzed, which is defined in historical data that the pieces arrive at station C with a Poisson distribution, at an average rate λ = 3.01.

To reformulate the arrival process, a random sample is taken by counting the number of pieces that arrive at the inspection station, the grouped data are shown in table 3.

TABLE 3. OBSERVED FREQUENCIES.

Number o pieces	Observations
0	2
1	2
2	9
3	13
4	13
5	8
6 or more	3
Total	50

From the parameter defined for the data, the hypotheses to be tested are proposed:

H_o: Poisson (λ =3)
H_1: Another type of distribution

Hypothesis tests are performed by applying Stat: Fit with a significance level of α = 0.05 shown in Figure 3. H0 is not rejected, the data behave according to a Poisson distribution close to λ = 3.01.

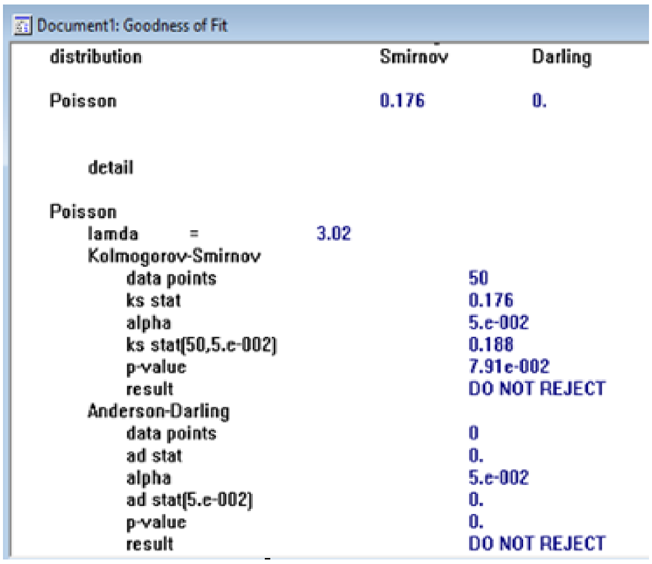

Figure 3. Hypothesis test results.

4.VSCA of the process

When validating the simulation model. the results obtained by Promodel are extracted, such as cycle time, WIP, total of pieces produced, the waiting time, etc., facilitating the analysis of value flow costs.

The cost of the value flow is generally calculated weekly and takes into account all costs in the value stream. No distinction is made between direct and indirect costs. All the costs of the value chain are considered direct. In this case, WIP costs and operating costs are included.

Define the value flow

Following the methodology proposed in the flow of value, the operations of the system, times and their jobs for the current situation are shown in table 4.

To define the flow of value, a monthly period is chosen, assuming that a daily shift of 8 hours is worked from Monday to Friday (1 month = 20 days x 8 hours by day).

TABLE 4.OPERATION AND NUMBER OF WORKERS IN THE PRODUCTION SYSTEM.

Process	Descripción	Time (min) (per machine)	Number of workers
Estation A	Cut	Exponential 30	2
Estation B	Polished	Exponential 30	2
Estation C	Painting	Exponential 15	1
Estation D	Print	Exponential 30	2
Total		105	7

Table 5 shows the operational analyzes with the most important performance measures to be controlled [10] which were calculated with Promodel.

TABLE 5.CURRENT OPERATIONAL SUMMARY.

	Operational summary			
	Cycle time (min)	Number of pieces entered into the system per month	Productivity (units by month)	WIP
Type piece a	9592.01	65	60	12
Type piece b	9590.53	400	368	48
Type piece c	9587.78	266	249	30
Type piece d	9588.34	265	260	20
Type piece e	9590.68	132	123	20
Total	47949.34	1128	1060	130

Table 6A) and B) shows the total costs of the value chain for the current month, in the process that totals the amount of 18939.78 dollars extracted from [10]. Because not all the pieces go through the same process, a value flow costing is performed for each piece taking as a reference the process route shown above in figure 2.

TABLE 6.A) VALUE FLOW COSTS (VSC) OF THE CURRENT SITUATION OF THE PROCESS.

Value flow cost	Material costs ($)	Workforce costs ($)	Costos de amortización ($)	Amortization costs ($)
Node A	935520	155920	155920	35861.6
Node B	935520	155920	155920	115770.6
Node C	935520	77960	58470	38980
Node D	935520	155920	155920	17151.2
Total	3742080	545720	526230	207763.4

TABLE 6. B) VALUE FLOW COSTS (VSC) OF THE CURRENT SITUATION OF THE PROCESS.

Value flow cost	Operation costs ($)	Machinery costs ($)	Other costs	Total costs
Node A	106606.0122	487250		1877078
Node B	157092.7133	487250	38465.9	2045939
Node C	52508.009	194900		1358338
Node D	162606.6292	487250		1914368
Total	478813.3637	1656650	38465.9	7195723

The calculation of the average cost for each type of piece is obtained by dividing the total cost (dollars) of the value chain by the number of units produced.

- Average cost per unit for piece a = 88022.59
- Average cost per unit for piece b = 15862.32
- Average cost per unit forpiece c = 15904.84
- Average cost per unit for piece d = 12443.90
- Average cost per unit for piece e =27677.04

Introduction of income accounts by value chain

Table 7 shows the unit price of sale for each type of piece. Typically, to calculate the unit sale price, 85% of the average cost per unit is added [11].

In this stage, the company's results accounts will be developed by value chains, as shown in table 8 A)toE).

TABLE 7. SALE PRICE FOR EACH TYPE OF PIECE.

Unit price of sale	
Piece	**Price ($)**
Type a	162841.6786
Type b	29345.3134
Type c	29423.8581
Type d	23021.0033
Type e	51202.3739

TABLE 8. A) INCOME STATEMENT BY VALUE CHAIN.

	Type of piece a	
	Manufacturing flow of value 1 ($)	**Total plant ($)**
Sales	9770500.716	9770500.7
Cost of materials	2806560	2806560
Personnel cost	389800	389800
Amortization cost	370310	370310
WIP cost	190612.2	190612.2
Cost of operation	316206.7345	316206.73
Profit / loss of the value stream	5697011.782	5697011.8
General expenses		116425.85
Plant benefits		5580585.9

TABLE 8. B) INCOME STATEMENT BY VALUE CHAIN.

	Type of piece b	
	Manufacturing flow of value 1 ($)	**Total plant ($)**
Sales	10799075.33	10799075
Cost of materials	2806560	2806560
Personnel cost	467760	467760
Amortization cost	467760	467760
WIP cost	168783.4	168783.4
Cost of operation	426305.3547	426305.35
Profit / loss of the value stream	6461906.577	6461906.6
General expenses		116425.85
Plant benefits		6345480.7

TABLE 8. C) INCOME STATEMENT BY VALUE CHAIN.

	Type of piece c	
	Manufacturing flow of value 1 ($)	**Total plant ($)**
Sales	7326540.667	7326541
Cost of materials	1871040	1871040
Personnel cost	311840	311840
Amortization cost	311840	311840
WIP cost	132921.8	132921.8
Cost of operation	319699.3425	319699.3
Profit / loss of the value stream	4379199.524	4379200
General expenses		116425.9
Plant benefits		4262774

TABLE 8. D) INCOME STATEMENT BY VALUE CHAIN.

	Type of piece d	
	Manufacturing flow of value 1 ($)	**Total plant ($)**
Sales	5985460.858	5985461
Cost of materials	1871040	1871040
Personnel cost	233880	233880
Amortization cost	214390	214390
WIP cost	74841.6	74841.6
Cost of operation	159114.0212	159114
Profit / loss of the value stream	3432195.237	3432195
General expenses		77960
Plant benefits		3354235

TABLE 8. E) INCOME STATEMENT BY VALUE CHAIN.

	Type of piece e	
	Manufacturing flow of value 1 ($)	**Total plant ($)**
Sales	6297891.99	6297892
Cost of materials	1871040	1871040
Personnel cost	233880	233880
Amortization cost	214390	214390
WIP cost	154750.6	154751
Cost of operation	209600.7223	209601
Profit / loss of the value stream	3614230.667	3614231
General expenses		116426
Plant benefits		3497805

Simulate capacity uses

In this stage, the VSCA will be introduced to evaluate the process in financial terms. For this purpose, the information corresponding to the time dedicated to productive activities and times dedicated to non-productive activities is calculated for each position. In this case, in Table 9 and 10 work stations, A and B respectively are analyzed.

TABLE 9) PRODUCTION CAPACITY ANALYSIS, NON-PRODUCTIVE AND AVAILABLE FROM WORK STATION A.

	Actual state				
	Activity	Quantity (units)	Cycle time	Number of operators	Number of machines
Productive	Manufacturing	688	28770.88	2	3
Not productive	Repairs	-	-	-	-
	Productive max	76.12	-	-	-
	Non-productive	23.88	-	-	-

TABLE 10) PRODUCTION CAPACITY ANALYSIS, NON-PRODUCTIVE AND AVAILABLE FROM WORK STATION B.

	Actual state				
	Activity	Quantity (units)	Cycle time (min)	Number of operators	Number of machines
Productive	Manufacturing	800	38361	2	3
Not productive	Repairs	-	-	-	-
	Productive max	84.25%	-	-	-
	Non-productive	15.75%	-	-	-

In later stages, the future state of the capacity analysis will be presented, expecting an increase in the production of units. Therefore, a reduction in the average cost of each piece produced.

After carrying out the cost analysis by implementing the VSCA tool, we proceed to calculate the minimum cost of the WIP of the production system simulated in Promodel. the processing times and inter-arrival times of the different types of piece are taken as a restriction to meet the demand to reduce the WIP.

5. Experimentation

Once the costs under the Lean Accounting approach were analyzed, they were used for optimization purposes and thus meet the objectives set in the research.

The cost of making the sub-assemblies wait in the row within the objective function shown in equations 1 to 4 is taken as a response variable. The objective is to find the service rate and the time between arrivals of the entities that minimizes the cost total of the value stream chain.

MIN CT = (C1* fila a maximum contents) (1)

MIN CT = (C1* fila b maximum contents) (2)

MIN CT = (C1* fila c maximum contents) (3)

MIN CT = (C1* fila d maximum contents) (4)

C1: Cost to keep the WIP in the system.

Queue maximum contents: Maximum number of WIP in the course of simulation.

CT: Total cost of the process.

The restrictions or decision variables for the problem are identified as follows:

$$137 \leq X_1 \leq 145$$
$$19 \leq X_2 \leq 24$$
$$31 \leq X_3 \leq 36$$
$$66 \leq X_4 \leq 71$$
$$5 \leq X_5 \leq 30$$
$$10 \leq X_6 \leq 15$$

X1: Time between arrivals of piece a - queue a

X2: Inter-arrival time of part b - queue a

X3: Inter-arrival time of part c and d - queue b

X4: Inter-arrival time of part e - queue a

X5: Processing time in station A, B and D

X6: Processing time in station C

Optimization

Execution of 25 experiments in the Simrunner optimization module, resulting in the best solution for experiment 10. Table 11 shows the suggestions that Simrunner makes to reduce the inventory of work in process and its costs both for WIP and for the times of process.

TABLE 11) VARIABLES FOR THE SIMULATED PRODUCTION SYSTEM PROPOSED BY SIMRUNNER.

Process times and inter-arrival times of the entities to the system proposed by simrunner	
Variable	**Exponential times**
Arrives piece a - queue a	140
Arrives piece b - queue a	22
Arrives piece c y d - queue a y b	34
Arrives piece e - queue b	71
Process times C	13
Process times A, B and D	25

In figure4 A) y B) it can be seen that with the suggestion provided by Simrunner subtracting the total cost of figure4 A) minus the total cost of figure4 B) a reduction of 134568.705 dollars pesos per month is obtained.

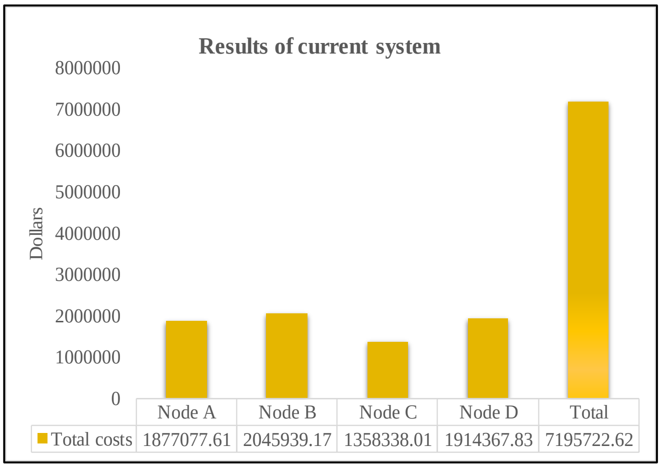

Figure 4 A). Hypothesis test results.

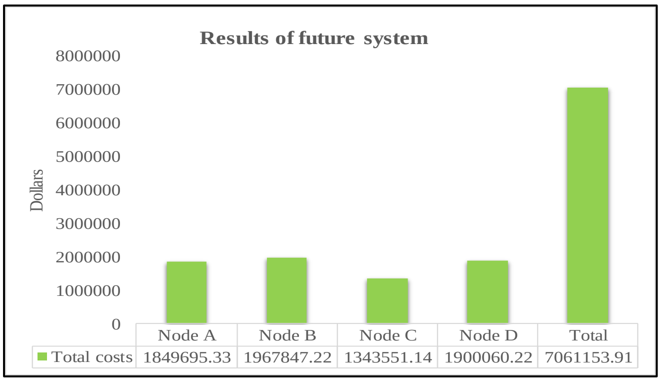

Figure 4 B). Hypothesis test results.

Simulation model was run for both lines with the data proposed by simrunner to observe the behavior of the average cost per unit and to verify that there is an improvement in the process. Because the operation times reduce their costs, they also generate less work inventory in process and increasing the total of pieces produced and completed of 97.62% in the demand.

Figure 5 A) to E) shows the reduction in the average cost for the types of pieces.

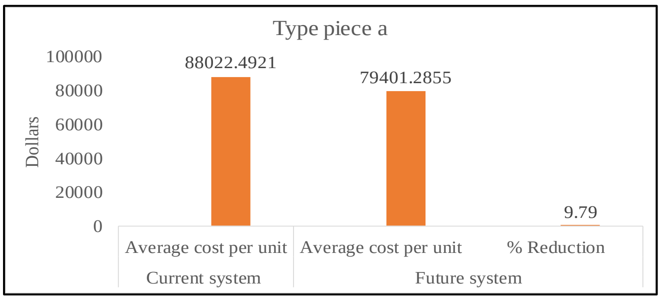

Figure 5 A). Reduction of current average cost against future average cost.

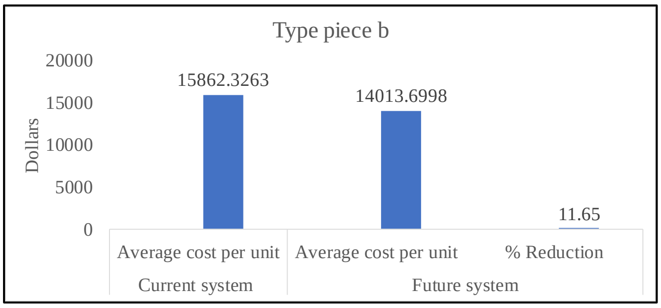

Figure 5 B). Reduction of current average cost against future average cost.

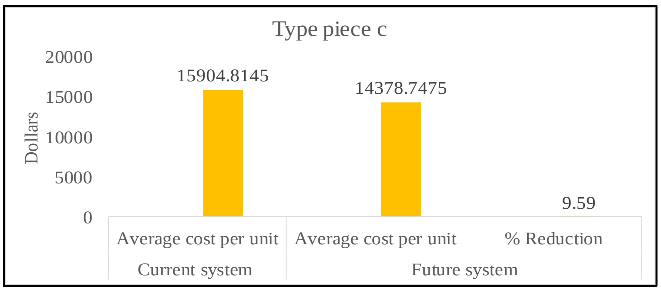

Figure 5 C). Reduction of current average cost against future average cost.

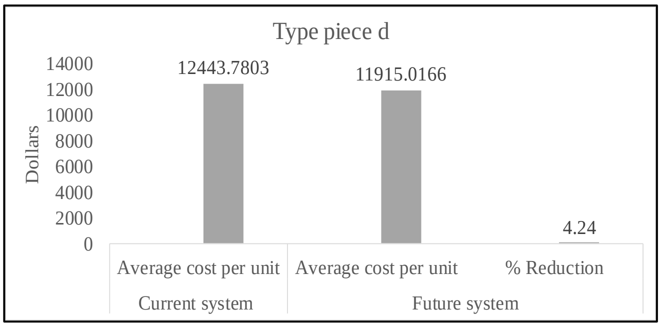

Figure 5 D). Reduction of current average cost against future average cost.

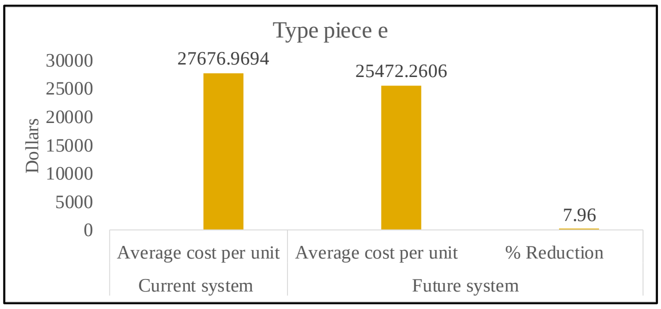

Figure 5 E). Reduction of current average cost against future average cost.

IV. CONCLUSIONS

The interaction of Lean tools, simulation and optimization applied in this cost analysis allowed to describe in a detailed and practical way the behavior of the work inventory in process and the waiting time for the production system simulated in Promodel mentioned in the description of the problem. Costs involved in the flow of value, were obtained by simplifying its method so that it was understood by the Lean team responsible and said costs were monitored over time without losing sight of the stated objective.

Simulating the model allowed building a system to carry out the optimization purposes that facilitated knowing the current and future state of the costs related to the flow of value and being able to make short-term decisions.

The value flow cost analysis shows that the best work option for the simulated system is to reduce the variables of the process time and time between arrivals in each of the stations. Minimizing the total cost of the value chain $ 6904.5 pesos per month equivalent to $ 82854 pesos per year. It is important to mention that the evolutionary algorithms that were applied to find the minimum solution in Simrunner, is a good estimate, but not the optimal one.

Calculating again the average costs for each type of piece, a reduction is observed in this, thus proving an improvement in the process and satisfying the demand an average 97.62%.

It is important to mention that the evolutionary algorithms that were applied to find the minimum solution in Simrunner, is a good estimate, but not the optimal one.

As future work we propose the application of this methodology to a real-world company, of the mechanical metal branch.

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