Discrete Event Simulation

Project: Improvement of the Production Line of Garden Dwarfs

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Table of Content

Context of Study

As part of our course “Discrete Event Simulation”, we have been assigned a project that allows us to apply our classroom knowledge practically and gain hands-on experience with Arena simulations. The project involves creating a simulation model in Arena to predict and assess the performance of a production line. Specifically, we are simulating the assembly processes involved in the production of garden dwarfs.

Objective

For this project, our main objective is to assist this company to evaluate the performance of its production in gradually increasing its production capacity from 1000 to 1100, and ultimately to 1250 garden dwarfs per week. The whole system involves multiple assembly processes.To achieve this, we need to propose various scenarios and modifications for enhancing the production line and provide reasonable justifications for each scenario. Additionally, we must compare the potential advantages and disadvantages of these scenarios to determine the most suitable and adaptable improvement strategy.

Assumption

For this project, after reviewing thorough details of the present production system of the company “Magic Lantern”, We have formulated the following assumptions that will be helpful to build a simplified model for our simulation as the provided information do not contain precise details and sufficient data at some stages of the production line, while ensuring that our simplified model is a valid representation of the physical system.

- **Supply of Dwarfs to Factory:**Raw dwarfs are delivered to the factory in total units of 2000 and this supply is efficiently managed with the supply by the use of a Kanban. Since the current factory capacity is about 1000 units, we are sure that the factory won’t run out of raw dwarfs. Therefore, for our model, we make an assumption of infinite availability of dwarfs, and exclude that and the supply kanban.

- **Movement of Raw dwarfs from inbound dock to painting entrance:** An assumption has been made to streamline the operation. Specifically, it has been assumed that there is no processing time involved in transporting the dwarfs from the inbound docks to the storage area as there is some lack of relevant information about the movement of dwarfs from inbound docks to the entrance of the painting shop. Therefore, this time is assumed negligible for the simulation.

- **Temporary storage on the 'Dwarf Production Line':** Since it is not explicitly stated, we assume that all storage systems on the dwarf production line are of infinite capacity and so do not limit the capacity of their downstream process. Therefore, we can exclude them from our model.

- **Drying Tunnel:** The report does not provide clear information about the drying tunnel, but it states that the movement of dwarfs from the painting shop to the drying tunnel is smooth and that they are transported on a conveyor. Based on this, an assumption has been made that the drying tunnel may operate as a memoryless process, specifically an $M/M/\infty$ process, which has infinite servers and therefore, no waiting time.

- **NC Polishing Machine:** After calculating using Markov Chain, we concluded, that the failure probability of the polishing machine is 3% and the probability that the machine is working is 97%.

- **Chip Manufacturing and Transfer:** From the information, it takes 3 - 37 mins for chip production and 40 minutes for the kanban transfer and set up time. We have no information on the production capacity of the chip workshop, but we know its production is managed by a kanban of quantity 26. We can assume that the kanban ensures that the dwarf production workshop is never delayed due to chip manufacturing. We make an assumption that chip workshop capacity is equal to the number of kanban.

- **Wiring Operation:** From the information, due to the criticality of the wiring operation, once components are available, operators from other workshops are called if nobody is available to carry out the operation - A concept in performance studies known as 'joking' and can make simulations complicated. To simplify our simulation, we 'assume that there is no joking in the system' i.e workers don't move from one workshop to another.

- **Lantern Supply to Production Floor:** The daily stock-up policy of the raw lantern is ' daily stock up to 300', the daily capacity of the production line is about 200 units, so we know that lantern availability is not an issue. We, therefore, exclude only this lantern supply from our model, while including the process to account for the rest of the value-added steps after this lantern supply.

- **Assembly with other Small Accessories**: Given the length and speed of the conveyor with three workers in series, it will take a total time of three minutes for the workers to assemble the lantern unto the dwarf. This conveyor process is simplified as a simple process of constant time 3 minutes

Explanation of Modeling Choices

We were provided with a brief explanation of the project describing the situation of the garden dwarf production line. Using this context study, we gathered relevant information about the production capacity of each step in the production process.

Initially, we developed a conceptual flow model to capture the overall process comprehensively. We then refined the model by incorporating specific details about each step of the process. Once our assumptions and justifications were reviewed and validated by our professor, we worked on it again to make it more efficient as per the comments of the professor. Our final conceptual model is present below.

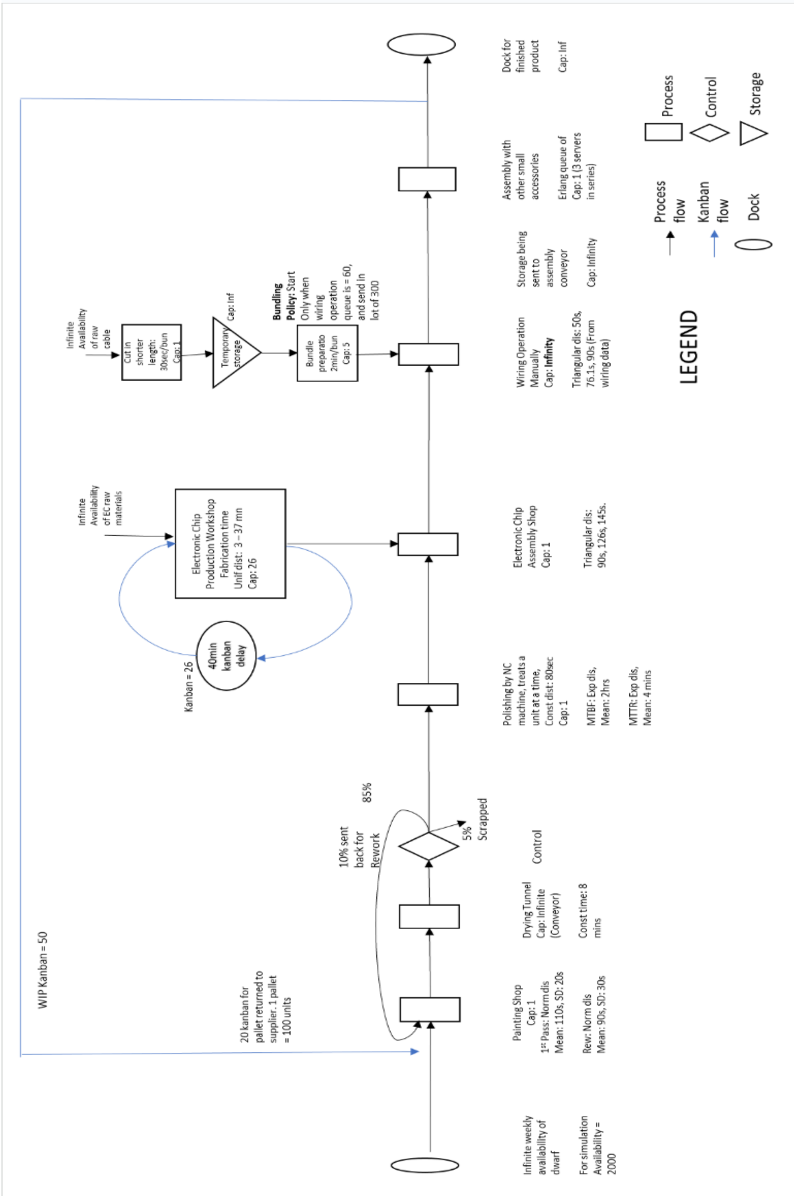


fig 1: conceptual flow mode

Further, we proceeded to create the final process flow model using the Arena modeling software, incorporating our assumptions and justifications which can be shown below.

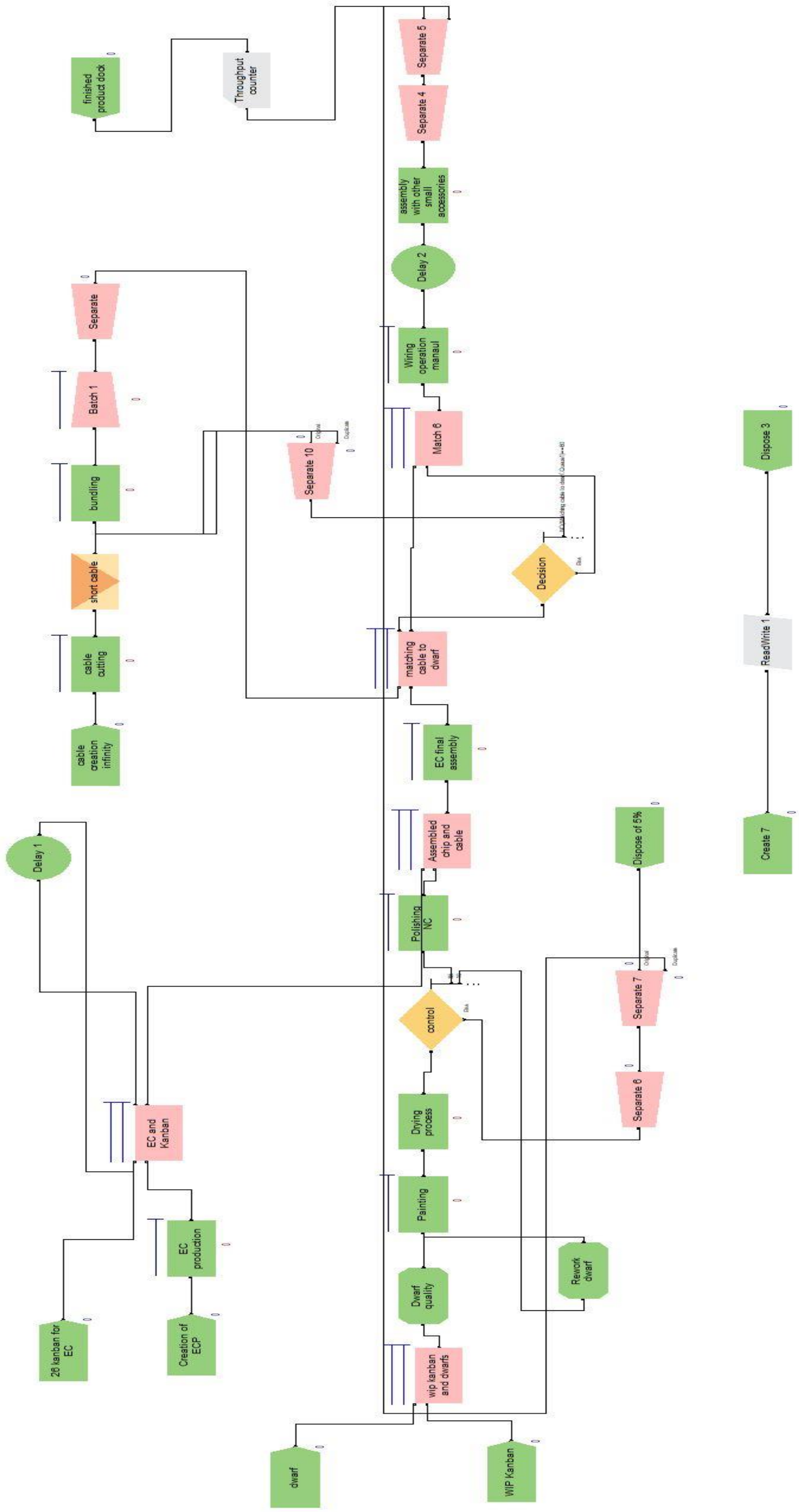
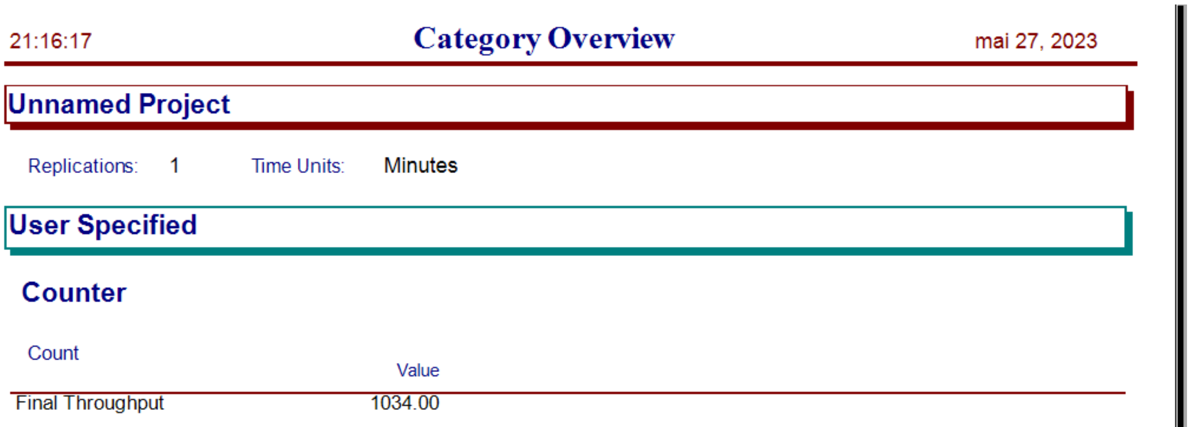


fig 2: Arena model

Initial Model Output

For a period of 5 days, the model gave an output of 1034 which can be seen below.


21:16:17 Category Overview mai 27, 2023

Unnamed Project

Replications: 1 Time Units: Minutes

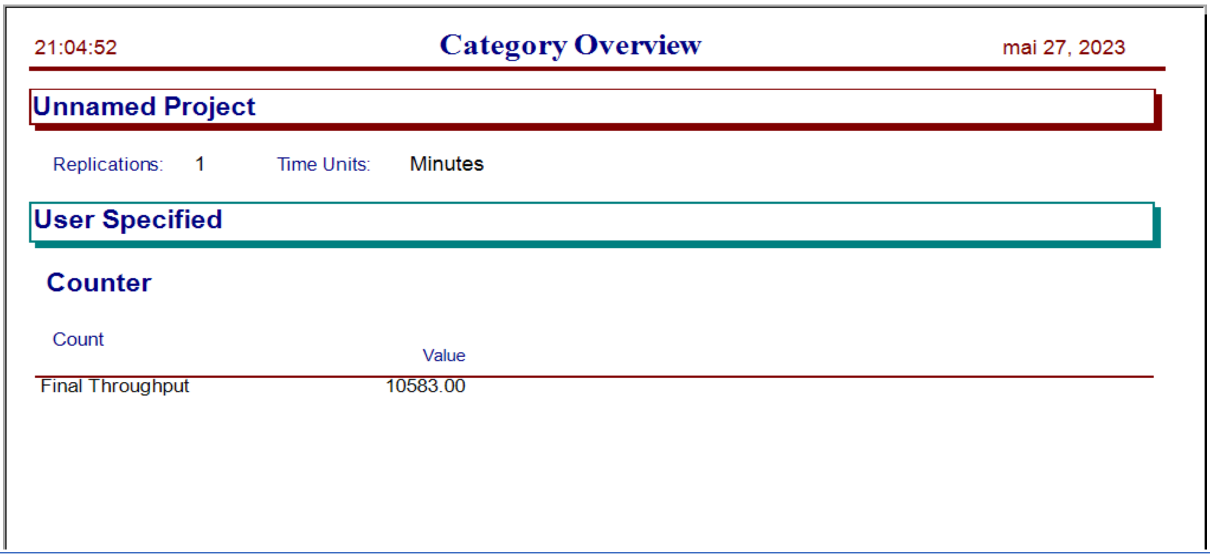
User Specified

Counter

Count	Value
Final Throughput	1034.00

fig 3: initial model output 1

For a period of 50 days, the model gave an output of 10583 which can be seen below.


21:04:52 Category Overview mai 27, 2023

Unnamed Project

Replications: 1 Time Units: Minutes

User Specified

Counter

Count	Value
Final Throughput	10583.00

fig 4: initial model output 2

Model Validation

Once our Arena model was created, and it was giving an output of about 1034 dwarfs (shown in the picture above), The model validation was carried out to verify if our model is a good representation of the physical production system, by comparing with the available actual production data over 10 weeks, using the Paired t-test method. The model is run for a period of 50 days, data is collected using the 'ReadWrite' function, and analyzed in the attached excel sheet.

so first, we proposed a null hypothesis stating, *H0: there is no correlation between the model and the actual system.*

Ha: there is a correlation between the model and the actual system.

After that, A comparison is made between the collected data and the actual data. For this, we used a paired t-test. Implemented the following steps for this test which was studied during the course.

1. Assumed Xj and Yj to be the number of daily production of the actual system and the model respectively.

2. Then calculate their difference i.e. $Z_j = X_j - Y_j$.

3. Took the average of the difference using this formula:

$$\overline{Z}(n) = \frac{\sum_{j=1}^{n} Z_j}{n}$$

4. Then calculate the sum of the squares of the difference of the Zj and the average difference Z bar. This value is then divided by the n(n-1) where n is the number of samples, which is 50 in our case. using the formula :

$$\hat{V}\left[\overline{Z}(n)\right] = \frac{\sum_{j=1}^{n}\left[Z_j - \overline{Z}(n)\right]^2}{n(n-1)}$$

5. The t-value obtained from the t-distribution table was t = 2.009 (with CI= 95% and n=50 samples, α = 5) also, the Mean of Z = - 3.7 and Standard Deviation = 0.523469. the intervals are (-4.71, -2.649).

Interpretation

0 does not lie within the interval, so, unfortunately, our model is not valid. The interval lies on the left-hand side of zero and suggests that our model is producing lower output than the actual system, which can also be observed by inspecting the model data over the period of these 50 days.

Calculation of Simulated Parameter Setting

As the process extends more than a single day and continues again to produce the garden dwarfs for the incoming day, there is a need to calculate parameters such as the warm-up and replication length. Here is a detailed explanation of our simulation parameter setting.

1.Warm-up period

To get a better understanding of warm-up period, let's have a look at its definition :

It represents the initial phase of a simulation where the system stabilizes before data collection or analysis begins.

To calculate the warm-up period, the Welch's procedure method is used. We performed eight replications of the simulation, each with a duration of 20 hours. Then, calculated the average of the data generated for each hour in each replication. We used the value of w = 1.

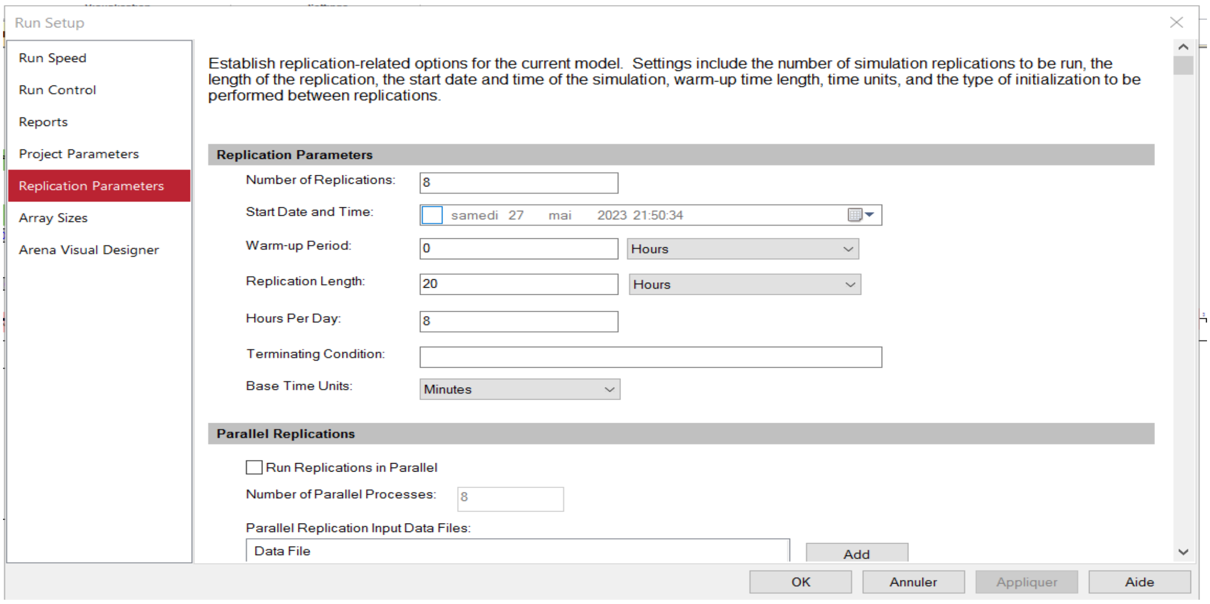


fig 5: Warm-up period setting

The second average is also calculated which is the mean between each three consecutive hours.

R1	R2	R3	R4	R5	R6	R7	R8	AVG 1	T BAR (w = 1)	Hours
0	0	0	0	0	0	0	0	0	0	1
18	0	0	0	0	0	0	0	2	8	2
50	18	19	19	18	19	19	19	23	24	3
37	49	48	48	48	49	48	48	47	36	4
28	41	44	38	43	37	39	39	39	38	5
26	28	27	28	28	28	28	28	28	31	6
27	25	26	26	25	25	26	26	26	27	7
26	28	27	27	28	28	27	27	27	26	8
27	26	26	26	26	26	26	26	26	26	9
25	26	26	27	26	27	26	26	26	26	10
27	26	26	25	26	25	26	26	26	26	11
26	27	27	27	27	27	27	27	27	26	12
27	26	26	26	26	26	26	26	26	27	13
26	27	27	28	27	27	27	27	27	26	14
28	26	26	25	26	26	27	26	26	27	15
26	28	28	28	28	28	27	28	28	27	16
27	25	25	25	25	26	25	26	26	27	17
26	28	28	28	28	27	28	27	28	27	18
27	25	26	25	26	26	26	26	26	27	19
27	28	27	28	27	27	27	27	27	27	20

Fig 6. Excel file output for calculating warm-up period time

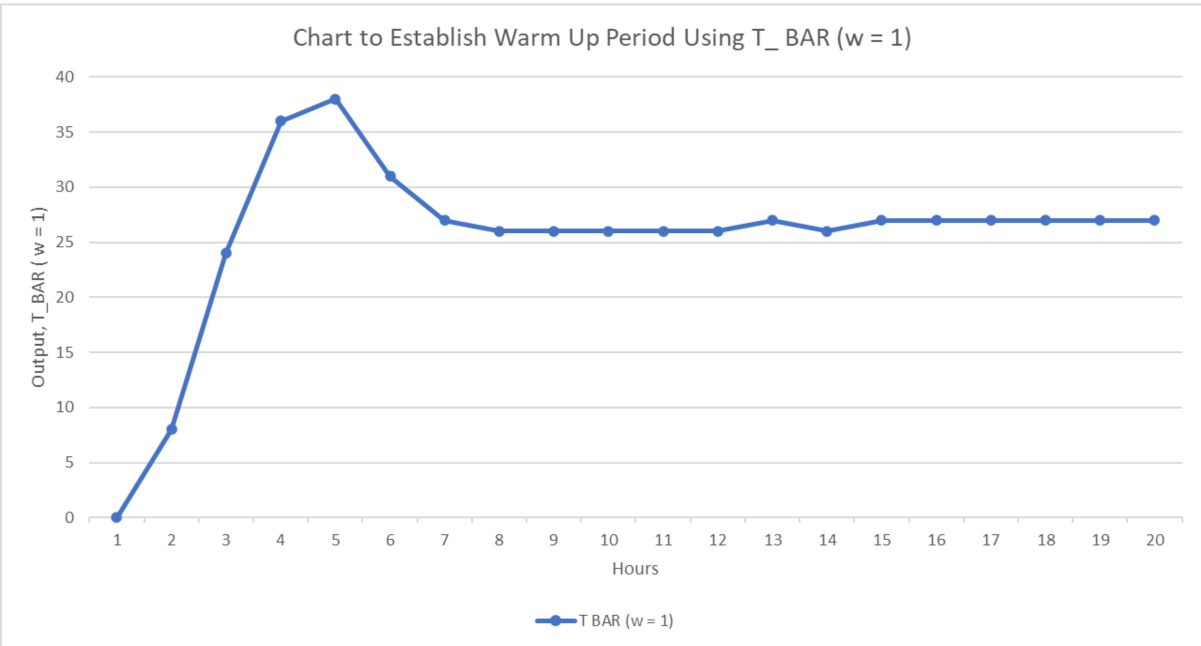


Fig7. Warm up period chart

From the table above, the chart is plotted. The chart attains equilibrium at the **7 hour**, so the warm up period is chosen as **7 hours**. The setup settings of the model are adjusted to this warm-up period of 7 hours.

2. Number of replications

Number of replications refers to the parameter that determines how many independent runs of the simulation model will be performed. Each replication generates a separate set of data, allowing for the analysis of different outcomes and variations in the system being modeled.

Also, we know that running a sufficient number of replications is essential to minimize variability and enhance the confidence level, credibility, and reliability of the results obtained from the simulation model. By conducting a well-replicated simulation, we can establish a reliable relationship between the independent variables and dependent variables. So to calculate the number of replications we used absolute error and relative error. Replications of 8 with a simulation length of 5 days are done by us.

Re-validation of Model (using new parameters)

After changing the model set up to include the warm up period and eight replications, the run for five days is repeated and the new output is 1060, different from the former result.

From this new output given below, we try to carry out a validation once again, to know if the new set up setting has any impact on the validity of the model. Results for 50 days are run and analyzed in Excel sheets.

22:25:44 **Category Overview** mai 27, 2023

Values Across All Replications

Unnamed Project

Replications: 8 Time Units: Minutes

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Final Throughput	1060.88	0,70	1060.00	1062.00

Fig8. new final output

New Average Final Output = 1060

New interval : (-29.63, 28.53)

Interpretation

0 lies within this interval, and so we can say that given the warm up period and number of replications, our model is valid

Experimentation Parameters

Experimentation parameters refer to the variables or factors that are adjusted and manipulated within the simulation model to investigate their impact on the system's behavior and performance.

For us the parameters are as follows:

- Number of kanbans
- Capacity of machine
- Service time of machine
- Working hours
- Delivery time of machine
- Delays during process

In this project we tried and tested variations in these parameters to obtain desired results.

Result Analysis

Arena automatically generates a comprehensive summary report after running the simulation, which offers valuable and detailed insights into the simulation's execution and highlights potential areas for improvement. So, now we will analyze the results from the beginning.

Replications: 8 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Assembled chip and cable.Queue1	3220.35	1 561,42	552.13	5888.39	170.99	6270.09
Assembled chip and cable.Queue2	0.00	0,00	0.00	0.00	0.00	0.00
Batch 1.Queue	59.0000	0,00	59.0000	59.0000	0.00	118.00
bundling.Queue	58.5499	1,41	55.8571	61.1739	0.00	118.00
cable cutting.Queue	0.00	0,00	0.00	0.00	0.00	0.00
EC and Kanban.Queue1	0.00	0,00	0.00	0.00	0.00	0.00
EC and Kanban.Queue2	4981.96	2 453,78	804.18	9190.30	198.10	9773.26
EC final assembly.Queue	0.01663465	0,00	0.01313625	0.01836218	0.00	0.4371
EC production.Queue	7599.88	4 631,97	0.00	15103.05	0.00	15376.72
Match 6.Queue1	32.5377	16,38	4.5411	60.5027	0.00	67.3383
Match 6.Queue2	0.00	0,00	0.00	0.00	0.00	0.00
matching cable to dwarf.Queue1	354.83	8,27	339.50	369.95	16.5953	693.49
matching cable to dwarf.Queue2	0.00	0,00	0.00	0.00	0.00	0.00
Painting.Queue	21.2329	12,04	8.6337	49.3191	0.00	73.3314
Polishing NC.Queue	581.60	267,34	119.71	1044.05	16.0468	1099.35
wip kanban and dwarfs.Queue1	10014.61	4 915,88	1615.58	18412.28	420.73	19619.75
wip kanban and dwarfs.Queue2	0.00	0,00	0.00	0.00	0.00	0.00
Wiring operation manaul.Queue	0.00000242	0,00	0.00	0.00001938	0.00	0.02058149

Other

fig 9 Waiting time

Replications: 8 Time Units: Minutes

Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
bundler 1	0.1795	0,02	0.1500	0.2000
cable cutter 1	0.00	0,00	0.00	0.00
EC Assembler 1	0.8908	0,00	0.8860	0.8950
EC Producer	0.7798	0,35	0.00	1.0000
NC Polisher	0.9758	0,00	0.9750	0.9763
painting 1	0.9873	0,01	0.9675	1.0000
Wirer 1	0.5453	0,00	0.5426	0.5476

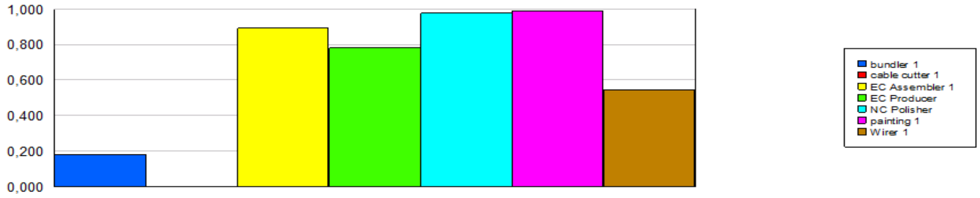


fig 10 Resource Utilization

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
bundler 1	1077.50	114,54	900.00	1200.00
cable cutter 1	0.00	0,00	0.00	0.00
EC Assembler 1	1064.50	0,63	1063.00	1065.00
EC Producer	2430.25	1 082,40	0.00	3155.00
NC Polisher	1064.50	0,63	1063.00	1065.00
painting 1	1324.25	12,94	1303.00	1351.00
Wirer 1	1060.88	0,83	1059.00	1062.00

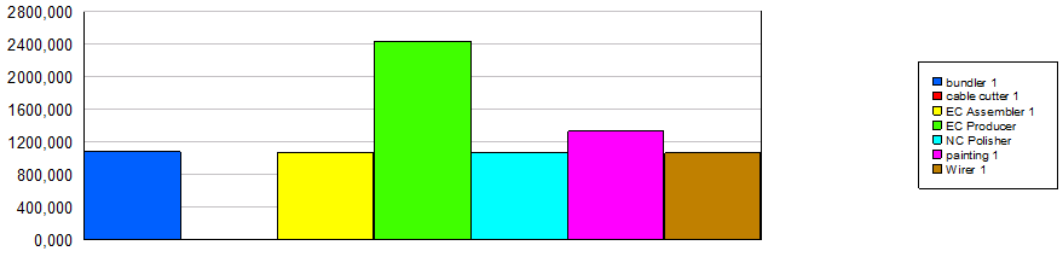


fig 11 Waiting time

From the two charts above, it is noticed that the wiring resource seizes / works on the least amount of dwarf during the 5 days period, and on the first glance may be considered as the bottleneck. However, the utilization result shows that the wiring resource is only busy 54.53% of the time and that its queue waiting time is zero. Therefore, we look at the machines at the upstream of this wiring process.

Observation of the results shows the NC polishing machine worked on only 1064.50 and was busy 97.58% of the time. The EC assembling process which is on its downstream side also worked on 1064.50 and was busy 89% of the time. Waiting time of 581.6 mins for the NC machine and 3220mins at the EC assembly point waiting for the electronic chip from the chip workshop.

Due to this high utilization and waiting time of these upstream processes (NC polishing and EC assembling), they are therefore the bottlenecks of the production system and not the wiring process. The result has other interesting information like the average number of entities waiting in each queue at a given time.

Improving Production Line

According to the results stated above, it has been identified that the existing weekly production capacity for dwarfs is approximately 1000 units.However, due to an anticipated growth in demand for dwarfs in the upcoming months, there is a need to propose various scenarios for improving the production line's capacity. The objective is to gradually increase the production capability from 1000 units per week to 1100 units and ultimately to 1250 units per week. Here are the proposed scenarios developed by us.

TARGET: 1100 Dwarfs Per Week

Scenario 1

"An extra working hour per day for the week"

The first thing that came into our mind for reaching our target was to increase the working hours. Hence, a simulation of overtime was run to achieve the required result. We increased the weekly production of dwarfs from 1000 to 1100, by adding an overtime of 1 hour per day. (we increased the hours from 8 to 9 per day). which can be seen in the figure given below.

We got the results of around 1193 dwarfs per week which was a bit more than our target.

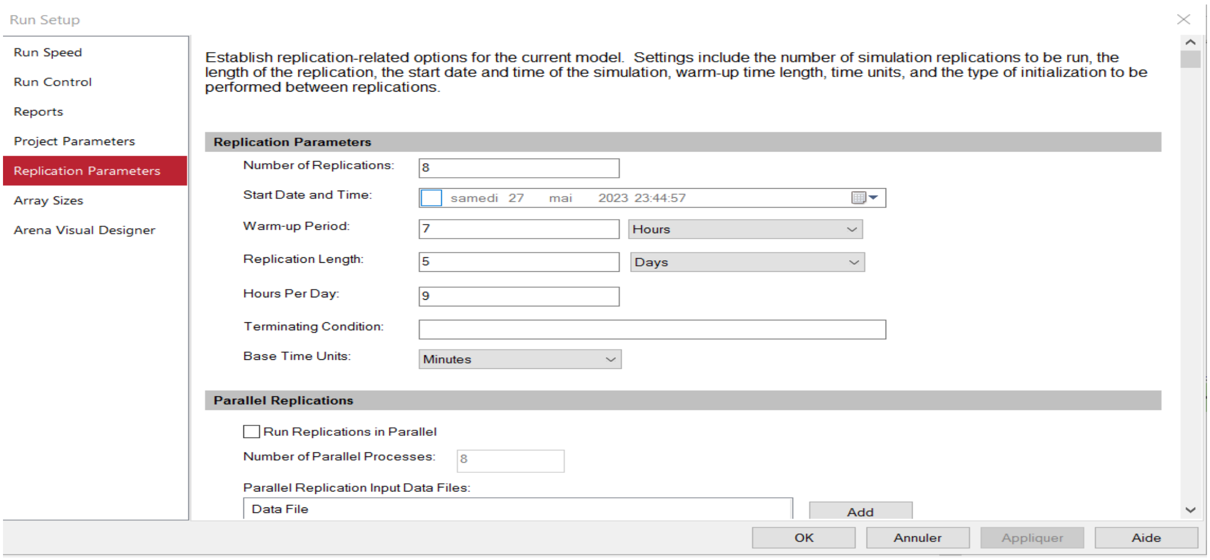
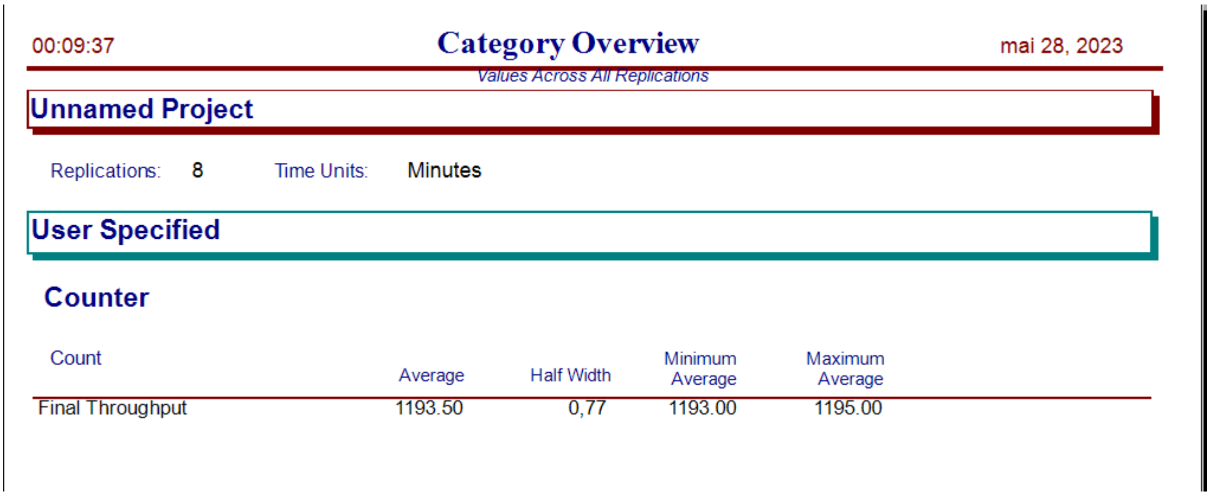


Fig 12: Replication parameters (set for 1 hour overtime/day)


00:09:37 **Category Overview** mai 28, 2023

Values Across All Replications

Unnamed Project

Replications: 8 Time Units: Minutes

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Final Throughput	1193.50	0,77	1193.00	1195.00

Fig 13: Weekly production of dwarfs with 1 hour overtime/day

Scenario 2

"Increasing the capacity of only the NC polisher to 2, and leaving every other thing constant."

We also think of the idea of improving our NC polisher machines performance by increasing its capacity from 1 to 2. As in the results we noticed that NC polisher is the bottleneck in our system so if we boost its capacity , it can work fast as a result giving us our desired output.

	Name	Type	Capacity	Busy / Hour	Idle / Hour	Per Use	StateSet Name	Failures	Report Statistics	Comment
1	painting 1	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑	
2	NC Polisher	Fixed Capacity	2	0.0	0.0	0.0		1 rows	☑	
3	EC Producer	Fixed Capacity	26	0.0	0.0	0.0		0 rows	☑	
4	cable cutter 1	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑	
5	bundler 1	Fixed Capacity	5	0.0	0.0	0.0		0 rows	☑	
6	EC Assembler 1	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑	
7	Wirer 1	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑	

Fig14. changing NC polisher capacity to 2

00:34:46 **Category Overview** mai 28, 2023

Values Across All Replications

Unnamed Project

Replications: 8 Time Units: Minutes

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Final Throughput	1133.00	16,28	1111.00	1170.00

fig 15. Output for capacity to 2.

After performing the simulation with increased capacity we got 1133 dwarfs per week, with the EC assembling process being the new bottleneck.

Proposal

Among these two scenarios , we believe that scenario 1 where workers do an extra hour of one hour daily, is more feasible compared to the alternative of investing in an additional NC machine. We believe that the cost of additional labor for overtime is more manageable compared to the expenses involved in acquiring and installing a new NC machine.

TARGET: 1250 Dwarfs Per Week

Scenario 1

“Further increase of working hours to 10 hours per day”

Now if we further increase the working hours to 10 hours per day we can achieve our target which is 1250. Hence, again, a simulation of overtime was run to achieve the required result. We increased the weekly production of dwarfs from 1100 to 1200, by adding an overtime of 2 hours per day. (we increased the hours from 8 to 10 per day). which can be seen in the figure given below.

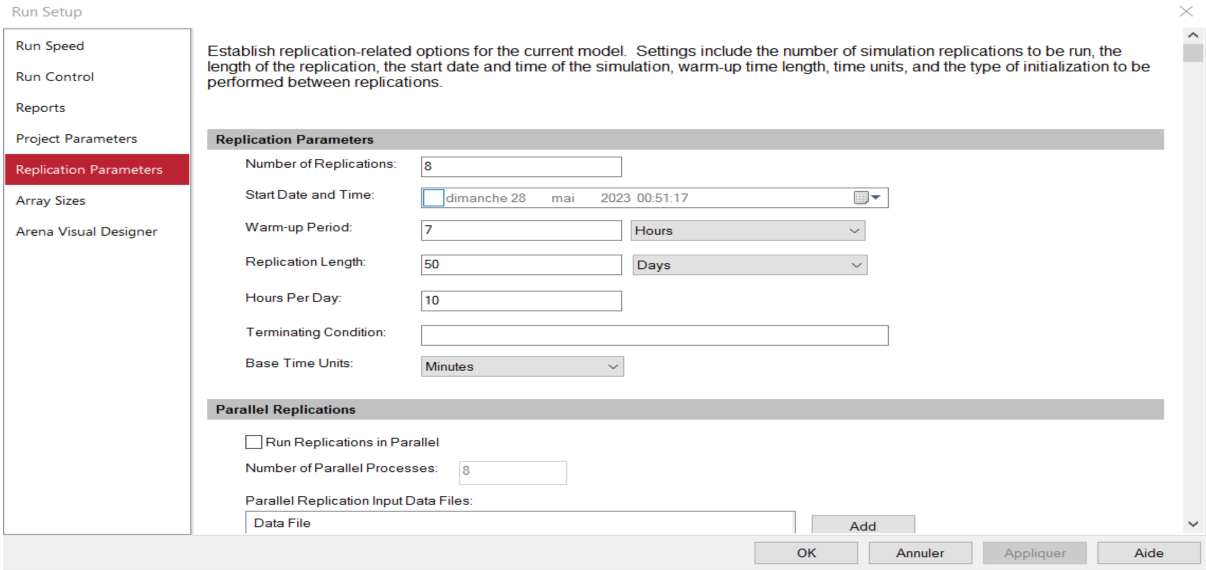


Fig 16: Replication parameters (set for 2 hour overtime/day)

We got the results of around 2332 dwarfs per week

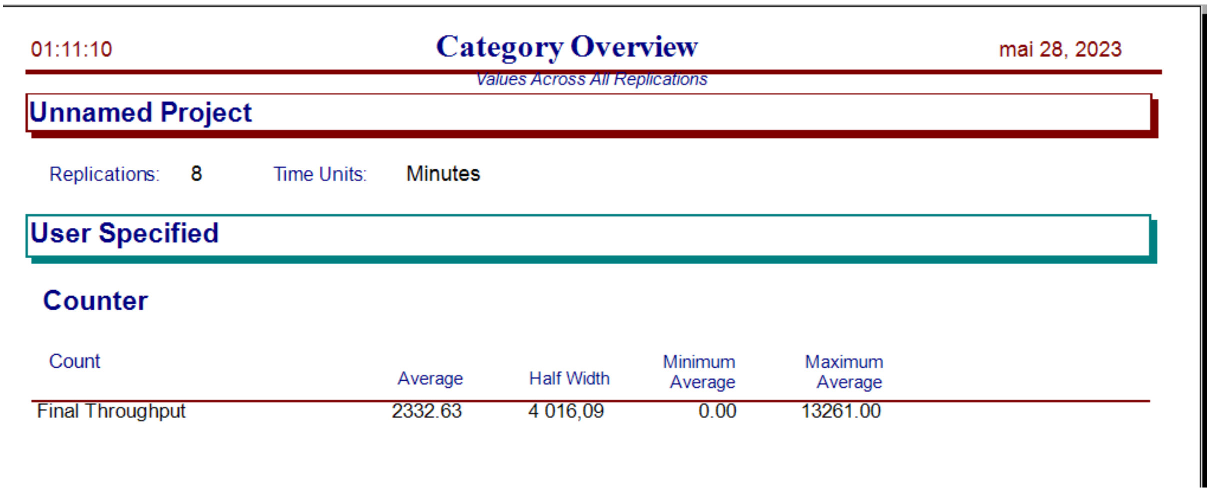


Fig 17: Weekly production of dwarfs with 2 hours overtime/day

Impact of Modification

Low utilization of some process resources

Electronic chip and Kanban waiting time: 2865 mins

EC assembly waiting for chip due to 26 kanban limitation: 2071 mins

Scenario 2
“At 9 hours per day, increase capacity of only NC polishing to 2”

Now if we increase an hour for daily working , along with that if we increase the capacity of NC polishers we can improve our outcome. so for this we used the working time of 9 hours per day and installed 2 servers in the NC polisher process instead of 1. by doing this we got the output of 1273 dwarfs week

01:34:43 **Category Overview** mai 28, 2023

Values Across All Replications

Unnamed Project

Replications: 8 Time Units: Minutes

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Final Throughput	1273.13	12,95	1253.00	1296.00

Fig 18: Output of scenario 2

Impact of Modification
High EC assembly utilization: 0.95

Electronic chip production, queue for 26 kanbans: 5998 mins

Scenario 3
“At 9 hours per day, EC Kanban to 34 and keep everything else constant.”

In this scenario, we thought to increase 1 hour working time and the EC kanban up to 34 numbers at the same time, in order to see if this case will give us the same outcome or not. so after implementing these specifications to the model we got an output of 1193 however our target was 1250 dwarfs. We were not able to reach our goal. So for this scenario it's not possible to create what we want. Outputs are attached below

02:00:14 **Category Overview** mai 28, 2023

Values Across All Replications

Unnamed Project

Replications: 8 Time Units: Minutes

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Final Throughput	1193.50	0,77	1193.00	1195.00

fig 20 Output for scenario 3 (Target not met)

Impact of modification

Good Resource utilization, and lower waiting time

Scenario 4

" Increasing EC kanban to 34, increasing NC polisher to 2 and keeping everything else constant."

For this last scenario, we kept everything constant, just increased the capacity of the NC polisher machine from 1 to 2 and also , increased the number of kanbans present in the EC process up to 34. After running the model we got the output of 1273 dwarfs

02:29:37 **Category Overview** mai 28, 2023

Values Across All Replications

Unnamed Project

Replications: 8 Time Units: Minutes

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Final Throughput	1273.13	12,95	1253.00	1296.00

fig 20 Output of scenario 4

Impact of Modification

- New Bottleneck at EC assembly with high waiting time and utilization of 0.95
- Good utilization of resources

Proposal

Considering working for 9 hours per day, with an increase in EC kanban from 26 to 34, and increasing capacity of NC polishing machines to 2. We aim to reduce waiting time, eliminate production bottlenecks, and improve the utilization of resources in the system. The extended work hours, increased EC kanbans, and additional NC polishing machines collectively contribute to enhancing the production capacity, ensuring that the system can meet the growing demand for dwarfs effectively and efficiently.

CONCLUSION

The company aims to evaluate the possibility of increasing their production to meet demand. From our evaluation of different scenarios, we can clearly observe that the weekly demand of 1100 dwarfs can be met with an increase in working hours of the employees. However, meeting the further weekly demand growth of 1250 would require significant investment in the production line for the purchasing and installation of an NC polishing machine into the system.

The project has also enabled us to get in depth understanding of studying a production line with the use of Arena software.