September 30, 2018

Contents

1 Executive Summary

Ever since the marketing initiatives undertaken by its VP of Marketing, Joe Keenan, Speed Gears Inc., an American manufacturing company, has experienced an increase in demand in it's SureFactor product line. However, due to issues in configuration, inefficient changeover policy, the company is experiencing a severe backlog problem. The lead time of model B15 and D25 far exceeds the promised lead time with the European clients, who are the two largest customers for the SureFactor line. Through our analysis, we find the problems mainly consist of low utilization for some of the equipment and problematic changeover policy.

In order to increase efficiency and fulfill the contract on time, we suggest that the company should immediately adopt a new configuration policy and schedule one more shift each week. They should also purchase another drill and an external chucker. In the long run, Speed Gears should maintain the configuration that we recommend with some minor reorganization. As for the N99 proposal, we suggest that Speed Gear should not take the deal because adding this model would overcrowd the mills and create backlog for the other models. Also because of its relatively low per-unit profit, we don't think it is worthwhile to dedicate the amount of time required to produce it.

2 Problem Description

Speed Gears Inc. wants to reduce the customer lead time for each model to 4 weeks. After receiving the orders, the factory spends one week to get the customized casting, and then goes through four operations: Internal Chucker, External Chucker, Mill, and Natco Drill in the order shown in Figure 1.

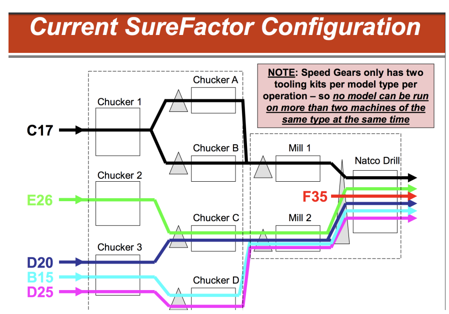


Figure 1: Current Model

The SureFactor production line meets severe backlog problem in models B15 , D25, D20 and E26. Since Speed Gears will encounter contract renewal soon, we aim to solve the backlog problem within four months. For the long term, Speed Gears is able to purchase up to four new equipment, and is met with a new production opportunity N99.

The current configuration has the following constraints:

1. Each model goes through pre-designated equipment as the figure shown.
2. If two or more models share the same equipment, an operator needs to manually set up the equipment during a changeover.

3. C17, E26, D25, D20, B15 have be processed through all four operations, while F35 only need to be drilled.

3 Diagnosis of Current Process

3.1 Assumptions of Current Changeover Policy

1. Under the current policy, changeovers happen at most every two weeks; this suggests that changeover frequency is not deterministic.
2. We used the given backlog data to infer the current prioritization policy.
   2.1. We used units short/week per product on average to infer the current configurations' prioritization of products (See Appendix for Calculation). Priority, in order from highest to lowest, is: F35 $\rightarrow$ E26 $\rightarrow$ D20 $\rightarrow$ C17 $\rightarrow$ D25 $\rightarrow$ B15
   2.2. Our calculations showed that in the past 50 weeks B15 was 1.16 units short per week on average while D20 was 0.3 units short per week. From this, we assumed that D20 was prioritized more often than B15, and thus using more machine time than B15. This was built into our Python Model (Figure 2) during the diagnosis stage.

3.2 Diagnosis Approach

Our team built a Python model that simulates the production process as shown in Figure 2. We cannot assume that our model is a perfect imitation of the current policy, but having used the given data and known product flow patterns to build the model, we believe that we can gauge key issues using our model. We aimed to remove as much uncertainty in our model as possible by running our model many times and averaging our collected data. The input of our model for diagnosis was the given demand data from the past 50 weeks of production.

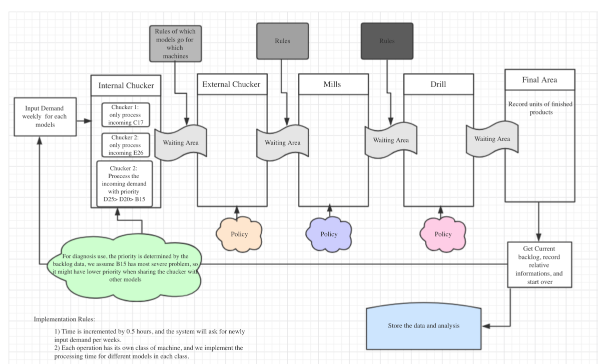


Figure 2: Code Diagram Displaying our Model

Data Collected, Averaged Over 5-Week Period, From Python Model:

1. Average Wait Time W_p before every operation for every product p. Wait times are averaged over every 5-week time period (9 periods).

2. Machining Time T_{M_y} is the total time each machine M_y where $y \in$ {set of machines} spends on all products produced p, up until the time period of collection t_c. i.e. $T_{M_y} = \sum_{p=1}^{p=6} \sum_{t=0}^{t=t_c} m_{y_{p,t}}$ where $m_{y_{p,t}}$ = machine y up time during time period $t = \{1, 2, ..., t_c\}$ for every product $p = \{1, 2, .., 6\}$

*note: data was aggregated for five week periods, in order to localize and smooth any changes in variability.

3.3 Diagnosis Findings Using Past 50-weeks of Demand Data

3.3.1 Wait Time W_p Analysis Shows the Drill is a Bottleneck

We identified processes with long average wait times W_p as a source of backlog, since one product waiting in a machine's queue means a missed opportunity for another product to be completed. Furthermore, if a product is waiting at a machine, it increases the total production time for any products waiting behind it.

The table in Figure 3 shows, on average, the percentage of time each product spent waiting before each operation (1,2,3,4) during each 5 week time period of 400 hours, where { 1: Internal Chucker, 2: External Chucker, 3: Mill, 4: Natco Drill }. The different colors in the table (Figure 3) show the level of wait time severity, where yellow is most severe and orange is second-most.

	E26	B15	D20	C17	D25	F35
1	21.2%	48.0%	32.0%	60.3%	45.3%	0.0%
2	38.0%	80.2%	36.5%	18.5%	41.3%	0.0%
3	28.9%	38.0%	57.4%	1.6%	87.5%	0.0%
4	9.7%	57.1%	13.2%	74.3%	52.8%	10.74%

Figure 3: Percentage Wait Time at Each Step Out of Every 400 Hours (5 weeks)

1. **Observation 1 on Chucker D**: B15 and D25 share Chucker D. Since D25's average waiting time is 41.3% at External Chucker D (2nd operation), this leads to excessive External Chucker D processing time for B15 at 80.2% . **Chucker D cannot handle the demand of B15 and D25 combined under the current policy.**

2. **Observation 2 on Chucker C**: Because E26 and D20 come from different internal chuckers before reaching Chucker C, the changeover policy utilized for Chucker C may reduce wait time. From this observation, we postulate that **Chucker C is changing over rather effectively**.

3. **Observation 3 on Chucker A** & **Chucker B**: C17 has relatively low average wait time percentage 18.5 % at Step 2 (External Chucker). This suggests that **more items besides C17 can be made using Chucker A and Chucker B**.

4. **Observation 4 on Mill 2**: E26, D20, B15, and D25 share Mill 2. For C17, which does not share Mill 1, the average wait time percentage is significantly smaller at 1.6% compared to the 28.9%-87.5% range on Mill 2. This suggests that too many different products running through Mill 2 is a source of backlog, whereas Mill 1, with it's low average wait time percentage, can handle more than it is currently processing. **More items besides C17 can be made with Mill 1 to reduce the wait time on Mill 2.**

5. **Observation 5 on Natco Drill**: A key finding is that most items have long waiting times before Drilling (Step 4). This suggests that drilling causes increased waiting times because of the high changeover needs. From this, wait time analysis **we mainly recommend adding another drill in the short run**; the financial and risk analysis and testing the effects of adding another drill is explored in further sections.

3.3.2 Apply Wait Time Analysis to Solution

We believe that Chucker C performs better than Chucker D in terms of wait time because the incoming products to Chucker C come from *different* internal Chuckers while incoming products to Chucker D come from the *same* internal Chucker. We use this hypothesis to create our new model; instead of sending the same products through the same steps/operations, we save waiting time by increasing changeovers and providing new machine options for each product to be processed by. (See section 5.3, Figure 7 for a diagram of our solution).

3.3.3 Machine Time T_m Analysis Shows the External Chuckers are Over-Utilized

Total machine run time for each machine collected and over 45 weeks is shown in Figure 3. We divided the total time by the time in 45 weeks (3600 hours) to produce the percentage of time each machine is in use as shown in Figure 4. The figures highlighted in red identify the most severely machines and the figures highlighted in yellow identify the second-most severely affected machines.

	Chucker 1	Chucker 2	Chucker 3	Chucker A	Chucker B	Chucker C	Chucker D	Mill 1	Mill 2	Drill 1
Machine Time	1884	1536	2796	2616	2408	3282	3245	2512	2882	2694

Figure 4: Total Machine Time out of 3600 Hours (45 weeks) Table

	Chucker 1	Chucker 2	Chucker 3	Chucker A	Chucker B	Chucker C	Chucker D	Mill 1	Mill 2	Drill 1
Tm as % Total Time	52.33%	42.67%	77.67%	72.67%	66.89%	91.17%	90.14%	69.78%	80.06%	74.83%

Figure 5: Percentage Total Machine Time Out of 3600 Hours (45 weeks)

In summary, the processing time for each equipment is highly uneven.

1. **Observation 1 on External Chuckers**. Chuckers A, C, and D are almost always in use in the past 45 weeks. This suggests that though in our analysis of waiting time, items do not

have a problematic waiting time before Chucker C, the External Chuckers are handling too much load. **Adding an External Chucker is necessary in the long run**

2. **Observation 2 on Chucker 1** & **Chucker 2** Chucker 1 only handles C17, and it is only utilized 52% of the time. This poses the possibility that whenever weekly demand for C17 is completed, the rest of the time, Chucker 1 is idle. Since E26 does not have as much weekly demand on average as other items ($AVG_{E26} = 2.96 < AVG_{allmodels} = 5.76$), it is possible that after the demand for E26 is finished each week, the machine is idle for the rest of the week.**The Internal Chuckers 1** & **2 are under-utilized**

3. **Observation 3 on Mill 1 vs. Mill 2:** Mill 1 has a lower percentage of Machine Up Time than Mill 2. This suggests that the Mills are unbalanced in the amount of work they are performing.

3.3.4 Apply Machine Time Analysis to Solution

We noticed that because Chucker 1 and Chucker 2 only produce one product and are idle a lot of the time. To avoid this problem, we implemented our new policy such that each Internal Chucker has a list of possible products and their priorities; whenever a machine finishes a week's demand for the first prioritized product on its list, the machine can begin fulfilling demand for the next priority on its list. This ensures that machines will not have excess idle time, and be utilized more fully. On the other hand, we noticed that most External Chuckers are running nearly at full capacity. This suggests that more External Chuckers are needed, especially in the long run when demand increases. Since it takes 3 months to install an External Chucker, this is not implemented in our short term solution, but in our long term solution (See Section 8.2, Figure 7).

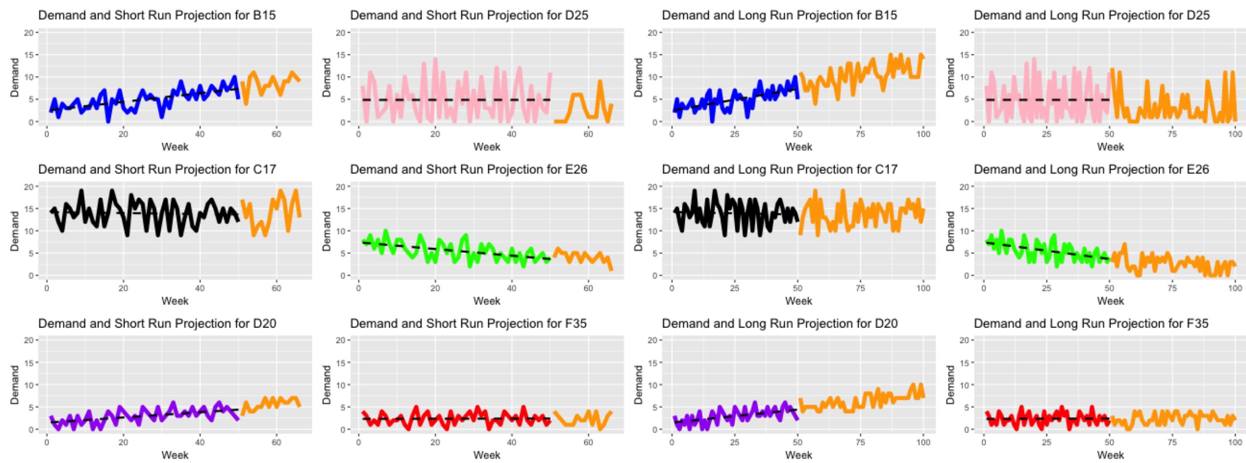
4 Demand Analysis

We analyzed historical demand for two purposes: 1) to gauge what products will need more machine time; 2) to project future demand as inputs to simulate the performance of our short-run and long-run solutions.

There are two characteristics in historical demand: trend and volatility.

To account for the trends in demand, we fit a linear model for the demand of each of the 6 models. It turned out that the demands for models B15 and D20 have statistically significant upward trends; that for model E26 has a statistically significant downward trend; those for models C17, D25 and F35 are flat, fluctuating around the same level.

The rapid fluctuations in historical demand suggest possible existence of time series structure. However, our time series analysis of the data shows no sign of such structure.



(a) 16-week Projection

(b) 50-week Projection

Figure 6: Linear Regression of Historical Demand and Future Demand Projections

4.1 Implications of Demand Analysis

1. Products B15 and D20 have significant upward trends $\implies$ B15 and D20 should be given more machine time and allocated to more machines.
2. Product E26 has a significant downward trend $\implies$ E26 will not need full utilization of Chucker 2 as it had in the past (current) configuration. This, along with the 42% machine time T_m of Chucker 2 in Section 4.2.2, suggested to us that, at the very least, Chucker 2 can handle more products than it is currently assigned.
3. The demand for products C17, D25 and F35 are flat, fluctuating around the same level.

4.2 Forecasting Future Demand

Based on our analysis of the weekly demand of the past 50 weeks, we predicted future demands for all products using bootstrap.

For products B15, D20 and E26, which exhibit linear trends in the past, we assumed that those trends will persist in the future. Therefore, we simulated their future demand with the following algorithm: Given a specific linear model of demand $y = x_0 + x_1 t + \epsilon$, where t is measured in weeks and ϵ is the noise term, we estimate demand at future time t_n: $y_t = x_0 + x_1 t_n + \epsilon_t$, where ϵ_t is a random draw from the 50 residuals from fitting the demand of past 50 weeks with the aforementioned linear model.

For products C17, D25 and F35, which exhibit no significant linear trend, we simulated their future demand simply by randomly drawing from their historical demand data points.

To address the problem that it is unknown if these linear trends will persist well into the long run this problem, we will use the 50 weeks of simulated demand after the initial 16 weeks as an estimate of the long run, under the assumption that the trends will eventually regress given time.

5 Short-Run Solution

5.1 Short-Run Objectives and Solution Approach

In order to successfully renew contracts with the two European distributors in 4 months, Speed Gears needs to focus on reducing lead time for all products to 4 weeks or less.

We redesigned the configuration and the changeover policy to be used for the next 4 months based on our diagnosis of wait time, machining time and count of backlog in order to achieve the following objectives: 1. To increase machine utilization. 2. To prioritize products of higher demand and longer production time needs.

5.2 Short-Run Solution

Speed Gears should immediately order a Natco Drill to be installed in 2 weeks and arrange for one shift of overtime each week for the next 16 weeks. In the mean time, it should train the 3 workers on the SureFactor production line to follow the configuration and changeover policy described in Figure 6 and specified below:

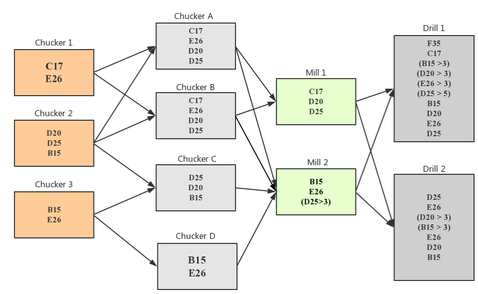


Figure 7: Short Term Configuration and Changeover Policy

1. All productss waiting to be processed by a procedure are placed in a designated "waiting area" of that procedure. Cases for new orders placed at the beginning of week $2i-1$ and $2i$ are moved into the "waiting area" of Internal Chucker at the beginning of week $2i+1, i = 1, 2, \ldots$.
2. Product names written on a specific machine show which models are dedicated to that machine and their priorities, with the one of the highest priority on top. For instance, a worker operating Chucker 1 should first feed all cases of model C17 into Chucker 1 if there is any in the "waiting area" or switch to model E26 if there isn't.
3. Statements with model names and inequality signs indicate how many of a model should accumulate in the "waiting area" before it is fed into the machine.

5.3 Performance Simulation of the Short-Term Solution

Figure 8 shows the result of one performance simulation of our short-term solution. In each plot, the orange line represents the sum of all demands most recent 3 weeks, and the non-orange line represents the backlog of that model at the end of that week. As long as the non-orange line touches or is below the orange line, the customer lead time is at or below 4 weeks.

As the plots demonstrate, our short-term solution successfully reduces customer lead time to 4 weeks or less within 16 weeks. In fact, our short-term solution achieved the objective 95 times out of 100 trials.

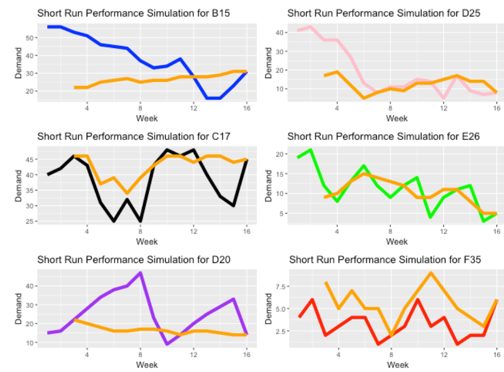


Figure 8: Simulated Performance of the Short-Term Solution

6 Long-Run Solution

6.1 Long-Run Objective and Solution Approach

Provided that Speed Gear reduces lead time for all models of the SureFactor line to 4 weeks or less, in the long run it should focus on increasing the efficiency of the line in order to keep the wait time down. We believe customer loyalty is the key to SureFactor line's long-term success, and thus should be given priority over profit maximization.

6.2 Long-Run Solution

We formulated the long-run solution by modifying the short-term solution based on our utilization analysis of all machines using future demand projection. Our analysis shows that the utilization of External Chuckers is sub-optimal when they are processing model B15 and D20.

6.2.1 Regarding N99

Model N99 brings stable profit with little material cost, but its unit profit is the second lowest among existing models and its 2-week lead time requirement puts considerable pressure on the entire production line.

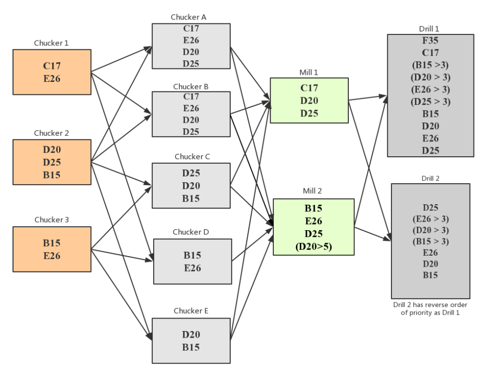
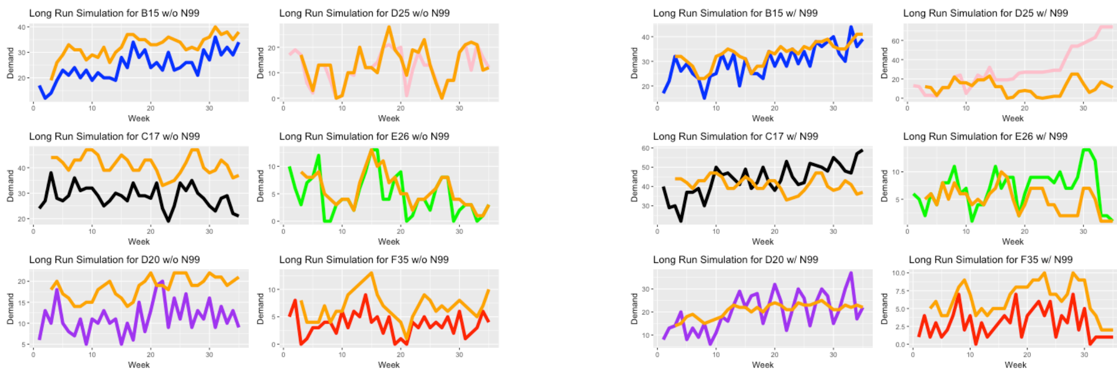


Figure 9: Long term configuration

We tested a version of our long-run solution which includes N99 production. We would only take the N99 if performance simulation of that solution shows no significant increase in lead time.



(a) Without N99

(b) With N99

Figure 10: Performance Simulation without and with N99 taken into account

Speed Gears should place an order for an additional External Chucker and time the purchase so that the new External Chucker is installed and put into use by the beginning of the 16th week from now. It should also train the 3 workers on the SureFactor production line to operate according to the configuration and changeover policy as described in Figure 8, starting the 16th week.

This solution is a modified version of the short-term solution. Two changes are made:

1. A new External Chucker E is added. It is dedicated to D20 and B15, with priority in that order.

2. A statement "D20 > 5" is added to Mill 2. It means that Mill 2 should start processing product D20 if and only if there are over 5 units of D20 waiting to be processed by the Mills. The statement is of the lowest priority at Mill 2.

6.2.2 Solution with N99

We formulated a version of our long-run solution with N99 taken into account. N99 product will pass through Chucker 1, Chucker C/E, Mill 2 and Drill 2, four machines showing the least work time in simulation. We tested this alternative solution to gauge the effect of N99 on existing models.

6.3 Performance Simulation of the Long-Run Solution

Figure 10(a) shows the result of one performance simulation of our long-run solution. The lead time of all models is kept at or under 4 weeks with very few exceptions within 34 weeks after the solution is implemented.

Figure 10(b) shows the negative effect of N99 on the system. After around 15 weeks, lead time of 4 out of 6 models gets out of control. **Therefore, we advise against taking the N99 opportunity**. Refer back to Section 5.3 for a detailed description of performance plots.

7 Financial Analysis

7.1 Feasibility of Adding Shift and Adding Drill on Short-Term Scenario

Based on the short-term recommendation, we test the impact of adding a 8-hour shift each week and adding a new Natco Drill to cash flow. The cost for Drill is a constant one-time cost, and the salary is calculated from yearly salary times different degree of overtime salary.

From the table, it is acceptable to undertake both cash outflow of adding one shift per week and the one time cost to purchase new Natco Drill given the previous operating income.

Category	1.5x Overtime	2x Overtime	3x Overtime
Previous OI	379600	379600	379600
Cost Adding Shift	12960	17280	21600
Cost Adding Drill	17500	17500	17500
Cash Outflow/OI	8.02%	9.16%	10.30%

7.2 Profitability of N99 Model

Regarding cost, the local distributor will be responsible for both the casting and material cost, the cost of producing N99 is trivial on Cash Flow Statement. Regarding profit, we compare N99 with D20 and D25, which have similar working time. We find unit profit from N99 is not ideal given similar working time as D20.

Category	D20	D25	N99
Unit Profit	450	600	300
Total Profit	140850	93000	75600

7.3 Incremental Cash Flow Analysis for Purchasing New Equipment

The incremental cash flow analysis is on Appendix 11.4. (We use 12% as marginal tax rate, and 6.82% as our WACC.) Without the loss of correctness, we aggressively predict the demand, which brings more pressure on the configuration but also more profit as a whole. It match the upward trend of overall demand. Also, because we solve the backlog problem, the profit from the backlog unit alleviate the cash outflow for workers' overtime salary in the first year.

In total, the pay back period for investing new drill and external chucker is 1.156, the Net Present Worth of incremental cash flow for 10 years is $646928.

8 Appendix

8.1 Backlog Analysis

The prediction of the prioritization methodology of the current configuration was based off of this data. Given total demand and current backlog, we computed the number of units produced per week. Then we subtracted units produced per week from average weekly demand to calculate the units short per week. The greater the units short, the less of a priority this product was compared to the other products in the current configuration.

Part Number	Tot Demand	Avg Weekly I	Current Back	Units Prod/V	**Units Short/**
B15	248	4.96	58	3.8	1.16
D25	243	4.86	40	4.06	0.8
C17	696	13.92	34	13.24	0.68
D20	148	2.96	15	2.66	0.3
E26	275	5.5	14	5.22	0.28
F35	118	2.36	3	2.3	0.06

Figure 11: Backlog Analysis & Prioritization Methodology

8.2 Utilization Calculations

Done for each machine over the past 10, 5 week periods

B15	Utilization W5	Utilization W10	Utilization W15	Utilization W	Utilization W	W30	W35	W40	W45	W50
1	0.585	0.48	0.465	0.45	0.33	0.285	0.285	0.36	0.255	0.225
2	0.78	0.64	0.62	0.6	0.44	0.38	0.38	0.48	0.34	0.3
3	0.39	0.32	0.31	0.3	0.22	0.19	0.24	0.24	0.17	0.15
4	0.14625	0.12	0.11625	0.1125	0.0825	0.07125	0.06375	0.09	0.06375	0.05625
C17										
1	0.51	0.5475	0.48	0.51	0.4875	0.5625	0.5775	0.495	0.5475	0.5025
2	0.68	0.73	0.64	0.68	0.65	0.75	0.77	0.66	0.73	0.67
3	0.68	0.73	0.64	0.68	0.65	0.75	0.77	0.66	0.73	0.67
4	0.255	0.27375	0.24	0.255	0.24375	0.28125	0.28875	0.2475	0.27375	0.25125
D20										
1	0.2025	0.23625	0.21375	0.21375	0.18	0.1575	0.19125	0.09	0.10125	0.07875
2	0.36	0.42	0.38	0.38	0.32	0.28	0.34	0.16	0.18	0.14
3	0.135	0.1575	0.1425	0.1425	0.12	0.105	0.1275	0.06	0.0675	0.0525
4	0.09	0.105	0.095	0.095	0.08	0.07	0.085	0.04	0.045	0.035
D25										
1	0.2475	0.34875	0.28125	0.2025	0.34875	0.18	0.315	0.27	0.21375	0.32625
2	0.44	0.62	0.5	0.36	0.62	0.32	0.56	0.48	0.38	0.58
3	0.165	0.2325	0.1875	0.135	0.2325	0.12	0.21	0.18	0.1425	0.2175
4	0.11	0.155	0.125	0.09	0.155	0.08	0.14	0.12	0.095	0.145
E26										
1	0.285	0.315	0.315	0.42	0.42	0.45	0.405	0.42	0.525	0.57
2	0.4275	0.4725	0.4725	0.63	0.63	0.675	0.6075	0.63	0.7875	0.855
3	0.21375	0.23625	0.23625	0.315	0.315	0.3375	0.30375	0.315	0.39375	0.4275
4	0.095	0.105	0.105	0.14	0.14	0.15	0.135	0.14	0.175	0.19

Figure 12: Utilization Calculation

8.3 Simulation Program

Rather than using existed simulation program, to fit the real problem, we wrote a specialized program for our production line. It works with Algorithm 1. Figure 13 is a Sample Output from the simulation program. The program will send out these messages at every time point, and it is convenient for manager and workers to check the producing status and what to do in the next time point.

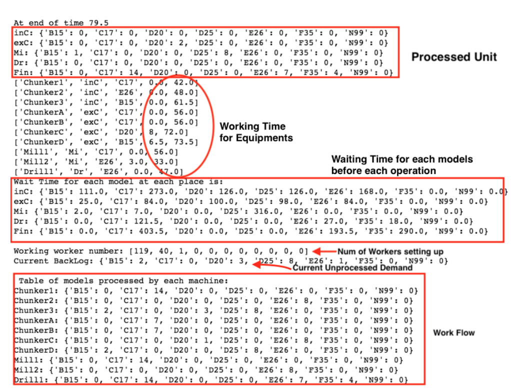


Figure 13: Sample Output from Python Simulation

Algorithm 1 Circuit of the Simulation Program

INPUT: Machine(Type,Name,Status...), Demand
while Time flows **do**
  if A new week starts from now **then**
    Get the demand from the customers.
    if Related instructions gotten **then**
      Following the instructions to add demand to the waiting line for corresponding machines.
    end if
  end if
  for All machines on the production line **do**
    Update their working status (How many hours do they need to finish current work).
  end for
  for All free machines on the production line **do**
    Using policy function to check what should they do next, and ask worker to help change toolkit if needed.
  end for
  if All machines are free **then**
    Alert: All model processing work added to the waiting line has been finished.
  end if
  Time goes by.
end while

8.4 Financial Analysis

New External Chucker/Drill option											
Year:	0	1	2	3	4	5	6	7	8	9	10
Incremental Income Statement											
Sale Revenue		$ 112,000	$ 179,750	$ 179,750	$ 179,750	$ 179,750	$ 179,750	$ 179,750	$ 179,750	$ 179,750	$ 179,750
Expense											
Material		($17,720)	($31,760)	($31,760)	($31,760)	($31,760)	($31,760)	($31,760)	($31,760)	($31,760)	($31,760)
Labor		($12,960)	$0	$0	$0	$0	$0	$0	$0	$0	$0
Maintainance and Op		($12,500)	($12,500)	($12,500)	($12,500)	($12,500)	($12,500)	($12,500)	($12,500)	($12,500)	($12,500)
Equipment Depreciation		($15,000)	($24,000)	($14,400)	($8,640)	($8,640)	($4,320)				
Taxable Income		$ 53,820	$ 111,490	$ 121,090	$ 126,850	$ 126,850	$ 131,170	$ 135,490	$ 135,490	$ 135,490	$ 135,490
Income Taxes		($11,302)	($23,413)	($25,429)	($26,639)	($26,639)	($27,546)	($28,453)	($28,453)	($28,453)	($28,453)
Net Income		$ 42,518	$ 88,077	$ 95,661	$ 100,212	$ 100,212	$ 103,624	$ 107,037	$ 107,037	$ 107,037	$ 107,037
Incremental Cash Flow											
Operating Activities											
Net Income		$ 42,518	$ 88,077	$ 95,661	$ 100,212	$ 100,212	$ 103,624	$ 107,037	$ 107,037	$ 107,037	$ 107,037
Equipment Depreciation		$15,000	$24,000	$14,400	$8,640	$8,640	$4,320	$0	$0	$0	$0
Investment Actitivities											
Equipment Purchase	($75,000)										
WIP Inventory Investment											
Financing Activities											
N/A											
Net Cash Flow	($75,000)	$ 57,518	$ 112,077	$ 110,061	$ 108,852	$ 108,852	$ 107,944	$ 107,037	$ 107,037	$ 107,037	$ 107,037
Net Present Worth:	$646,928										
BERR: (internal return rate)	110%										
Pay Back Period:	1.156										

Figure 14: Financial Analysis Incremental Calculations