A Three-Phased Solution for Speed Gears Inc.

Brittany Stenekes, Sirawich Tippawanich, Jin Lee, Sami Smalling

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Executive Summary

Problem Statement

Speed Gears, Inc. is suffering a backlog problem on the SureFactor production line that is causing customer dissatisfaction. This problem must be resolved before the contract renewal period at the end of the year to retain our customers.

An additional concern is the opportunity to produce SureFactor N99, which potentially can boost our revenue if the manufacturing capacity of the SureFactor production line can be sufficiently improved.

Solution

Upon conducting manufacturing throughput analysis on the SureFactor production line, we found three major problems: bottlenecks, insufficient operating hours, and inefficient changeover scheme.

We developed alternative manufacturing configurations to resolve these deficiencies. These configurations were iteratively improved through simulations based on demand projections. Our final scheme entails a new work schedule for the operators as well as the redistribution of SureFactor models between the manufacturing equipment,

Our new manufacturing scheme should be applied with two additional actions: we recommend Speed Gears, Inc. to purchase a second Natco drill and to increase weekly operating hours from 80 to 168 hours each week. Our proposal will be fully implemented in 6 months in three phases.

Costs and Benefits

The implementation of our proposal will drastically improve the manufacturing capacity of the SureFactor production line. The current backlog will be eliminated in 4 months and the machining lead times for all SureFactor units will be kept at 2.5 weeks for at least the next three years. Speed Gears, Inc. will also gain the capacity to produce N99, further increasing profits.

According to our 10-year economic analysis, our proposal will incur additional expenses of approximately \$2.7m per year. The benefits, however, greatly outweigh the costs as the annual revenue will increase by 50% by the end of Year 1, and the total additional revenue is expected to be \$6.2m. This results in a 10-year ROI of 230%. The 10-year net present worth is expected to increase by 60%, from \$1.5m to \$2.4m.

Problem Analysis

To determine the cause of the backlog, we conducted a steady-state flow analysis of the manufacturing configuration. In the analysis, we used Little's Law, given in Equation 1:

$$L = \lambda \cdot W, \tag{1}$$

where $L =$ the number of units in the system, $\lambda =$ the throughput rate, and $W =$ the average amount of time a unit spends in the system.

The capacity of each machine can be interpreted as the time it is available for operation during a certain interval. Inputting the demand averaged over a period as the number of units in the system and the inverse of the machining times of each model for each machine type as the throughput rate, it was possible to get W, the average amount of time a unit spends in the system. Summing the W, we determined the time each machine operates.

We found that that External Chucker D and the Drill were required under the current demand to operate longer than the operating hours permit and thus are bottlenecks. Meanwhile, certain equipment such as Internal Chuckers 1 and 2 were under-utilized.

As this preliminary analysis assumed steady-state, it is only robust when parameters remain unchanged. Disruption caused by production line queues and addition of units during the analysis time frame cannot be represented by steady-state models. Therefore, we determined that simulation modeling was required to develop a robust solution based on our initial findings.

Simulation Development and Verification

We created a simulation model using Python to test new configuration ideas and determine which of these ideas increased efficiency and remediated the issues with the current configuration. Our simulation runs are defined by an event list that tracks events of types "machine finished", "operator free", and "new demand" to monitor incoming demand and the availability of machines and operators.

Event = (Time of Event, Event Type, Product Being Manufactured, Machine)

Since the demand for each model has a clear minimum value, maximum value, and mode, we first fit triangular distributions to the data. The KS-test gave us over 95% confidence that the demand for most models follow a triangular distribution with input parameters specified in Table 1.

For the demand for D25, however, a triangular distribution was not the best fit. In many weeks in the past year, the demand for D25 was 0. As periodicity could not be detected, we split the demand for D25 into two cases based on how many weeks out of the year the demand for D25 was 0. Case 1, occurring with 20% probability, modelled D25 weekly demand as 0. Case 2, occurring with 80% probability, modelled D25 weekly demand to be greater than 0. After fitting a triangular distribution to D25 demand that is greater than 0, we recovered a p-value that exceeds 0.05. The input parameters for each unit are listed in Table 1.

Table 1: Distribution Input Parameters Based on Weekly Demand Data of the Past 50 Weeks

	B15	C17	D20	D25	E26	F35	D25 Case 1	D25 Case 2
Mode	5	15	3	0	5	3	-	1
Minimum	0	9	0	0	2	0	-	1
Maximum	10	19	6	14	10	5	-	14

As the overall demand for speed reducers has been steadily increasing, we expected the demand to continue to rise at a modest rate, in accordance with the past year's demand. We examined a moving average demand, using a 9-week window to neglect outdated data, to measure expected demand. In the past year, B15 and D20's moving average demand increased by approximately 1.5 units and 1 units, respectively, every 4 months. Meanwhile, E26's average moving demand decreased at a rate of 1.2 units/4 months. The moving average demands for the remaining models, C17, D25, and F35, remained constant.

We developed linear trajectories for the moving average demand to reflect the increases in B15 and D20 and decrease in E26 as listed in Table 2. Each linear trajectory had an R^2 value above 0.90, which indicates low variability in the moving average demand. In the simulations, we use these moving average trajectories to predict future input parameters. The input demand for each product was modeled as the original triangular distribution parameters adjusted by the expected rate of change while ensuring the demand for E26 did not become negative.

Table 2: Demand Parameter Prediction (w: number of weeks since Jan. 1^{st})

	B15	C17	D20	D25	E26	F35
Predicted Average Demand	$0.0972w + 2.416$	14.11	$0.0604w + 1.4979$	4.67	$-0.0724w + 7.344$	2.33

For example, demand for B15 is expected to increase by $0.0972 \cdot 10 \approx 1$ unit over 10 weeks. Therefore, we estimated demand for B15 at Week 60 to be Triangular(0+0.97, 5+0.97 , 10+0.97).

Figure 1 displays the demand for B15 and the corresponding linear fit.

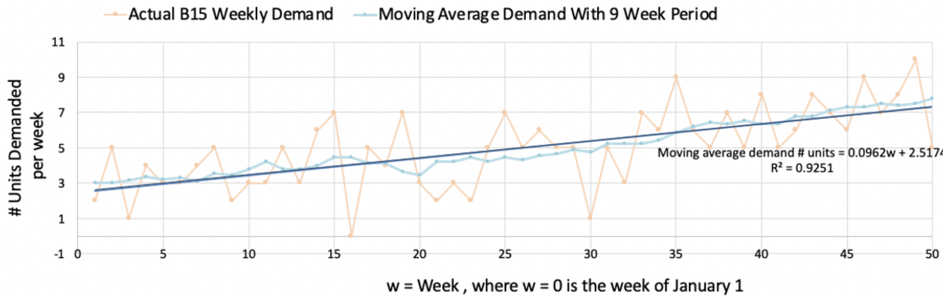

Figure 1: B15 Demand and Linear Fit

Once we solidified our input distributions, we wrote a simulation in Python based on the following assumptions:

1. Demand is triangularly distributed with initial parameters specified in Table 1.
2. Demand for B15 and D20 continues to increase, while demand for E26 continues to decrease by rates specified in Table 2.
3. Demand arrives in batches at the beginning of each week.
4. Operators' travel time between machines is negligible. That is, if an operator is available, they can immediately start the next setup process.
5. All equipment is assumed to have no downtime which may arise from upstream delays.
6. A machine currently processing model X will continue to process as much of model X that is in its queue for up to a maximum of 1 week.
7. Once a machine finishes processing, the next machine, if available, immediately begins processing.
8. Once a model finishes with a particular machine, it will check for an open machine to go to next. If the next machine(s) are busy, it will arbitrarily choose a queue to join.
9. N99 Demand remains between 5 and 6 units.
10. C17 inventory can be stored.
11. For simulations starting at Week 50, we add the current existing backlog (58 units B15, 34 units C17, 15 units D20, 40 units D25, 14 units E26, 3 units F35) to the initial demand.
12. Machining and setup times for each unit/machine pair are as stated in the case file.

Each simulation run records machining lead time for each SureFactor product, as well as the units that have not yet finished processing by the end of the period being simulated. We performed each experiment 100 times and recorded averages of lead times and backlog for each SureFactor model.

Under the assumptions and demand input outlined above, we verified that the simulation was reasonable with respect to current lead times. First, we tested the simulation on the original machining configuration. We compared the machining lead times to the 4+ and 8+ week lead times that Speed Gears is currently enduring. As visible in Figure 2, the discrepancies between the data provided and the simulation's results are minimal given the breadth of assumptions made.

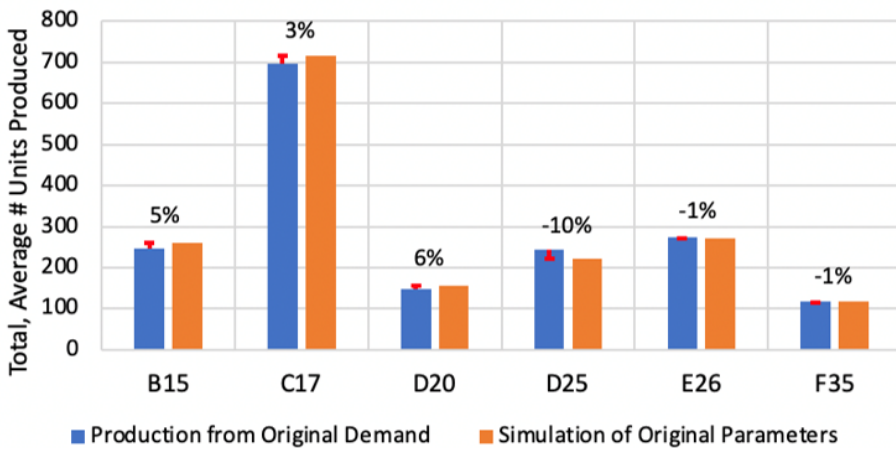

Figure 2: Simulation Verification

Short-Term Simulation Results

To maintain key customer contracts, the current backlog must be significantly reduced by the end of the year, i.e. in approximately 4 months. Additionally, machining lead times need to be under 3 weeks to keep our promise to ship orders within 4 weeks. The backlog problem can be immediately mitigated by improving the assignment scheme of SureFactor models to machines. Extension of operating hours will also expedite the rate of backlog depletion.

Based on the steady-state flow analysis, four preliminary equipment routing configurations were developed, each keeping the total operating time of each machine below the daily limit of 16 hours. From the simulation results on the configurations, we found the configuration with the shortest overall machining lead times, and chose it as our starting point.

We then iteratively improved the preliminary configuration towards a local minimum of the lead times and backlog, making minor alterations, such as changes in working hours per week. Downstream analysis was then conducted on the resultant configuration.

The simulations also confirmed our previous finding that the drill was overloaded. Therefore, we recommend purchasing a second drill to remove the bottleneck. Purchasing equipment other than the drill is not useful in the short-term because it takes over three months to put them into production.

The short-term solution is divided into two phases. At the start of Phase 1, an order for a drill is made and weekly operating hours are increased from 80 to 168 hours. In two weeks, the drill will be put into production. This marks the beginning of Phase 2, during which the backlog will be eliminated. The floor configuration for Phase 2 is shown in Figure 3. In Phase 1, the only difference is that F35 is also assigned to Drill 1.

Internal Chucker →	External Chucker →	Mills →	Drill
Chucker 1: **C17** & **D20**	Chucker A: **C17**, **D20**, & **D25**	Mill 1: **C17** & **D20**	Drill 1: **C17**, **D20**, **E26**, **B15**, & **D25**
Chucker 2: **D25** & **E26**	Chucker B: **C17** & **D20**	Mill 2: **E26**, **B15**, & **D25**	Drill 2: **F35**
Chucker 3: **B15**	Chucker C: **E26**, **B15**, & **D25**		
	Chucker D: **E26** & **B15**		

Figure 3: Phase 2 Floor Configuration

Long-Term Simulation Results

Having found a short-term solution, we assessed the longevity of our new configuration. Assuming the demand increases at the same rate, we continued to change the configuration iteratively while simulating over years 1-3 both with and without N99 production. The long-term simulation results showed that N99 production is sustainable for the next 3 years, with machining lead times below 2 weeks for all models. The lead times for each model in years 1-3 can be found in Figure 6 in Appendix A.

The floor configuration for Phase 3, which incorporates N99 production and is to be implemented at the 6-month mark, is shown in Figure 4.

Internal Chucker →	External Chucker →	Mill →	Drill
Chucker 1: **C17** & **D20**	Chucker A: **C17**, **D20**, & **D25**	Mill 1: **C17** & **D20**	Drill 1: **C17**, **D20**, **E26**, **B15**, **D25**, & **N99**
Chucker 2: **D25** & **E26**	Chucker B: **C17** & **D20**	Mill 2: **E26**, **B15**, **D25**, & **N99**	Drill 2: **F35**
Chucker 3: **B15** & **N99**	Chucker C: **E26**, **B15**, **D25**, & **N99**		
	Chucker D: **E26**, **B15**, & **N99**		

Figure 4: Phase 3 Floor Configuration

Although we also investigated the option to purchase new equipment, we found that equipment purchase did not significantly impact production performance, and that an increase in operating hours was again necessary to meet demand. The N99 lead times based on different operating hours and equipment purchase options can be found in Figure 7 in Appendix A.

Solution Overview

Table 3: Proposal Summary

Phase of Implementation	**Time Frame**	**Proposed Changes**
Phase 1: Short-term A	Weeks 1-2	• Change operator shift schedule to increase hours per week to 168 hours • Complete procurement process for an additional Natco Drill to be ready for use at the start of week 3
Phase 2: Short-term B	Weeks 3-24	• Commission new drill with new floor plan • Manufacture 14 units of C17/week and store excess as inventory. If demand for C17 exceeds 14 and there is not enough inventory to cover the difference, manufacture the remaining units needed to exactly meet demand.
Phase 3: Long-Term	Weeks 25- 50	•Produce N99

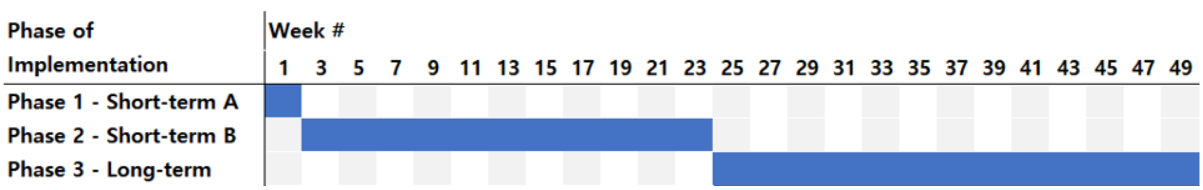

Figure 5: Gantt Chart for the Three Phases

As shown in Table 3 and Figure 5, our proposal is split into three phases. Phase 1 is the first two weeks, and reforms operators' shift schedules. Two 12-hour shifts per day are each manned by two operators. The other two operators are on leave for two weeks after which they will relieve one of the two on-duty operators. The 4-weeks on and 2-weeks off pattern of three operator shifts will enable around the clock production. A drill should also be procured and installed during these two weeks. Phase 2 begins with integrating the drill to the production line and assigning F35 to it. Lastly, Phase 3 initiates N99 production. This three-phased solution will not only solve the pending backlog problem within the necessary timeframe of 4 months, but will also drastically improve machining lead times, as visible in Figure 8 in Appendix A, and revenue.

Economic Analysis

Based on our three-phase solution, the 10-year NPW is $2.44m, about 60% higher than the 10-year NPW based on the status quo. The payback period for the drill is 2 weeks, and the BERR is approximately 2200%. The full I/S and cash flow statement is attached to the appendix as Figure 9.

The revenue is expected to increase by from $860,300 to $1,282,100 in Year 1, $1,348,800 in Year 2, and $1,525,400 in Years 3 and thereafter. M&O costs are expected to approximately double, as weekly work hours increase from 80 to 168. It is also expected that on average 5 units of C17 will be held in inventory, amounting to $440 per week of carrying cost. Labor cost will increase by a factor of 1.64, due to increased work hours and overtime pay. Total additional expenses over the 10-year period is $2.7m. The revenue over the same 10-year period will increase by about 72%, from $8.60m to $14.83m. This gives us additional revenue of $6.2m and a 10-year ROI of 230%.

If we choose not to implement N99 production, NPW and ROI become $2.1m and 200%, respectively.

Here we list the assumptions we made in the economic analysis:

1. The marginal tax rate is 21% per the U.S. corporate tax rate currently defined by the TCJA.[1]
2. The interest rate is 13%, a conservative annual interest rate for business loans from banks.[2,3]
3. Overtime pay should be at least 1.5 times the regular rate and must be paid for hours worked over 40 in a workweek according to the DOL.[4]
4. The ratio of wages and benefits is 30%, based a report by the BLS from last June.[5]
5. Annual M&O costs are linearly extrapolated based on weekly operating hours: 80 to 168 hours.
6. The carrying cost of C17 is approximately 30% of the inventory value.
7. As equipment used in the manufacturing of primary nonferrous metal products fall in asset class 33.2, the 7-year MACRS depreciation schedule, with the half-year convention, is used.[6]
8. Demand is modeled as in the Simulations section and assumed to plateau from Year 3.
9. Sales revenue and material costs are linearly extrapolated based on demand.

Risk Analysis and Sensitivity Study

Risk assessment was conducted on the performance of the SureFactor production line. A risk matrix was developed to classify scenarios in terms of their likelihood and severity. Production and financial impacts of selected scenarios were further assessed by varying the degrees of the causing events. Possible events that were assessed fall into two broad categories: disruption in the production line and acute demand shift. It is not uncommon that full production time is not realized due to circumstances such as unanticipated absence of staff. On the other hand, market forces can unpredictably cause a surge or depletion of demand for certain models.

Scenario A - Short-term Manpower Shortage

The impact on lead times of a temporarily understaffed production line was assessed by varying the reduction in operating hours per week for a period of one month. We found that model N99's lead times of under 2 weeks can be maintained during the month if the line is operated for more than 140 hours a week. Even if weekly production hours drop to 90 for one month, the company can still adhere to the committed lead times for all models except N99.

Scenario B - Long-term Manpower Shortage

As in Scenario A, we varied the weekly operating hours for a period of two months. We found that the line can sustain the intended N99 lead times with 135 operating hours a week. A reduction of weekly operating hours to 90 hours will still enable the company to deliver all of its original models under the 3-weeks lead time. Figure 10 in the appendix shows the results of risk analysis on Scenarios A and B.

Scenario C - Demand Surge for Individual Models

To assess the impact of changes in product demand on the performance of the production line, the effects of doubling of demand for each model were determined. Simulations were performed for a period of two years with the assumption that the demand of a model has been doubled. We found that a doubling of model B15 demand will cause the lead time of model N99 to be just above the committed lead time of 2 weeks.

Scenario D - Loss of Demand for Individual Models

The changes in cash flow of the Speed Gears associated with the absence of demand for each SureFactor model were examined. Due to the relatively large demand for B15 and C17, revenue will drop by 25% if the demand for either disappears. This also will reduce the 10-year NPW of the SureFactor production line by more than 10%. As the NPW remains positive for all cases, however, the proposed solution will remain feasible if the demand for any of the models completely disappears.

Conclusion

Our three phase solution, involving revising the manufacturing configuration, purchasing a drill, and increasing weekly operating hours, will maximize the production capacity of the SureFactor production line and thereby greatly benefit Speed Gears, Inc. in both the short-term and the long-term. It will eliminate the current backlog in time to earn back the trust of our key customers, and will prevent a similar problem from occurring in the future. The ability to keep up with increasing demand will translate to a steady increase in revenue, especially with the addition of N99 to the production line.

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Appendix

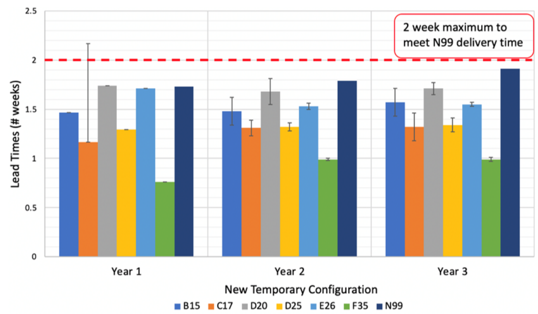

Figure 6: Phase 3 Lead Times

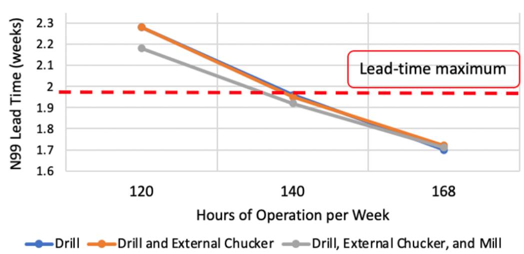

Figure 7: N99 Lead Times with Additional Equipment

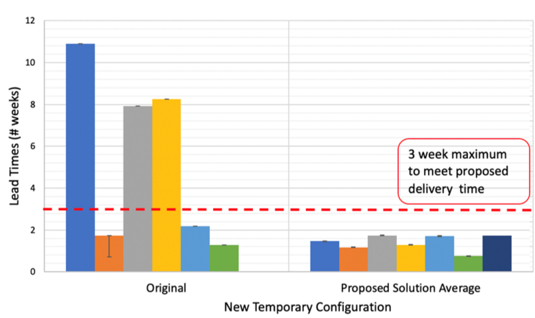

Figure 8: Lead Time Comparison - Status Quo vs. Proposal

Marginal Income Tax Rate:	21%		
Interest Rate:	13%		
10-Year NPW	$2,442,788.12		
Payback Period	0.54	in months	
10-Year ROI	228.66%		
10-Year Revenue	$ 14,834,100.00		

Decisions:	
Int Chucker	0
Ext Chucker	0
Mill	0
Natco Drill	1
N99 (Y/N)	Y
Op. Hrs / wk	168
C17 AtO (Y/N)	Y

Shift Changes	Y
Working Weeks	34
Hours/week	84
Std Hrs/wk	40
Std Wks/yr	50
OT Modifier	1.5
Benefits Ratio	0.3
Labor Modifier	1.64

Labor Costs:	$ (442,800.00)
M&O Costs:	$ (162,700.00)
Eq. Purchase:	$ (15,000.00)

7-Year MACRS Depreciation Schedule (w/ half-year convention)							
Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
14.29%	24.49%	17.49%	12.49%	8.93%	8.92%	8.93%	4.46%

Year:	0	1	2	3	4	5	6	7	8	9	10
Incremental Income Statement											
Sales Revenue		$1,282,100.00	$1,348,800.00	$1,525,400.00	$1,525,400.00	$1,525,400.00	$1,525,400.00	$1,525,400.00	$1,525,400.00	$1,525,400.00	$1,525,400.00
Expenses											
Materials		$ (257,040.00)	$ (258,640.00)	$ (292,560.00)	$ (292,560.00)	$ (292,560.00)	$ (292,560.00)	$ (292,560.00)	$ (292,560.00)	$ (292,560.00)	$ (292,560.00)
Labor		$ (442,800.00)	$ (442,800.00)	$ (442,800.00)	$ (442,800.00)	$ (442,800.00)	$ (442,800.00)	$ (442,800.00)	$ (442,800.00)	$ (442,800.00)	$ (442,800.00)
Maintenance & Operating		$ (162,700.00)	$ (162,700.00)	$ (162,700.00)	$ (162,700.00)	$ (162,700.00)	$ (162,700.00)	$ (162,700.00)	$ (162,700.00)	$ (162,700.00)	$ (162,700.00)
Equipment Depreciation		$ (2,143.50)	$ (3,673.50)	$ (2,623.50)	$ (1,873.50)	$ (1,339.50)	$ (1,338.00)	$ (1,339.50)	$ (669.00)	$ -	$ -
Taxable Income		$ 417,416.50	$ 480,986.50	$ 624,716.50	$ 625,466.50	$ 626,000.50	$ 626,002.00	$ 626,000.50	$ 626,671.00	$ 627,340.00	$ 627,340.00
Income Taxes		$ 87,657.47	$ 101,007.17	$ 131,190.47	$ 131,347.97	$ 131,460.11	$ 131,460.42	$ 131,460.11	$ 131,600.91	$ 131,741.40	$ 131,741.40
Net Income (Loss)		$ 329,759.04	$ 379,979.34	$ 493,526.04	$ 494,118.54	$ 494,540.40	$ 494,541.58	$ 494,540.40	$ 495,070.09	$ 495,598.60	$ 495,598.60
Incremental Cash Flow Statement											
Operating Activities											
Net Income		$ 329,759.04	$ 379,979.34	$ 493,526.04	$ 494,118.54	$ 494,540.40	$ 494,541.58	$ 494,540.40	$ 495,070.09	$ 495,598.60	$ 495,598.60
Equipment Depreciation		$ 2,143.50	$ 3,673.50	$ 2,623.50	$ 1,873.50	$ 1,339.50	$ 1,338.00	$ 1,339.50	$ 669.00	$ -	$ -
Investment Activities											
Equipment Purchase	$ (15,000.00)										
WIP Inventory Investment											
Financing Activities											
N/A											
Net Cash Flow	$ (15,000.00)	$ 331,902.54	$ 383,652.84	$ 496,149.54	$ 495,992.04	$ 495,879.90	$ 495,879.58	$ 495,879.90	$ 495,739.09	$ 495,598.60	$ 495,598.60

Figure 9: 10-Year I/S and Cash Flow Statement

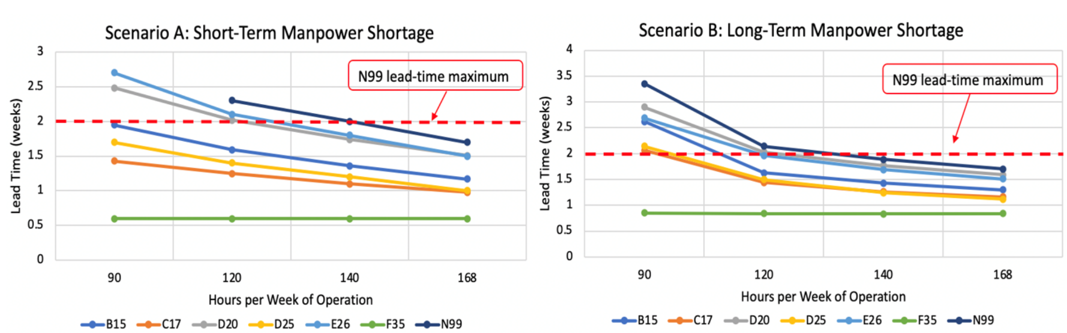

Figure 10: Risk Analysis Scenarios A and B