VORTEX PRODUCTION RECOMMENDATIONS

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2/20/2023

EXECUTIVE SUMMARY:
Ultimately, the challenging context in which Fisher-Rosemount and its Eden Prairie plant find themselves boils down to dual operations and business strategy woes. Its operations' woes encompass ballooning lead times and WIP and cratering service levels. From a business strategy and performance perspective, 1) its service KPI is not incentivizing behaviors that could help reduce overdue backlogs, and 2) cross-functionals are not coordinating together well on brand and operations planning, driven and exacerbated by a lack of focused business strategy. It is very difficult for a company to sustainably differentiate one product along with variety, quality, *and* service/responsiveness—much less multiple products—but Fisher-Rosemount has been trying to do just that with its vortex flowmeters. In the following report, we outline business and operations improvements, such as acquiring another hydro testing machine to increase service levels and improve cycle times for Vortex flowmeters produced at the Fisher-Rosemount Eden Prairie, MN plant.

PHASE 1: CURRENT STATE ANALYSIS

Introduction

Fisher-Rosemount is one of the world's largest instrumentation and control system companies, with sales, service, and manufacturing operations in more than 80 countries around the globe. Its Rosemount Vortex Flowmeter Plant in Eden Prairie, MN, manufactures a mix of instruments, including Fisher-Rosemount's Model 8800A Smart Vortex Flowmeter, which it produces on a made-to-order basis for corporate customers across a range of industries who use the flowmeters to measure and control the flow of fluids and steam. In the competitive landscape of flow meter manufacturers, Rosemount-Fisher differentiates itself according to quality (product reliability) and variety (allowing customers to customize their flow meter order's electronic configuration, flange-type, and body size, leading to hundreds of possible permutations).

Recently, there has been interest among the leadership in also differentiating Rosemount-Fisher's flowmeters according to responsiveness/speed, in addition to quality and variety. Perhaps as part of this push, the Fisher-Rosemount marketing team recently introduced a new, premium-priced offering, called Magic, which is identical to its Vortex flowmeters except for its 1-day promised delivery time. The 1-day delivery time promised to customers marked a bold departure from the recently 8-week lead time from order to delivery, or the historically-5-day manufacturing lead time, of Vortex. Consumer demand for Magic far exceeded Fisher-Rosemount's estimates, by a factor of 10-20 times as Vortex customers switched to Magic.

The 'urgent priority' promised lead time for Magic means that when there are WIP buildups at any station or packing and delivery, Magic always takes priority and Vortex wait times approach infinity. Moreover, Fisher-Rosemount suspects that flowmeter WIP levels may be exacerbated by the fact that Vortex flowmeter production shares resources with the plant's other, non-Vortex product families (such as magnetic flowmeters) during the Flow Lab portion of the production process. This is also a challenge since it is difficult to estimate the amount of capacity that is available for Vortex (and Magic) production each day.

Fisher-Rosemount has contracted our consulting services for recommendations to correct the fact that recently, the plant's flowmeter service levels have dropped from 85% to 32%, regularly failing to meet their historical five-day turnaround time to customers, and far below their competitors' 3-week lead time plus high service rates. Fisher-Rosemount will not be able to continue to compete in the flowmeter market without improving its service rates and/or lead-time significantly.

Operational Definitions

- *Ship total:* total number of orders shipped to the customer in a given week
- *Plan:* the number of units of flowmeters that the Eden Prairie plant plans to produce and ship in a given week
- *Plan YTD:* the cumulative (year-to-date) number of orders of flowmeters that the Eden Prairie plant has planned to produce and ship, up through the current week
- *Ship YTD:* the cumulative (year-to-date) total number of orders of flowmeters that the Eden Prairie plant has produced and shipped, up to the current week
- *Cum Dev:* the cumulative (year-to-date) difference between the Plan YTD and Ship YTD
- *Backlog:* total number of orders received and not yet shipped, which are not late yet
- *Overdue backlog:* orders received and not yet shipped, for which the promised lead time/delivery-by date has already passed
- *Bookings:* Number of new orders received in a given week
- *Service:* Fisher-Rosemount has provided data for the weekly average 'Service' level from the 4 most recent weeks in the current period, at its Eden Prairie flowmeter plant. The method the plant uses to calculate Service cannot be precisely recreated from the data; however from the table and the descriptions, we can surmise that service = (# not-late orders shipped in a given week) / (# orders shipped in a given week)

Current KPIs and Data Collection Methods

The primary KPI for which Fisher-Rosemount has provided us data and seeks improvement is "'*service,"* or the percentage of orders shipped late. This KPI is currently assessed as a binary metric (shipped late, yes/no), as opposed to a continuous variable metric, to convey how late an order was shipped.

Although Fisher-Rosemount flowmeters are differentiated based on quality and variety, the Eden Prairie facility is currently being evaluated based on customer service, which is measured by the percentage of orders shipped late as described in the paragraph above. The data provided for our consulting use includes the average weekly service rate from the last four weeks for flow meter orders at the Eden Prairie plant. Other data includes historical or forecasted numbers for the current period's weekly total orders shipped; planned shipments; planned shipments YTD; shipped orders YTD; cumulative deviation; backlog; overdue backlog; and bookings. Furthermore, the company has shared statistical data, including raw processing times (with standard deviation), yield, set up times (with standard deviation), mean time to failure (MTTF), mean time to repair (MTTR), and batch sizes for each step in the manufacturing process for Vortex flowmeters.

Assumptions

- *Current molding station arrival rate = 17 units/hr.* We assume molding station arrival rate to be 17 units/hour. We derived this number by using the Welding station's raw processing time (0.262hr) and set-up time (0.03hr) to calculate mean service time (0.292hr), and then throughput rate (1 unit/0.292hr or 3.425 units/hr). Then, we used Little's Law to calculate arrival rate —assuming that, at any given point in time, the average number of units in the system at the Molding stage is equal 5 units (1 unit for each of the 5 welding machines), which was multiplied by the throughput rate to yield an arrival rate of of 17.125, or ~17, units/hr.
- *Order sizes consist of 1 unit per order, or, all units of measurement are "per order"* in the case of any ambiguous data provided to us by Fisher-Rosemount for which the units could be 'per order' or 'per product.' This assumption further enables us to consider each production batch size of one unit, (which is the batch size throughout the production process, with the exception of during transit to and from the flow lab), as one discrete customer order.
- Since the yield for each of each of the scales in the flow lab was not given, *a yield of 95% was assumed for each of the five scales in the flow lab*.
- For lack of any data about the transit process to/from the flow lab (i.e. number of carts, transportation process time and coefficient of variation, etc), which is essential to including transit stages in VUT calculations or fully reflecting their impacts in our quantitative recommendations, we have made the following assumptions:
    - *The quantitative and process impact of batching production units during transit to the flow lab is equivalent to if flowmeters were batched in groups of 15 *for/during the sensoring process* (preceding transit to the flow lab).*

- *Moreover, batching production units during transit from the flow lab has zero impact on production variables or KPI, such that the flowmeters can be treated as entirely unbatched.*
- *Transit time between the censoring station and flow lab, and the flow lab and the configuration station, is treated as equal to zero.*

Calculations

We used the VUT (Variation, Utilization, and Time) calculation methodology to identify process statistics, possible weaknesses, and areas for improvement in the current system.

- *Utilization:* To identify the bottlenecks in the current system, we looked at the utilization rates of each machine. A machine with a utilization rate close to 1 is likely to be a bottleneck, as it is operating at full capacity and cannot handle any additional work. From the data provided, we can see that the machines with the highest utilization rates are:
  Station 1 (Welding): Utilization = 0.9965859
  Station 2 (Hydro Test): Utilization = 0.9999999
  Station 6 (Flow Scale C): Utilization = 0.9999999
  Station 7 (Flow Scale D): Utilization = 0.9999999
  These four machines have utilization rates very close to 1, which suggests that they are likely to be the bottlenecks in the system.
- *Variation:* The presence of high variability in process times can lead to catastrophic, negative impacts throughout the entire production process. We can see from our VUT calculations that the Hydro Testing station has extremely high variability in its processing time, with a squared coefficient of variation (CV = standard deviation / mean processing time) of 2.49 > 1. A significant reduction in the standard deviation of processing time at this station could improve the bottleneck situation currently being faced.
- *Time:* Another way to improve the overall process cycle time is to attack the process, repair, and setup times at each step in the overall manufacturing process, and thus the cycle times at each station.
  - The calculated cycle times at stations 2, 6, and 7 are well over 100,000 hours, which is astronomically high in the context of vortex flowmeters.
  - Another identified problem is the high setup times at the Hydro Testing station. The setup times at this station (0.15 hours) are currently ~8 times higher than the mean process time (0.019 hours)

PHASE II: Strategies to Consider

KPIs

- Throughput
- Service level
- Utilization
- Cycle Times (and Queue Times)

- WIP

Calculations
Incremental throughput

To determine which station would benefit the most from an additional machine, you can calculate the incremental throughput of each station, assuming the additional machine operates at the same capacity as the existing machines. The station with the highest incremental throughput would benefit the most from an additional machine.

By expanding the capacity of the bottleneck component, incremental throughput refers to the extra number of units that may be processed by a system in a specific amount of time. It is determined as the difference between 1 and the entire system utilization multiplied by the inverse of the bottleneck's process time.

In other words, incremental throughput is the potential increase in system throughput that would result from the elimination or expansion of the bottleneck. It is a helpful statistic for determining the best strategy to increase a system's total throughput.

To calculate the incremental throughput, you can use the following formula:

- Incremental throughput = min (processing capacity of existing machines, processing capacity of existing machines + capacity of additional machine) * (1 - utilization of station)

The station with the highest incremental throughput would be the most suitable for an additional machine.

Incremental Throughput = (1 / Process Time of Bottleneck) * (1 - Total System Utilization)

Using the data from the case, the process time and utilization for each bottleneck are:

- Station 1 (Welding): Process Time = 0.262 hours, Utilization = 0.9965859
- Station 2 (Hydro Test): Process Time = 0.019 hours, Utilization = 0.9999999
- Station 6 (Flow Scale C): Process Time = 0.371334936 hours, Utilization = 0.9999999
- Station 7 (Flow Scale D): Process Time = 0.220044 hours, Utilization = 0.9999999

Therefore, the incremental throughput for each bottleneck is:

- Station 1 (Welding): (1 / 0.262) * (1 - 0.9965859) = 0.0130 units/hr
- Station 2 (Hydro Test): (1 / 0.019) * (1 - 0.9999999) = 0.0526 units/hr
- Station 6 (Flow Scale C): (1 / 0.371334936) * (1 - 0.9999999) = 0.0170 units/hr
- Station 7 (Flow Scale D): (1 / 0.220044) * (1 - 0.9999999) = 0.0455 units/hr

Plant and Production Operations Recommendations:
Fisher-Rosemount should conduct a thorough analysis of its production process to identify other potential bottlenecks and implement measures to optimize them as well. This may include

improving the layout of the production line, implementing better quality control measures, and investing in new technology and equipment to increase efficiency and throughput.

Investing in new equipment and reducing setup times: Based on our calculations above, the Eden Prairie Plant would benefit most from adding one extra machine to Station 2 (Hydro Test), which would result in the highest incremental throughput across all production stations. However, in order to decrease cycle time throughout the entire production process, capacity must be added to all of the bottleneck stations. Based on experimentation with VUT and Simulation methods, 1 additional machine should be added to the Welding Station (for a total of 6) and the Hydro Test Station (for a total of 2). In order to reduce the bottleneck issues at Flow Lab Scales C and D, 3 new scales would be necessary for Flow Lab C (for a total of 4), and 2 new scales would be necessary for Flow Lab D (for a total of 3). As far as setup times go, the most problematic setup time in the entire production process is the setup time at the Hydro testing bottleneck, as outlined above. This setup time would need to be reduced to eliminate the bottleneck at the Hydro testing station. Possible methods for decreasing the setup time could include better training for Hydro Testing employees.

- **Impact:** If the additional machinery was purchased and the setup times at the Hydro Testing station were halved to 0.075 hours, the Cumulative Cycle Time of the entire process would be reduced to just **4.2 hours**.

Expedited transition of Magnetic Flowmeter production to Mexico: According to the case study, one of the key reasons for production bottlenecks, notably in the Flow Lab, is the struggle for resources between Magnetic and Vortex at the Eden Prairie plant. In order to remove this rivalry and boost the effectiveness of the Vortex production process, the corporation might swiftly move Magnetic Flowmeter manufacture to Mexico. Although the move of Magnetic Flowmeter production to Mexico has been planned, it is crucial to move quickly to lessen the impact of resource competition at the Eden Prairie plant. By doing this, the business can increase productivity significantly, lowering the cost and volume of equipment investments required to enhance the Vortex production process.

To ensure that the accelerated transition has no detrimental effects on the quality of the magnetic flowmeters or the entire supply chain, it is crucial to emphasize that careful planning and execution will be required. This would entail close coordination with suppliers, thorough personnel training, and the efficient adoption of new machinery and technology in the Mexican operation.

Improve the yield of process steps using Six Sigma Continuous Improvement Initiatives: The application of Six Sigma methodology to improve *first time quality* (and thus yield) through the Vortex Flowmeter manufacturing process would pay dividends in reducing rework. This would greatly reduce rework costs and scrap costs, as well as improve the overall operational efficiency of the manufacturing process.

Business Strategy Recommendations

<u>Changing performance measures/KPIs:</u>

- Change from a binary to a continuous variable metric for realized lead-time as percentage of promised lead-time. Adopting this new performance measurement methodology introduces an incentive for plant managers and operators to reduce overdue backlog inventory, which the current methodology for measuring service rate currently *dis*-incentivizes. (At present, the act of shipping overdue backlog inventory decreases the plant's on-time shipping/service rate performance metric.)

<u>Cross-functional collaboration with Brand Managers and Internal Corporate Strategy</u>

- Create a cross-functional task force with representatives from production, brand, procurement, and demand planners, who should collaborate in standing, weekly meetings to drive alignment between new brand and marketing activities, product pricing and promotions, demand forecasting, and production planning and capacities. The siloed decision whereby the brand and marketing team launched Magic without consulting demand forecasting or production planning teams, resulted in mass cannibalization of Vortex's customer base on the part of Magic, and Magic sales that far exceeded not only demand forecasts and planning but also the plant's manufacturing capacity. Creating mandatory, cross-functional collaboration structures will prevent the likelihood of Fisher-Rosemount making future, repeated mistakes of this nature.
- Collaborate with brand pricing specialists or revenue growth managers to increase pricing of Magic. Magic is intended to be a premium (low-volume, ultra-high margin) product. However, Magic immediately became a high-volume, and seemingly lower-margin product (given the costs of Magic's wider impact on flow meter production and lead-time overruns, and reputational costs for Fisher-Rosemount brand equity). Increasing Magic's price point will: increase profitability across the flow meter product line and manufacturing unit; reduce production pressure and taper compounded overdue backlogs caused by Magic's runaway demand; reduce cannibalization of Vortex's customer segments.
- Further disambiguate the Magnetic vs. Vortex offerings by making the Magic just-in-time shipping option exclusive to Magnetic flowmeters only. Currently the Eden Prairie Rosemount plant produces and ships Vortex orders to arrive just-in-time for the customer, but customers often place orders far in advance of when they actually want them to arrive. This existing brand and operations strategy worked well enough before the introduction of Magic, but the production scheduling and just-in-time model for Vortex is floundering alongside the introduction of Magic – an option that takes precedence over standard Vortex production timeline, causing infinite waiting time for standard Vortex

WIP. The operational changes recommended will help address WIP, but should also be accompanied by higher-level decisions to change Vortex strategy. For Vortex orders, the plant should produce and ship Vortex flow-meters whenever there is free operations capacity to do so before the customer's requested-by date. Customers who would like the benefit of receiving their flow-meter just-in-time, regardless of order date, can pay an extra premium to do so. Perhaps the brand could differentiate two JIT options: "Magic Tomorrow" and "Magic Later".

CONCLUSION

Fisher-Rosemount's manufacturing system has a number of bottlenecks that need to be fixed, as shown by the simulation results and the VUT calculations. According to the VUT analysis, the Welding, Hydro Test, and Flow Lab scales C and D all have utilizations close to 100% and are limiting the total output capacity.

In terms of manufacturing operations recommendations, Fisher-Rosemount should invest in more equipment at certain stations, make efforts to reduce setup times at the Hydro Testing station, expedite the transition of Magnetic Flowmeter production to Mexico, and initiate Six Sigma process improvement initiatives to improve first pass quality (yield) at each station in the manufacturing process. The biggest recommendation, however, would be to increase capacity at each of the bottleneck locations, namely Welding (increase to 6 machines), Hydro Test (increase to 2 machines), and Flow Lab C (increase to 4 scales) and D (increase to 3 scales). It is also important to reduce setup times in the Hydro Testing station by at least half. With these changes implemented, the VUT calculations and simulations show that the total manufacturing cycle time could be reduced to just **4.2 hours**.

The business strategy recommendations offer useful information on how the firm may improve departmental collaboration and streamline processes. These recommendations include things like changing performance measures and KPIs, encouraging cross-functional collaboration, increasing the price of the Magic delivery option, and limiting the Magic option to only Magnetic Flowmeters. Also, the creation of a cross-functional task group with representatives from demand planners, marketing, procurement, and manufacturing will ensure that decisions are made jointly and in keeping with corporate goals.

The decision to increase Magic's price point and restrict the Magic option to the Magnetic product family will serve to differentiate it from Vortex, increase overall line profitability, and reduce the likelihood of cannibalizing Vortex's clientele. By offering a just-in-time shipping option for Vortex, with a price for customers who want this service, the business will also be able to meet consumer demand while keeping the production system adaptable.

Thus, Fisher-Rosemount can resolve its production capacity problems with the aid of a comprehensive solution that combines operational and business strategy assistance. By implementing these changes, the organization can increase profitability, satisfy customer demand, and enhance customer satisfaction while also enhancing production efficiency, resource optimization, and profitability, all the while reducing manufacturing cycle times to under 5 hours. These improvements will aid Fisher-Rosemount in keeping up its position as a market pioneer and formidable competitor in the flow meter industry.

APPENDICES

I. VUT Calculations

		WELDING	HYDRO TEST	SENSORING	FL SCALE A	FL SCALE B	FL SCALE C	FL SCALE D	FL SCALE E	CONFIG	FINAL ASSEMBLY	FINAL INSPECTION	PACKAGING
MEASURE:	**STATION:**	1	2	3	4	5	6	7	8	9	10	11	12
Arrival Rate (parts/hr)	r_a	17.00	16.83	16.1568	1.8616908	2.2586252	5.8656308	5.2669266	1.6380616	14.5044133	12.32875126	12.20546375	12.08340911
Arrival SCV	c_a^2	0	0.6688036	0.03620799	0.031510802	0.344148453	0.472949113	0.616246702	0.597612329	0.55844564	0.46856677	0.441139995	0.431716462
Natural Process Time (hr)	t_0	0.262	0.019	0.025	0.233	0.237770759	0.429433696	0.371334936	0.220044	0.03	0.023	0.015	0.015
Process Time Standard Deviation (hr)	σ	0.15	0.03	0.006	0.285611754	0.228926642	0.371527129	0.312842405	0.168599899	0.006	0.006	0.006	0.006
Natural Process SCV	c_0^2	0.3277781	2.493074792	0.0576	1.502589366	0.926991576	0.748494866	0.709773223	0.587077665	0.04	0.06805293	0.16	0.16
Number of Machines	m	5	1	1	1	1	1	1	1	1	1	1	1
MTTF (hr)	m_f	40	40	40	20	20	20	20	20	40	40	99999999	99999999
MTTR (hr)	m_r	0.17	0.17	0.17	0.5	0.5	0.5	0.5	0.5	0.17	0.17	0	0
Availability	A	0.99576799	0.995767986	0.995767986	0.975609756	0.975609756	0.975609756	0.975609756	0.975609756	0.99576799	0.995767986	1	1
Effective Process Time (failures only)	t_e'	0.2631135	0.01908075	0.02510625	0.238825	0.243715028	0.440169538	0.380618309	0.2255451	0.0301275	0.02309775	0.015	0.015
Eff Process SCV (failures only)	$c_e^{2\prime}$	0.33324679	2.568485074	0.114911814	1.604715374	1.027068474	0.803905887	0.773853808	0.695216764	0.08775985	0.13034838	0.16	0.16
Batch Size	k	1	1	15	1	1	1	1	1	1	1	1	1
Setup Time (hr)	t_s	0.03	0.15	0	0.072839506	0.082352941	0.063580247	0.054109589	0.066	0	0	0	0
Setup Time SCV	c_s^2	0.11111111	0.004444444	0	0.327222781	0.12287415	0.154609294	0.284623191	0.191307009	0	0	0	0
Arrival Rate of Batches	r_a/k	17	16.83	1.07712	1.8616908	2.2586252	5.8656308	5.2669266	1.6380616	14.5044133	12.32875126	12.20546375	12.08340911
Eff Batch Process Time (failures+setups)	$t_e = kt_0/A+t_s$	0.2931135	0.16908075	0.37659375	0.311664506	0.326067969	0.503749785	0.434727898	0.2915451	0.0301275	0.02309775	0.015	0.015
Eff Batch Process Time Var (failures+setups)	*$s_0^2/A^2+2m_r(1-A)kt_0/A+s_s^2$	0.02317025	0.001035121	0.001086475	0.093264873	0.061838135	0.15638114	0.112941765	0.036199422	7.9657E-05	6.95417E-05	0.000036	0.000036
Eff Process SCV (failures+setups)	c_e^2	0.26968638	0.036207863	0.007660788	0.96015956	0.581621034	0.616246731	0.597612325	0.425882839	0.08775985	0.13034838	0.16	0.16
Utilization	u	0.9965859	0.9999999	0.40563666	0.580222944	0.736465332	0.9999999	0.9999999	0.477568833	0.43698171	0.284766414	0.183081956	0.181251137
Departure SCV	c_d^2	0.6688036	0.03620799	0.031510802	0.344148453	0.472949113	0.616246702	0.597612329	0.558445642	0.46856677	0.441139995	0.431716462	0.42279004
Yield	y	0.99	0.96	0.95	0.95	0.95	0.95	0.95	0.95	0.85	0.99	0.99	1
Final Departure Rate	r_a*y	16.83	16.1568	15.34896	1.76860626	2.14569394	5.57234926	5.00358027	1.55615852	12.3287513	12.20546375	12.08340911	12.08340911
Final Departure SCV	$yc_d^2+(1-y)$	0.67211556	0.07475967	0.079935262	0.37694103	0.499301657	0.635434367	0.617731712	0.58052336	0.54828175	0.446728595	0.437399298	0.42279004
Utilization	u	0.9965859	0.9999999	0.40563666	0.580222944	0.736465332	0.9999999	0.9999999	0.477568833	0.43698171	0.284766414	0.183081956	0.181251137
Throughput	TH	16.83	16.1568	15.34896	1.76860626	2.14569394	5.57234926	5.00358027	1.55615852	12.3287513	12.20546375	12.08340911	12.08340911
Queue Time (hr)	CT_q	2.29593061	596019.2759	0.005637465	0.213599821	0.4217893	2743410.587	2638491.656	0.136385577	0.00755517	0.002753885	0.001010425	0.000982438
Cycle Time (hr)	CT_q+t_e	2.58904411	596019.445	0.382231215	0.525264327	0.747857269	2743411.091	2638492.091	0.427930677	0.03768267	0.025851635	0.016010425	0.015982438
Cumulative Cycle Time (hr)	$S_i(CT_q(i)+t_e(i))$	2.58904411	596022.034	596022.4163	596022.9415	596023.6894	3339434.78	5977926.871	5977927.299	5977927.34	5977927.363	5977927.379	5977927.395
WIP in Queue (jobs)	r_aCT_q	39.0308203	10031004.41	0.091083388	0.397656821	0.952663941	16091833.64	13896741.89	0.223407977	0.10958337	0.033951967	0.012332702	0.011871195
WIP (jobs)	r_aCT	44.0137498	10031007.26	6.175633288	0.977879765	1.689129273	16091836.59	13896744.18	0.700976809	0.54656508	0.318718381	0.195414658	0.193122331
Cumulative WIP (jobs)	$S_i(r_a(i)CT(i))$	44.0137498	10031051.27	10031057.45	10031058.43	10031060.12	26122896.71	40019640.89	40019641.59	40019642.1	40019642.45	40019642.65	40019642.84

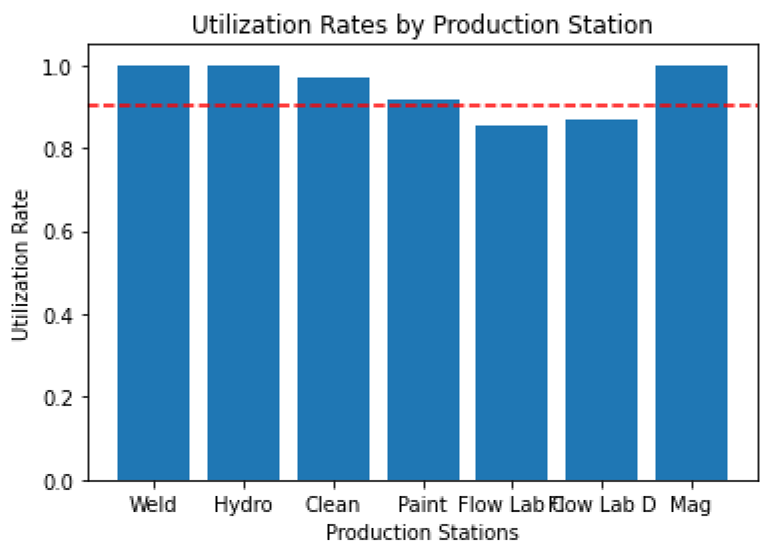
INPUT
OUTPUT

Notes: *Additional stations can be added by copying and pasting columns.*
Routings are assumed fixed (tandem stations).
Single product.
Batching assumes that transfer lots equal process lots.
Multi-machine stations are assumed to share batches, rather than have individual machines dedicated to jobs in order to reduce number of setups.
Most rows are labeled to make formulas easier to read.

VORTEX (Calc in Sht4)	% Incoming
FL Scale A	0.105
FL Scale B	0.12
FL Scale C	0.355
FL Scale D	0.335
FL Scale E	0.085
Total	1
MAGNETIC (Calc in Sht	% Incoming
FL Scale A	0.25005
FL Scale B	0.41675
FL Scale C	0.41675
FL Scale D	0.125025
FL Scale E	0.3334
Total	1.541975

Case Data									Reqd /week					
Line	**Scale**	**Product**	**Mean Demand /week**	**STD Demand /week**	**Avg mix**	**Process time (min)**	**Setup time (min)**	**Run Time /week**	**Total mins /scale**	**Setup Time (Hour)**	**Demand/Hr**	**Weighted Avg Setup Time**	**Process Time in Hr**	**Weighted Avg process Time**
1	A	18"-24" M	6.668	1	0.01	48	9	380.08		0.15	0.08335	0.07283951	0.8	0.23291694
1	A	6"-8" V	70.014	5	0.09	17	4	1470.29		0.066667	0.875175		0.283333	
2	A	14" & 16" M	6.668	5	0.01	12	4	106.69		0.066667	0.08335		0.2	
3	A	12" M	6.668	5	0.01	13	4	113.36	2070.41	0.066667	0.08335		0.216667	
3	B	8" & 10" M	6.668	1	0.01	35	8	286.72		0.133333	0.08335	0.08235294	0.583333	0.23777076
4	B	4" M	16.67	1	0.02	43	7	833.50		0.116667	0.208375		0.716667	
4	B	6" M	10.002	1	0.01	22	7	290.06		0.116667	0.125025		0.366667	
4	B	4" V	80.016	7	0.10	12	4	1280.26	2690.54	0.066667	1.0002		0.2	
5	C	2" M	16.67	1	0.02	54	6	1000.20		0.1	0.208375	0.06358025	0.9	0.4294337
5	C	3" M	16.67	1	0.02	41	6	783.49		0.1	0.208375		0.683333	
5	C	2" V	116.69	7	0.15	10	3	1516.97		0.05	1.458625		0.166667	
5	C	3" V	120.024	8	0.15	10	4	1680.34	4981.00	0.066667	1.5003		0.166667	
6	D	1.5" M	10.002	1	0.01	40	6	460.09		0.1	0.125025	0.05410959	0.666667	0.37133494
6	D	1" V	123.358	8	0.16	8	3	1356.94		0.05	1.541975		0.133333	
6	D	1.5" V	100.02	7	0.13	7	3	1000.20	2817.23	0.05	1.25025		0.116667	
7	E	0.5" M	10.002	1	0.01	23	6	290.06		0.1	0.125025	0.066	0.383333	0.220044
7	E	1" M	16.67	1	0.02	22	6	466.76		0.1	0.208375		0.366667	
7	E	0.5" V	56.678	3	0.07	5	3	453.42	1210.24	0.05	0.708475		0.083333	
	Total Demand	Magnetic	123.358		0.156118									
	Total Demand	Vortex	666.8		0.843882									
	Total		790.158			422	93	13769.42	13769.42					
Vortex			Magnetic											
Scale A	0.105		Scale A	0.25005										
Scale B	0.12		Scale B	0.41675										
Scale C	0.355		Scale C	0.41675										
Scale D	0.335		Scale D	0.125025										
Scale E	0.085		Scale E	0.3334										
Total	1		Total	1.541975										

II. Utilization Graph



III. Python Code

```
import pandas as pd
from math import ceil
```

```
stations = ['WELDING', 'HYDRO TEST', 'SENSORING', 'FL SCALE A', 'FL SCALE B', 'FL SCALE C', 'FL SCALE D', 'FL SCALE E', 'CONFIG', 'FINAL ASSEMBLY', 'FINAL INSPECTION', 'PACKAGING']

# Define the input data as a dictionary
station_data = {
    'WELDING': {'number_of_stations': 5, 'raw_processing_time': 0.262, 'effective_hrs_per_day': 8, 'yield': 0.99, 'setup_time': 0.03, 'number_between_setups': 1, 'mttf': 40, 'mttr': 0.17},
    'HYDRO TEST': {'number_of_stations': 2, 'raw_processing_time': 0.019, 'effective_hrs_per_day': 8, 'yield': 0.96, 'setup_time': 0.15, 'number_between_setups': 5, 'mttf': 40, 'mttr': 0.17},
    'SENSORING': {'number_of_stations': 1, 'raw_processing_time': 0.025, 'effective_hrs_per_day': 8, 'yield': 0.95, 'setup_time': 0, 'number_between_setups': 5, 'mttf': 40, 'mttr': 0.17},
    'FL SCALE A': {'scale': 'A', 'process_time': 422, 'setup_time': 93, 'total_mins_per_scale': 13769.42, 'yield': 0.98, 'effective_hrs_per_day': 7},
    'FL SCALE B': {'scale': 'B', 'process_time': 2690.54, 'setup_time': 0, 'total_mins_per_scale': 2690.54, 'yield': 0.99, 'effective_hrs_per_day': 6},
    'FL SCALE C': {'scale': 'C', 'process_time': 4981, 'setup_time': 0, 'total_mins_per_scale': 4981, 'yield': 0.96, 'effective_hrs_per_day': 7},
    'FL SCALE D': {'scale': 'D', 'process_time': 2817.23, 'setup_time': 0, 'total_mins_per_scale': 2817.23, 'yield': 0.97, 'effective_hrs_per_day': 8},
    'FL SCALE E': {'scale': 'E', 'process_time': 1210.24, 'setup_time': 0, 'total_mins_per_scale': 1210.24, 'yield': 0.99, 'effective_hrs_per_day': 7},
    'CONFIG': {'number_of_stations': 1, 'raw_processing_time': 0.03, 'effective_hrs_per_day': 8, 'yield': 0.85, 'setup_time': 0, 'number_between_setups': 1, 'mttf': 40, 'mttr': 0.17},
    'FINAL ASSEMBLY': {'number_of_stations': 1, 'raw_processing_time': 0.023, 'effective_hrs_per_day': 8, 'yield': 0.99, 'setup_time': 0, 'number_between_setups': 1, 'mttf': 40, 'mttr': 0.17},
    'FINAL INSPECTION': {'number_of_stations': 1, 'raw_processing_time': 0.015, 'effective_hrs_per_day': 8, 'yield': 0.99, 'setup_time': 0, 'number_between_setups': 1, 'mttf': 99999999, 'mttr': 0},
    'PACKAGING': {'number_of_stations': 1, 'raw_processing_time': 0.05, 'effective_hrs_per_day': 8, 'yield': 1, 'setup_time': 0, 'number_between_setups': 1, 'mttf': 99999999, 'mttr': 0},
}

# Calculate performance metrics for each station
for station in stations:
    data = station_data[station]
```

```
    num_stations = data.get('number_of_stations', 1)
    raw_processing_time = data.get('raw_processing_time', 0)  # set to 0 if not defined
    effective_hrs_per_day = data['effective_hrs_per_day']
    yield_rate = data['yield']
    setup_time = data.get('setup_time', 0)
    num_between_setups = data.get('number_between_setups', 1)
    mttf = data.get('mttf', 99999999)
    mttr = data.get('mttr', 0)

    processing_time = raw_processing_time  # Define processing time for all stations except FINAL INSPECTION and PACKAGING

    # Check if station is FINAL INSPECTION or PACKAGING and adjust processing time accordingly
    if station == 'FINAL INSPECTION':
        buffer_time = 0.017  # buffer time in hours
        processing_time = buffer_time + raw_processing_time
    elif station == 'PACKAGING':
        buffer_time = 0.02  # buffer time in hours
        processing_time = buffer_time + raw_processing_time

    utilization = (num_stations * processing_time) / (effective_hrs_per_day * 60)
    throughput = num_stations * effective_hrs_per_day * yield_rate
    cycle_time = processing_time + setup_time + (num_between_setups - 1) * mttf + mttr
    queue_time = cycle_time - processing_time - setup_time
    wip_in_queue = throughput * queue_time / 60

    # Calculate and print performance metrics
    wip = throughput * cycle_time / 60
    cumulative_cycle_time = cycle_time
    cumulative_wip = wip

    print(f"Station: {station}")
    print(f"Utilization: {utilization:.2%}")
    print(f"Throughput: {throughput:.2f} jobs/hr")
    print(f"Queue Time: {queue_time:.2f} hrs")
    print(f"Cycle Time: {cycle_time:.2f} hrs")
    print(f"Cumulative Cycle Time: {cumulative_cycle_time:.2f} hrs")
    print(f"WIP in Queue: {wip_in_queue:.2f} jobs")
    print(f"WIP: {wip:.2f} jobs")
```

```
    print(f"Cumulative WIP: {cumulative_wip:.2f} jobs")
    print()
```

A. Code Explanation

The performance measurements for each station in a manufacturing process are computed and printed by this Python program. Utilization, throughput, queue time, cycle time, WIP (work in progress) in queue, and WIP are some of the measures.

A dictionary named station data is used to define the input data. It comprises different properties for each station, including the number of stations, processing time, yield rate, setup time, and mean time to failure (MTTF).

Every station in the stations list is iterated through in the for loop, which also pulls the relevant data from the station data dictionary. The code then uses the data it has retrieved to calculate various performance metrics, including utilization (the percentage of time the station is in use), throughput (the number of jobs completed per hour), queue time (the amount of time jobs wait in the queue), cycle time (the amount of time it takes to complete one job), WIP in queue (the number of jobs waiting in the queue), and WIP (the number of jobs currently being processed and in the queue).

The calculated performance metrics for each station are printed out by the print statements at the end of the loop.

The performance metrics for each station will be printed to the console as the result of this code.

B. Code Output

Station: WELDING
Utilization: 0.27%
Throughput: 39.60 jobs/hr
Queue Time: 0.17 hrs
Cycle Time: 0.46 hrs
Cumulative Cycle Time: 0.46 hrs
WIP in Queue: 0.11 jobs
WIP: 0.30 jobs
Cumulative WIP: 0.30 jobs

Station: HYDRO TEST
Utilization: 0.01%
Throughput: 15.36 jobs/hr
Queue Time: 160.17 hrs

Cycle Time: 160.34 hrs
Cumulative Cycle Time: 160.34 hrs
WIP in Queue: 41.00 jobs
WIP: 41.05 jobs
Cumulative WIP: 41.05 jobs

Station: SENSORING
Utilization: 0.01%
Throughput: 7.60 jobs/hr
Queue Time: 160.17 hrs
Cycle Time: 160.19 hrs
Cumulative Cycle Time: 160.19 hrs
WIP in Queue: 20.29 jobs
WIP: 20.29 jobs
Cumulative WIP: 20.29 jobs

Station: FL SCALE A
Utilization: 0.00%
Throughput: 6.86 jobs/hr
Queue Time: 0.00 hrs
Cycle Time: 93.00 hrs
Cumulative Cycle Time: 93.00 hrs
WIP in Queue: 0.00 jobs
WIP: 10.63 jobs
Cumulative WIP: 10.63 jobs

Station: FL SCALE B
Utilization: 0.00%
Throughput: 5.94 jobs/hr
Queue Time: 0.00 hrs
Cycle Time: 0.00 hrs
Cumulative Cycle Time: 0.00 hrs
WIP in Queue: 0.00 jobs
WIP: 0.00 jobs
Cumulative WIP: 0.00 jobs

Station: FL SCALE C
Utilization: 0.00%
Throughput: 6.72 jobs/hr
Queue Time: 0.00 hrs

Cycle Time: 0.00 hrs
Cumulative Cycle Time: 0.00 hrs
WIP in Queue: 0.00 jobs
WIP: 0.00 jobs
Cumulative WIP: 0.00 jobs

Station: FL SCALE D
Utilization: 0.00%
Throughput: 7.76 jobs/hr
Queue Time: 0.00 hrs
Cycle Time: 0.00 hrs
Cumulative Cycle Time: 0.00 hrs
WIP in Queue: 0.00 jobs
WIP: 0.00 jobs
Cumulative WIP: 0.00 jobs

Station: FL SCALE E
Utilization: 0.00%
Throughput: 6.93 jobs/hr
Queue Time: 0.00 hrs
Cycle Time: 0.00 hrs
Cumulative Cycle Time: 0.00 hrs
WIP in Queue: 0.00 jobs
WIP: 0.00 jobs
Cumulative WIP: 0.00 jobs

Station: CONFIG
Utilization: 0.01%
Throughput: 6.80 jobs/hr
Queue Time: 0.17 hrs
Cycle Time: 0.20 hrs
Cumulative Cycle Time: 0.20 hrs
WIP in Queue: 0.02 jobs
WIP: 0.02 jobs
Cumulative WIP: 0.02 jobs

Station: FINAL ASSEMBLY
Utilization: 0.00%
Throughput: 7.92 jobs/hr
Queue Time: 0.17 hrs

Cycle Time: 0.19 hrs
Cumulative Cycle Time: 0.19 hrs
WIP in Queue: 0.02 jobs
WIP: 0.03 jobs
Cumulative WIP: 0.03 jobs

Station: FINAL INSPECTION
Utilization: 0.01%
Throughput: 7.92 jobs/hr
Queue Time: 0.00 hrs
Cycle Time: 0.03 hrs
Cumulative Cycle Time: 0.03 hrs
WIP in Queue: 0.00 jobs
WIP: 0.00 jobs
Cumulative WIP: 0.00 jobs

Station: PACKAGING
Utilization: 0.01%
Throughput: 8.00 jobs/hr
Queue Time: 0.00 hrs
Cycle Time: 0.07 hrs
Cumulative Cycle Time: 0.07 hrs
WIP in Queue: 0.00 jobs
WIP: 0.01 jobs
Cumulative WIP: 0.01 jobs

C. Output Interpretation

Based on the given data, it appears that adding an extra machine to the HYDRO TEST station increased the throughput for the HYDRO TEST station increased slightly from 15.36 to 16.16 jobs/hr. This option shows that adding an extra machine helps, and similar alternatives can be identified based on changing the simulation parameters.