GROUP 11

CDS512 BUSINESS INTELLIGENCE
AND DECISION ANALYTICS

UNIVERSITI SAINS MALAYSIA

Capacity Planning and Resource Allocation in Assembly Line using Linear Programming

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PROBLEM IDENTIFICATION

Project Motivation

Manufacturing firms apply different policies to fulfill customer orders. Some firms choose to fill out orders by the inventory of finished goods. Other companies only choose to begin work on an order after it has been placed. The preparation of capacity requirements plays a major role in determining the position of the company to competitors and, as a result, the company's long-term viability. Capacity planning determines an organization's resource requirement for sustaining a given demand across a planning horizon. The planning of capacity requirements ensures a company can meet the changing demands for its products.

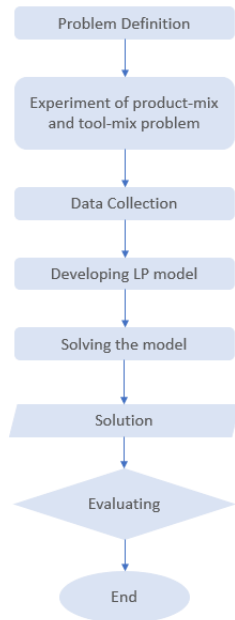
Discrepancies between capacity requirements and actual production output can result in product shortages that lead to long delays in the delivery of products that cause the company to leave the orders of some customers completely unfulfilled [1]. Not meeting customer demand often means losing customers to competitors. The former may be a severe cost, but the latter may result in loss of sales and potential reputational loss.

Problem Statements

Our client is a manufacturing company located in Bayan Lepas, Penang. Due to the company policy, the actual name of the company was anonymized and renamed as Company XYZ. Company XYZ is a manufacturing company with a diverse product portfolio that often face capacity planning problems due to their diversity of the products, complicated manufacturing flow, and the fluctuation of the demand stream. They are having a hard time minimizing the discrepancies between their capacity and the demands of their customers. The former can be a significant expense, but the latter may result in loss of revenue, loss of customers, and possible reputational damage. Furthermore, they are currently using a trial-and-error method which is very time consuming or based on their previous experiences to find a proper capacity plan. Suppose they want to find a proper capacity plan, they would just try several different combinations, check the cost, and calculate the resource utilization. Since all possible combinations are not being tried out, the optimum combination is not likely to be found. As a result, inadequate capacity planning results in customer and business loss while excess capacity can drain the resources of the company and prevent investment in more lucrative ventures.

ANALYSIS

Research Methodology



The research is designed to cover capacity planning and resource allocation for at least sixteen months. In the first step, we identify a problem related to the study area, investigate that problem, and define the problem identified are involved. In the second step, similar previous studies on product-mix and tool-mix problem and their solution methods are studied to identify the appropriate technique to solve the problem.

The next step deals with data collection. For this purpose, we have investigated the overall quantity combination of the twenty-nine products produced by Company XYZ. This has been made possible by the records (e.g. product workflow, tool performance and availability report, time study report, and demand forecast report) kept by the Production and the Sales Departments relating to the different items produced by the firm. We also had a personal interview with Production Line Manager, Industrial Engineering Manager, and Planning Manager to gain some primary source of data especially in the step of problem definition. Developing the LP model to determine the optimal allocation of each resource is in the fourth step.

In the next step, the model was implemented in "PuLP". The PuLP is an LP modeler written in Python. The PuLP can generate MPS or LP files and call GLPK, COIN CLP/CBC, CPLEX, or GUROBI to solve linear problems [2]. Studying the solution and determining the optimal product-mix composition are considered in the solution step. Finally, the model is evaluated by visualizing the results as well as performing the sensitivity analysis to come up with some managerial insights driven from the outputs.

Problem Modeling and Model Formulation

Problem Modeling

Company XYZ primarily manufactures twenty-nine products. Most of the products need to pass through the four different processes before they are shipped. The processes are pressing, clinching, heat staking, and testing. Using “Product_70” as an example, it is having two different alternative tools (resources) that could be used for every single process. Some products may have up to five different tools that could be used in a single process. A product is allowed to be produced using a combination of more than one tool in a process as long as their total quantity produced is the same as the demand. Hence, the cost and process time incurred per unit in a process may not be the same every time as it will be subjected to the tool selected. Following tables are the data collected from the Company XYZ:

Table 2.1: Cost and Process Time per Unit of Pressing and Clinching

Product	***Pressing***		***Clinching***		
	HydraulicPress_01	*Or HydraulicPress_Subcon*	*Clincher_01*	*Or Clincher_02*	*Or Clincher_Subcon*
Product_14	$0.3 ; 24.8s	$0.6 ; 24.8s	--	$1.8 ; 30s	$3.6 ; 30s
Product_17	$1 ; 7.2s	$2 ; 7.2s	--	$2.3 ; 20.3s	$4.6 ; 20.3s
Product_22	$1.5 ; 372.4s	$3 ; 372.4s	--	$2.7 ; 124.1s	$5.4 ; 124.1s
Product_25	$0.6 ; 24.8s	$1.2 ; 24.8s	--	$2.4 ; 41.4s	$4.8 ; 41.4s
Product_26	$1.5 ; 99.3s	$3 ; 99.3s	--	$2.7 ; 40s	$5.4 ; 40s
Product_27	$1.5 ; 99.3s	$3 ; 99.3s	--	$2.7 ; 40s	$5.4 ; 40s

Product_28	$1.2 ; 24.8s	$2.4 ; 24.8s	--	$2.9 ; 59s	$5.8 ; 59s
Product_29	$1.2 ; 24.8s	$2.4 ; 24.8s	--	$2.9 ; 59s	$5.8 ; 59s
Product_37	$0.3 ; 24.8s	$0.6 ; 24.8s	--	$1.5 ; 36.4s	$3 ; 36.4s
Product_41	$0.5 ; 446.9s	$1 ; 446.9s	--	$1.5 ; 240s	$3 ; 240s
Product_46	$1.8 ; 124.1s	$3.6 ; 124.1s	--	$2.3 ; 40s	$4.6 ; 40s
Product_47	$1.9 ; 124.1s	$3.8 ; 124.1s	--	$2.2 ; 40s	$4.4 ; 40s
Product_48	$1.9 ; 124.1s	$3.8 ; 124.1s	--	$2.2 ; 40s	$4.4 ; 40s
Product_57	$0.6 ; 270s	$1.2 ; 270s	$1.4 ; 60s	--	$2.8 ; 60s
Product_58	$0.6 ; 270s	$1.2 ; 270s	$1.4 ; 60s	--	$2.8 ; 60s
Product_59	$1 ; 420s	$2 ; 420s	$1.4 ; 90s	--	$2.8 ; 90s
Product_60	$1 ; 420s	$2 ; 420s	$1.4 ; 90s	--	$2.8 ; 90s
Product_66	$0.4 ; 300s	$0.8 ; 300s	--	$1.2 ; 128.6s	$2.4 ; 128.6s
Product_67	$0.4 ; 300s	$0.8 ; 300s	--	$1.2 ; 128.6s	$2.4 ; 128.6s
Product_69	$1.7 ; 24.8s	$3.4 ; 24.8s	--	$2.4 ; 28.1s	$4.8 ; 28.1s
Product_70	$2 ; 24.8s	$4 ; 24.8s	--	$1.8 ; 26.1s	$3.6 ; 26.1s
Product_73	$1.3 ; 198.6s	$2.6 ; 198.6s	$2.4 ; 40s	--	$4.8 ; 40s
Product_74	$1.3 ; 198.6s	$2.6 ; 198.6s	$2.4 ; 40s	--	$4.8 ; 40s
Product_75	$1.6 ; 74.5s	$3.2 ; 74.5s	$2.4 ; 10s	--	$4.8 ; 10s
Product_76	$1.6 ; 74.5s	$3.2 ; 74.5s	$2.4 ; 10s	--	$4.8 ; 10s
Product_77	$1.8 ; 49.7s	$3.6 ; 49.7s	--	$2.2 ; 30s	$4.4 ; 30s
Product_79	$1.8 ; 49.7s	$3.6 ; 49.7s	--	$2.2 ; 30s	$4.4 ; 30s
Product_85	$1.1 ; 24.8s	$2.2 ; 24.8s	--	$2.2 ; 59s	$4.4 ; 59s
Product_86	$1.1 ; 24.8s	$2.2 ; 24.8s	--	$2.2 ; 59s	$4.4 ; 59s

Table 2.2: Cost and Process Time per Unit of Heat Staking

Product	***Heat Staking***							
	HeatStake_04	*Or HeatStake_05*	*Or HeatStake_06*	*Or HeatStake_07*	*Or HeatStake_08*	*Or HeatStake_09*	*Or HeatStake_10*	*Or HeatStake_Subcon*
Product_14	--	--	--	--	--	--	--	--
Product_17	--	--	--	$6.5 ; 21s	$5.8 ; 32s	--	$6.8 ; 19.8s	$11.6 ; 19.8s
Product_22	--	--	$4.5 ; 120s	--	--	--	--	$9 ; 120s
Product_25	--	--	--	--	--	--	--	--
Product_26	--	--	--	--	--	--	--	--
Product_27	--	--	--	--	--	--	--	--
Product_28	--	$3.6 ; 60s	--	--	--	--	--	$7.2 ; 60s
Product_29	--	$3.6 ; 60s	--	--	--	--	--	$7.2 ; 60s
Product_37	$5.4 ; 23s	--	$5.4 ; 28.1s	--	--	--	--	$10.8 ; 23s
Product_41	$4.6 ; 180s	--	--	--	--	--	--	$9.2 ; 180s
Product_46	--	--	--	--	--	--	--	--
Product_47	--	--	--	--	--	--	--	--
Product_48	--	--	--	--	--	--	--	--
Product_57	--	--	$7.5 ; 50s	$7.3 ; 72s	$7.3 ; 65s	$7.9 ; 44s	--	$14.6 ; 44s
Product_58	--	--	$7.5 ; 50s	$7.3 ; 72s	$7.3 ; 65s	$7.9 ; 44s	--	$14.6 ; 44s
Product_59	--	--	--	$5.7 ; 60s	$6 ; 55s	--	--	$11.4 ; 55s
Product_60	--	--	--	$5.7 ; 60s	$6 ; 55s	--	--	$11.4 ; 55s
Product_66	--	--	--	$8 ; 65s	$7 ; 60s	--	--	$14 ; 60s
Product_67	--	--	--	$8 ; 65s	$7 ; 60s	--	--	$14 ; 60s
Product_69	--	--	$5.1 ; 20s	--	--	--	--	$10.2 ; 20s
Product_70	--	--	$3.4 ; 27.1s	--	--	--	--	$6.8 ; 27.1s
Product_73	$5 ; 40s	--	--	--	--	$6.6 ; 60s	--	$10 ; 40s
Product_74	$5 ; 40s	--	--	--	--	$6.6 ; 60s	--	$10 ; 40s
Product_75	$5 ; 40s	--	--	--	--	$3.2 ; 60s	--	$6.4 ; 40s
Product_76	$5 ; 40s	--	--	--	--	$3.2 ; 60s	--	$6.4 ; 40s
Product_77	--	--	--	--	--	--	--	--
Product_79	--	--	--	--	--	--	--	--
Product_85	--	$3.1 ; 60s	--	--	--	--	--	$6.2 ; 60s
Product_86	--	$3.1 ; 60s	--	--	--	--	--	$6.2 ; 60s

Table 2.3: Cost and Process Time per Unit of Testing

Product	***Testing***							
	Tester_04	*Or Tester_05*	*Or Tester_06*	*Or Tester_07*	*Or Tester_08*	*Or Tester_09*	*Or Tester_10*	*Or Tester_Subcon*
Product_14	--	--	--	--	--	--	--	--
Product_17	--	--	--	$3 ; 15s	$2 ; 13s	--	$1.1 ; 12.3s	$2.2 ; 12.3s
Product_22	--	--	$3 ; 30s	--	--	--	--	$6 ; 30s
Product_25	--	--	--	--	--	--	--	--
Product_26	--	--	--	--	--	--	--	--
Product_27	--	--	--	--	--	--	--	--
Product_28	--	$1.2 ; 40s	--	--	--	--	--	$2.4 ; 40s
Product_29	--	$2.6 ; 40s	--	--	--	--	--	$5.2 ; 40s
Product_37	$2.3 ; 25s	--	$2.3 ; 22s	--	--	--	--	$4.6 ; 22s
Product_41	$2.3 ; 30.5s	--	--	--	--	--	--	$4.6 ; 30.5s
Product_46	--	--	--	--	--	--	--	--
Product_47	--	--	--	--	--	--	--	--
Product_48	--	--	--	--	--	--	--	--

Product_57	--	--	$2.5 ; 48s	$2.7 ; 52s	$2.9 ; 60s	$3 ; 41s	--	$5 ; 41s
Product_58	--	--	$2.5 ; 48s	$2.7 ; 52s	$2.9 ; 60s	$3 ; 41s	--	$5 ; 41s
Product_59	--	--	--	$2.9 ; 36s	$3.5 ; 32s	--	--	$5.8 ; 32s
Product_60	--	--	--	$2.9 ; 36s	$3.5 ; 32s	--	--	$5.8 ; 32s
Product_66	--	--	--	$1.2 ; 42s	$1.5 ; 42s	--	--	$2.4 ; 42s
Product_67	--	--	--	$1.2 ; 42s	$1.5 ; 42s	--	--	$2.4 ; 42s
Product_69	--	--	$1.8 ; 22s	--	--	--	--	$3.6 ; 22s
Product_70	--	--	$1.1 ; 22s	--	--	--	--	$2.2 ; 22s
Product_73	$2.6 ; 30s	--	--	--	--	$2.6 ; 30s	--	$5.2 ; 30s
Product_74	$2.6 ; 30s	--	--	--	--	$2.6 ; 30s	--	$5.2 ; 30s
Product_75	$1.9 ; 30s	--	--	--	--	$1.9 ; 30s	--	$3.8 ; 30s
Product_76	$1.9 ; 30s	--	--	--	--	$1.9 ; 30s	--	$3.8 ; 30s
Product_77	--	--	--	--	--	--	--	--
Product_79	--	--	--	--	--	--	--	--
Product_85	--	$2.7 ; 40s	--	--	--	--	--	$5.4 ; 40s
Product_86	--	$2.7 ; 40s	--	--	--	--	--	$5.4 ; 40s

The demand for each product is given in monthly quantity. Company XYZ operates for twenty-four hours a day, seven days a week. Monthly capacity of each resource can be calculated as follows:

For example, the capacity of Clincher_01

= Tool Quantity x Operating hour x Operating Day per Month (let say is June)

= 3tools x 24hrs x 30days x 3600s

= 777600s

Table 2.2: Resource Capacity and Product Demand of June 19

Tool	Tool Quantity	Operating Hour per Day	Operating Day per Month	Capacity (s)
HydraulicPress_01	26	24	30	67392000
HydraulicPress_Subcon	99	24	30	256608000
Clincher_01	3	24	30	7776000
Clincher_02	7	24	30	18144000
Clincher_Subcon	99	24	30	256608000
HeatStake_04	1	24	30	2592000
HeatStake_05	1	24	30	2592000
HeatStake_06	1	24	30	2592000
HeatStake_07	1	24	30	2592000
HeatStake_08	1	24	30	2592000
HeatStake_09	1	24	30	2592000
HeatStake_10	1	24	30	2592000
HeatStake_Subcon	99	24	30	256608000
Tester_04	1	24	30	2592000
Tester_05	1	24	30	2592000
Tester_06	1	24	30	2592000
Tester_07	1	24	30	2592000
Tester_08	1	24	30	2592000
Tester_09	1	24	30	2592000
Tester_10	1	24	30	2592000
Tester_Subcon	99	24	30	256608000

Product	Demand (June 19)
Product_14	0
Product_17	181431
Product_22	3416
Product_25	0
Product_26	0
Product_27	0
Product_28	0
Product_29	0
Product_37	129851
Product_41	28
Product_46	0
Product_47	0
Product_48	0
Product_57	15022
Product_58	0
Product_59	11659
Product_60	17134
Product_66	8791
Product_67	1706
Product_69	316480
Product_70	73389
Product_73	18601
Product_74	13851
Product_75	9008
Product_76	12833
Product_77	0
Product_79	0
Product_85	305
Product_86	6456

Model Formulation

The mathematical model presented in this work is using June 2019 data as input. It shows how important resource constraints can be included in capacity planning and resource allocation on a regular and routine basis. The model can be used by firms to determine the product quantity allocation for each tool with several "what-if" scenarios. However, the model is comprehensive and incorporates several diverse issues such as:

I. Multiple products, each with its resource usage per unit of the product

II. Product demands per month

III. Finite resource capacity

IV. Distinct resource costs

For each issue listed above, we present a real-life situation to prove their practical relevance and applicability. The objective of the mathematical model is to determine the quantity of each product allocated on each tool that will minimize the cost of the company with the given constraints. The resulting mathematical model in this scenario is a linear programming model. The outputs of the model give the firm precise information regarding which tool should be used, and in what product quantities. Furthermore, the model shows which production and demand constraints increase the firm cost so that the firm can carefully study these problem areas. The given constraints of the LP model are as following:

I. The total time used by each tool must not exceed the tool capacity provided
II. The total quantity of each product allocated in each process must be the same as the demand provided
III. Non-negativity restrictions. The decision variables (quantity allocated) must be non-negative.

The mathematical model below is derived from the verbal description of the constraints and objectives using June 19 data as constraint input.

Select decision variables:

Let

$X_{14}P_{01}$ = Qty of Product_14 that produced in HydraulicPress_01
$X_{14}P_{su}$ = Qty of Product_14 that produced in HydraulicPress_Subcon
$X_{14}C_{02}$ = Qty of Product_14 that produced in Clincher_02
$X_{14}C_{su}$ = Qty of Product_14 that produced in Clincher_Subcon
$X_{17}P_{01}$ = Qty of Product_17 that produced in HydraulicPress_01
$X_{17}P_{su}$ = Qty of Product_17 that produced in HydraulicPress_Subcon
$X_{17}C_{02}$ = Qty of Product_17 that produced in Clincher_02
$X_{17}C_{su}$ = Qty of Product_17 that produced in Clincher_Subcon
$X_{17}H_{07}$ = Qty of Product_17 that produced in HeatStake_07
$X_{17}H_{08}$ = Qty of Product_17 that produced in HeatStake_08
$X_{17}H_{10}$ = Qty of Product_17 that produced in HeatStake_10
$X_{17}H_{su}$ = Qty of Product_17 that produced in HeatStake_Subcon
$X_{17}T_{07}$ = Qty of Product_17 that produced in Tester_07
$X_{17}T_{08}$ = Qty of Product_17 that produced in Tester_08
$X_{17}T_{10}$ = Qty of Product_17 that produced in Tester_10
$X_{17}T_{su}$ = Qty of Product_17 that produced in Tester_Subcon
$X_{22}P_{01}$ = Qty of Product_22 that produced in HydraulicPress_01
$X_{22}P_{su}$ = Qty of Product_22 that produced in HydraulicPress_Subcon
$X_{22}C_{02}$ = Qty of Product_22 that produced in Clincher_02
$X_{22}C_{su}$ = Qty of Product_22 that produced in Clincher_Subcon
$X_{22}H_{06}$ = Qty of Product_22 that produced in HeatStake_06
$X_{22}H_{su}$ = Qty of Product_22 that produced in HeatStake_Subcon
$X_{22}T_{06}$ = Qty of Product_22 that produced in Tester_06
$X_{22}T_{su}$ = Qty of Product_22 that produced in Tester_Subcon
$X_{25}P_{01}$ = Qty of Product_25 that produced in HydraulicPress_01
$X_{25}P_{su}$ = Qty of Product_25 that produced in HydraulicPress_Subcon
$X_{25}C_{02}$ = Qty of Product_25 that produced in Clincher_02
$X_{25}C_{su}$ = Qty of Product_25 that produced in Clincher_Subcon
$X_{26}P_{01}$ = Qty of Product_26 that produced in HydraulicPress_01
$X_{26}P_{su}$ = Qty of Product_26 that produced in HydraulicPress_Subcon
$X_{26}C_{02}$ = Qty of Product_26 that produced in Clincher_02
$X_{26}C_{su}$ = Qty of Product_26 that produced in Clincher_Subcon
$X_{27}P_{01}$ = Qty of Product_27 that produced in HydraulicPress_01
$X_{27}P_{su}$ = Qty of Product_27 that produced in HydraulicPress_Subcon
$X_{27}C_{02}$ = Qty of Product_27 that produced in Clincher_02
$X_{27}C_{su}$ = Qty of Product_27 that produced in Clincher_Subcon
$X_{28}P_{01}$ = Qty of Product_28 that produced in HydraulicPress_01
$X_{28}P_{su}$ = Qty of Product_28 that produced in HydraulicPress_Subcon
$X_{28}C_{02}$ = Qty of Product_28 that produced in Clincher_02
$X_{28}C_{su}$ = Qty of Product_28 that produced in Clincher_Subcon
$X_{28}H_{05}$ = Qty of Product_28 that produced in HeatStake_05
$X_{28}H_{su}$ = Qty of Product_28 that produced in HeatStake_Subcon
$X_{28}T_{05}$ = Qty of Product_28 that produced in Tester_05
$X_{28}T_{su}$ = Qty of Product_28 that produced in Tester_Subcon
$X_{29}P_{01}$ = Qty of Product_29 that produced in HydraulicPress_01
$X_{29}P_{su}$ = Qty of Product_29 that produced in HydraulicPress_Subcon
$X_{59}H_{08}$ = Qty of Product_59 that produced in HeatStake_08
$X_{59}H_{su}$ = Qty of Product_59 that produced in HeatStake_Subcon
$X_{59}T_{07}$ = Qty of Product_59 that produced in Tester_07
$X_{59}T_{08}$ = Qty of Product_59 that produced in Tester_08
$X_{59}T_{su}$ = Qty of Product_59 that produced in Tester_Subcon
$X_{60}P_{01}$ = Qty of Product_60 that produced in HydraulicPress_01
$X_{60}P_{su}$ = Qty of Product_60 that produced in HydraulicPress_Subcon
$X_{60}C_{01}$ = Qty of Product_60 that produced in Clincher_01
$X_{60}C_{su}$ = Qty of Product_60 that produced in Clincher_Subcon
$X_{60}H_{07}$ = Qty of Product_60 that produced in HeatStake_07
$X_{60}H_{08}$ = Qty of Product_60 that produced in HeatStake_08
$X_{60}H_{su}$ = Qty of Product_60 that produced in HeatStake_Subcon
$X_{60}T_{07}$ = Qty of Product_60 that produced in Tester_07
$X_{60}T_{08}$ = Qty of Product_60 that produced in Tester_08
$X_{60}T_{su}$ = Qty of Product_60 that produced in Tester_Subcon
$X_{66}P_{01}$ = Qty of Product_66 that produced in HydraulicPress_01
$X_{66}P_{su}$ = Qty of Product_66 that produced in HydraulicPress_Subcon
$X_{66}C_{02}$ = Qty of Product_66 that produced in Clincher_02
$X_{66}C_{su}$ = Qty of Product_66 that produced in Clincher_Subcon
$X_{66}H_{07}$ = Qty of Product_66 that produced in HeatStake_07
$X_{66}H_{08}$ = Qty of Product_66 that produced in HeatStake_08
$X_{66}H_{su}$ = Qty of Product_66 that produced in HeatStake_Subcon
$X_{66}T_{07}$ = Qty of Product_66 that produced in Tester_07
$X_{66}T_{08}$ = Qty of Product_66 that produced in Tester_08
$X_{66}T_{su}$ = Qty of Product_66 that produced in Tester_Subcon
$X_{67}P_{01}$ = Qty of Product_67 that produced in HydraulicPress_01
$X_{67}P_{su}$ = Qty of Product_67 that produced in HydraulicPress_Subcon
$X_{67}C_{02}$ = Qty of Product_67 that produced in Clincher_02
$X_{67}C_{su}$ = Qty of Product_67 that produced in Clincher_Subcon
$X_{67}H_{07}$ = Qty of Product_67 that produced in HeatStake_07
$X_{67}H_{08}$ = Qty of Product_67 that produced in HeatStake_08
$X_{67}H_{su}$ = Qty of Product_67 that produced in HeatStake_Subcon
$X_{67}T_{07}$ = Qty of Product_67 that produced in Tester_07
$X_{67}T_{08}$ = Qty of Product_67 that produced in Tester_08
$X_{67}T_{su}$ = Qty of Product_67 that produced in Tester_Subcon
$X_{69}P_{01}$ = Qty of Product_69 that produced in HydraulicPress_01
$X_{69}P_{su}$ = Qty of Product_69 that produced in HydraulicPress_Subcon
$X_{69}C_{02}$ = Qty of Product_69 that produced in Clincher_02
$X_{69}C_{su}$ = Qty of Product_69 that produced in Clincher_Subcon
$X_{69}H_{06}$ = Qty of Product_69 that produced in HeatStake_06
$X_{69}H_{su}$ = Qty of Product_69 that produced in HeatStake_Subcon
$X_{69}T_{06}$ = Qty of Product_69 that produced in Tester_06
$X_{69}T_{su}$ = Qty of Product_69 that produced in Tester_Subcon
$X_{70}P_{01}$ = Qty of Product_70 that produced in HydraulicPress_01
$X_{70}P_{su}$ = Qty of Product_70 that produced in HydraulicPress_Subcon
$X_{70}C_{02}$ = Qty of Product_70 that produced in Clincher_02

$X_{29}C_{02}$ = Qty of Product_29 that produced in Clincher_02
$X_{29}C_{Su}$ = Qty of Product_29 that produced in Clincher_Subcon
$X_{29}H_{05}$ = Qty of Product_29 that produced in HeatStake_05
$X_{29}H_{Su}$ = Qty of Product_29 that produced in HeatStake_Subcon
$X_{29}T_{05}$ = Qty of Product_29 that produced in Tester_05
$X_{29}T_{Su}$ = Qty of Product_29 that produced in Tester_Subcon
$X_{37}P_{01}$ = Qty of Product_37 that produced in HydraulicPress_01
$X_{37}P_{Su}$ = Qty of Product_37 that produced in HydraulicPress_Subcon
$X_{37}C_{02}$ = Qty of Product_37 that produced in Clincher_02
$X_{37}C_{Su}$ = Qty of Product_37 that produced in Clincher_Subcon
$X_{37}H_{04}$ = Qty of Product_37 that produced in HeatStake_04
$X_{37}H_{06}$ = Qty of Product_37 that produced in HeatStake_06
$X_{37}H_{Su}$ = Qty of Product_37 that produced in HeatStake_Subcon
$X_{37}T_{04}$ = Qty of Product_37 that produced in Tester_04
$X_{37}T_{06}$ = Qty of Product_37 that produced in Tester_06
$X_{37}T_{Su}$ = Qty of Product_37 that produced in Tester_Subcon
$X_{41}P_{01}$ = Qty of Product_41 that produced in HydraulicPress_01
$X_{41}P_{Su}$ = Qty of Product_41 that produced in HydraulicPress_Subcon
$X_{41}C_{02}$ = Qty of Product_41 that produced in Clincher_02
$X_{41}C_{Su}$ = Qty of Product_41 that produced in Clincher_Subcon
$X_{41}H_{04}$ = Qty of Product_41 that produced in HeatStake_04
$X_{41}H_{Su}$ = Qty of Product_41 that produced in HeatStake_Subcon
$X_{41}T_{04}$ = Qty of Product_41 that produced in Tester_04
$X_{41}T_{Su}$ = Qty of Product_41 that produced in Tester_Subcon
$X_{46}P_{01}$ = Qty of Product_46 that produced in HydraulicPress_01
$X_{46}P_{Su}$ = Qty of Product_46 that produced in HydraulicPress_Subcon
$X_{46}C_{02}$ = Qty of Product_46 that produced in Clincher_02
$X_{46}C_{Su}$ = Qty of Product_46 that produced in Clincher_Subcon
$X_{47}P_{01}$ = Qty of Product_47 that produced in HydraulicPress_01
$X_{47}P_{Su}$ = Qty of Product_47 that produced in HydraulicPress_Subcon
$X_{47}C_{02}$ = Qty of Product_47 that produced in Clincher_02
$X_{47}C_{Su}$ = Qty of Product_47 that produced in Clincher_Subcon
$X_{48}P_{01}$ = Qty of Product_48 that produced in HydraulicPress_01
$X_{48}P_{Su}$ = Qty of Product_48 that produced in HydraulicPress_Subcon
$X_{48}C_{02}$ = Qty of Product_48 that produced in Clincher_02
$X_{48}C_{Su}$ = Qty of Product_48 that produced in Clincher_Subcon
$X_{57}P_{01}$ = Qty of Product_57 that produced in HydraulicPress_01
$X_{57}P_{Su}$ = Qty of Product_57 that produced in HydraulicPress_Subcon
$X_{57}C_{01}$ = Qty of Product_57 that produced in Clincher_01
$X_{57}C_{Su}$ = Qty of Product_57 that produced in Clincher_Subcon
$X_{57}H_{06}$ = Qty of Product_57 that produced in HeatStake_06
$X_{57}H_{07}$ = Qty of Product_57 that produced in HeatStake_07
$X_{57}H_{08}$ = Qty of Product_57 that produced in HeatStake_08
$X_{57}H_{09}$ = Qty of Product_57 that produced in HeatStake_09
$X_{57}H_{Su}$ = Qty of Product_57 that produced in HeatStake_Subcon
$X_{57}T_{06}$ = Qty of Product_57 that produced in Tester_06
$X_{57}T_{07}$ = Qty of Product_57 that produced in Tester_07
$X_{57}T_{08}$ = Qty of Product_57 that produced in Tester_08
$X_{57}T_{09}$ = Qty of Product_57 that produced in Tester_09
$X_{57}T_{Su}$ = Qty of Product_57 that produced in Tester_Subcon
$X_{58}P_{01}$ = Qty of Product_58 that produced in HydraulicPress_01
$X_{58}P_{Su}$ = Qty of Product_58 that produced in HydraulicPress_Subcon
$X_{58}C_{01}$ = Qty of Product_58 that produced in Clincher_01
$X_{58}C_{Su}$ = Qty of Product_58 that produced in Clincher_Subcon
$X_{58}H_{06}$ = Qty of Product_58 that produced in HeatStake_06
$X_{58}H_{07}$ = Qty of Product_58 that produced in HeatStake_07
$X_{58}H_{08}$ = Qty of Product_58 that produced in HeatStake_08
$X_{58}H_{09}$ = Qty of Product_58 that produced in HeatStake_09
$X_{58}H_{Su}$ = Qty of Product_58 that produced in HeatStake_Subcon
$X_{58}T_{06}$ = Qty of Product_58 that produced in Tester_06
$X_{58}T_{07}$ = Qty of Product_58 that produced in Tester_07
$X_{58}T_{08}$ = Qty of Product_58 that produced in Tester_08
$X_{58}T_{09}$ = Qty of Product_58 that produced in Tester_09
$X_{58}T_{Su}$ = Qty of Product_58 that produced in Tester_Subcon
$X_{59}P_{01}$ = Qty of Product_59 that produced in HydraulicPress_01
$X_{59}P_{Su}$ = Qty of Product_59 that produced in HydraulicPress_Subcon
$X_{59}C_{01}$ = Qty of Product_59 that produced in Clincher_01
$X_{59}C_{Su}$ = Qty of Product_59 that produced in Clincher_Subcon
$X_{59}H_{07}$ = Qty of Product_59 that produced in HeatStake_07
$X_{70}C_{Su}$ = Qty of Product_70 that produced in Clincher_Subcon
$X_{70}H_{06}$ = Qty of Product_70 that produced in HeatStake_06
$X_{70}H_{Su}$ = Qty of Product_70 that produced in HeatStake_Subcon
$X_{70}T_{06}$ = Qty of Product_70 that produced in Tester_06
$X_{70}T_{Su}$ = Qty of Product_70 that produced in Tester_Subcon
$X_{73}P_{01}$ = Qty of Product_73 that produced in HydraulicPress_01
$X_{73}P_{Su}$ = Qty of Product_73 that produced in HydraulicPress_Subcon
$X_{73}C_{01}$ = Qty of Product_73 that produced in Clincher_01
$X_{73}C_{Su}$ = Qty of Product_73 that produced in Clincher_Subcon
$X_{73}H_{04}$ = Qty of Product_73 that produced in HeatStake_04
$X_{73}H_{09}$ = Qty of Product_73 that produced in HeatStake_09
$X_{73}H_{Su}$ = Qty of Product_73 that produced in HeatStake_Subcon
$X_{73}T_{04}$ = Qty of Product_73 that produced in Tester_04
$X_{73}T_{09}$ = Qty of Product_73 that produced in Tester_09
$X_{73}T_{Su}$ = Qty of Product_73 that produced in Tester_Subcon
$X_{74}P_{01}$ = Qty of Product_74 that produced in HydraulicPress_01
$X_{74}P_{Su}$ = Qty of Product_74 that produced in HydraulicPress_Subcon
$X_{74}C_{01}$ = Qty of Product_74 that produced in Clincher_01
$X_{74}C_{Su}$ = Qty of Product_74 that produced in Clincher_Subcon
$X_{74}H_{04}$ = Qty of Product_74 that produced in HeatStake_04
$X_{74}H_{09}$ = Qty of Product_74 that produced in HeatStake_09
$X_{74}H_{Su}$ = Qty of Product_74 that produced in HeatStake_Subcon
$X_{74}T_{04}$ = Qty of Product_74 that produced in Tester_04
$X_{74}T_{09}$ = Qty of Product_74 that produced in Tester_09
$X_{74}T_{Su}$ = Qty of Product_74 that produced in Tester_Subcon
$X_{75}P_{01}$ = Qty of Product_75 that produced in HydraulicPress_01
$X_{75}P_{Su}$ = Qty of Product_75 that produced in HydraulicPress_Subcon
$X_{75}C_{01}$ = Qty of Product_75 that produced in Clincher_01
$X_{75}C_{Su}$ = Qty of Product_75 that produced in Clincher_Subcon
$X_{75}H_{04}$ = Qty of Product_75 that produced in HeatStake_04
$X_{75}H_{09}$ = Qty of Product_75 that produced in HeatStake_09
$X_{75}H_{Su}$ = Qty of Product_75 that produced in HeatStake_Subcon
$X_{75}T_{04}$ = Qty of Product_75 that produced in Tester_04
$X_{75}T_{09}$ = Qty of Product_75 that produced in Tester_09
$X_{75}T_{Su}$ = Qty of Product_75 that produced in Tester_Subcon
$X_{76}P_{01}$ = Qty of Product_76 that produced in HydraulicPress_01
$X_{76}P_{Su}$ = Qty of Product_76 that produced in HydraulicPress_Subcon
$X_{76}C_{01}$ = Qty of Product_76 that produced in Clincher_01
$X_{76}C_{Su}$ = Qty of Product_76 that produced in Clincher_Subcon
$X_{76}H_{04}$ = Qty of Product_76 that produced in HeatStake_04
$X_{76}H_{09}$ = Qty of Product_76 that produced in HeatStake_09
$X_{76}H_{Su}$ = Qty of Product_76 that produced in HeatStake_Subcon
$X_{76}T_{04}$ = Qty of Product_76 that produced in Tester_04
$X_{76}T_{09}$ = Qty of Product_76 that produced in Tester_09
$X_{76}T_{Su}$ = Qty of Product_76 that produced in Tester_Subcon
$X_{77}P_{01}$ = Qty of Product_77 that produced in HydraulicPress_01
$X_{77}P_{Su}$ = Qty of Product_77 that produced in HydraulicPress_Subcon
$X_{77}C_{02}$ = Qty of Product_77 that produced in Clincher_02
$X_{77}C_{Su}$ = Qty of Product_77 that produced in Clincher_Subcon
$X_{79}P_{01}$ = Qty of Product_79 that produced in HydraulicPress_01
$X_{79}P_{Su}$ = Qty of Product_79 that produced in HydraulicPress_Subcon
$X_{79}C_{02}$ = Qty of Product_79 that produced in Clincher_02
$X_{79}C_{Su}$ = Qty of Product_79 that produced in Clincher_Subcon
$X_{85}P_{01}$ = Qty of Product_85 that produced in HydraulicPress_01
$X_{85}P_{Su}$ = Qty of Product_85 that produced in HydraulicPress_Subcon
$X_{85}C_{02}$ = Qty of Product_85 that produced in Clincher_02
$X_{85}C_{Su}$ = Qty of Product_85 that produced in Clincher_Subcon
$X_{85}H_{05}$ = Qty of Product_85 that produced in HeatStake_05
$X_{85}H_{Su}$ = Qty of Product_85 that produced in HeatStake_Subcon
$X_{85}T_{05}$ = Qty of Product_85 that produced in Tester_05
$X_{85}T_{Su}$ = Qty of Product_85 that produced in Tester_Subcon
$X_{86}P_{01}$ = Qty of Product_86 that produced in HydraulicPress_01
$X_{86}P_{Su}$ = Qty of Product_86 that produced in HydraulicPress_Subcon
$X_{86}C_{02}$ = Qty of Product_86 that produced in Clincher_02
$X_{86}C_{Su}$ = Qty of Product_86 that produced in Clincher_Subcon
$X_{86}H_{05}$ = Qty of Product_86 that produced in HeatStake_05
$X_{86}H_{Su}$ = Qty of Product_86 that produced in HeatStake_Subcon
$X_{86}T_{05}$ = Qty of Product_86 that produced in Tester_05
$X_{86}T_{Su}$ = Qty of Product_86 that produced in Tester_Subcon

Cost minimization (objective function):

$0.3X_{14}P_{01} + 0.6X_{14}P_{Su} + 1.8X_{14}C_{02} + 3.6X_{14}C_{Su} + 1X_{17}P_{01} + 2X_{17}P_{Su} + 2.3X_{17}C_{02} + 4.6X_{17}C_{Su} + 6.5X_{17}H_{07} + 5.8X_{17}H_{08} + 6.8X_{17}H_{10} + 11.6X_{17}H_{Su} + 3X_{17}T_{07} + 2X_{17}T_{08} + 1.1X_{17}T_{10} + 2.2X_{17}T_{Su} + 1.5X_{22}P_{01} + 3X_{22}P_{Su} + 2.7X_{22}C_{02} + 5.4X_{22}C_{Su} + 4.5X_{22}H_{06} + 9X_{22}H_{Su} + 3X_{22}T_{06} + 6X_{22}T_{Su} + 0.6X_{25}P_{01} + 1.2X_{25}P_{Su} + 2.4X_{25}C_{02} + 4.8X_{25}C_{Su} + 1.5X_{26}P_{01} + 3X_{26}P_{Su} + 2.7X_{26}C_{02} + 5.4X_{26}C_{Su} + 1.5X_{27}P_{01} + 3X_{27}P_{Su} + 2.7X_{27}C_{02} + 5.4X_{27}C_{Su} + 1.2X_{28}P_{01} + 2.4X_{28}P_{Su} + 2.9X_{28}C_{02} + 5.8X_{28}C_{Su} + 3.6X_{28}H_{05} + 7.2X_{28}H_{Su} + 1.2X_{28}T_{05} + 2.4X_{28}T_{Su} + 1.2X_{29}P_{01} + 2.4X_{29}P_{Su} + 2.9X_{29}C_{02} + 5.8X_{29}C_{Su} + 3.6X_{29}H_{05} + 7.2X_{29}H_{Su} + 2.6X_{29}T_{05} + 5.2X_{29}T_{Su} + 0.3X_{37}P_{01} + 0.6X_{37}P_{Su} + 1.5X_{37}C_{02} + 3X_{37}C_{Su} + 5.4X_{37}H_{04} + 5.4X_{37}H_{06} + 10.8X_{37}H_{Su} + 2.3X_{37}T_{04} + 2.3X_{37}T_{06} + 4.6X_{37}T_{Su} + 0.5X_{41}P_{01} + 1X_{41}P_{Su} + 1.5X_{41}C_{02} + 3X_{41}C_{Su} +$

$4.6X_{41}H_{04} + 9.2X_{41}H_{Su} + 2.3X_{41}T_{04} + 4.6X_{41}T_{Su} + 1.8X_{46}P_{01} + 3.6X_{46}P_{Su} + 2.3X_{46}C_{02} + 4.6X_{46}C_{Su} + 1.9X_{47}P_{01} + 3.8X_{47}P_{Su} + 2.2X_{47}C_{02} + 4.4X_{47}C_{Su} + 1.9X_{48}P_{01} + 3.8X_{48}P_{Su} + 2.2X_{48}C_{02} + 4.4X_{48}C_{Su} + 0.6X_{57}P_{01} + 1.2X_{57}P_{Su} + 1.4X_{57}C_{01} + 2.8X_{57}C_{Su} + 7.5X_{57}H_{06} + 7.3X_{57}H_{07} + 7.3X_{57}H_{08} + 7.9X_{57}H_{09} + 14.6X_{57}H_{Su} + 2.5X_{57}T_{06} + 2.7X_{57}T_{07} + 2.9X_{57}T_{08} + 3X_{57}T_{09} + 5X_{57}T_{Su} + 0.6X_{58}P_{01} + 1.2X_{58}P_{Su} + 1.4X_{58}C_{01} + 2.8X_{58}C_{Su} + 7.5X_{58}H_{06} + 7.3X_{58}H_{07} + 7.3X_{58}H_{08} + 7.9X_{58}H_{09} + 14.6X_{58}H_{Su} + 2.5X_{58}T_{06} + 2.7X_{58}T_{07} + 2.9X_{58}T_{08} + 3X_{58}T_{09} + 5X_{58}T_{Su} + 1X_{59}P_{01} + 2X_{59}P_{Su} + 1.4X_{59}C_{01} + 2.8X_{59}C_{Su} + 5.7X_{59}H_{07} + 6X_{59}H_{08} + 11.4X_{59}H_{Su} + 2.9X_{59}T_{07} + 3.5X_{59}T_{08} + 5.8X_{59}T_{Su} + 1X_{60}P_{01} + 2X_{60}P_{Su} + 1.4X_{60}C_{01} + 2.8X_{60}C_{Su} + 5.7X_{60}H_{07} + 6X_{60}H_{08} + 11.4X_{60}H_{Su} + 2.9X_{60}T_{07} + 3.5X_{60}T_{08} + 5.8X_{60}T_{Su} + 0.4X_{66}P_{01} + 0.8X_{66}P_{Su} + 1.2X_{66}C_{02} + 2.4X_{66}C_{Su} + 8X_{66}H_{07} + 7X_{66}H_{08} + 14X_{66}H_{Su} + 1.2X_{66}T_{07} + 1.5X_{66}T_{08} + 2.4X_{66}T_{Su} + 0.4X_{67}P_{01} + 0.8X_{67}P_{Su} + 1.2X_{67}C_{02} + 2.4X_{67}C_{Su} + 8X_{67}H_{07} + 7X_{67}H_{08} + 14X_{67}H_{Su} + 1.2X_{67}T_{07} + 1.5X_{67}T_{08} + 2.4X_{67}T_{Su} + 1.7X_{69}P_{01} + 3.4X_{69}P_{Su} + 2.4X_{69}C_{02} + 4.8X_{69}C_{Su} + 5.1X_{69}H_{06} + 10.2X_{69}H_{Su} + 1.8X_{69}T_{06} + 3.6X_{69}T_{Su} + 2X_{70}P_{01} + 4X_{70}P_{Su} + 1.8X_{70}C_{02} + 3.6X_{70}C_{Su} + 3.4X_{70}H_{06} + 6.8X_{70}H_{Su} + 1.1X_{70}T_{06} + 2.2X_{70}T_{Su} + 1.3X_{73}P_{01} + 2.6X_{73}P_{Su} + 2.4X_{73}C_{01} + 4.8X_{73}C_{Su} + 5X_{73}H_{04} + 6.6X_{73}H_{09} + 10X_{73}H_{Su} + 2.6X_{73}T_{04} + 2.6X_{73}T_{09} + 5.2X_{73}T_{Su} + 1.3X_{74}P_{01} + 2.6X_{74}P_{Su} + 2.4X_{74}C_{01} + 4.8X_{74}C_{Su} + 5X_{74}H_{04} + 6.6X_{74}H_{09} + 10X_{74}H_{Su} + 2.6X_{74}T_{04} + 2.6X_{74}T_{09} + 5.2X_{74}T_{Su} + 1.6X_{75}P_{01} + 3.2X_{75}P_{Su} + 2.4X_{75}C_{01} + 4.8X_{75}C_{Su} + 5X_{75}H_{04} + 3.2X_{75}H_{09} + 6.4X_{75}H_{Su} + 1.9X_{75}T_{04} + 1.9X_{75}T_{09} + 3.8X_{75}T_{Su} + 1.6X_{76}P_{01} + 3.2X_{76}P_{Su} + 2.4X_{76}C_{01} + 4.8X_{76}C_{Su} + 5X_{76}H_{04} + 3.2X_{76}H_{09} + 6.4X_{76}H_{Su} + 1.9X_{76}T_{04} + 1.9X_{76}T_{09} + 3.8X_{76}T_{Su} + 1.8X_{77}P_{01} + 3.6X_{77}P_{Su} + 2.2X_{77}C_{02} + 4.4X_{77}C_{Su} + 1.8X_{79}P_{01} + 3.6X_{79}P_{Su} + 2.2X_{79}C_{02} + 4.4X_{79}C_{Su} + 1.1X_{85}P_{01} + 2.2X_{85}P_{Su} + 2.2X_{85}C_{02} + 4.4X_{85}C_{Su} + 3.1X_{85}H_{05} + 6.2X_{85}H_{Su} + 2.7X_{85}T_{05} + 5.4X_{85}T_{Su} + 1.1X_{86}P_{01} + 2.2X_{86}P_{Su} + 2.2X_{86}C_{02} + 4.4X_{86}C_{Su} + 3.1X_{86}H_{05} + 6.2X_{86}H_{Su} + 2.7X_{86}T_{05} + 5.4X_{86}T_{Su}$

Subjected to

Constraint I: The total time used by each tool must not exceed the tool capacity provided

$24.83X_{14}P_{01} + 7.24X_{17}P_{01} + 372.41X_{22}P_{01} + 24.83X_{25}P_{01} + 99.31X_{26}P_{01} + 99.31X_{27}P_{01} + 24.83X_{28}P_{01} + 24.83X_{29}P_{01} + 24.83X_{37}P_{01} + 446.9X_{41}P_{01} + 124.14X_{46}P_{01} + 124.14X_{47}P_{01} + 124.14X_{48}P_{01} + 270X_{57}P_{01} + 270X_{58}P_{01} + 420X_{59}P_{01} + 420X_{60}P_{01} + 300X_{66}P_{01} + 300X_{67}P_{01} + 24.83X_{69}P_{01} + 24.83X_{70}P_{01} + 198.62X_{73}P_{01} + 198.62X_{74}P_{01} + 74.48X_{75}P_{01} + 74.48X_{76}P_{01} + 49.66X_{77}P_{01} + 49.66X_{79}P_{01} + 24.83X_{85}P_{01} + 24.83X_{86}P_{01} <= 67392000$	*(HydraulicPress_01)*
$24.83X_{14}P_{Su} + 7.24X_{17}P_{Su} + 372.41X_{22}P_{Su} + 24.83X_{25}P_{Su} + 99.31X_{26}P_{Su} + 99.31X_{27}P_{Su} + 24.83X_{28}P_{Su} + 24.83X_{29}P_{Su} + 24.83X_{37}P_{Su} + 446.9X_{41}P_{Su} + 124.14X_{46}P_{Su} + 124.14X_{47}P_{Su} + 124.14X_{48}P_{Su} + 270X_{57}P_{Su} + 270X_{58}P_{Su} + 420X_{59}P_{Su} + 420X_{60}P_{Su} + 300X_{66}P_{Su} + 300X_{67}P_{Su} + 24.83X_{69}P_{Su} + 24.83X_{70}P_{Su} + 198.62X_{73}P_{Su} + 198.62X_{74}P_{Su} + 74.48X_{75}P_{Su} + 74.48X_{76}P_{Su} + 49.66X_{77}P_{Su} + 49.66X_{79}P_{Su} + 24.83X_{85}P_{Su} + 24.83X_{86}P_{Su} <= 256608000$	*(HydraulicPress_Subcon)*
$60X_{57}C_{01} + 60X_{58}C_{01} + 90X_{59}C_{01} + 90X_{60}C_{01} + 40X_{73}C_{01} + 40X_{74}C_{01} + 10X_{75}C_{01} + 10X_{76}C_{01} <= 7776000$	*(Clincher_01)*
$30X_{14}C_{02} + 20.34X_{17}C_{02} + 124.14X_{22}C_{02} + 41.38X_{25}C_{02} + 40X_{26}C_{02} + 40X_{27}C_{02} + 59.02X_{28}C_{02} + 59.02X_{29}C_{02} + 36.36X_{37}C_{02} + 240X_{41}C_{02} + 40X_{46}C_{02} + 40X_{47}C_{02} + 40X_{48}C_{02} + 128.57X_{66}C_{02} + 128.57X_{67}C_{02} + 28.13X_{69}C_{02} + 26.09X_{70}C_{02} + 30X_{77}C_{02} + 30X_{79}C_{02} + 59.02X_{85}C_{02} + 59.02X_{86}C_{02} <= 18144000$	*(Clincher_02)*
$30X_{14}C_{Su} + 20.34X_{17}C_{Su} + 124.14X_{22}C_{Su} + 41.38X_{25}C_{Su} + 40X_{26}C_{Su} + 40X_{27}C_{Su} + 59.02X_{28}C_{Su} + 59.02X_{29}C_{Su} + 36.36X_{37}C_{Su} + 240X_{41}C_{Su} + 40X_{46}C_{Su} + 40X_{47}C_{Su} + 40X_{48}C_{Su} + 60X_{57}C_{Su} + 60X_{58}C_{Su} + 90X_{59}C_{Su} + 90X_{60}C_{Su} + 128.57X_{66}C_{Su} + 128.57X_{67}C_{Su} + 28.13X_{69}C_{Su} + 26.09X_{70}C_{Su} + 40X_{73}C_{Su} + 40X_{74}C_{Su} + 10X_{75}C_{Su} + 10X_{76}C_{Su} + 30X_{77}C_{Su} + 30X_{79}C_{Su} + 59.02X_{85}C_{Su} + 59.02X_{86}C_{Su} <= 256608000$	*(Clincher_Subcon)*
$23X_{37}H_{04} + 180X_{41}H_{04} + 40X_{73}H_{04} + 40X_{74}H_{04} + 40X_{75}H_{04} + 40X_{76}H_{04} <= 2592000$	*(HeatStake_04)*
$60X_{28}H_{05} + 60X_{29}H_{05} + 60X_{85}H_{05} + 60X_{86}H_{05} <= 2592000$	*(HeatStake_05)*
$120X_{22}H_{06} + 28.13X_{37}H_{06} + 50X_{57}H_{06} + 50X_{58}H_{06} + 20X_{69}H_{06} + 27.07X_{70}H_{06} <= 2592000$	*(HeatStake_06)*
$21X_{17}H_{07} + 72X_{57}H_{07} + 72X_{58}H_{07} + 60X_{59}H_{07} + 60X_{60}H_{07} + 65X_{66}H_{07} + 65X_{67}H_{07} <= 2592000$	*(HeatStake_07)*
$32X_{17}H_{08} + 65X_{57}H_{08} + 65X_{58}H_{08} + 55X_{59}H_{08} + 55X_{60}H_{08} + 60X_{66}H_{08} + 60X_{67}H_{08} <= 2592000$	*(HeatStake_08)*
$44X_{57}H_{09} + 44X_{58}H_{09} + 60X_{73}H_{09} + 60X_{74}H_{09} + 60X_{75}H_{09} + 60X_{76}H_{09} <= 2592000$	*(HeatStake_09)*
$19.78X_{17}H_{10} <= 2592000$	*(HeatStake_10)*
$19.78X_{17}H_{Su} + 120X_{22}H_{Su} + 60X_{28}H_{Su} + 60X_{29}H_{Su} + 23X_{37}H_{Su} + 180X_{41}H_{Su} + 44X_{57}H_{Su} + 44X_{58}H_{Su} + 55X_{59}H_{Su} + 55X_{60}H_{Su} + 60X_{66}H_{Su} + 60X_{67}H_{Su} + 20X_{69}H_{Su} + 27.07X_{70}H_{Su} + 40X_{73}H_{Su} + 40X_{74}H_{Su} + 40X_{75}H_{Su} + 40X_{76}H_{Su} + 60X_{85}H_{Su} + 60X_{86}H_{Su} <= 256608000$	*(HeatStake_Subcon)*
$25X_{37}T_{04} + 30.51X_{41}T_{04} + 30X_{73}T_{04} + 30X_{74}T_{04} + 30X_{75}T_{04} + 30X_{76}T_{04} <= 2592000$	*(Tester_04)*
$40X_{28}T_{05} + 40X_{29}T_{05} + 40X_{85}T_{05} + 40X_{86}T_{05} <= 2592000$	*(Tester_05)*
$30X_{22}T_{06} + 21.95X_{37}T_{06} + 48X_{57}T_{06} + 48X_{58}T_{06} + 21.95X_{69}T_{06} + 21.95X_{70}T_{06} <= 2592000$	*(Tester_06)*
$15X_{17}T_{07} + 52X_{57}T_{07} + 52X_{58}T_{07} + 36X_{59}T_{07} + 36X_{60}T_{07} + 42X_{66}T_{07} + 42X_{67}T_{07} <= 2592000$	*(Tester_07)*
$13X_{17}T_{08} + 60X_{57}T_{08} + 60X_{58}T_{08} + 32X_{59}T_{08} + 32X_{60}T_{08} + 42X_{66}T_{08} + 42X_{67}T_{08} <= 2592000$	*(Tester_08)*
$41X_{57}T_{09} + 41X_{58}T_{09} + 30X_{73}T_{09} + 30X_{74}T_{09} + 30X_{75}T_{09} + 30X_{76}T_{09} <= 2592000$	*(Tester_09)*
$12.33X_{17}T_{10} <= 2592000$	*(Tester_10)*
$12.33X_{17}T_{Su} + 30X_{22}T_{Su} + 40X_{28}T_{Su} + 40X_{29}T_{Su} + 21.95X_{37}T_{Su} + 30.51X_{41}T_{Su} + 41X_{57}T_{Su} + 41X_{58}T_{Su} + 32X_{59}T_{Su} + 32X_{60}T_{Su} + 42X_{66}T_{Su} + 42X_{67}T_{Su} + 21.95X_{69}T_{Su} + 21.95X_{70}T_{Su} + 30X_{73}T_{Su} + 30X_{74}T_{Su} + 30X_{75}T_{Su} + 30X_{76}T_{Su} + 40X_{85}T_{Su} + 40X_{86}T_{Su} <= 256608000$	*(Tester_Subcon)*

Constraint II: The total quantity of each product allocated in each process must be the same as the demand provided

$X_{14}P_{01} + X_{14}P_{Su} = 0$	*(Product_14 - Pressing)*	$X_{59}T_{07} + X_{59}T_{08} + X_{59}T_{Su} = 11659$	*(Product_59 - Testing)*
$X_{14}C_{02} + X_{14}C_{Su} = 0$	*(Product_14 - Clinching)*	$X_{60}P_{01} + X_{60}P_{Su} = 17134$	*(Product_60 - Pressing)*
$X_{17}P_{01} + X_{17}P_{Su} = 181431$	*(Product_17 - Pressing)*	$X_{60}C_{01} + X_{60}C_{Su} = 17134$	*(Product_60 - Clinching)*
$X_{17}C_{02} + X_{17}C_{Su} = 181431$	*(Product_17 - Clinching)*	$X_{60}H_{07} + X_{60}H_{08} + X_{60}H_{Su} = 17134$	*(Product_60 - HeatStaking)*
$X_{17}H_{07} + X_{17}H_{08} + X_{17}H_{10} + X_{17}H_{Su} = 181431$	*(Product_17 - HeatStaking)*	$X_{60}T_{07} + X_{60}T_{08} + X_{60}T_{Su} = 17134$	*(Product_60 - Testing)*
$X_{17}T_{07} + X_{17}T_{08} + X_{17}T_{10} + X_{17}T_{Su} = 181431$	*(Product_17 - Testing)*	$X_{66}P_{01} + X_{66}P_{Su} = 8791$	*(Product_66 - Pressing)*
$X_{22}P_{01} + X_{22}P_{Su} = 3416$	*(Product_22 - Pressing)*	$X_{66}C_{02} + X_{66}C_{Su} = 8791$	*(Product_66 - Clinching)*
$X_{22}C_{02} + X_{22}C_{Su} = 3416$	*(Product_22 - Clinching)*	$X_{66}H_{07} + X_{66}H_{08} + X_{66}H_{Su} = 8791$	*(Product_66 - HeatStaking)*
$X_{22}H_{06} + X_{22}H_{Su} = 3416$	*(Product_22 - HeatStaking)*	$X_{66}T_{07} + X_{66}T_{08} + X_{66}T_{Su} = 8791$	*(Product_66 - Testing)*
$X_{22}T_{06} + X_{22}T_{Su} = 3416$	*(Product_22 - Testing)*	$X_{67}P_{01} + X_{67}P_{Su} = 1706$	*(Product_67 - Pressing)*
$X_{25}P_{01} + X_{25}P_{Su} = 0$	*(Product_25 - Pressing)*	$X_{67}C_{02} + X_{67}C_{Su} = 1706$	*(Product_67 - Clinching)*

$X_{25}C_{02} + X_{25}Csu = 0$ (Product_25 - Clinching)

$X_{26}P_{01} + X_{26}Psu = 0$ (Product_26 - Pressing)

$X_{26}C_{02} + X_{26}Csu = 0$ (Product_26 - Clinching)

$X_{27}P_{01} + X_{27}Psu = 0$ (Product_27 - Pressing)

$X_{27}C_{02} + X_{27}Csu = 0$ (Product_27 - Clinching)

$X_{28}P_{01} + X_{28}Psu = 0$ (Product_28 - Pressing)

$X_{28}C_{02} + X_{28}Csu = 0$ (Product_28 - Clinching)

$X_{28}H_{05} + X_{28}Hsu = 0$ (Product_28 - HeatStaking)

$X_{28}T_{05} + X_{28}Tsu = 0$ (Product_28 - Testing)

$X_{29}P_{01} + X_{29}Psu = 0$ (Product_29 - Pressing)

$X_{29}C_{02} + X_{29}Csu = 0$ (Product_29 - Clinching)

$X_{29}H_{05} + X_{29}Hsu = 0$ (Product_29 - HeatStaking)

$X_{29}T_{05} + X_{29}Tsu = 0$ (Product_29 - Testing)

$X_{37}P_{01} + X_{37}Psu = 129851$ (Product_37 - Pressing)

$X_{37}C_{02} + X_{37}Csu = 129851$ (Product_37 - Clinching)

$X_{37}H_{04} + X_{37}H_{06} + X_{37}Hsu = 129851$ (Product_37 - HeatStaking)

$X_{37}T_{04} + X_{37}T_{06} + X_{37}Tsu = 129851$ (Product_37 - Testing)

$X_{41}P_{01} + X_{41}Psu = 28$ (Product_41 - Pressing)

$X_{41}C_{02} + X_{41}Csu = 28$ (Product_41 - Clinching)

$X_{41}H_{04} + X_{41}Hsu = 28$ (Product_41 - HeatStaking)

$X_{41}T_{04} + X_{41}Tsu = 28$ (Product_41 - Testing)

$X_{46}P_{01} + X_{46}Psu = 0$ (Product_46 - Pressing)

$X_{46}C_{02} + X_{46}Csu = 0$ (Product_46 - Clinching)

$X_{47}P_{01} + X_{47}Psu = 0$ (Product_47 - Pressing)

$X_{47}C_{02} + X_{47}Csu = 0$ (Product_47 - Clinching)

$X_{48}P_{01} + X_{48}Psu = 0$ (Product_48 - Pressing)

$X_{48}C_{02} + X_{48}Csu = 0$ (Product_48 - Clinching)

$X_{57}P_{01} + X_{57}Psu = 15022$ (Product_57 - Pressing)

$X_{57}C_{01} + X_{57}Csu = 15022$ (Product_57 - Clinching)

$X_{57}H_{06} + X_{57}H_{07} + X_{57}H_{08} + X_{57}H_{09} + X_{57}Hsu = 15022$ (Product_57 - HeatStaking)

$X_{57}T_{06} + X_{57}T_{07} + X_{57}T_{08} + X_{57}T_{09} + X_{57}Tsu = 15022$ (Product_57 - Testing)

$X_{58}P_{01} + X_{58}Psu = 0$ (Product_58 - Pressing)

$X_{58}C_{01} + X_{58}Csu = 0$ (Product_58 - Clinching)

$X_{58}H_{06} + X_{58}H_{07} + X_{58}H_{08} + X_{58}H_{09} + X_{58}Hsu = 0$ (Product_58 - HeatStaking)

$X_{58}T_{06} + X_{58}T_{07} + X_{58}T_{08} + X_{58}T_{09} + X_{58}Tsu = 0$ (Product_58 - Testing)

$X_{59}P_{01} + X_{59}Psu = 11659$ (Product_59 - Pressing)

$X_{59}C_{01} + X_{59}Csu = 11659$ (Product_59 - Clinching)

$X_{59}H_{07} + X_{59}H_{08} + X_{59}Hsu = 11659$ (Product_59 - HeatStaking)

$X_{67}H_{07} + X_{67}H_{08} + X_{67}Hsu = 1706$ (Product_67 - HeatStaking)

$X_{67}T_{07} + X_{67}T_{08} + X_{67}Tsu = 1706$ (Product_67 - Testing)

$X_{69}P_{01} + X_{69}Psu = 316480$ (Product_69 - Pressing)

$X_{69}C_{02} + X_{69}Csu = 316480$ (Product_69 - Clinching)

$X_{69}H_{06} + X_{69}Hsu = 316480$ (Product_69 - HeatStaking)

$X_{69}T_{06} + X_{69}Tsu = 316480$ (Product_69 - Testing)

$X_{70}P_{01} + X_{70}Psu = 73389$ (Product_70 - Pressing)

$X_{70}C_{02} + X_{70}Csu = 73389$ (Product_70 - Clinching)

$X_{70}H_{06} + X_{70}Hsu = 73389$ (Product_70 - HeatStaking)

$X_{70}T_{06} + X_{70}Tsu = 73389$ (Product_70 - Testing)

$X_{73}P_{01} + X_{73}Psu = 18601$ (Product_73 - Pressing)

$X_{73}C_{01} + X_{73}Csu = 18601$ (Product_73 - Clinching)

$X_{73}H_{04} + X_{73}H_{09} + X_{73}Hsu = 18601$ (Product_73 - HeatStaking)

$X_{73}T_{04} + X_{73}T_{09} + X_{73}Tsu = 18601$ (Product_73 - Testing)

$X_{74}P_{01} + X_{74}Psu = 13851$ (Product_74 - Pressing)

$X_{74}C_{01} + X_{74}Csu = 13851$ (Product_74 - Clinching)

$X_{74}H_{04} + X_{74}H_{09} + X_{74}Hsu = 13851$ (Product_74 - HeatStaking)

$X_{74}T_{04} + X_{74}T_{09} + X_{74}Tsu = 13851$ (Product_74 - Testing)

$X_{75}P_{01} + X_{75}Psu = 9008$ (Product_75 - Pressing)

$X_{75}C_{01} + X_{75}Csu = 9008$ (Product_75 - Clinching)

$X_{75}H_{04} + X_{75}H_{09} + X_{75}Hsu = 9008$ (Product_75 - HeatStaking)

$X_{75}T_{04} + X_{75}T_{09} + X_{75}Tsu = 9008$ (Product_75 - Testing)

$X_{76}P_{01} + X_{76}Psu = 12833$ (Product_76 - Pressing)

$X_{76}C_{01} + X_{76}Csu = 12833$ (Product_76 - Clinching)

$X_{76}H_{04} + X_{76}H_{09} + X_{76}Hsu = 12833$ (Product_76 - HeatStaking)

$X_{76}T_{04} + X_{76}T_{09} + X_{76}Tsu = 12833$ (Product_76 - Testing)

$X_{77}P_{01} + X_{77}Psu = 0$ (Product_77 - Pressing)

$X_{77}C_{02} + X_{77}Csu = 0$ (Product_77 - Clinching)

$X_{79}P_{01} + X_{79}Psu = 0$ (Product_79 - Pressing)

$X_{79}C_{02} + X_{79}Csu = 0$ (Product_79 - Clinching)

$X_{85}P_{01} + X_{85}Psu = 305$ (Product_85 - Pressing)

$X_{85}C_{02} + X_{85}Csu = 305$ (Product_85 - Clinching)

$X_{85}H_{05} + X_{85}Hsu = 305$ (Product_85 - HeatStaking)

$X_{85}T_{05} + X_{85}Tsu = 305$ (Product_85 - Testing)

$X_{86}P_{01} + X_{86}Psu = 6456$ (Product_86 - Pressing)

$X_{86}C_{02} + X_{86}Csu = 6456$ (Product_86 - Clinching)

$X_{86}H_{05} + X_{86}Hsu = 6456$ (Product_86 - HeatStaking)

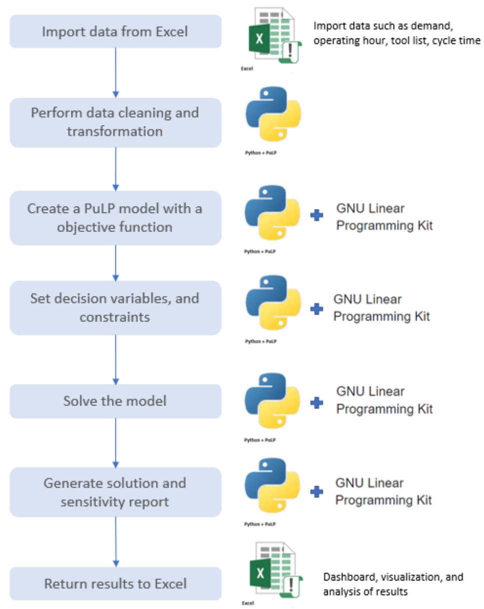
$X_{86}T_{05} + X_{86}Tsu = 6456$ (Product_86 - Testing)

Constraint III: The quantity allocated must be non-negative

$X_{14}P_{01}, X_{14}Psu, X_{14}C_{02}, X_{14}Csu, X_{17}P_{01}, X_{17}Psu, X_{17}C_{02}, X_{17}Csu, X_{17}H_{07}, X_{17}H_{08}, X_{17}H_{10}, X_{17}Hsu, X_{17}T_{07}, X_{17}T_{08}, X_{17}T_{10}, X_{17}Tsu, X_{22}P_{01}, X_{22}Psu, X_{22}C_{02}, X_{22}Csu,$ $X_{22}H_{06}, X_{22}Hsu, X_{22}T_{06}, X_{22}Tsu, X_{25}P_{01}, X_{25}Psu, X_{25}C_{02}, X_{25}Csu, X_{26}P_{01}, X_{26}Psu, X_{26}C_{02}, X_{26}Csu, X_{27}P_{01}, X_{27}Psu, X_{27}C_{02}, X_{27}Csu, X_{28}P_{01}, X_{28}Psu, X_{28}C_{02}, X_{28}Csu,$ $X_{28}H_{05}, X_{28}Hsu, X_{28}T_{05}, X_{28}Tsu, X_{29}P_{01}, X_{29}Psu, X_{29}C_{02}, X_{29}Csu, X_{29}H_{05}, X_{29}Hsu, X_{29}T_{05}, X_{29}Tsu, X_{37}P_{01}, X_{37}Psu, X_{37}C_{02}, X_{37}Csu, X_{37}H_{04}, X_{37}H_{06}, X_{37}Hsu, X_{37}T_{04},$ $X_{37}T_{06}, X_{37}Tsu, X_{41}P_{01}, X_{41}Psu, X_{41}C_{02}, X_{41}Csu, X_{41}H_{04}, X_{41}Hsu, X_{41}T_{04}, X_{41}Tsu, X_{46}P_{01}, X_{46}Psu, X_{46}C_{02}, X_{46}Csu, X_{47}P_{01}, X_{47}Psu, X_{47}C_{02}, X_{47}Csu, X_{48}P_{01}, X_{48}Psu,$ $X_{48}C_{02}, X_{48}Csu, X_{57}P_{01}, X_{57}Psu, X_{57}C_{01}, X_{57}Csu, X_{57}H_{06}, X_{57}H_{07}, X_{57}H_{08}, X_{57}H_{09}, X_{57}Hsu, X_{57}T_{06}, X_{57}T_{07}, X_{57}T_{08}, X_{57}T_{09}, X_{57}Tsu, X_{58}P_{01}, X_{58}Psu, X_{58}C_{01}, X_{58}Csu,$ $X_{58}H_{06}, X_{58}H_{07}, X_{58}H_{08}, X_{58}H_{09}, X_{58}Hsu, X_{58}T_{06}, X_{58}T_{07}, X_{58}T_{08}, X_{58}T_{09}, X_{58}Tsu, X_{59}P_{01}, X_{59}Psu, X_{59}C_{01}, X_{59}Csu, X_{59}H_{07}, X_{59}H_{08}, X_{59}Hsu, X_{59}T_{07}, X_{59}T_{08}, X_{59}Tsu,$ $X_{60}P_{01}, X_{60}Psu, X_{60}C_{01}, X_{60}Csu, X_{60}H_{07}, X_{60}H_{08}, X_{60}Hsu, X_{60}T_{07}, X_{60}T_{08}, X_{60}Tsu, X_{66}P_{01}, X_{66}Psu, X_{66}C_{02}, X_{66}Csu, X_{66}H_{07}, X_{66}H_{08}, X_{66}Hsu, X_{66}T_{07}, X_{66}T_{08}, X_{66}Tsu,$ $X_{67}P_{01}, X_{67}Psu, X_{67}C_{02}, X_{67}Csu, X_{67}H_{07}, X_{67}H_{08}, X_{67}Hsu, X_{67}T_{07}, X_{67}T_{08}, X_{67}Tsu, X_{69}P_{01}, X_{69}Psu, X_{69}C_{02}, X_{69}Csu, X_{69}H_{06}, X_{69}Hsu, X_{69}T_{06}, X_{69}Tsu, X_{70}P_{01}, X_{70}Psu,$ $X_{70}C_{02}, X_{70}Csu, X_{70}H_{06}, X_{70}Hsu, X_{70}T_{06}, X_{70}Tsu, X_{73}P_{01}, X_{73}Psu, X_{73}C_{01}, X_{73}Csu, X_{73}H_{04}, X_{73}H_{09}, X_{73}Hsu, X_{73}T_{04}, X_{73}T_{09}, X_{73}Tsu, X_{74}P_{01}, X_{74}Psu, X_{74}C_{01}, X_{74}Csu,$ $X_{74}H_{04}, X_{74}H_{09}, X_{74}Hsu, X_{74}T_{04}, X_{74}T_{09}, X_{74}Tsu, X_{75}P_{01}, X_{75}Psu, X_{75}C_{01}, X_{75}Csu, X_{75}H_{04}, X_{75}H_{09}, X_{75}Hsu, X_{75}T_{04}, X_{75}T_{09}, X_{75}Tsu, X_{76}P_{01}, X_{76}Psu, X_{76}C_{01}, X_{76}Csu,$ $X_{76}H_{04}, X_{76}H_{09}, X_{76}Hsu, X_{76}T_{04}, X_{76}T_{09}, X_{76}Tsu, X_{77}P_{01}, X_{77}Psu, X_{77}C_{02}, X_{77}Csu, X_{79}P_{01}, X_{79}Psu, X_{79}C_{02}, X_{79}Csu, X_{85}P_{01}, X_{85}Psu, X_{85}C_{02}, X_{85}Csu, X_{85}H_{05}, X_{85}Hsu,$ $X_{85}T_{05}, X_{85}Tsu, X_{86}P_{01}, X_{86}Psu, X_{86}C_{02}, X_{86}Csu, X_{86}H_{05}, X_{86}Hsu, X_{86}T_{05}, X_{86}Tsu >= 0$

APPLICATION

Technique and Algorithm



The model is solved using Python PuLP. The PuLP is an open-source linear programming package for Python. The PuLP can be installed using pip. PuLP supports open-source linear programming solvers such as CBC and GLPK, as well as commercial solvers such as Gurobi and IBM's CPLEX [3]. The default solver is CBC, which comes packaged with PuLP upon installation. However, we are using GLPK as our PuLP LP solver because GLPK can generate sensitivity reports which we required when doing what-if or sensitivity analysis.

Whilst the LP formula as defined in section 2 could be formulated into Python, there is a more efficient way that we choose to use in this project. The decision variables, objective, and constraints all could be formulated into PuLP model directly using list or dictionary comprehension from our Excel data. Hence, no manual typing of the LP formula (like section 2) is required. The activities involved in solving this model are presented in Figure 3.1.

All the data provided by Company XYZ such as demand, operating hour, tool list, and cycle time are kept in one Excel Workbook. Hence in the first step, we use Python to import all these data. The next step deals with data cleaning and transformation of these imported data. In this step, we need to process our imported data and prepare the following things:

- The set of decision variables
- A linear objective function to minimize
- The set of linear constraints on those variables

After data preprocessing we proceed to create a PuLP model instance. Notice that the problem constructor receives a problem name and LpMinimize, which means we want to minimize our objective function. In our case, this is the cost of manufacturing different types of products.

In the next step, we define the decision variables. In PuLP, a useful way to define variables in PuLP is using the dictionary function. This can be very useful for our project as we need to define a large number of variables of the same type and bounds. variable names would be a list of keys for the dictionary which we created in the previous data preprocessing step. So based on the project objectives, the decision variables for the model are the quantity of each product allocated on each tool. We also build up our constraints in this step. The constraint III which is non-negativity restrictions are pre-included into solver by itself. Hence, we only need to build up the first two constraints:

- Constraint I: The total time used by each tool must not exceed the tool capacity provided
- Constraint II: The total quantity of each product allocated in each process must be the same as the demand provided

After we defined everything necessary in our linear programming problem, we call the solve method using GLPK to solve our cost minimization problem. Finally, the solution and sensitivity report generated by PuLP are exported to Excel in which we visualize our results and analysis there.

Results and Discussion

Optimum Solution

The solver was able to find an optimal solution for our cost minimization problem. The demand for June 19 can be produced using the total cost of $10540932. The detailed cost of each process is presented in Table 3.1.

Table 3.1: Cost of Each Process

Process		Cost
Pressing	$	1,036,894
Clinching	$	1,813,101
HeatStaking	$	5,757,345
Testing	$	1,933,592
Total Cost (Objective Function)	**$**	**10,540,932**

Table 3.2: Quantity of Each Product Allocated on Each Tool

product	*demand (June 19)*	*HydraulicPress_01*	*HydraulicPress_Subcon*	*Clincher_01*	*Clincher_02*	*Clincher_Subcon*	*HeatStake_10*	*HeatStake_07*	*HeatStake_08*	*HeatStake_Subcon*	*HeatStake_06*	*HeatStake_05*	*HeatStake_04*	*HeatStake_09*	*Tester_10*	*Tester_07*	*Tester_08*	*Tester_Subcon*	*Tester_06*	*Tester_05*	*Tester_04*	*Tester_09*
Product_14	0	0	0		0	0																
Product_17	181431	181431	0		181431	0	126239	0	55192	0					181431	0	0	0				
Product_22	3416	3416	0		0	3416				3416	0							0	3416			
Product_25	0	0	0		0	0																
Product_26	0	0	0		0	0																
Product_27	0	0	0		0	0																
Product_28	0	0	0		0	0				0		0						0		0		
Product_29	0	0	0		0	0				0		0						0		0		
Product_37	129851	129851	0		100341	29510				17155	0		112696					0	26205		103646	
Product_41	28	28	0		0	28				28			0					0			28	
Product_46	0	0	0		0	0																
Product_47	0	0	0		0	0																
Product_48	0	0	0		0	0																
Product_57	15022	15022	0	15022		0		12006	3016	0	0			0		15022	0	0	0			0
Product_58	0	0	0	0		0		0	0	0	0			0		0	0	0	0			0
Product_59	11659	11659	0	11659		0		11659	0	0						11659	0	0				
Product_60	17134	17134	0	17134		0		17134	0	0						17134	0	0				
Product_66	8791	8791	0		0	8791		0	8791	0						8791	0	0				
Product_67	1706	1706	0		0	1706		0	1706	0						1706	0	0				
Product_69	316480	316480	0		316480	0				186880	129600							229525	86955			
Product_70	73389	73389	0		73389	0				73389	0							73389	0			
Product_73	18601	18601	0	18601		0				0			0	18601				0			0	18601
Product_74	13851	13851	0	13851		0				0			0	13851				0			0	13851
Product_75	9008	9008	0	9008		0				0			0	9008				0			0	9008
Product_76	12833	12833	0	12833		0				11093			0	1740				0			0	12833
Product_77	0	0	0		0	0																
Product_79	0	0	0		0	0																
Product_85	305	305	0		0	305				0		305						0		305		
Product_86	6456	6456	0		0	6456				0		6456						0		6456		

It is not enough to simply focus on allocating resources correctly. It is also essential to be able to measure how well resources are being utilized and to make meaningful adjustments. By using the solution obtained from the solver, we further summarize the data into a tool utilization table (Table 3.3). A tool utilization can be calculated by using the formula below:

$$\boldsymbol{tool\ utilisation}\ (\%) = \frac{\boldsymbol{time\ usage\ (s)}}{\boldsymbol{tool\ capacity\ (s)}}\ \boldsymbol{x\ 100\%}$$

$$\boldsymbol{tool\ balance\ time\ (s) = tool\ capacity\ (s) - time\ usage\ (s)}$$

$$\boldsymbol{equivalent\ tool\ balance\ quantity} = \frac{\boldsymbol{tool\ balance\ time\ (s)}}{\boldsymbol{24\ x\ 30\ x\ 3600\ (s)}}$$

The tool utilization summary is very useful for us to further drill down the analysis. For example, by looking at Table 3.3, we observe that some inhouse tools such as HeatStake_05, Tester_05, and Tester_08 are underutilized (utilization < 20%). We can explore undiscovered opportunities for these underutilized tools for more cost reduction. When possible, underutilized resources should be converted for other purposes to maximize resource usage.

Table 3.3: Tool Utilisation Summary

Process	Tool	Time Usage (s)	Tool Capacity (s)	Tool Utilsation	Unit Produced	Tool Balance Time (s)	Equivalent Tool Balance Quantity
Pressing	HydraulicPress_01	43017885	67392000	63.8%	819961	24374115	9.4
Pressing	HydraulicPress_Subcon	0	256608000	0.0%	0	256608000	99.0
Clinching	Clincher_01	5009180	7776000	64.4%	98108	2766820	1.1
Clinching	Clincher_02	18144003	18144000	100.0%	671641	0	0.0
Clinching	Clincher_Subcon	3253626	256608000	1.3%	50212	253354374	97.7
HeatStaking	HeatStake_04	2592008	2592000	100.0%	112696	0	0.0
HeatStaking	HeatStake_05	405660	2592000	15.7%	6761	2186340	0.8
HeatStaking	HeatStake_06	2592000	2592000	100.0%	129600	0	0.0
HeatStaking	HeatStake_07	2591998	2592000	100.0%	40799	2	0.0
HeatStaking	HeatStake_08	2591999	2592000	100.0%	68705	1	0.0
HeatStaking	HeatStake_09	2592000	2592000	100.0%	43200	0	0.0
HeatStaking	HeatStake_10	2499532	2592000	96.4%	126239	92468	0.0
HeatStaking	HeatStake_Subcon	6979694	256608000	2.7%	291961	249628306	96.3
Testing	Tester_04	2592004	2592000	100.0%	103674	0	0.0
Testing	Tester_05	270440	2592000	10.4%	6761	2321560	0.9
Testing	Tester_06	2592000	2592000	100.0%	116576	0	0.0
Testing	Tester_07	2258566	2592000	87.1%	54312	333434	0.1
Testing	Tester_08	0	2592000	0.0%	0	2592000	1.0
Testing	Tester_09	1628790	2592000	62.8%	54293	963210	0.4
Testing	Tester_10	2231601	2592000	86.1%	181431	360399	0.1
Testing	Tester_Subcon	6664108	256608000	2.6%	302914	249943892	96.4

Sensitivity Report

The Sensitivity Report details how changes in the coefficients of the objective function affect the solution and how changes in the constants on the right-hand side of the constraints affect the solution. In this regard, the shadow price for constraints may be used to evaluate this impotent concern. The result of this specific sensitivity analysis is presented in Table 3.4. Technically, the shadow price of the constraint shows the amount by which the optimal Z value will be improved if the constrain allocation increases by one unit. Shadow price analysis is mostly applied to figure out how much cost will be reduced for one additional unit of resource, decision-makers, sometime, might like to know how many resources they are allowed to allocate with no change in the current optimal solution. To find the answers, decision-makers must technically calculate allowable fluctuation in the current optimal solution. This information was given in the right-hand side ranges section of the model output, mentioned in Table 3.4. Upper Allowable Range and Lower Allowable Range in the model output should be considered to obtain the limitations to make the changes with the current basis remaining optimal. For instance, if the right-hand side value of the Clincher_02 – Capacity constraint is increased by one unit (i.e. one second), it can reduce $0.041 more to the cost with no change in the current basis optimal model as long as the increase of RHS 2 still falls within the Upper Allowable Range. If the management wants to reduce more cost in the clinching process, they should consider increasing the capacity of Clincher_02 to 19218200s.

Table 3.4: Sensitivity Report

Constraint Description	Final Value	Shadow Price	RHS 1	RHS 2	Lower Allowable Range	Upper Allowable Range
Clincher_01 - Capacity	5009180	0	0	7776000	3959870	5009180
Clincher_02 - Capacity	18144000	-0.04121	0	18144000	14491600	19218200
Clincher_Subcon - Capacity	3253630	0	0	256608000	3253630	4302940
HeatStake_04 - Capacity	2592000	-0.23478	0	2592000	0	2986570
HeatStake_05 - Capacity	405660	0	0	2592000	387360	405660
HeatStake_06 - Capacity	2592000	-0.255	0	2592000	0	6329600
HeatStake_07 - Capacity	2592000	-0.02821	0	2592000	2426480	2809160
HeatStake_08 - Capacity	2592000	-0.03125	0	2592000	2442570	6631660
HeatStake_09 - Capacity	2592000	-0.05333	0	2592000	2487600	3257580
HeatStake_10 - Capacity	2499540	0	0	2592000	2404110	2982400
HeatStake_Subcon - Capacity	6979690	0	0	256608000	6979690	7049290
HydraulicPress_01 - Capacity	43017900	0	0	67392000	43005400	43017900
HydraulicPress_Subcon - Capacity	0	0	0	256608000	0	12513

Tester_04 - Capacity	2592000	-0.072	0	2592000	418129	3247130
Tester_05 - Capacity	270440	0	0	2592000	258240	270440
Tester_06 - Capacity	2592000	-0.08182	0	2592000	678994	7641550
Tester_07 - Capacity	2258570	0	0	2592000	1477420	2258570
Tester_08 - Capacity	0	0	0	2592000	0	901320
Tester_09 - Capacity	1628790	0	0	2592000	1358550	2244690
Tester_10 - Capacity	2231600	0	0	2592000	0	2231600
Tester_Subcon - Capacity	6664110	0	0	256608000	6664110	6664210
Product_14 - Clinching	0	0	0	0	0	121747
Product_14 - Pressing	0	0	0	0	0	982827
Product_17 - Clinching	181431	3.13654	181431	181431	128516	361353
Product_17 - HeatStaking	181431	6.8	181431	181431	55192	186101
Product_17 - Pressing	181431	1	181431	181431	0	3566720
Product_17 - Testing	181431	1.1	181431	181431	0	210732
Product_22 - Clinching	3416	5.4	3416	3416	0	2044950
Product_22 - HeatStaking	3416	9	3416	3416	0	2083650
Product_22 - Pressing	3416	1.5	3416	3416	0	68867
Product_22 - Testing	3416	5.45455	3416	3416	0	67183
Product_25 - Clinching	0	0	0	0	0	88222
Product_25 - Pressing	0	0	0	0	0	982827
Product_26 - Clinching	0	0	0	0	0	91310
Product_26 - Pressing	0	0	0	0	0	245459
Product_27 - Clinching	0	0	0	0	0	91310
Product_27 - Pressing	0	0	0	0	0	245459
Product_28 - Clinching	0	0	0	0	0	61905
Product_28 - HeatStaking	0	0	0	0	0	36439
Product_28 - Pressing	0	0	0	0	0	982827
Product_28 - Testing	0	0	0	0	0	58039
Product_29 - Clinching	0	0	0	0	0	61905
Product_29 - HeatStaking	0	0	0	0	0	36439
Product_29 - Pressing	0	0	0	0	0	982827
Product_29 - Testing	0	0	0	0	0	58039
Product_37 - Clinching	129851	3	129851	129851	100341	7090140
Product_37 - HeatStaking	129851	10.8	129851	129851	112696	10983300
Product_37 - Pressing	129851	0.3	129851	129851	0	1112680
Product_37 - Testing	129851	4.1	129851	129851	103646	216806
Product_41 - Clinching	28	3	28	28	0	1055670
Product_41 - HeatStaking	28	9.2	28	28	0	1386850
Product_41 - Pressing	28	0.5	28	28	0	54568
Product_41 - Testing	28	4.496	28	28	0	71302
Product_46 - Clinching	0	0	0	0	0	91310
Product_46 - Pressing	0	0	0	0	0	196407
Product_47 - Clinching	0	0	0	0	0	91310
Product_47 - Pressing	0	0	0	0	0	196407
Product_48 - Clinching	0	0	0	0	0	91310
Product_48 - Pressing	0	0	0	0	0	196407
Product_57 - Clinching	15022	1.4	15022	15022	0	61136
Product_57 - HeatStaking	15022	9.33125	15022	15022	12006	17321
Product_57 - Pressing	15022	0.6	15022	15022	0	105296
Product_57 - Testing	15022	2.7	15022	15022	0	21434
Product_58 - Clinching	0	0	0	0	0	46114
Product_58 - HeatStaking	0	0	0	0	0	2299
Product_58 - Pressing	0	0	0	0	0	90274
Product_58 - Testing	0	0	0	0	0	6412
Product_59 - Clinching	11659	1.4	11659	11659	0	42401
Product_59 - HeatStaking	11659	7.39271	11659	11659	8040	14418
Product_59 - Pressing	11659	1	11659	11659	0	69693
Product_59 - Testing	11659	2.9	11659	11659	0	20921
Product_60 - Clinching	17134	1.4	17134	17134	0	47876
Product_60 - HeatStaking	17134	7.39271	17134	17134	13515	19893
Product_60 - Pressing	17134	1	17134	17134	0	75168
Product_60 - Testing	17134	2.9	17134	17134	0	26396
Product_66 - Clinching	8791	2.4	8791	8791	0	1978890
Product_66 - HeatStaking	8791	8.875	8791	8791	0	11281
Product_66 - Pressing	8791	0.4	8791	8791	0	90038
Product_66 - Testing	8791	1.2	8791	8791	0	16730
Product_67 - Clinching	1706	2.4	1706	1706	0	1971800
Product_67 - HeatStaking	1706	8.875	1706	1706	0	4196
Product_67 - Pressing	1706	0.4	1706	1706	0	82953
Product_67 - Testing	1706	1.2	1706	1706	0	9645
Product_69 - Clinching	316480	3.55797	316480	316480	278253	446459
Product_69 - HeatStaking	316480	10.2	316480	316480	129600	12797900
Product_69 - Pressing	316480	1.7	316480	316480	0	1299310
Product_69 - Testing	316480	3.6	316480	316480	86955	11677600
Product_70 - Clinching	73389	2.87555	73389	73389	32233	213328
Product_70 - HeatStaking	73389	6.8	73389	73389	0	9284770
Product_70 - Pressing	73389	2	73389	73389	0	1056220

Product_70 - Testing	73389	2.2	73389	73389	0	11434500
Product_73 - Clinching	18601	2.4	18601	18601	0	87772
Product_73 - HeatStaking	18601	9.8	18601	18601	7508	20341
Product_73 - Pressing	18601	1.3	18601	18601	0	141331
Product_73 - Testing	18601	2.6	18601	18601	0	50708
Product_74 - Clinching	13851	2.4	13851	13851	0	83022
Product_74 - HeatStaking	13851	9.8	13851	13851	2758	15591
Product_74 - Pressing	13851	1.3	13851	13851	0	136581
Product_74 - Testing	13851	2.6	13851	13851	0	45958
Product_75 - Clinching	9008	2.4	9008	9008	0	285690
Product_75 - HeatStaking	9008	6.4	9008	9008	0	10748
Product_75 - Pressing	9008	1.6	9008	9008	0	336177
Product_75 - Testing	9008	1.9	9008	9008	0	41115
Product_76 - Clinching	12833	2.4	12833	12833	0	289515
Product_76 - HeatStaking	12833	6.4	12833	12833	1740	6253540
Product_76 - Pressing	12833	1.6	12833	12833	0	340002
Product_76 - Testing	12833	1.9	12833	12833	0	44940
Product_77 - Clinching	0	0	0	0	0	121747
Product_77 - Pressing	0	0	0	0	0	490425
Product_79 - Clinching	0	0	0	0	0	121747
Product_79 - Pressing	0	0	0	0	0	490425
Product_85 - Clinching	305	4.4	305	305	0	4294450
Product_85 - HeatStaking	305	3.1	305	305	0	36744
Product_85 - Pressing	305	1.1	305	305	0	983132
Product_85 - Testing	305	2.7	305	305	0	58344
Product_86 - Clinching	6456	4.4	6456	6456	0	4300600
Product_86 - HeatStaking	6456	3.1	6456	6456	0	42895
Product_86 - Pressing	6456	1.1	6456	6456	0	989283
Product_86 - Testing	6456	2.7	6456	6456	0	64495

Managerial Implications: What-If Analysis

To improve the policymaking and capacity planning process in the Company XYZ, the model described here can also be used by decision-makers to quickly analyze several what-if scenarios. Based on the findings of the study, a considerable amount of unused tool capacity is remaining in the process. It indicates the unnecessary cost in the production process. Hence, the management should highly take action to eliminate the unnecessary cost to improve production productivity. The strategy could be made by referring to the sensitivity report.

For example, the heat staking manager proposes the conversion of low utilization HeatStake_05 into the same profile with HeatStake_06 would reduce the total cost. By checking the sensitivity report, the shadow price of HeatStake_06 is -$0.255 and the upper range is 6329600s which meant that we could reduce the total cost by increasing the available time of HeatStake_06. Decrease in cost = (6329600s-259200s) x (-$0.255) = (-$9530880) which meant that if we could increase our HeatStake_06 available time from 2592000s(1 tool) to 6329600s(2.44 tools), we could reduce the total cost by $9530880. HeatStake_05 has very less utilization (only used 405660s). The equipment engineering told us that they can make HeatStake_05 having the same profile (same recipe, performance, product cost) with HeatStake_06. However, they need 4 days (345600) to reconfigure the HeatStake_05 which meant that after deducting 345600s for the setup time, we still have a balance 1840740s (2592000s-405660s-345600s). The total setup cost (labor cost, spare part cost) is about $50000. Hence after reconfiguration of HeatStake_05 into the same profile with HeatStake_06, we can assume that capacity of HeatStake_06 now is increased by 1840740s. We can expect cost reduction of about (1840740 x $0.255) - $50000 = $419389. The proposal is feasible.

ORGANIZATION OF BUSINESS IDEA

Preliminary Business Model

A business model is a framework for how a company will create value. Ultimately, it distills the potential of a business down to its essence. It answers fundamental questions about the problem we are going to solve, how we will solve it and the growth opportunity within a given market. A business model should answer important questions about our business and set out a strong vision for the business. The key components of a business model should include relating to our target customers, the market, organization strengths and challenges, essential elements of the product, and how it will be sold [4]. Here is a list of essential components included in our business model:

Table 4.1: Our Business Model Components

Component	Definition
Vision	A high-level introduction to the company and business model
Objectives	Definition of the top-level goals and how they will be measured
Customer targets and challenges	Description of the different types of customers to be targeted and their pain points
Solution	How the product will solve those pain points
Value	The key characteristics that differentiate the product offering
Pricing	A view into what the solution will cost and how it will be sold
Go-to-market	Channels that will be used to reach and sell to customers
Investment required	Costs required to make the solution successful

Vision

Our vision is to provide our customers with a strategic partner who is focused on providing value-added consulting services in the areas of capacity planning and resource allocation strategy through a system of proven tools that produce measurable results.

Objectives

Our goal is to become number one in capacity planning and resource allocation consulting services provider. We have the aim to capture at least 50% of the market share in Malaysia

Customer Targets and Challenges

Our customer targets are the manufacturing company that often faces capacity planning problems due to their diversity of the products, complicated manufacturing flow, and the fluctuation of the demand stream. They are very likely to have a hard time minimizing the discrepancies between their capacity and the demands of their customers. Furthermore, they are also quite likely to use the trial-and-error method which is very time consuming or based on their previous experiences to find a proper capacity plan. Suppose they want to find a proper capacity plan, they would just try several different combinations, check the cost, and calculate the resource utilization. Since all possible combinations are not tried, the optimum combination will probably not be found. As a result, inadequate capacity planning can lead to the loss of the customer and business meanwhile excess capacity can drain the company's resources and prevent investments into more lucrative ventures

Solution

An essential tool in Supply Chain Analytics is using optimization analysis to assist in decision making. Our automated model will transform supply chain activities from guessing to ones that make a decision using data. It allows our clients to speed up their capacity planning process and also find a feasible solution based on minimum cost.

Value

Modeling is Fast and Easy

- Users will find our automated capacity model to be an easy and powerful tool for solving optimization problems. Most users can begin modeling within minutes of installation.

Large Scale Optimization Models

- Our automated solver will efficiently solve our client's biggest, toughest models. The linear solvers in our automated model have been designed for large scale commercial use and field-tested on real-world cases.

Convenient Data Options

- Our automated model takes the time and hassle out of managing the client's data. It allows the client to build models that pull information directly from the data stored in spreadsheets. Similarly, it can output solution and sensitivity report right into spreadsheets making it easier for them to generate reports in the application of their choice.

Pricing

Our pricing model would be subscription-based. In the subscription-based pricing model, customers pay regularly for our service or product. Subscription pricing is different than pricing for traditional products, as pricing is often based on the length of the subscription, making longer subscriptions the cheapest options.

Go-to-market

In order to reach and sell to customers, we will adopt a wide range of marketing strategies:

Offer a free trial

- Especially if we are a small, unknown company, we need to provide something to help potential customers see that our product is not a scam, and it will work for them.

Include A Video of How Our Product Works

- We have a two-minute video explaining our product or service someplace obvious on our website. The animation is great for a simple product breakdown, and a video of employees can give a human side to technical service folks might not understand.

Solicit Independent Third-Party Reviews

- Anyone can tell you their products are worth buying, so it is best to have an honest third party referral. We encourage our customers to tell their stories of why they selected our product and how it meets their challenge is the best way to get our message out and sell our product. We are capturing these stories in case studies, an interactive online forum, or blog postings.

Market Across Channels

- Effective multichannel marketing programs can accelerate the adoption of digital services. For example, we are using a mix of marketing strategies--advertising (online, affiliate, print), co-op programs with content developers, consumer electronics partnerships, and freemium/trial promotions--to grow our customer base.

Search Forums To Find Prospective Customers

- Forums are great because people looking to buy products often go there to ask questions. We can use the search box to locate prospects that have asked questions about our type of product. We will type in phrases about our kind of offering, and see in the results who have asked questions about it. We respond to people with advice on how to solve their problems, along with a link for them to check out our product.

Investment Required

Very minimal investment is required to make our solution works as the software to build the LP model and data processing come from free and open-source projects such as Python and GLPK.

SWOT ANALYSIS

What is SWOT?

SWOT stands for strengths, weaknesses, opportunities, and threats. SWOT analysis is just one of the tools in a project manager's toolbox, along with things such as project management software and SMART criteria, and it can be very helpful during strategic planning and decision making. SWOT can be used to analyze teams, projects, businesses, organizations, or even individual products [5]. Here's a quick glance at each element of SWOT of our solution.

S STRENGTHS	W WEAKNESSES	O OPPORTUNITIES	T THREATS
• *Save time and effort* • *Balanced workload throughout available resources and possible early release of equipment*	• *Strict conditions/rules needed on data collection and running the model for analysis*	• *Distribution of tasks evenly to resources can help in freeing up some resources sooner* • *Aids in checking incoming orders whether demand is over capacity & deadline of order delivery*	• *Possibility of the machines breaking down, more than one at a time* • *Economic outlook is in uncertainty*

Strengths

Save Time And Effort

By implementing an automated model, the capacity planning for a particular month and even several months that are ahead can be completed in seconds only with a few tweaks and clicks, compared to manually assigning the resources with available tasks. A fixed set of results whereby which resource can be allocated with a particular amount and whether the assignment will be effective can be extracted earlier in the planning stage instead of the current trial and error method where we can only obtain the result of the effectiveness of the resource allocation only after the plan has been implemented. Since currently the capacity planning is being done manually and based on trial and error method, it can be deduced the application of a linear programming model to solve this problem will allow Company XYZ to save both time and effort.

Balanced Workload Throughout Available Resources & Possible Early Release Of Equipment

This is highly likely to be connected to the effectiveness of the strength mentioned above, by using the model being proposed as the solution, each of the available resources will be assigned with almost equal tasks. The data analysis will allow the resources to be utilized to the maximum with no doubts or guesses. This will lead to each resource having a balanced workload fitting to its' capacity. For example, there is 11 equipment under the testing process: namely from Tester_01 to Tester_11. Currently may be via manual planning or trial and error, not all the equipment is utilized, instead, a selected few based on their availability is used to its maximum capacity. With the help of the capacity planning proposed, the same task can be distributed to all the available machines instead of with foresight on which combination is suitable and will have a better output. This may result in faster completion of the requested process leading to an earlier release of the machines and allowing the company to move on to the next batch of processing.

Weaknesses

Strict Conditions Or Rules Needed On Data Collection And Running The Model For Analysis

Our weakness in the model is it too emphasizes strict conditions or rules needed on data collection and running the model for analysis. Good conditioning or rules signifies well-structured process flow and meets business expectation. Or else, it may disrupt process flow and might have a false result when reality should be a positive result. For example, data is collected has null values (uncleaned data) may interpret the result incorrectly as there are many possibilities to clean null values data such as removing null values or replace it with median or mean values. Either way for cleaning the null values process has its unique result. However, those results need to signify correctly whether it meets business expectation or directly to wrong path.

Opportunities

Distribution Of Tasks Evenly To Resources Helps To Free Up Some Of The Resources Sooner

The very first opportunity gained from our business idea is the distribution of tasks evenly to resources helps to free up some of the resources sooner. There are 4 important processes namely Clincher, HeatStake, HydraulicPress, and Tester that require all incoming products to undergo these processes. Hence, distributing all these processes equally to different machines able to reduce workload capacity. Thus, those machines that have had complete the process able to move on to the next task. A proper evenly task or process distribution establishes good product on-time delivery and organized workflow with a hassle-free environment.

Aids in checking incoming orders whether demand is over capacity and deadline of order delivery

Aids in checking incoming orders whether demand is over capacity and deadline of order delivery emphasizes the next opportunity point for our business ideas. Capacity planning model comprises data of process flow, product allocation, equipment or tool utilization, constraints, and other important details that help to provide information on whether any incoming product’s demand is over capacity or any nearby product deadlines. This information eventually helps in a managerial decision in the aspect of planning solutions or re-organize workflow to overcome any demand overcapacity issues or meet product deadlines thoroughly. As late product deliverables impact customer dissatisfaction and demand overcapacity risks in business loss. Considering the impact of external factors (demand overcapacity and late deliverables), the capacity planning model improves internal factors such as in-depth checking over available data and well-structured process distribution.

Threats

Possibility Of The Machines Breaking Down, More Than One At A Time

There will be certain periods where each equipment involved in each process must be sent into maintenance. It can be one machine at a time which will have a slightly mild effect on planning or a few of the machines can have the same maintenance period which will possibly cause a greater drawback in capacity planning and resource allocation. Maintenance is usually scheduled, and the dates are noted down beforehand, therefore the shortage of equipment can be handled by planning with the availability of lesser resources beforehand. However, the more critical aspect that can be considered as a threat is the possibility of the machines breaking down at unexpected times and not necessarily only one at a time. This may cause an unforeseen delay which may result in the current resource allocation planning be affected for days or weeks depending on the time taken to restore the affected equipment. Therefore, during planning a certain buffer period based on the equipment capacity estimate must be considered to help soften the blow if such a situation does end up happening in the future.

Economic Outlook Is In Uncertainty

The economic outlook is not predictable, especially in the future. For example, even now the whole world is affected by the Covid-19 pandemic which caused the economic level to drop globally. There is no solid proof that claims situations like this may not happen in the future. A fluctuation in the market will result in a drop in demand which will cause a drop in product orders. These are one of the unavoidable types of situation which is unpredictable and best to be prepared for.

REFERENCES AND APPENDICES

References

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[3] https://benalexkeen.com/linear-programming-with-python-and-pulp-part-2/

[4] https://www.aha.io/roadmapping/guide/product-strategy/what-are-some-examples-of-a-business-model

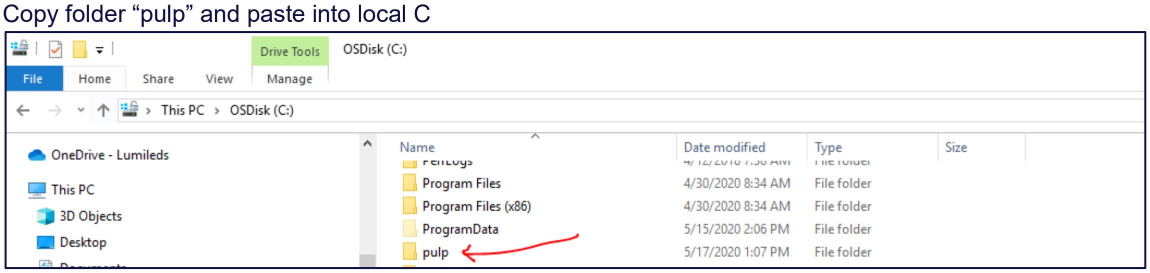
[5] https://blog.capterra.com/s-w-o-t-analysis-examples-for-beginners

Appendices

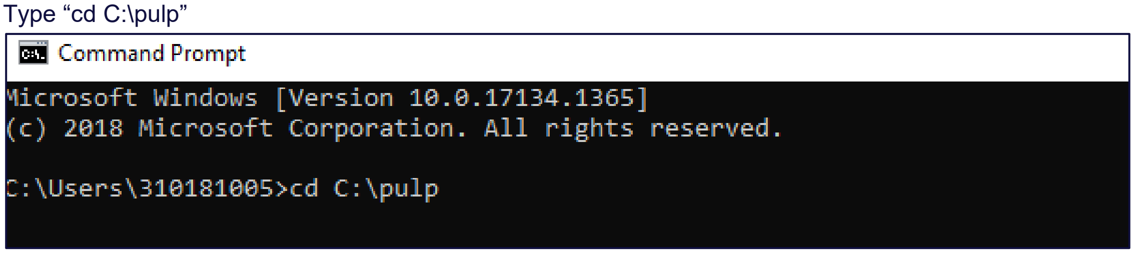
Appendix 01 – Installation Guide

1. Install anaconda.

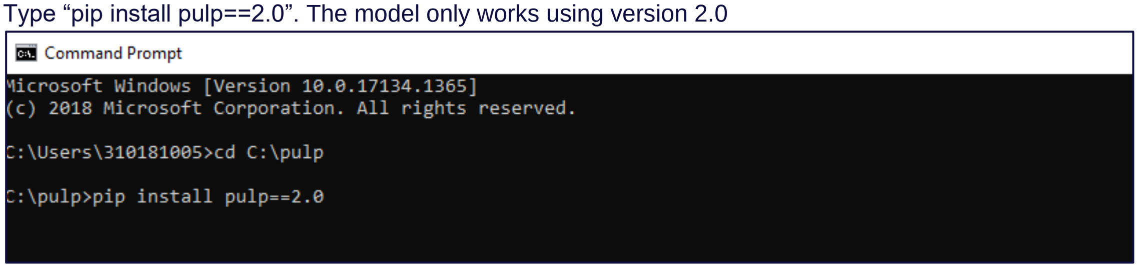
2. Copy folder "pulp" and paste into local C



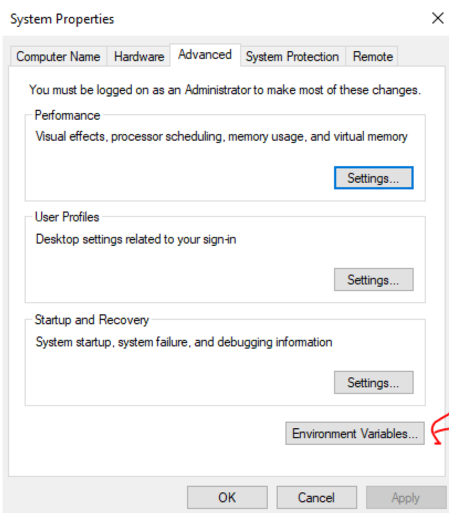
3. Open command prompt
   Type "cd C:\pulp"

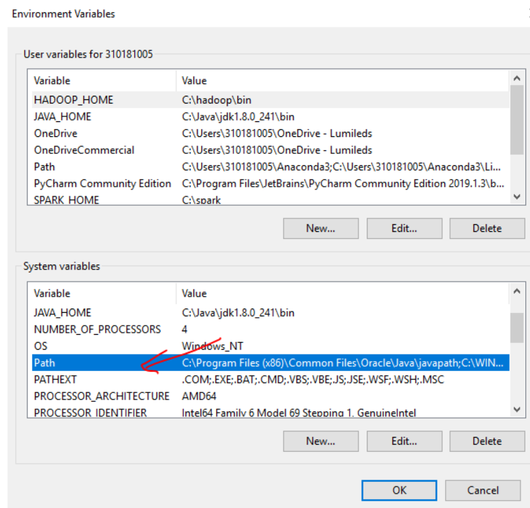


4. Type "pip install pulp==2.0". The model only works using version 2.0

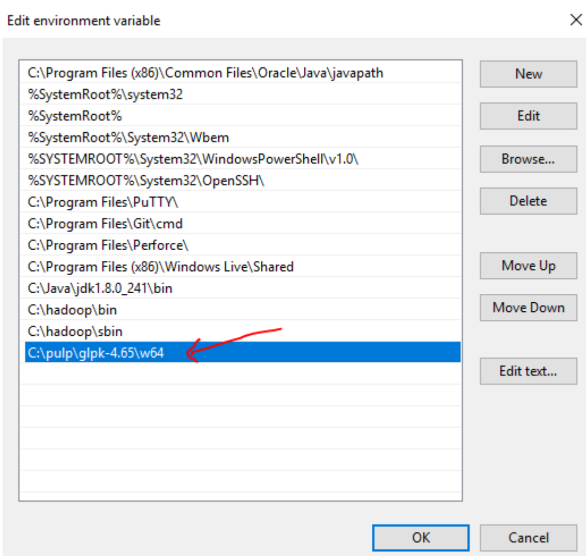


5. Setup GLPK solver in the system path

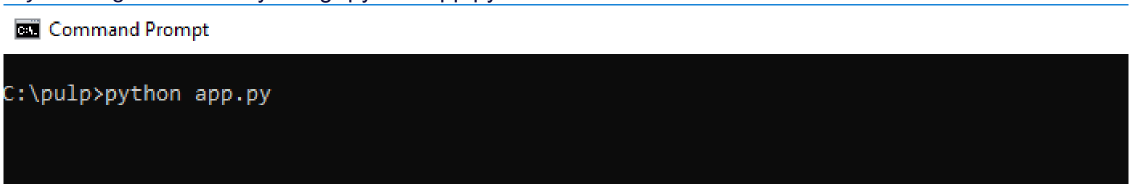




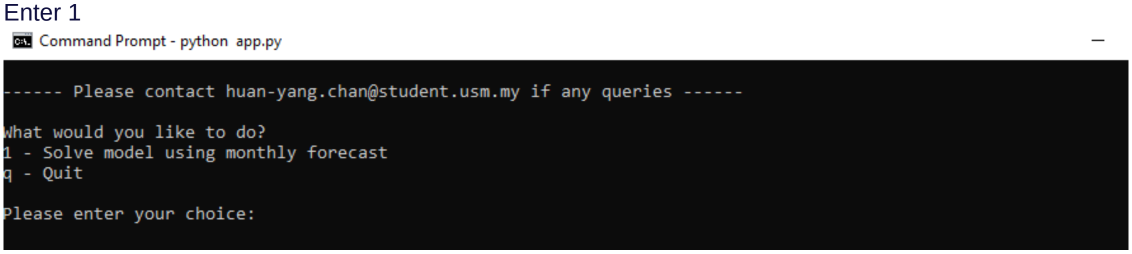
6. Add in the path of GLPK location “C:\pulp\glpk-4.65\w64”
   Click ok – ok - ok to close the box



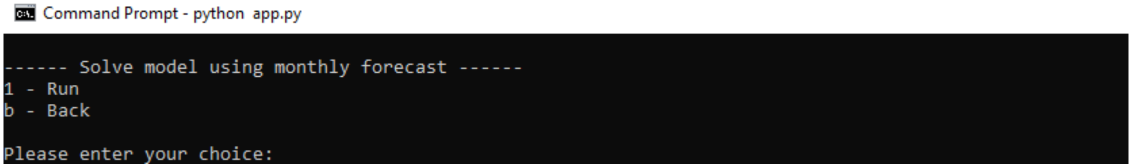
7. Try running the model by using “python app.py”



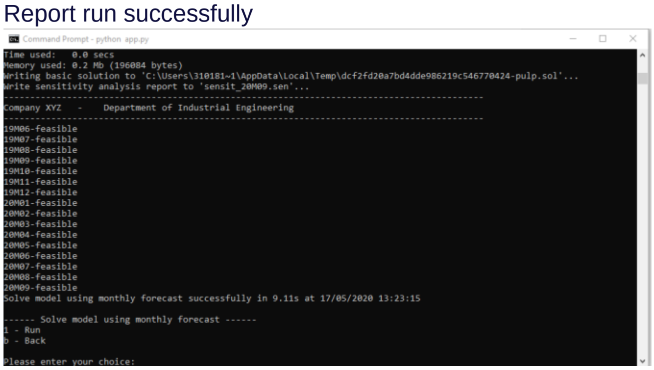
8. Enter 1



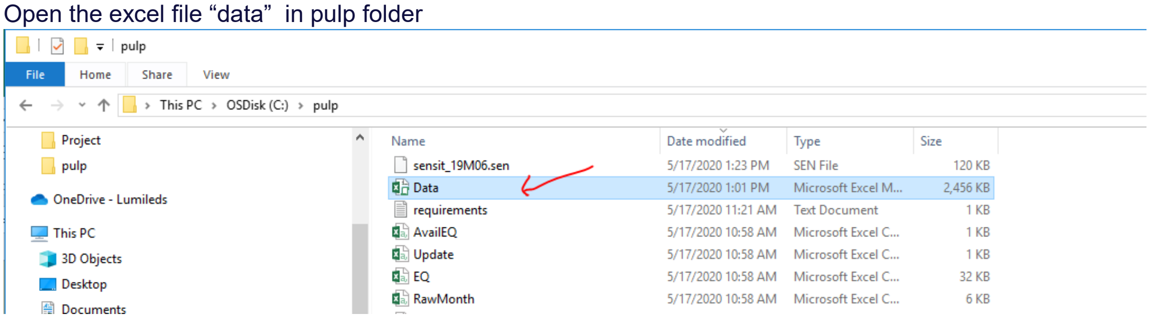
9. Enter 1 again



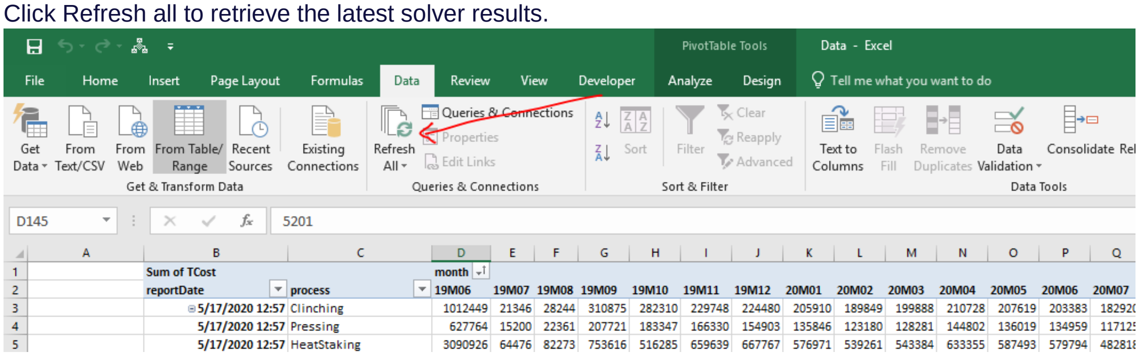
10. Report run successfully



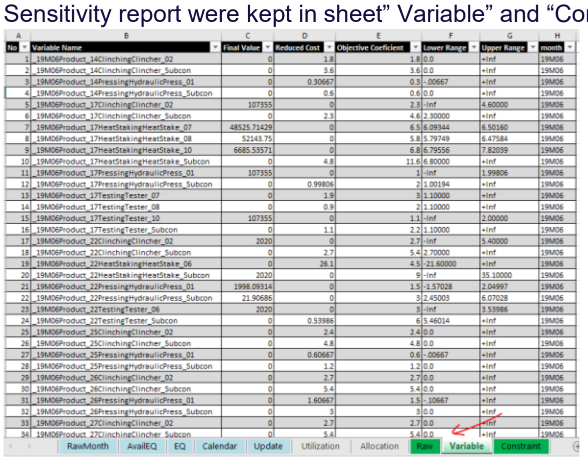
11. Open the excel file “data” in pulp folder



12. Click Refresh all to retrieve the latest solver results.



13. Sensitivity report were kept in sheet” Variable” and “Constraint”



No	Constraint Name	Final Value	Shadow Price	RHS 1	RHS 2	Lower Range	Upper Range	month	Description
1	_C1	0	0	0.0	0	0	449522.673	19M06	_19M06Product_14PressingHydraulicPress_01 + _19M06Product_14PressingHydraulicPress_Subcon = 0
2	_C10	2020	2.7	2020.00000	2020	0	15079.94627	19M06	_19M06Product_22ClinchingClincher_02 + _19M06Product_22ClinchingClincher_Subcon = 2020
3	_C100	14074600	0	-Inf	15876000	14070300	14074600	19M06	33.333333333333336*_19M06Product_14ClinchingClincher_02 + 22.599999999999998*_19M06Product_17ClinchingClincher_02 + 137.93333333333334*_19M06Product_22ClinchingClincher_02 + 45.977777777777778*_19M06Product_25ClinchingClincher_02 + 44.44444444444444*_19M06Product_26ClinchingClincher_02 + 44.44444444444444*_19M06Product_27ClinchingClincher_02 + 65.57777777777778*_19M06Product_28ClinchingClincher_02 + 65.57777777777778*_19M06Product_29ClinchingClincher_02 + 40.4*_19M06Product_37ClinchingClincher_02 + 266.6666666666667*_19M06Product_41ClinchingClincher_02 + 44.44444444444444*_19M06Product_46ClinchingClincher_02 + 44.44444444444444*_19M06Product_47ClinchingClincher_02 + 44.44444444444444*_19M06Product_48ClinchingClincher_02 + 142.85555555555555*_19M06Product_66ClinchingClincher_02 + 142.85555555555555*_19M06Product_67ClinchingClincher_02 + 31.255555555555553*_19M06Product_69ClinchingClincher_02 + 28.988888888888887*_19M06Product_70ClinchingClincher_02 + 33.333333333333336*_19M06Product_77ClinchingClincher_02 + 33.333333333333336*_19M06Product_79ClinchingClincher_02 + 65.57777777777778*_19M06Product_85ClinchingClincher_02 + 65.57777777777778*_19M06Product_86ClinchingClincher_02 <= 15876000.0
									33.333333333333336*_19M06Product_14ClinchingClincher_Subcon + 22.599999999999998*_19M06Product_17ClinchingClincher_Subcon + 137.93333333333334*_19M06Product_22ClinchingClincher_Subcon + 45.977777777777778*_19M06Product_25ClinchingClincher_Subcon + 44.44444444444444*_19M06Product_26ClinchingClincher_Subcon + 44.44444444444444*_19M06Product_27ClinchingClincher_Subcon + 65.57777777777778*_19M06Product_28ClinchingClincher_Subcon + 65.57777777777778*_19M06Product_29ClinchingClincher_Subcon + 40.4*_19M06Product_37ClinchingClincher_Subcon +

RawMonth | AvailEQ | EQ | Calendar | Update | Utilization | Allocation | Raw | Variable | Constraint

14. Optimum cost and unit produced of each tool was kept in sheet "Allocation"

Sum of TCost		month														
reportDate	process	19M06	19M07	19M08	19M09	19M10	19M11	19M12	20M01	20M02	20M03	20M04	20M05	20M06	20M07	20M08	20M09
5/17/2020 12:57	Clinching	1012449	21346	28244	310875	282310	229748	224480	205910	189849	199888	210728	207619	203383	182920	89823	67499
5/17/2020 12:57	Pressing	627764	15200	22361	207721	183347	166330	154903	135846	123180	128281	144802	136019	134959	117125	54898	43386
5/17/2020 12:57	HeatStaking	3090926	64476	82273	753616	516285	659639	667767	576971	539261	543384	633355	587493	579794	482818	201651	163316
5/17/2020 12:57	Testing	1050313	32904	36130	288582	202625	260530	252864	219869	198704	204688	232953	216680	215284	186515	75777	61222
Grand Total		5781452	133925	169008	1560793	1184567	1316246	1300013	1138597	1050993	1076241	1221839	1147811	1133419	969379	422149	335423

cost

Sum of solver_qty			month														
reportDate	product	eqp	19M06	19M07	19M08	19M09	19M10	19M11	19M12	20M01	20M02	20M03	20M04	20M05	20M06	20M07	20M08	20M09
5/17/2020 12:57	Product_14	HydraulicPress_01	0	0	0	0	0	0	38	148	135	154	166	142	174	136	102	85
5/17/2020 12:57	Product_14	Clincher_02	0	0	0	0	0	0	38	148	135	154	166	142	174	136	102	85
5/17/2020 12:57	Product_14	Clincher_Subcon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_14	HydraulicPress_Subcon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	HydraulicPress_01	107355	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	Clincher_02	107355	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	Clincher_Subcon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	HydraulicPress_Subcon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	HeatStake_10	6685.54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	HeatStake_07	48525.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	HeatStake_08	52143.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	Tester_10	107355	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	Tester_07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	Tester_08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	Tester_Subcon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_17	HeatStake_Subcon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_22	HydraulicPress_01	1998.09	39	8	110	1885	709	13	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_22	Clincher_02	2020	39	8	110	1885	709	13	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_22	Clincher_Subcon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_22	HydraulicPress_Subcon	21.9069	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_22	Tester_Subcon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_22	HeatStake_Subcon	2020	0	0	110	0	0	0	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_22	HeatStake_06	0	39	8	0	1885	709	13	0	0	0	0	0	0	0	0	0
5/17/2020 12:57	Product_22	Tester_06	2020	39	8	110	1885	709	13	0	0	0	0	0	0	0	0	0

Unit produced

RawMonth | AvailEQ | EQ | Calendar | Update | Utilization | Allocation | Raw | Variable | Constraint

15. Sheets "RawMonth", "AvailEQ", "EQ", "Calendar", "Update" keep all the metadata of our problem. We can resend modified data to python pulp for solving again by simply click the button "Export" in sheet "RawMonth"

Export

product	cpn	19M06	19M07	19M08	19M09	19M10	19M11	19M12
Product_69	A2LQ-0000100010320	187266.0000	0.0000	0.0000	82787.0000	32054.0000	40790.0000	39895.0
Product_22	QPWG-N734	200.0000	0.0000	0.0000	0.0000	212.0000	47.0000	0.0
Product_37	QPWG-N740	76834.0000	0.0000	0.0000	26626.0000	19745.0000	24352.0000	23273.0
Product_41	QPWG-N744	16.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0
Product_22	A2LQ-0000100010420	0.0000	0.0000	2.0000	48.0000	191.0000	42.0000	0.0
Product_17	HPWG-N510	107355.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0
Product_14	QPWG-N527	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	38.0
Product_22	QPWG-N663	547.0000	0.0000	0.0000	0.0000	1170.0000	308.0000	0.0
Product_48	QPWG-N699	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0
Product_25	QPWG-N705	0.0000	0.0000	0.0000	4890.0000	7913.0000	2235.0000	4384.0
Product_22	QPWG-N707	1273.0000	39.0000	6.0000	62.0000	312.0000	312.0000	13.0
Product_26	QPWG-N711	0.0000	0.0000	0.0000	0.0000	2900.0000	0.0000	0.0
Product_27	QPWG-N712	0.0000	0.0000	0.0000	0.0000	26839.0000	0.0000	0.0
Product_28	QPWG-N713	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0
Product_29	QPWG-N714	0.0000	0.0000	0.0000	16.0000	30.0000	5.0000	0.0
Product_47	QPWG-N698	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0
Product_79	QPWG-N571	0.0000	0.0000	0.0000	0.0000	960.0000	0.0000	0.0
Product_77	QPWG-N572	0.0000	0.0000	0.0000	0.0000	10.0000	0.0000	0.0
Product_46	QPWG-N697	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0
Product_85	A2LQ-0000200010380	180.0000	0.0000	0.0000	7.0000	29.0000	5.0000	1.0
Product_85	A2LQ-0000200010400	0.0000	0.0000	0.0000	9.0000	104.0000	18.0000	0.0
Product_86	A2LQ-0000300010370	3820.0000	368.0000	1.0000	0.0000	0.0000	0.0000	0.0
Product_70	A2LQ-0000100010330	43425.0000	1123.0000	5273.0000	18998.0000	16349.0000	16709.0000	11082.0
Product_66	A2LQ-0000200010230	5201.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2655.0
Product_67	A2LQ-0000200010240	1009.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2977.0
Product_57	A2XQ-0000200010190	0.0000	118.0000	2408.0000	3841.0000	7398.0000	10051.0000	9956.0
Product_58	A2XQ-0000200010200	0.0000	0.0000	0.0000	3041.0000	6579.0000	8368.0000	10225.0
Product_59	A2XQ-0000200010210	6898.0000	3154.0000	3154.0000	4229.0000	6852.0000	10632.0000	9840.0
Product_60	A2XQ-0000200010220	10138.0000	5278.0000	3216.0000	4257.0000	6857.0000	10439.0000	10035.0
Product_73	A2XQ-0000200010280	11006.0000	1018.0000	1018.0000	694.0000	0.0000	0.0000	0.0
Product_74	A2XQ-0000200010290	8195.0000	0.0000	0.0000	0.0000	284.0000	1091.0000	171.0

RawMonth | AvailEQ | EQ | Calendar | Update | Utilization | Allocation | Raw | Variable | Constraint

PROBLEM AND PITFALL

By Chan Huan Yang

Mistakes

Every project potentially faces countless mistakes that affect projects, cause delays, and in some cases, contribute to complete project failure. Here are some of the project management mistakes that we experienced.

Lack Of Resources And Skills

Inadequate resources needed for the project nearly cause us to fail. For example, although we have four members in our team however only me how to use PuLP and GLPK properly, it will be hard for the project to succeed. Poor resource matching also gave an adverse effect. I should ensure that we have all the skills we need before choosing PuLP and GLPK as our solver.

Failure To Communicate Properly

Due to Movement Control Order, I found out that it is very difficult to communicate with other members. The meetings were done using Microsoft Team and we found out that a voice call meeting is not as effective as a face-to-face meeting. If there is a change of direction or decision, we can't convey it clearly to all members. Hence, when misunderstanding happens, everybody points fingers and blames each other.

Knowledge and Experiences Gained

Throughout the project implementation, I have gained several meaningful pieces of knowledge and experience. They are as following.

Learn How To Apply Linear Programming To Solve An Actual Industry Problem

This project is important because we take the concept from the textbook to the real world. In these projects, we apply our knowledge to authentic scenarios from the perspective of a business owner. We walk through knowledge application by engaging in a team, partner, or independent projects. Throughout the projects, we have an opportunity to determine the best use of money, time, and people to minimize both resource cost and waste.

Learn How To Use PuLP And GLPK To Solve A Linear Programming Problem

During the CDS512 lectures, we learned all about predictive modeling techniques using Excel Solver. However, the major problem is that spreadsheet models do not scale well when they passed a certain level of complexity. Imagine a product routing where we have thousands of nodes and some metadata about them such as demand, cycle time, or tool availability, and that we need to enter many constraints for each node based on this metadata and some complicated business rules. That sounds terrible, especially if what we're doing is not just one ad hoc analysis but is part of a larger, continuing workflow. Hence we decided to learn new tools such as PuLP to solve our project scalability issue.

Learn How To Create A Business Model

Through this project, we also learn to appreciate the importance of having a business model. A business model tells a story that helps everyone in an organization grasp what the company is trying to create. As a result, the model helps everyone see how to adjust their behavior to improve execution.

PROBLEM AND PITFALL

By Mohaniswary

Mistakes

Each project is different and unique but typically mistake cannot be avoided in certain circumstance which impact the project completion. Projects can be completed on schedule and within budget, and still fail, unless a project achieves the desired results and efficiency, it can hardly be judged as good. Hence, here are mistakes that we experienced and solution on tackle those issue.

Lack of Exposure and Skills on use PuLP and GLPK.

It is very first time experiencing on using the PuLP and GLPK technology for this project implementation. Due to this reason, it took some time to adopt on the learning curve of this linear programming modeler and solver even though we have been exposes with linear programming using excel solver in our classes. We managed to tackle this issue since one of our group members who have good experience on using PuLP and GLPK and willing to share the knowledge among other members.

No regular communication and meetings with members

Due to the Movement Control Order, we have adapted new normal by meeting through Microsoft Team and WhatApp tools that are available for frequently update on the current project progress and task managements.

Knowledge and Experiences Gained

Throughout the project implementation, we have gained several meaningful pieces of knowledge and experience. They are as following.

Defined the Problem Statement in Details

As for this project, I was assigned to define the problem statement of the case studies. Based on the problem that we have found; we need to perform details studies such as how the issue is impacting the efficiency and work performance of the organization. For each problem identification, we manage to link with the impact on organization because not meeting customer demand often means losing customers to competitors. Planning for poor capacity requirements can also result in overproduction of products that do not sell.

Learn How to Use PuLP and GLPK To Solve A Linear Programming Problem

This project not only access our skill but also help us on knowledge exploration. In addition to existence technology we learn from class, we managed to further explore new linear programming software package that able to tackle issue on solving large scale linear optimization and mixed integer linear optimization problems throughout this project and self-learning from my end. Besides, PuLP and GLPK are open source and cross platform software which can be easily install in multiple operating system.

Learn How to Create A Business Model

Furthermore, we also learn to pitch a good business model for our project on Capacity Planning and Resource Allocation in Assembly Line using Linear Programming. A good business model will pitch the selling point and attract customer or potential investor to invest in our project or purchase our service and product.

PROBLEM AND PITFALL

By Keshalini

Mistakes

By default, no project execution is flawless. Even though a project may be executed and completed on time with customer demands able to be met on time as per request, only those that are involved throughout the execution of the project know the ups and downs faced by the team in order to complete the project on time and at the same time producing output of great quality.

Lack of Knowledge on how to use PuLP

As for me, personally I had no prior experience in using PuLP for any purpose; previous coursework assignments or workplace like. I've learnt how to work on creating Linear Programming model via the classes that I've attended, however incorporating PuLP with linear programming especially in handling real time data for capacity planning was something that I started of with a lot of questions. Luckily this gap was filled by helpful team members that were willing to share their knowledge and guide me throughout the project and also by self learning and further exploring from my end.

Lack of Face to Face communication and meetings

Since usually group meetings for project or assignment discussions are done face to face and usually when we are in class, the meetings held onlines in the wake of MCO proved to be a challenge. If previously when in class, team mates can just be gathered up for a quick discussion, for online meetings instead will have to find and fix a particular time where all four of us available with the presence of a proper internet connection and a laptop.

Knowledge and Experiences Gained

Throughout the project implementation, we have gained several meaningful pieces of knowledge and experience. They are as following.

Adapting project planning and sync up via online meetings

Eventhough face-to-face meetings used to be the normal way of project planning and sync ups, because of the current situation we had to adapt a new method of doing so which is via online meeting in Microsoft Teams of progress updates via WhatsApp groups. This whole project has been a timeline which exposed us more to utilized online platforms for project discussion and task distribution as well as status updates allowing us to gain more experience.

Expanded knowledge of PuLP and capacity planning throughout the project

I've gained more knowledge on implementing linear programming models using PuLP through this project. For someone that does not have prior experience neither in using PuLP not performing capacity planning, this project has been a good exposure.

Learnt to do a proper SWOT analysis

A SWOT analysis was required for our proposal. We have heard and came across of SWOT analysis online for external projects but never had the chance to implement it ourselves. Through this project, we got the chance of learning and performing a proper SWOT analysis for our proposal using existing data from a real company.

PROBLEM AND PITFALL

By Renouthani

Mistakes

There is always flaws on every project that cause late deliverables, have an impact on subsequent tasks or worst scenario would be project failure. These factors will give customer dissatification and even business loss. Hence, highlighting the mistakes would improvise self and company. Thus, here are few of the mistakes that we experienced while doing this project.

Lack of experiences and training

There is a lack of experience in using PuLP and GLPK. Due to this, there is long period of time taken to understand basic concept on how to use both PuLP and GLPK. One of the person in our group who has the experience and skill on it, had spent his time to train 3 of our members. Of course, there is always a need of self-training as the addition knowledge for better learning curve. However, there was not any on-hand related training namely practicals that would help us to know exactly which part we made mistake, cause of the mistake and how to solve effectively. Thus, we need look up from online resources to study on PuLP and GLPK so that we know how LP model is built and linear programming is used as solver towards this project problem.

Too focus on current problem, No future precaution

Our focus was to improve old method namely trial-error method with appropriate LP model to solve the capacity planning. However this focus is onto solving current problem, how about possibilities or planning for future work. Future work can be useful for the purpose of upgrading or enhance the LP model.

Knowledge and Experiences Gained

Throughout the project implementation, we have gained several meaningful pieces of knowledge and experience. They are as following.

Learn How To Analyse Data Effectively

We learned how to use 'What-If' analysis in excel to see how changing a value affects the outcome result is indeed good especially when the data consists of too many information namely process, utilization, allocation et cetera. Therefore, this would be good insights to for capacity planning so that could avoid potential excessive capacity.

Learn How To Think Out Of Box

To build LP model, we could have used the resources that obtained from our CDS512 lecture notes. However, we initated with PuLP and GLPK which is quite new and interesting to explore especially when it help to solve real-world problem. We figure out an alternative way to build LP model for our current problem since the introduced techniques is free licensed and has good adaptability (*easy to install and setup on different laptops*).