Optimization of the Allocation of Production Specialist Working in a Semiconductor Company Under the Compressed Skeletal Workforce Schedule Using Linear Programming

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Abstract

Manufacturing is the processing of raw materials to finished products. Originally, these products were processed manually until Industrial Revolution has allowed these products to be produced by machines. Most of the manufacturing lines in the industries use the combination of manual processing and machine processing. This is referred to as semi-automated production line. Thus, there are two factors affecting the productivity of this production line- manpower and machine efficiency. During the Covid-19 pandemic, skeletal workforce was strictly implemented in almost every sector across the globe. Reassignment of manpower allocation has therefore been a problem of the management. This paper focuses on manpower allocation of a Bumping Area of a Semiconductor Company in the Philippines. Factors affecting manpower allocation such as maximum machine capacity, minimum output requirement and number of qualified production specialist were studied and taken into consideration. Using Linear Programming, optimal number of manpower was determined and the target output of 64,000 unit moves daily was achieved. However, this can be further improved by utilizing the excess production specialist through cross-training them in different module. Machine capacity can also be maximized by hiring more production specialist to operate on them.

Keywords
Linear Programming, Manpower Utilization, Semiconductor Production

1. Introduction

Manufacturing is the mass processing, fabrication or production of components and finished products from raw materials (Kenton, 2020). This includes all foods, chemicals, textiles, metals, lumbers, woods, pulps, etc (Working Draft Framework, 1996). Through the years, manufacturing production lines have evolved from manual production line to semi-automated production lines to fully automated production lines. Manual production has products produced by hands. Introduction of machines are seen on semi-automated production lines. Here, the raw materials are loaded in a machine then the finished product is unloaded from the machine. However, there are still some processes which require human intervention. Thus, there are two factors affecting the productivity of a semi-automated production line. These are machine efficiency and manpower (Kurata, Matias, & Grepo, 2015). Unlike in a fully automated production line wherein all processes are done by machines, the role of human has fully changed from sensorimotor tasks to predominantly monitoring tasks, being responsible only for decision making and malfunction interventions (Butzler, Kuz, Petruck, Faber, & Schlick, 2015)

Production output of a manufacturing line is directly related to the workers' performance making human workforce as one of the most important assets of a company (Egilmez, Erenay, & Suer, 2014). Effective manpower allocation has therefore been a critical management problem. During the planning period, these people are determined by their experiences that will be a factor in their delegation the proper levels and positions. Allocation of manpower may be determined by the number of processes a manufacturing line has, available space, span of control, worker skills and availability of machines (stochastic, 41).

In this paper, focus was on the manpower utilization of production specialists working on a semiconductor company located in the Philippines. According to the company, workforce will have to be reduced as mandated by the government in response to the COVID-19 Pandemic (Office of the President of the Philippines Malacañang, 2020). Those who are working originally on shifting schedule for six days of eight hours each day has been reduced to four days for twelve hours each day. The goal is to effectively allocate the cross-trained production specialists across the production area's modules. To meet the demand as it is forecasted that semiconductor products will surge for the next three years, target number of movement across modules is at 64,000 unit moves per day or more (Trends Impacting the Semiconductor Industry in the Next Three Years, 2019). These products will be of use in communications, computing, transportation, military system and most especially in health care. (Semiconductor Industry Association) Factors such as maximum machine capacity, minimum output requirement and number of qualified production specialist affecting manpower allocation will be taken into account.

2. Methodology

2.1. Presentation of Available Data

Data were obtained from production supervisors of a Bump Production Area in a Semiconductor Company located in the Philippines. There are a total of ten modules in this production area; processes under each respective module are grouped according to the order of occurrence in the whole product processing. There is no particular sequence of modules in this production area since most of the products-wafers have several chemical layers, meaning the wafer will have to pass through some module twice, thrice and at most four times. Figure 1 is an overview of the process flow of a one-layered product.

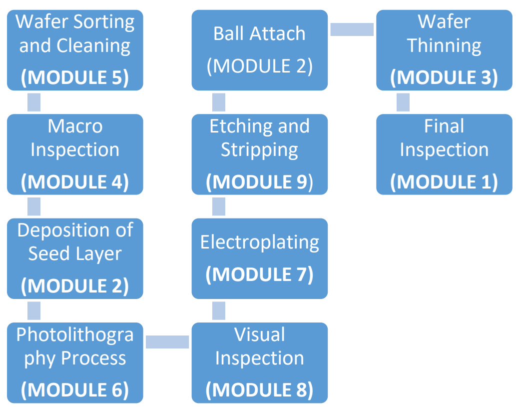

Figure 1. Bumping Process Flow

Wafers will be received and cleaned in the wafer sorting and cleaning module. This module is responsible for counting and validating the wafers received from the wafer fab.

Washing is also in done in the presumption of contaminants added on the bare wafers during transportation. Wafers will be then passed on the macro inspection module. This module is responsible for the scanning of pre-processing defects on the wafers. Thin films of metals are deposited on the wafers in the next module. This will help in the connection of the balls that will be placed in the latter processes. Wafers will then pass on the next module wherein pattern will be printed on the wafers. This module is composed of three major processes, coating, exposing and developing. Wafers will then undergo visual inspection before going to the next module. Having the patterns distinct and visible, it will be plated with metals. These metals will serve as a connection in the wafers. Excess chemicals from the thin film and coating process will be removed in etching and stripping. Wafer is now ready for the attachment of balls or bumps. After this, wafers will be reduced in thinner thickness in preparation to the wafer sawing in next area. Finally, before leaving the Bump Area, a final visual inspection will be done.

Module 1 is the outgoing module or the last module in this production area; here all the wafers are visually inspected via automation and then classified manually. There are 25 production specialists qualified in this module since this module is critical in determining the final output of the whole area. Module 2 is where the ball attachment takes place. This requires big machines in order to properly attach these balls using high temperature. There are 19 production specialists qualified in this area since more people are needed to mobilize within these machines. Module 3 is where wafer thinning in accordance to customer specification takes place. Machines here are automated and medium sized.

There are usually no preloading procedures done and only 12 production specialists are qualified in this module.

Module 4 has fully automated machines wherein human intervention is minimal. 1 production specialist may suffice and will be able to handle all of these machines. Module 5 is the receiving area of incoming peripherals and wafers. There are 6 production specialists qualified in this module since there should be at least one production specialist present per shift to do wafer starts. Module 6 is the largest module in this area. This is the most critical module since this serves as the baseline of the whole wafer. A single mistake in just one of these processes will induce scrappage of the wafer. It is composed of almost one-half of all the processes in the area. This module is in need of many production specialists. There are 43 qualified production specialists in this module. This module is further divided into submodules focusing on key processes.

Module 7 is where metals are being deposited in the wafers. Production specialists qualified in this area are required to do some chemical analysis before starting the loading procedure. There are a total of 26 production specialists qualified in this module. In module 8, wafers are manually inspected before it exits module 6. There are 42 qualified production specialists in this module. Most of these production specialists are also trained in module 6 since the defect they are inspecting wafers processed in this module. Familiarity is the skill needed by these production specialists. Module 9 has medium scale machines. Chemicals are also being deposited in this module but unlike in module 7, production specialists are not required to do chemical analysis. There are a total of 16 production specialists qualified in this module.

Lastly, for module 10, this is where stripping and etching takes place. Stripping and etching are the removal of unnecessary chemicals in some parts of the units according to the product design. Chemicals are being analyzed in this module as well. There are a total of 27 production specialists qualified in this module. All of these data already existed and used for the original eight-hour shift schedule before the pandemic began as shown in Table 1. Number of machines available for each of the respective modules is seen on Table 1 as well.

Table 1. Number of Qualified Production Specialist in Each Module

MODULE	NUMBER OF MACHINES	NUMBER OF QUALIFIED PRODUCTION SPECIALIST
MODULE 1	8	25
MODULE 2	10	19
MODULE 3	13	12
MODULE 4	5	1
MODULE 5	1	6
MODULE 6	40	43
MODULE 7	11	26
MODULE 8	17	42
MODULE 9	13	17
MODULE 10	12	27

For Table 2 shown below, machine capacity and minimum output requirement for each production specialist is presented. These data were calculated by the manufacturing planner of Bump production area last March as soon as the skeletal workforce was temporarily implemented. Minimum output requirement for each production specialist was calculated by dividing the minimum output required for each production specialist during the eight hour shift by eight to get the minimum output requirement per hour and then multiplying this by 12 hours. There are still no studies by the IE department on the feasible minimum requirement for 12 hours shift as the company is still deciding on whether they will adapt this new workforce schedule or return to the previous one.

Table 2. Machine Capacity and Minimum Output for each Production Specialist Data

MODULE	MACHINE	MACHINE CAPACITY (24 hours)		MINIMUM OUTPUT PER PRODUCTION SPECIALIST (12 hour shift)	
		PRODUCT 1	PRODUCT 2	PRODUCT 1	PRODUCT 2
MODULE 1	1-A	134		1590	
	1-B	268		1590	
	1-C	268		1590	
	1-D	268		1590	
	1-E	268		1590	
	1-F	784		1590	
	1-G	784		1590	
	1-H	784		1590	
MODULE 2	2-A	401		760	
	2-B	401		760	
	2-C	359		760	
	2-D	359		760	
	2-E	359		760	
	2-F	150		760	
	2-G	700		760	
	2-H	550		760	
	2-I	550		760	
	2-J	550		760	
MODULE 3	3-A	672		1421	
	3-B	672		1421	
	3-C	326		1421	
	3-D	326		1421	
	3-E	326		1421	
	3-F	326		1421	
	3-G	2040		1421	
	3-H	710		1421	
	3-I	710		1421	
	3-J	2591		1421	
	3-K	1203		1421	
	3-L	1920		1421	
	3-M	768		1421	
MODULE 4	4-A	1824		2400	1800
	4-B	912		2400	1800
	4-C	912		2400	1800
	4-D	912		2400	1800
	4-E	912		2400	1800
MODULE 5	5-A	2000		1186	1354
MODULE 6	6-A	751	0	3508	0
	6-B	710	0	3508	0
	6-C	710	0	3508	0
	6-D	710	0	3508	0
	6-E	626	0	3508	0
	6-F	710	0	3508	0
	6-G	710	428	3508	2300
	6-H	626	0	1616	0
	6-I	626	0	1616	0
	6-J	606	0	1616	0
	6-K	898	0	1616	0
	6-L	835	0	1775	0
	6-M	585	0	1775	0
	6-N	313	313	1775	856
	6-O	313	438	1775	856
	6-P	689	0	2485	0
	6-Q	731	731	2485	1502
	6-R	219	459	2485	1502
	6-S	731	0	2485	0
	6-T	324	0	1616	0
	6-U	950	0	1555	0
	6-V	605	0	1775	0
	6-W	639	0	0	0

	6-X	640	0	0	0
	6-Y	641	0	0	0
	6-Z	0	626	0	2300
	6-AA	0	469	0	2300
	6-AB	0	425	0	2300
	6-AC	0	438	0	2300
	6-AD	0	428	0	2300
	6-AE	0	438	0	2300
	6-AF	0	139	0	1619
	6-AG	0	428	0	1619
	6-AH	0	800	0	1619
	6-AI	0	529	0	1619
	6-AJ	0	426	0	856
	6-AK	0	438	0	856
	6-AL	0	668	0	1502
	6-AM	0	438	0	886
	6-AN	0	454	0	886
MODULE 7	7-A	1050	1050	2400	1800
	7-B	1200	1200	2400	1800
	7-C	1200	1200	2400	1800
	7-D	1050	1050	2400	1800
	7-E	1050	1050	2400	1800
	7-F	1050	1050	2400	1800
	7-G	1050	1050	2400	1800
	7-H	3600	3600	2400	1800
	7-I	3600	3600	2400	1800
	7-J	3600	3600	2400	1800
	7-K	3600	3600	2400	1800
MODULE 8	8-A	653	0	1421	0
	8-B	653	0	1421	0
	8-C	653	0	1421	0
	8-D	403	0	1421	0
	8-E	375	0	1421	0
	8-F	653	0	1421	0
	8-G	1274	0	1912	0
	8-H	1274	0	1912	0
	8-I	1274	0	1912	0
	8-J	637	0	1912	0
	8-K	0	277	0	1367
	8-L	0	495	0	1367
	8-M	0	422	0	1367
	8-N	0	579	0	1367
	8-O	0	583	0	1296
	8-P	0	1296	0	1296
	8-Q	0	1296	0	1296
MODULE 9	9-A	780	0	1699	0
	9-B	780	0	1699	0
	9-C	1186	0	2371	0
	9-D	1186	0	2371	0
	9-E	700	0	2371	0
	9-F	700	0	2371	0
	9-G	0	685	0	1200
	9-H	0	182	0	1200
	9-I	0	1122	0	1200
	9-J	0	1061	0	1200
	9-K	0	1117	0	1806
	9-L	0	1003	0	1806
	9-M	0	1023	0	1806
MODULE 10	10-A	787	0	1503	0
	10-B	342	0	1503	0
	10-C	787	0	1503	0
	10-D	342	0	1503	0
	10-E	548	0	1503	0
	10-F	0	453	0	2099
	10-G	0	342	0	2099
	10-H	0	118	0	2099

	10-I	0	342	0	2099
	10-J	0	291	0	2099
	10-K	0	512	0	2099
	10-L	0	137	0	2099

2.2. Pre-Calculation

There are a total of 101 production specialists working in ABCD area as computed from the data presented in Table 1. Table 3 below shows the pattern of assigning a working schedule for a production specialist. Since they should report for 4 days a week, it would be best if they can be present for consecutive days so they can enjoy their 3 consecutive days off as well. Each employee is not encouraged to work overtime; however, they should be able to comply with the minimum output requirement in the respective they are assigned to each day. Sample computation would total for at least 56 and at most 59 production specialists reporting for a single day. P means "Present" or the production specialist is reporting on that day. Names of the production specialists were hidden due to confidentiality purposes.

Table 3. Number of Production Specialists Working Each Day

PRODUCTION SPECIALIST	DAYS IN A WEEK						
	SUN	MON	TUES	WED	THURS	FRI	SAT
1	P	P	P	P			
2		P	P	P	P		
3			P	P	P	P	
4				P	P	P	P
5	P				P	P	P
6	P	P				P	P
7	P	P	P				P
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
101			P	P	P	P	
TOTAL	57	58	59	59	58	57	56

Table 4 shows the adjusted number of qualified production specialist calculated by multiplying the original number of qualified production specialist by 0.64. This multiplier was obtained by getting the percentage of the number of production specialist reporting each day for the skeletal workforce schedule compared to the original workforce schedule which is 86 production specialists daily.

Table 4. Modified Number of Qualified Production Specialist

MODULE	NUMBER OF QUALIFIED PRODUCTION SPECIALIST
MODULE 1	25 x 0.64 = 16
MODULE 2	19 x 0.64 = 12
MODULE 3	12 x 0.64 = 7
MODULE 4	1 x 0.64 = 1
MODULE 5	6 x 0.64 = 3
MODULE 6	43 x 0.64 = 27
MODULE 7	26 x 0.64 = 16
MODULE 8	42 x 0.64 = 26
MODULE 9	17 x 0.64 = 10
MODULE 10	27 x 0.64 = 17

2.3. Linear Programming

Using linear programming, the succeeding data shows the representation of the decision variables in the format of X_{ijk} wherein i is the shift (1- shift 1 and 2- shift 2), j is the module (1-module 1, 2-module 2, …, 10-module 10) and k is the product (1- product 1, 2- product 2). These decision variables were modeled to accurately calculate the optimal number of moves with the basis to the minimum output requirement per production specialist summing to 108 decision variables.

There are 51 constraints bounded by the total number of production specialists reporting daily, number of qualified personnel per module, minimum number of production specialist needed per shift per module and machine capacity per module per product.

<u>Decision Variables:</u>

X_{ij}- be the number of personnel working at module i for product j

Wherein i is 1 for module 1
2 for module 2
3 for module 3
4 for module 4
5 for module 5
6 for module 6
7 for module 7
8 for module 8
9 for module 9
10 for module 10

j is 1 for product 1
2 for product 2

*For decision variables with modules having different machine capacities,

X_{61A}- be the number of personnel working of module 6 for product 1 at machines A through G
X_{61B}- be the number of personnel working of module 6 for product 1 at machines H through K and T
X_{61C}- be the number of personnel working of module 6 for product 1 at machines L through O and V
X_{61D}- be the number of personnel working of module 6 at for product 1 machines P through S
X_{61E}- be the number of personnel working of module 6 at for product 1 at machines U
X_{61F}- be the number of personnel working of module 6 at for product 1 at machine W through Y
X_{61G}- be the number of personnel working of module 6 at for product 1 at machine Z through AE
X_{61H}- be the number of personnel working at module 6 at for product 1 at machines AF through AI
X_{61I}- be the number of personnel working of module 6 at for product 1 at machines AJ through AK
X_{61J}- be the number of personnel working of module 6 at for product 1 at machine AL
X_{61K}- be the number of personnel working of module 6 at for product 1 at machines AM through AN
X_{62A}- be the number of personnel working of module 6 at for product 2 at machines A through G
X_{62B}- be the number of personnel working of module 6 at for product 2 at machines H through K and T
X_{62C}- be the number of personnel working of module 6 at for product 2 at machines L through O and V
X_{62D}- be the number of personnel working of module 6 at for product 2 at machines P through S
X_{62E}- be the number of personnel working of module 6 at for product 2 at machines U
X_{62F}- be the number of personnel working of module 6 at for product 2 at machine W through Y
X_{62G}- be the number of personnel working of module 6 at for product 2 at machine Z through AE
X_{62H}- be the number of personnel working of module 6 at for product 2 at machines AF through AI
X_{62I}- be the number of personnel working of module 6 at for product 2 at machines AJ through AK
X_{62J}- be the number of personnel working of module 6 at for product 2 at machine AL
X_{62K-} be the number of personnel working of module 6 at for product 2 at machines AM through AN
X_{81A}- be the number personnel working of module 8 at for product 1 at machines A through F
X_{81B}- be the number personnel working of module 8 at for product 1 at machines G through J
X_{81C}- be the number personnel working of module 8 at for product 1 at machines K through N
X_{81D}- be the number personnel working of module 8 at for product 1 at machines O through Q
X_{82A}- be the number personnel working of module 8 at for product 1 at machines A through F
X_{82B}- be the number personnel working of module 8 at for product 1 at machines G through J
X_{82C}- be the number personnel working of module 8 at for product 2 at machines K through N
X_{82D}- be the number personnel working of module 8 at for product 2 at machines O through Q
X_{91A}- be the number personnel working of module 9 at for product 1 at machines A through B
X_{91B}- be the number personnel working of module 9 at for product 1 at machines C through F
X_{91C}- be the number personnel working of module 9 at for product 1 at machines G through J
X_{91D}- be the number personnel working of module 9 at for product 1 at machines K through M
X_{92A}- be the number personnel working of module 9 at for product 2 at machines A through B
X_{92B}- be the number personnel working of module 9 at for product 2 at machines C through F

X_{92C}- be the number personnel working of module 9 at for product 2 at machines G through J
X_{92D}- be the number personnel working of module 9 at for product 2 at machines K through M
X_{101A}- be the number personnel working of module 10 at for product 1 at machines A through E
X_{101B}- be the number personnel working of module 10 at for product 1 at machines F through L
X_{102A}- be the number personnel working of module 10 at for product 2 at machines A through E
X_{102B}- be the number personnel working of module 10 at for product 2 at machines F through L

Objective Function:

$$\text{Max } Z = 1590X_{11} + 1590X_{12} + 760X_{21} + 760X_{22} + 1421X_{31} + 1421X_{32} + 2400X_{41} + 1800X_{42} + 1186X_{51} + 1354X_{52} + 3508X_{61A} + 1616X_{61B} + 1775X_{61C} + 2485X_{61D} + 1555X_{61E} + X_{61F} + X_{61G} + X_{61H} + X_{61I} + X_{61J} + X_{61K} + 2300X_{62A} + X_{62B} + 856X_{62C} + 1502X_{62D} + X_{62E} + X_{62F} + 2300X_{62G} + 1619X_{62H} + 856X_{62I} + 1502X_{62J} + 886X_{62K} + 2400X_{71} + 1800X_{72} + 1421X_{81A} + 1912X_{81B} + X_{81C} + X_{81D} + X_{82A} + X_{82B} + 1367X_{82C} + 1296X_{82D} + 1699X_{91A} + 2371X_{91B} + X_{91C} + X_{91D} + X_{92A} + X_{92B} + 1200X_{92C} + 1806X_{92D} + 1503X_{101A} + X_{101B} + X_{102A} + 2099X_{102B}$$

Constraints:

$X_{11} + X_{12} + X_{21} + X_{22} + X_{31} + X_{32} + X_{41} + X_{42} + X_{51} + X_{52} + X_{61A} + X_{61B} + X_{61C} + X_{61D} + X_{61E} + X_{61F} + X_{61G} + X_{61H} + X_{61I} + X_{61J} + X_{61K} + X_{62A} + X_{62B} + X_{62C} + X_{62D} + X_{62E} + X_{62F} + X_{62G} + X_{62H} + X_{62I} + X_{62J} + X_{62K} + X_{71} + X_{72} + X_{81A} + X_{81B} + X_{81C} + X_{81D} + X_{82A} + X_{82B} + X_{82C} + X_{82D} + X_{91A} + X_{91B} + X_{91C} + X_{91D} + X_{92A} + X_{92B} + X_{92C} + X_{92D} + X_{101A} + X_{101B} + X_{102A} + X_{102B} = 28$ (Total number of production specialist in a shift)

$X_{11} + X_{12} <= 25$ (Module 1 qualified production specialist)

$X_{21} + X_{22} <= 19$ (Module 2 qualified production specialist)

$X_{31} + X_{32} <= 12$ (Module 3 qualified production specialist)

$X_{41} + X_{42} <= 1$ (Module 4 qualified production specialist)

$X_{51} + X_{52} <= 6$ (Module 5 qualified production specialist)

$X_{61A} + X_{61B} + X_{61C} + X_{61D} + X_{61E} + X_{61F} + X_{61G} + X_{61H} + X_{61I} + X_{61J} + X_{61K} + X_{62A} + X_{62B} + X_{62C} + X_{62D} + X_{62E} + X_{62F} + X_{62G} + X_{62H} + X_{62I} + X_{62J} + X_{62K} <= 43$ (Module 6 qualified production specialist)

$X_{71} + X_{72} <= 26$ (Module 7 qualified production specialists)

$X_{81A} + X_{81B} + X_{81C} + X_{81D} + X_{82A} + X_{82B} + X_{82C} + X_{82D} <= 42$ (Module 8 qualified production specialists)

$X_{91A} + X_{91B} + X_{91C} + X_{91D} + X_{92A} + X_{92B} + X_{92C} + X_{92D} <= 17$ (Module 9 qualified production specialists)

$X_{101A} + X_{101B} + X_{102A} + X_{102B} <= 27$ (Module 10 qualified production specialists)

$X_{11} + X_{12} >= 1$ (Module 1 minimum number of production specialist)

$X_{21} + X_{22} >= 1$ (Module 2 minimum number of production specialist)

$X_{31} + X_{32} >= 1$ (Module 3 minimum number of production specialist)

$X_{41} + X_{42} >= 1$ (Module 4 minimum number of production specialist)

$X_{51} + X_{52} > 1$ (Module 5 minimum number of production specialist)

$X_{61A} + X_{61B} + X_{61C} + X_{61D} + X_{61E} + X_{61F} + X_{61G} + X_{61H} + X_{61I} + X_{61J} + X_{61K} + X_{62A} + X_{62B} + X_{62C} + X_{62D} + X_{62E} + X_{62F} + X_{62G} + X_{62H} + X_{62}I + X_{62J} + X_{62K} >= 1$ (Module 6 minimum number of production specialist)

$X_{71} + X_{72} >= 1$ (Module 7 minimum number of production specialist)

$X_{81A} + X_{81B} + X_{81C} + X_{81D} + X_{82A} + X_{82B} + X_{82C} + X_{82D} >= 1$ (Module 8 minimum number of production specialist)

$X_{91A} + X_{91B} + X_{91C} + X_{91D} + X_{92A} + X_{92B} + X_{92C} + X_{92D} >= 1$ (Module 9 minimum number of production specialist)

$X_{101A} + X_{101B} + X_{102A} + X_{102B} >= 1$ (Module 10 minimum number of production specialist)

$1590X_{11} <= (134 + 268 + 268 + 268 + 268 + 784 + 784 + 784)/2$ (Module 1 Machine Capacity for product 1)

$1590X_{12} <= (134 + 268 + 268 + 268 + 268 + 784 + 784 + 784)/2$ (Module 1 Machine Capacity for product 2)

$760X_{21} <= (401 + 401 + 359 + 359 + 359 + 150 + 700 + 550 + 550 + 550)/2$ (Module 2 Machine Capacity for product 1)

$760X_{22} <= (401 + 401 + 359 + 359 + 359 + 150 + 700 + 550 + 550 + 550)/2$ (Module 2 Machine Capacity for product 2)

$1421X_{31} <= (672 + 672 + 326 + 326 + 326 + 326 + 2040 + 710 + 710 + 2591 + 1203 + 1920 + 768)/2$ (Module 3 Machine Capacity for product 1)

$1421X_{32} <= (672 + 672 + 326 + 326 + 326 + 326 + 2040 + 710 + 710 + 2591 + 1203 + 1920 + 768)/2$ (Module 3 Machine Capacity for product 2)

$2400X_{41} <= (1824 + 912 + 912 + 912 + 912)/2$ (Module 4 Machine Capacity for product 1)

$1800X_{42} <= (1824 + 912 + 912 + 912 + 912)/2$ (Module 4 Machine Capacity for product 2)

$1186X_{51} <= (2000)/2$ (Module 5 Machine Capacity for product 1)

$1354X_{52} <= (2000)/2$ (Module 5 Machine Capacity for product 2)

$3508X_{61A} + 1616X_{61B} + 1775X_{61C} + 2485X_{61D} + 1555X_{61E} + X_{61F} + X_{61G} + X_{61H} + X_{61I} + X_{61J} + X_{61K} <= (751 + 710 + 710 + 710 + 626 + 710 + 710 + 626 + 626 + 606 + 898 + 835 + 585 + 313 + 313 + 689 + 731 + 219 + 731 + 324 + 950 + 605 + 639 + 640 + 641)/2$ (Module 6 Machine Capacity for product 1)

$2300X_{62A} + X_{62B} + 856X_{62C} + 1502X_{62D} + X_{62E} + X_{62F} + 2300X_{62G} + 1619X_{62H} + 856X_{62I} + 1502X_{62J} + 886X_{62K} <=$ (428 (Module 6 Machine Capacity for product 2)

+ 313 + 438 + 731 + 459 + 626 + 469 + 425 + 438 + 428 + 438 + 139 + 428 + 800 + 529 + 426 + 438 + 668 + 438 + 454)/2

$2400X_{71} <= (1050 + 1050 + 1050 + 1050 + 1050 + 1200 + 1200 + 3600 + 3600 + 3600 + 3600)/2$ (Module 7 Machine Capacity for product 1)

$1800X_{72} <= (1050 + 1050 + 1050 + 1050 + 1050 + 1200 + 1200 + 3600 + 3600 + 3600 + 3600)/2$ (Module 7 Machine Capacity for product 2)

$1421X_{81A} + 1912X_{81B} + X_{81C} + X_{81D} <= (653 + 653 + 653 + 403 + 375 + 653 + 1274 + 1274 + 1274 + 637)/2$ (Module 8 Machine Capacity for product 1)

$X_{82A} + X_{82B} + 1367X_{82C} + 1296X_{82D} <= (277 + 495 + 422 + 579 + 583 + 1296 + 1296)/2$ (Module 8 Machine Capacity for product 2)

$1699X_{91A} + 2371X_{91B} + X_{91C} + X_{91D} <= (780 + 780 + 1186 + 1186 + 700 + 700)/2$ (Module 9 Machine Capacity for product 1)

$X_{92A} + X_{92B} + 1200X_{92C} + 1806X_{92D} <= (685 + 182 + 1122 + 1061 + 1117 + 1003 + 1023)/2$ (Module 9 Machine Capacity for product 2)

$1503X_{101A} + X_{101B} <= (787 + 787 + 342 + 342 + 548)/2$ (Module 10 Machine Capacity for product 1)

$X_{102A} + 2099X_{102B} <= (453 + 342 + 118 + 342 + 291 + 512 + 317)/2$ (Module 10 Machine Capacity for product 2)

3. Results and Discussion

Using Excel Solver in Linear programming, below are the results obtained. Table 5 shows the optimal number of moves per 12-hour shift is 64,546 moves. Doubling it to get a day's worth of moves is 129,092 moves. This is more than 2 times the target number of moves which is 64,000.

Table 5. Result of Objective Function

Name	Final Value
Number of Moves	64546

Table 6 shows the values for each decision variable or where and how many production specialists should be allocated per module. 1 production specialist should be allocated to at module 1 for product 1, 1 production specialist should be allocated at module 2 for product 1, 1 production specialist should be allocated at module 3 for product 1, 1 production specialist should be allocated at module 4 for product 1, 1 production specialist should be allocated to module 5 for product 2, 4 production specialists should be allocated to machines A through G of module 6 for product 1, 3 production specialist should be allocated to machines Z through AE of module 6 for product 2, 9 production specialists should be allocated to module 7 for product 1, 4 production specialists should be allocated to machines G through J of module 8 for product 1, 2 production specialists should be allocated to machines C through F of module 9 for product 1 and 1 production specialist should be allocated to Machines F through L of module 10 for product 2. This will sum up to 28 production specialists for a shift. All other decision variables not seen on Table 6 is equal to 0.

Table 6. Result of Decision Variables

Name	Final Value
Number of personnel working at module 1 for product 1	1
Number of personnel working at module 2 for product 1	1
Number of personnel working at module 3 for product 1	1
Number of personnel working at module 4 for product 1	1
Number of personnel working at module 5 for product 2	1
Number of personnel working at module 6 for product 1 for machines A through G	4
Number of personnel working at module 6 for product 2 for machines Z through AE	3
Number personnel working at module 7 for product 1	9
Number personnel working at module 8 for product 1 for machines G through J	4
Number personnel working at module 9 for product 1 for machines C through F	2
Number personnel working at module 10 for product 2 for machines F through L	1
All other decision variables	0

Table 7 shows which constrains are binding and which are not binding. Changes in binding constraints will affect the optimal solution while changing the not binding constrains will have no effect on the optimal solution. Values in the slack column are the excess number of production specialist for each of the respective constraints.

Modules 1, 2, 3, 4, 6, 7, 8, 9 and 10 qualified production specialists are all not binding constraints, meaning there are excess for each. Since we only modeled this for the minimum number of production specialist working for a day, which is 56 production specialists, we can allocate the one to three additional production specialists that will report on the other days to these modules. However, there are still a lot more excess qualified production specialists for each on the respective modules. Qualifying some of them to module 4 which is considered a binding constraint will change the solution and will increase the product moves.

All module capacity for all products is not binding constraints. Module capacity is not being maximized as well. Some products have zero machine utilization and at most, 97.96%. This may be due to the lack of production specialist allocated in that module. Increasing the total number of production specialist present per shift will increase the maximization of tool capacity since this will allow more production specialist to be allocated.

Modules 1, 2, 3, 4, 5 and 10 minimum number of production specialist are binding constraints while module 6, 7, 8 and 9 are all not binding constraints. This may be due to the fact that more product moves will be obtained if production specialists will be allocated to modules with the most number of minimum output requirement, however, it should be taken note of that in order for the whole production area to produce an output, all modules should have at least one production specialist to keep the product moving.

Table 7. Result of Constraints

Name	Cell Value	Status	Slack
Module 2 qualified production specialist	1	Not Binding	11
Module 3 qualified production specialist	1	Not Binding	6
Module 4 qualified production specialist	1	Binding	0
Module 5 qualified production specialist	1	Not Binding	2
Module 6 qualified production specialist	7	Not Binding	20
Module 7 qualified production specialists	9	Not Binding	7
Module 8 qualified production specialists	4	Not Binding	22
Module 9 qualified production specialists	2	Not Binding	8
Module 10 qualified production specialists	1	Not Binding	16
Module 1 Machine Capacity for product 1	1590	Not Binding	1968
Module 1 Machine Capacity for product 2	0	Not Binding	3558
Module 2 Machine Capacity for product 1	760	Not Binding	3619
Module 2 Machine Capacity for product 2	0	Not Binding	4379
Module 3 Machine Capacity for product 1	1421	Not Binding	11169
Module 3 Machine Capacity for product 2	0	Not Binding	12590
Module 4 Machine Capacity for product 1	2040	Not Binding	3432
Module 4 Machine Capacity for product 2	0	Not Binding	5472
Module 5 Machine Capacity for product 1	0	Not Binding	2000
Module 5 Machine Capacity for product 2	1354	Not Binding	646
Module 6 Machine Capacity for product 1	14032	Not Binding	738
Module 6 Machine Capacity for product 2	6900	Not Binding	1893
Module 7 Machine Capacity for product 1	21600	Not Binding	450
Module 7 Machine Capacity for product 2	0	Not Binding	22050
Module 8 Machine Capacity for product 1	7648	Not Binding	201
Module 8 Machine Capacity for product 2	0	Not Binding	4948
Module 9 Machine Capacity for product 1	4742	Not Binding	590
Module 9 Machine Capacity for product 2	0	Not Binding	6193
Module 10 Machine Capacity for product 1	0	Not Binding	2806
Module 10 Machine Capacity for product 2	2099	Not Binding	276
Module 1 minimum number of production specialist	1	Binding	0
Module 2 minimum number of production specialist	1	Binding	0
Module 3 minimum number of production specialist	1	Binding	0
Module 4 minimum number of production specialist	1	Binding	0
Module 5 minimum number of production specialist	1	Binding	0
Module 6 minimum number of production specialist	7	Not Binding	6
Module 7 minimum number of production specialist	9	Not Binding	8
Module 8 minimum number of production specialist	4	Not Binding	3
Module 9 minimum number of production specialist	2	Not Binding	1
Module 10 minimum number of production specialist	1	Binding	0
Total number of production specialist per day	28	Binding	0
Module 1 qualified production specialist	1	Not Binding	15

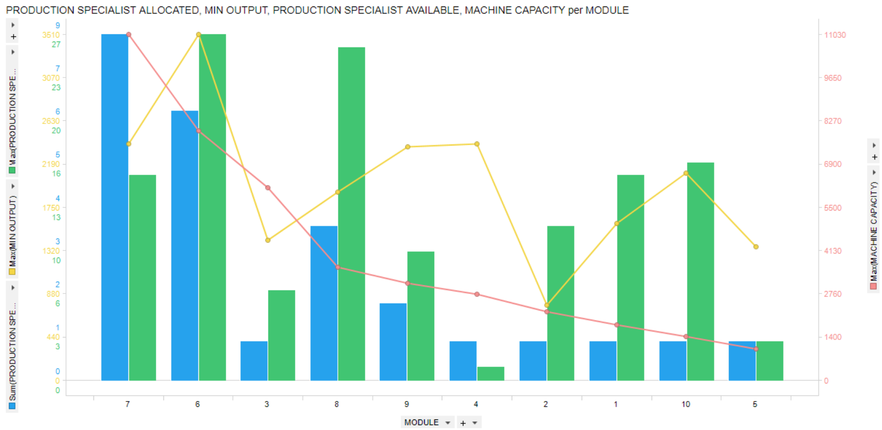

Figure 2. Number of Production Specialist Allocated and Minimum Output Requirement vs Machine Capacity

To visualize the results better, Figure 2 is a combination chart showing the correlation between production specialists allocated per module, qualified production specialist per module, minimum output requirement per module and the machine capacity per module. Bar graph in blue color shows the number of production specialist allocated to each module, bar graph in green color shows number of production specialist qualified in each module, line graph in yellow color shows the minimum output needed per module and the line graph in pink color shows the machine capacity for each module. From the figure, it can be seen that the number of production specialist allocated is directly proportional to the machine capacity; however, in module 3, since number of production specialist available is only seven, production specialist allocated is one.

4. Conclusion

In conclusion, allocation of production specialist per module is dependent on the machine capacity however; it is also limited by the number of production specialist qualified in every module. There is no direct relationship between the number of allocated production specialist per module and minimum output requirement per module.

In this model, goal of allocating at least one production specialist per module was achieved. The target of 64,000 moves per day was doubled into 129,092 moves while machine capacity and minimum output requirement per module were satisfied. However, this can be further improved by maximizing the utilization of machine capacity. This will result to greater output of the production line. It is suggested to hire more production specialists and to cross train them across the modules.

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