Chapter 6

A Hybrid Algorithm for Cobacabana

Job shop environments are one of the many configurations used by stochastic environment companies (Muda and Hendry, 2003). The term ‘job shop’ is employed to indicate a process characterized by a production of a large number of different products with highly variable routings and processing times. The two extreme configurations are the job shop and a flow shop as shown in Figure 6.1. However, most shops probably do not lie at the extremes. The direction of material flow is the key difference between them (Stevenson et al., 2005). Oosterman et al. (2000) purported that shop characteristics are an important issue in stochastic environments.

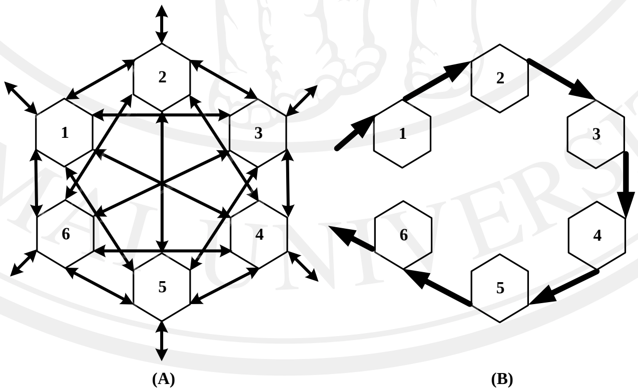


Figure 6.1 Flows in (A) the pure job shop and (B) the pure flow shop

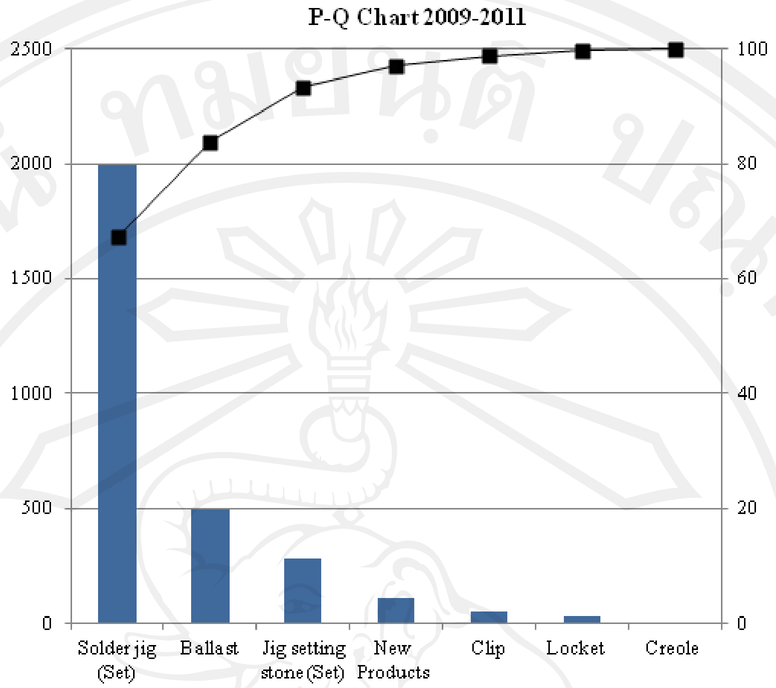
Source: Adapted from Oosterman et al., (2000)

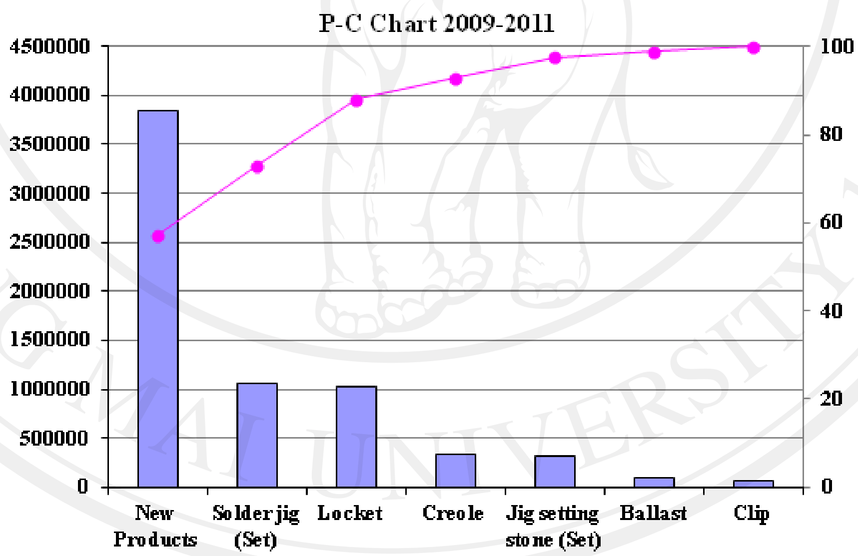
The pure flow shop operates with each job operating in one direction across an exact sequence of work stations. In a general flow shop, each job still travels in the same routing, but a movement is allowed to visit a subset of work stations. A pure job shop performs completely random routing sequences and the flow of jobs is undirected. However, the pure job shop is unlikely to be found in reality (Stevenson and Hendry, 2006). Moreover, the real life job shop has more in common with the general flow shop (Enns, 1995). A general job shop travels with a dominant flow path on a multi-directional routing.

WLC was a suggested mechanism for job shop environments as previous described in Section 2.2.5. Later, Cobacabana was elaborated on the theoretical concept of this mechanism. However, this card-based had a number of topics which require further researches. This Chapter attempted at filling the gap by presenting a three-phase model which was very interesting. A first phase aimed to apply VNM for supporting data in order entry phase. A second phase aimed to explore the implementation results by applying Cobacabana via simulation studies. A final phase aimed to find optimal parameters in Cobacabana by using a hybrid optimal algorithm.

6.1 Value Network Mapping in Workload Control Concept

First of all, the product's quantity and product's cost data were obtained based on 2009 to 2011 for product type's selection. The case study had six main types of products comprised new products, solder jigs, locket, ballast, jig setting stones and creoles. Initial target products were selected for boosting the overall performance of the case study. The product quantity cost analysis was performed to classify product types in the matrix form as shown in Figure 6.2. The matrix demonstrated that new products and solder jigs were influencing product types from the product mix for implementing in this phase.





		Quantity		
		A	B	C
Cost	A		**New Products**	
	B	**Solder Jig (Set)**		Locket
	C		Ballast Jig setting stone (Set)	Clip Creole

Figure 6.2 PQC analysis matrix

Five illustrative selected products from new products and solder jigs were displayed in the form of MPPC as shown in Figure 6.3. The use of MPPC was preferable to deal with a number of products. This tool could be used not only as input for a cluster analysis procedure, but also exploration the identification process.

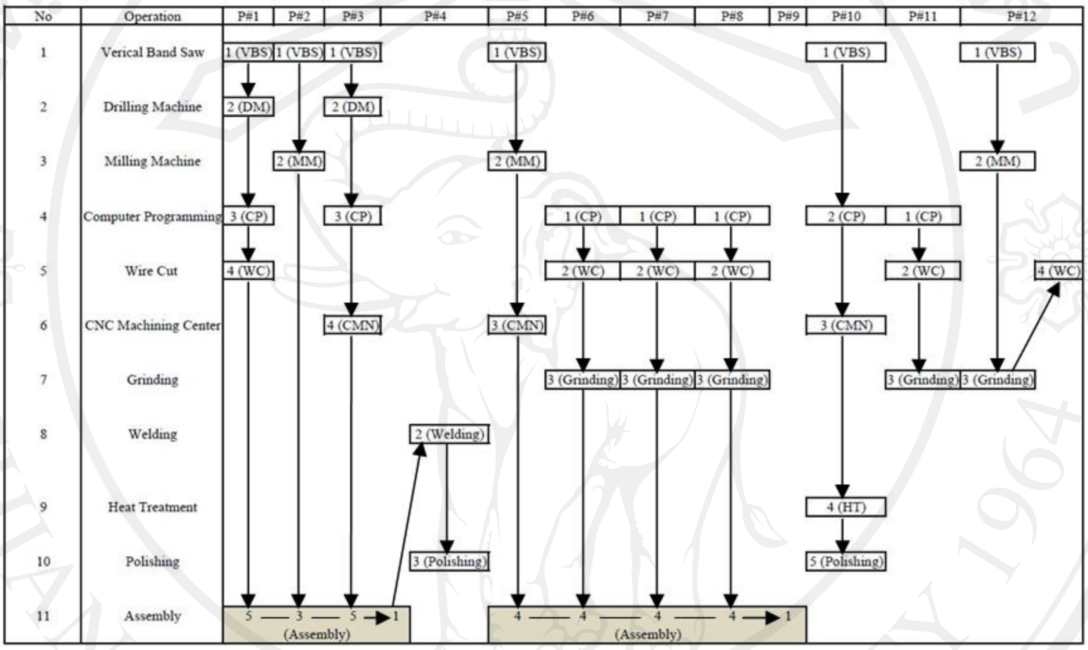


Figure 6.3 The multi-product process chart

Each product was recorded in enhanced FPC to illustrate the chronological step involved in production procedure. Distance data between machines were measured from the case study's facility layout as depicted in Appendix H. Figure 6.4 displays the enhanced FPC for one component in the case study. A cluster analysis was operated to group components with similar manufacturing path into same families. The PWSC, which is exhibited in Table 6.1, was calculated by applying Equation 3.30 ("Jaccard" similarity function) with the MPPC. The "Jaccard" similarity function for P#1 and P#2 was illustrated as a sample computation.

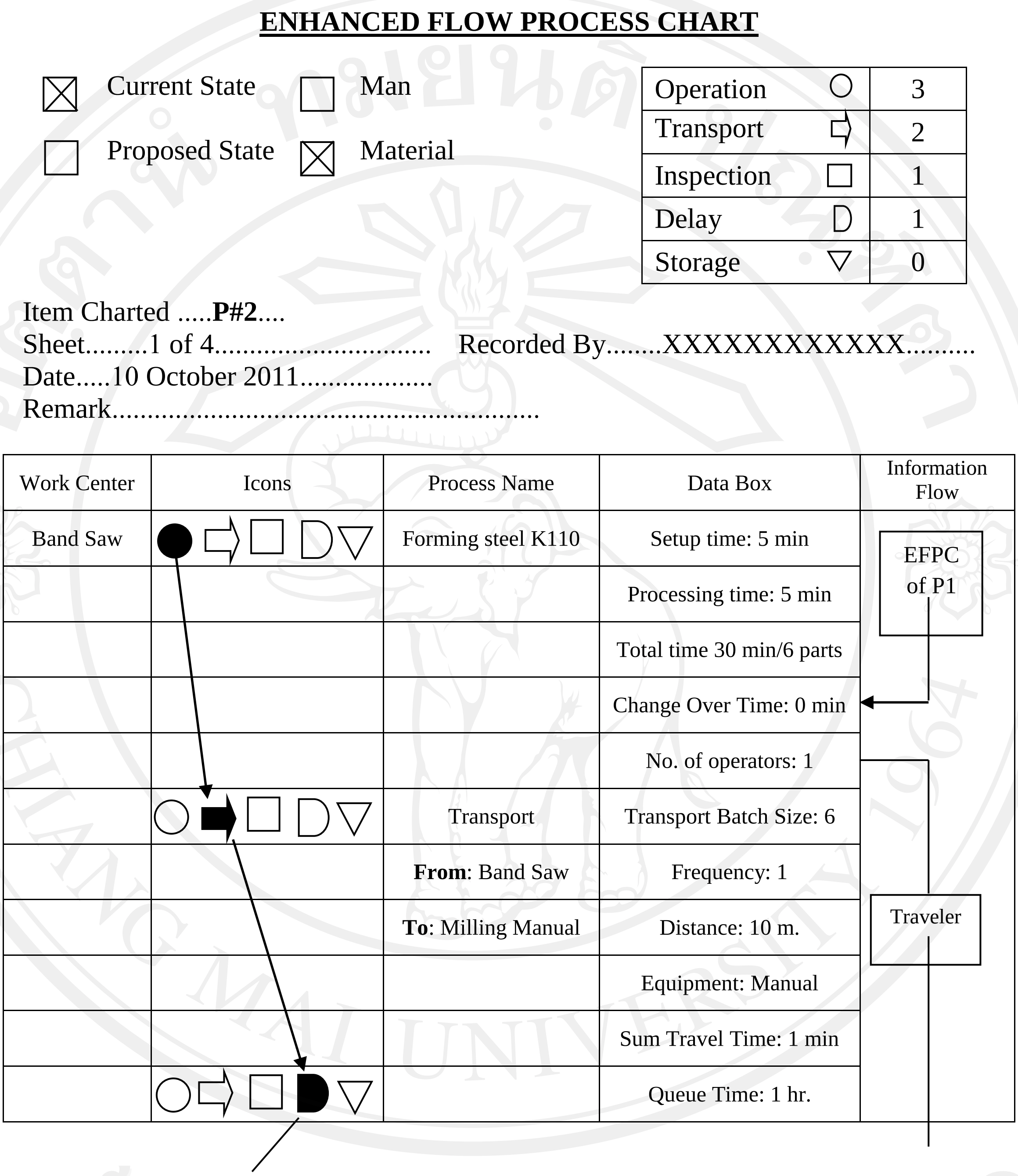


Figure 6.4 A sample of enhanced flow process chart

$$S_{12} = \frac{2+\sqrt{2 \bullet 5}}{2+3+1+\sqrt{2 \bullet 5}}$$

It was benefit to visualize the arrangement of the cluster in dendrogram that is shown in Figure 6.5. The clustering dendrogram stated that components could be partitioned into three clusters; {7,8,6,11,1,3}, {2,5,12} and {4,9} with one exceptional component 10.

Table 6.1 Jaccard similarity matrix

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
P1	1	0.563	0.775	0.333	0.475	0.696	0.696	0.696	0.463	0.426	0.563	0.491
P2		1	0.563	0.463	0.883	0.393	0.393	0.393	0.657	0.333	0.000	0.646
P3			1	0.333	0.696	0.491	0.491	0.491	0.463	0.618	0.333	0.281
P4				1	0.393	0.393	0.393	0.393	0.657	0.333	0.000	0.000
P5					1	0.333	0.333	0.333	0.549	0.491	0.000	0.563
P6						1	1.000	1.000	0.549	0.281	0.883	0.563
P7							1	1.000	0.549	0.281	0.883	0.563
P8								1	0.549	0.281	0.883	0.563
P9									1	0.000	0.000	0.000
P10										1	0.333	0.281
P11											1	0.646
P12												1

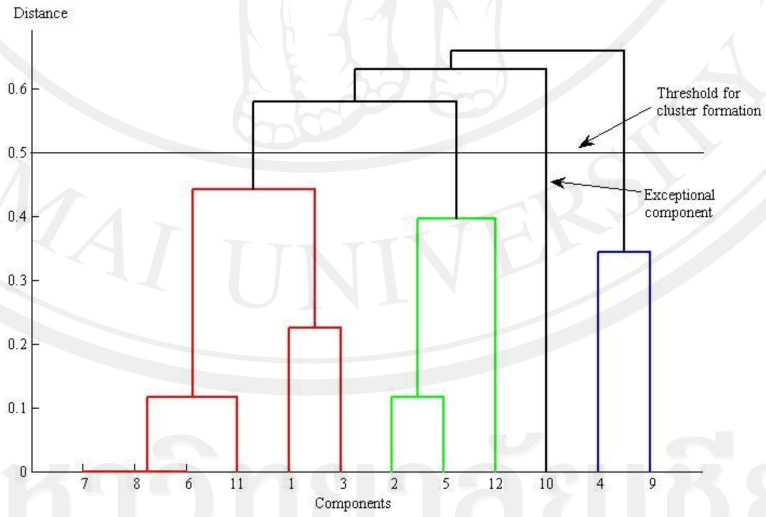


Figure 6.5 Part family dendrogram

Finally, a large number of different flows could be divided at two levels. MPPC and enhanced FPC were integrated to map the flows of a complete family of products at level 1. At level 2, each family flow was mapped by using MPPC, enhanced FPC and the cluster dendrogram. Level 1 and level 2 diagrams for component family 1 are presented in Figure 6.6 and 6.7, respectively

The case study produced a wide range of products that used different combination of parts, whose routing will characterize different work centers located in the same facility. Both levels of flow mapping attempted to combine and /or merge several flows in order to generate more compact flow diagram without eliminating any components.

6.2 Exploring Applicability of Cobacabana in Job Shop Environments

This section discussed the results of the simulation study for the workload norms and release period lengths investigated. The simulation was performed on a computer with an Intel® Core™2 Duo CPU P8700 running at 2.53 GHz with 4 GB of RAM. An experiment consisted of fifty independent replications. Each replication was terminated after a run of one hundred finished goods. Common random numbers were adopted to diminish the variance across experiments. Six sub-models including modules from Elements panel and Blocks panel were illustrated in Cobacabana.doe.

Numerical experiments using a historical data set of processing times for each product, due date allowance and order quantities were obtained by examining company records. Six selected product types were produced on eight different machines as shown in Figure 6.8. Each product had variable processing times and the routing variety was performed at three to five workstations. Statistical distributions were tested by using goodness-of-fit tests (the Kolmogorov-Smirnov test or the chi-square test).

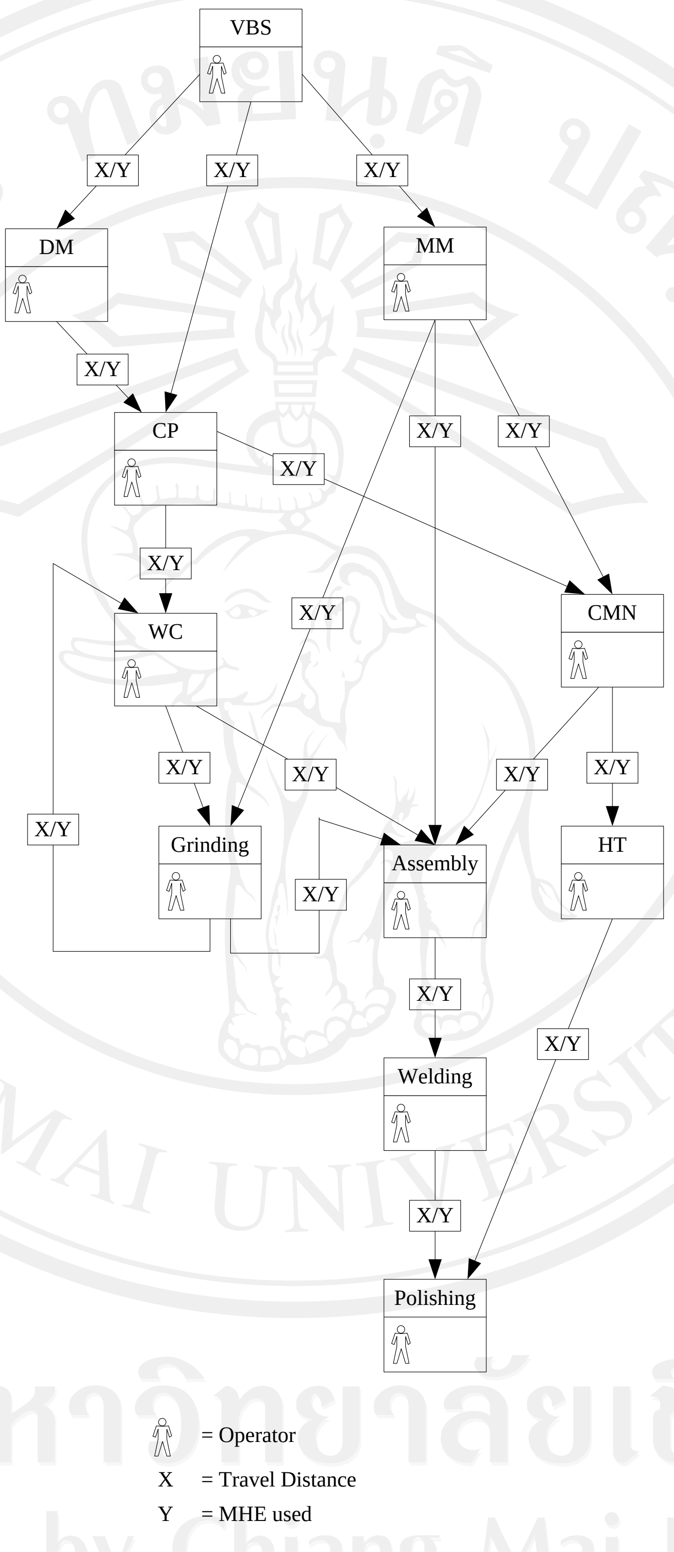


Figure 6.6 VNM at level 1

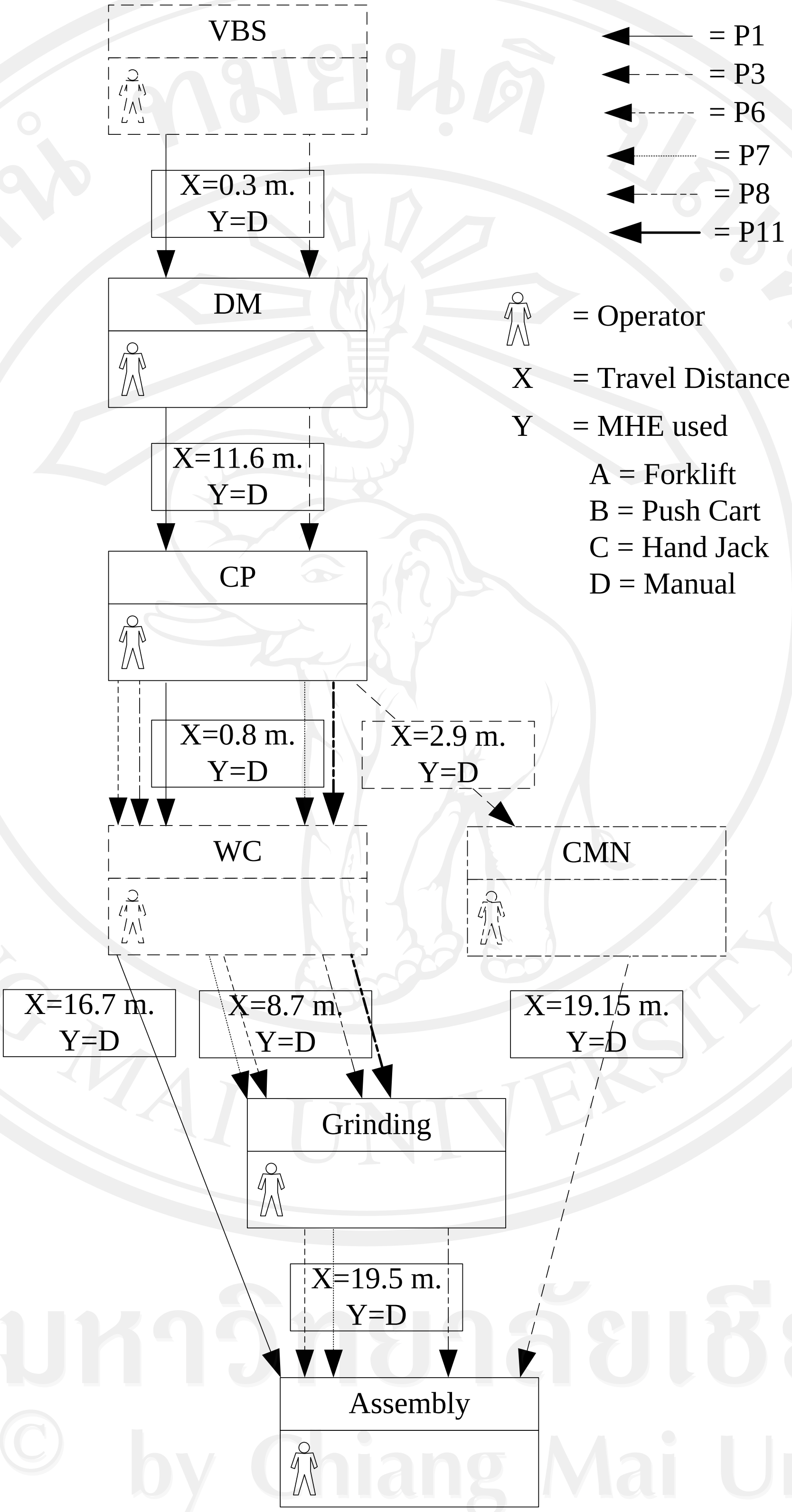


Figure 6.7 VNM at level 2 for component family 1

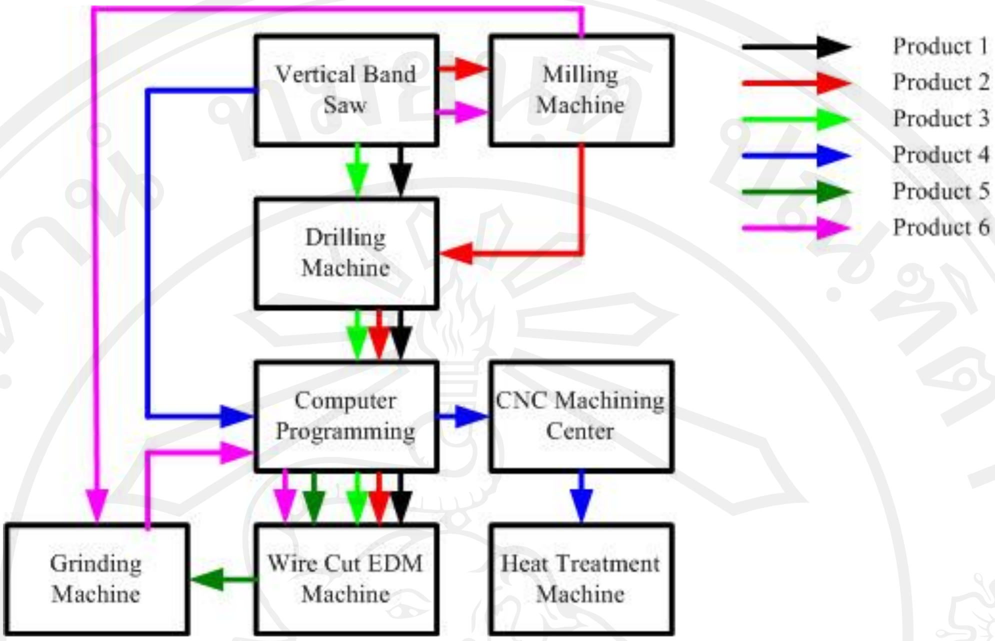


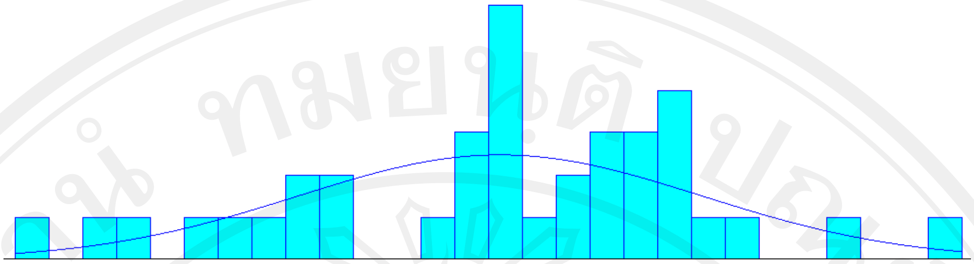
Figure 6.8 Operation flows of selected products

Next, the Input Analyzer was used on the collected historical data. This tool was used to analyze the observed data to fit for proper distribution and estimate parameters. Table 6.2 shows the content of observations on time line of selected products. The Input Analyzer displayed a histogram of the due date allowance in the top part and a summary of the data characteristics in the bottom part as shown in Figure 6.9. It was formed as a normal distribution (Corresponding p-value = 0.0751).

Order quantities was distributed with a gamma distribution (Corresponding p-value = 0.108). A simulated distribution of processing time was important. If the processing times model with 2-Erlang distribution, it might be a better approach than others distribution (Oosterman et al., 2000). Thus, the processing time was modeled using a 2-Erlang distribution for all machines as shown in Table 6.3. These distributed processing times were validated by the engineering manager. Orders arrive could not be retrieved from the company's data. Thus, interviews with the engineering manager was conducted and led to the assumption that inter-arrival times could be described as an exponential distribution. All jobs were sequenced on a first-come-first-served basis in the queue of each workstation. The basic characteristics of the simulate model are listed in Table 6.4.

Table 6.2 Time line of selected products

Product no.	Request Date	Due Date	Finished Date	Delivery Date
1	23-Jan-10	10-Feb-10	6-Mar-10	6-Mar-10
3	14-Jan-10	5-Feb-10	3-Feb-10	3-Feb-10
6	19-Jan-10	11-Feb-10	10-Feb-10	10-Feb-10
3	22-Jan-10	15-Feb-10	12-Feb-10	12-Feb-10
2	19-Feb-10	12-Mar-10	23-Mar-10	23-Mar-10
1	16-Feb-10	12-Mar-10	15-Mar-10	15-Mar-10
5	23-Apr-10	18-May-10	19-May-10	19-May-10
5	6-May-10	31-May-10	29-May-10	29-May-10
3	2-May-10	31-May-10	24-May-10	24-May-10
4	19-Apr-10	17-May-10	19-May-10	19-May-10
1	14-Apr-10	14-May-10	14-May-10	15-May-10
6	15-Apr-10	14-May-10	14-May-10	15-May-10
4	4-Apr-10	4-May-10	12-May-10	13-May-10
3	4-Apr-10	4-May-10	13-May-10	14-May-10
1	18-Apr-10	17-May-10	12-May-10	13-May-10
2	17-Apr-10	17-May-10	14-May-10	15-May-10
2	19-May-10	25-Jun-10	27-May-10	27-May-10
3	14-Jun-10	14-Jul-10	9-Jul-10	12-Jul-10
5	10-Jun-10	14-Jul-10	9-Jul-10	9-Jul-10
6	25-Jun-10	14-Jul-10	12-Jul-10	12-Jul-10
4	12-Jun-10	16-Jul-10	10-Aug-10	11-Aug-10
3	30-Jun-10	16-Jul-10	10-Aug-10	11-Aug-10
2	13-Jun-10	16-Jul-10	10-Aug-10	11-Aug-10
5	8-Oct-10	8-Nov-10	8-Nov-10	8-Nov-10
	….	….	….	….



Distribution Summary

Distribution: Normal

Expression: NORM(29.8, 5.98)

Square Error: 0.027659

Chi Square Test

Number of intervals = 6

Degrees of freedom = 3

Test Statistic = 7.03

Corresponding p-value = 0.0751

Data Summary

Number of Data Points = 37

Min Data Value = 16

Max Data Value = 43

Sample Mean = 29.8

Sample Std Dev = 6.06

Histogram Summary

Histogram Range = 15.5 to 43.5

Number of Intervals = 28

Figure 6.9 Histogram and the data characteristics of the due date allowance

Table 6.3 Operation processing time in 2-Erlang distributed (unit: minute)

Workstation	**Product**					
	1	2	3	4	5	6
Vertical band saw	(2,2)	(4/3,2)	(6/5,2)	(1,2)		(6/5,2)
Milling machine		(1,2)				(1,2)
Drilling machine	(3,2)	(2/3,2)	(4/5,2)			
Computer programming	(1/2,2)	(1/3,2)	(1/5,2)	(1/2,2)	(0.5,2)	(1/3,2)
CNC machining center				(8,2)		
Grinding machine					(20,2)	(18,2)
Wire cut EDM machine	(37.4,2)	(83/5,2)	(10.1,2)		(96/5,2)	(32,2)
Heat treatment machine				(9.9,2)		

Table 6.4 Summary of simulated model characteristics

Shop	Eight workstations, all equal capacity
No. of operations per product	Three to five, no re-entrant loops
Inter-arrival times	Exponential distributed (mean: 50)
Due date allowance	Normal distributed (30,6) [Time unit: Day]
Order quantities	2.5 + gamma distribution, beta = 10.3, alpha = 1.35
Priority dispatching rule	FCFS
Time unit	Minute

This simulation model was verified by adopting a structured walkthrough technique to verify the simulation model. Event validity was done by comparing results from the simulation model and actual system. For example, actual throughput time of product two was 19.80 minutes, as shown in Table 6.5. Then, the simulation output data were compared with this result. Generally, the simulation report generates a column called “half width”, which determine the reliability of the simulated results. The mean average throughput time from twenty replications of the simulation model was 19.95 minutes with the half width of 1, as display in Figure 6.10. The hypotheses are

H_1: The model is valid for the acceptable range of the 95% confidence interval on the expected value of the output result under the experimental conditions

H_2: The model is invalid for the acceptable range of the 95% confidence interval on the expected value of the output result under the experimental conditions

Therefore, H_1 was accepted. The model throughput differed from the historical throughput by less than one percent. Thus, it appeared that the model was reasonably valid.

Table 6.5 Processing data of product two

Workstation	Process Name	Data Box
Vertical band saw	Cut materials	Total time: 40 minutes/30 sets
Milling machine	Prepare materials	Total time: 30 minutes/30 sets
Drilling machine	Drill materials	Total time: 20 minutes/30 sets
Computer programming	Create a program	Total time: 10 minutes/30 sets
Wire cut EDM machine	Setup the machine	Total time: 14 minutes/30 sets
	Run the machine	Total time: 480 minutes/30 sets
	Total Time	594 minutes/30 sets
	Throughput time	19.8 minutes

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Delivery Reliability	0.3762	0.02	0.2776	0.4330	0.00	0.7960
Lead Time	17.0818	0.91	13.1642	21.2968	0.2500	40.2815
On Time Delivery	0.9394	0.01	0.8975	0.9627	0.00	0.9952
System Utilization	0.4053	0.01	0.3590	0.4298	0.1250	0.4505
Throughput Time	19.9516	1.00	15.4702	24.3100	0.4607	45.6538
WorkStation 1 Throughput	178.61	9.89	131.32	214.52	0.00	425.70
WorkStation 2 Throughput	1.9112	0.25	1.1884	3.2198	0.00	3.5765
WorkStation 3 Throughput	6.5827	0.77	4.4518	10.5315	0.00	11.7296
WorkStation 4 Throughput	0.3756	0.03	0.2524	0.5186	0.00	0.6265
WorkStation 5 Throughput	151.21	10.60	108.75	198.14	0.00	458.69
WorkStation 6 Throughput	0.00	0.00	0.00	0.00	0.00	0.00
WorkStation 7 Throughput	0.00	0.00	0.00	0.00	0.00	0.00
WorkStation 8 Throughput	0.00	0.00	0.00	0.00	0.00	0.00

Figure 6.10 The user specified report for product two

Limits were considered starting from 0.5 days of work up to 3.5 days as illustrated in Figure 6.11. When the workload norms were tightened, the lead time was significantly decreased because of the contribution from load balancing function and timing function. Because the norm was tight at a ratio of 0.5, the lead time was driven up to 28.09 days. This phenomenon could be attributed to the tighter norms, which might agitate the planned release sequence.

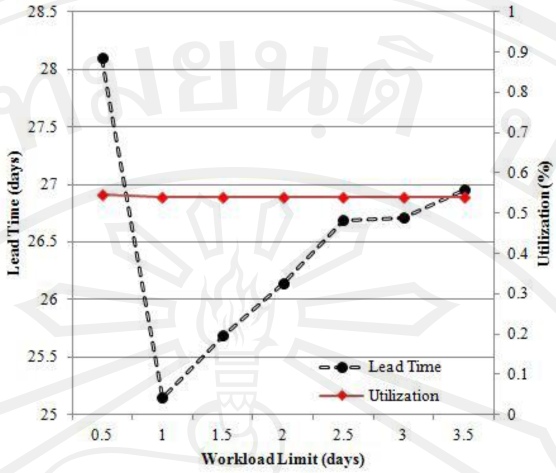


Figure 6.11 Workloads limit analysis

The adjusted aggregate load approach constructed even utilization levels for this research. Figure 6.12 represents a shop floor with two bottleneck machines that operate at almost 100% utilization.

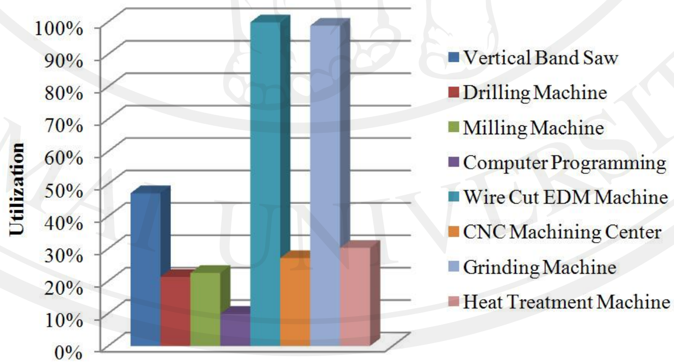


Figure 6.12 Workstation utilization levels

Next, the effect of release period length was observed. Figure 6.13 depicts the influence on the lead time and delivery reliability when the workload limit equals one. Because the lead time was the sum of the pool time and the shop floor time, the increasing lead time was clearly related to the higher release period length. In terms of delivery reliability, the same trend was seen. This situation was discussed in previous sections.

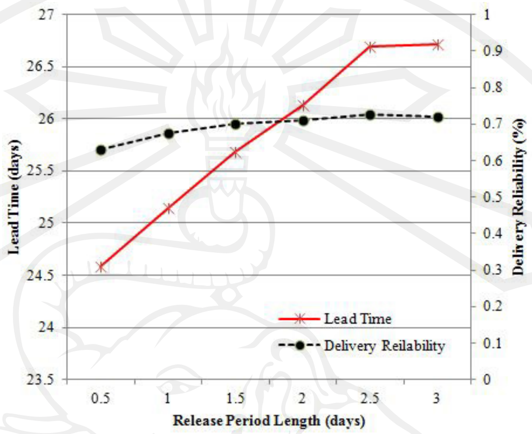


Figure 6.13 Release period length analysis.

The contribution of each order could be calculated for the release cards on the shop floor and the acceptance cards at the pool waiting times by using Equations 2.11 and 2.13, which are shown in Figures 6.14 and 6.15, respectively.

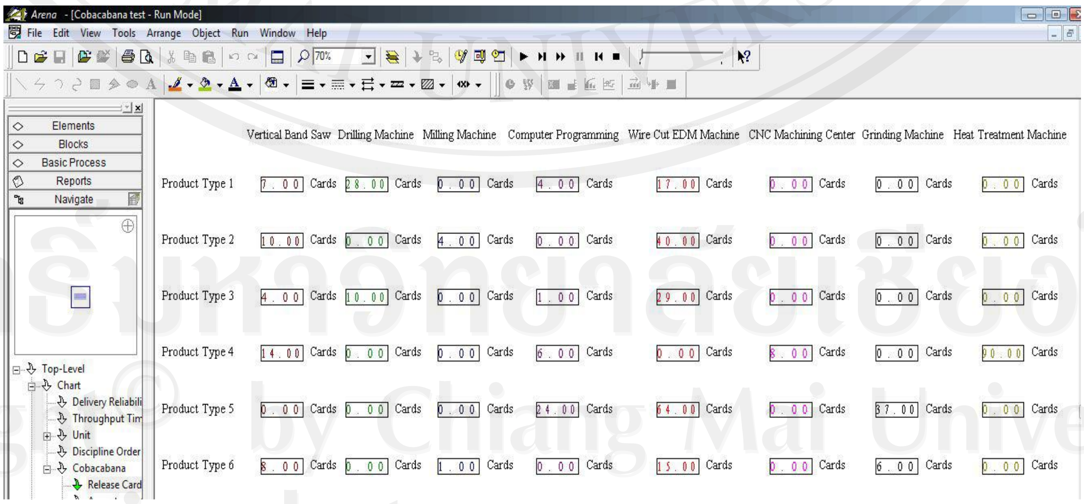


Figure 6.14 Number of requested release cards at day 10 (each card equals 10%).

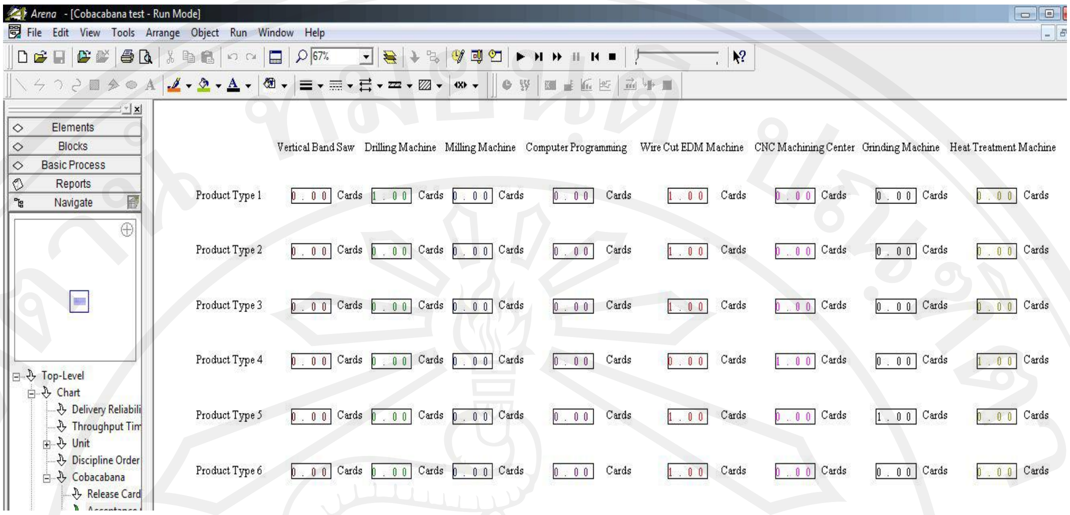


Figure 6.15 Number of requested acceptance cards at day 10 (each card equals one-tenth of a day).

6.3 A Hybrid Algorithm

As prior described in Chapter 3 for simulated model characteristics, this section proposed the optimization paradigm. For ant system (AS) algorithm, many parameters such as α, β, and ρ are implemented to obtain objective results for any combinatorial optimization problem. Then, the AS algorithm work efficiently depends on setting good parameters. The unknown parameters were estimated using various stratification strategies and various number of searching artificial ants.

All tests with the number of artificial ants exceeding 150% of the exhaustive runs led to basically the same results (Abbaspour et al, 2001). Each parameter was divided into ten strata, which produced a total of one hundred exhaustive runs. After running Antcoba by performing the AS' parameters with small-scale data, the considered parameters and two hundred ants with one thousand iterations per experiment were launched as given in Table 6.6.

Table 6.6 Initial parametric setting

α	β	ρ	Number of ants	Number of iterations
1	1.5	0.1	200	1,000

Algorithm Antcoba

Step 1 form an initial pheromone trails by set $\tau_{ij} = 1\times10^{-4}$ and set all parameters.

Step 2 place 200 ants to the complete parameter space.

Step 3 generate construction steps. Each ant k choose a probabilistic action choice rule to decide which stratum to visit next as

$$p_{ij}^{k} = \frac{\left[\tau_{ij}\right]^{1}\left[0.06757\right]^{1.5}}{\sum l \in N_i^k \left[\tau_{ij}\right]^{1}\left[0.06757\right]^{1.5}}, ifj \in N_i^k$$

Step 4 update pheromones after all ants have constructed their path. This is done by lowering the pheromone value on all paths by a constant factor and adding pheromone on the paths that ants have moved in their paths as

$$\tau_{ij} \leftarrow (1-0.1)\tau_{ij} + \sum_{k=1}^{m} \Delta\tau_{ij}^{k}, \forall (i, j) \in L$$

The simulation testing from ARENA consisted of ten independent replications for each parameter. Each termination replication was determined at 172,800 time unit. The ten replicated simulation results were prepared for Antcoba algorithm (See appendix I) to discover Cobacabana parameters. The lead time and delivery reliability acquisition results are listed in Table 6.7 and Table 6.8, respectively.

Table 6.7 The simulation results for lead time by using ten replications

Lead time	Release Period Length (Day)										
		0.5	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
Workload Ratio	**0.5**	-	23.0508	21.3161	21.5104	21.0626	21.3804	22.8885	21.5623	21.1977	21.8214
	1	22.3371	22.4792	22.5749	22.3401	22.4037	22.3204	22.5980	22.3666	21.8579	23.3372
	1.5	23.8898	23.3490	23.2144	22.9577	22.6081	23.3085	23.3497	22.4401	**22.1304**	22.3898
	2	24.9313	24.1751	23.3789	23.5805	23.4600	24.1768	23.7215	23.0602	23.1404	23.3560
	2.5	25.4627	24.7395	24.0008	23.8665	23.5125	24.2057	24.1208	23.6540	23.5202	24.4111
	3	26.3696	25.2237	24.3361	24.6278	24.8150	25.6652	24.4232	24.4070	23.7371	24.9483
	3.5	26.0344	25.7722	25.4537	24.4104	24.9243	25.1369	25.3740	24.5469	24.3330	24.8954
	4	27.0122	25.6399	25.3965	25.2781	25.1730	25.7911	25.3610	25.2470	25.3612	25.3769
	4.5	27.4318	25.6025	26.1128	25.0042	26.0098	25.4666	25.4293	25.1422	25.0703	25.8239
	5	28.2430	26.7830	25.7896	25.9482	26.4053	25.9788	25.8019	25.9919	25.7543	26.2480

Table 6.8 The simulation results for delivery reliability by using ten replications

Delivery Reliability	**Release Period Length (Day)**										
		0.5	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
	0.5	-	0.5186	0.5697	0.5418	0.4560	0.5235	0.5275	0.5607	0.5620	0.5355
	1	0.6984	0.6235	0.6552	0.6508	0.6408	0.6440	0.6221	0.6345	0.6591	0.6693
	1.5	0.7116	0.6649	0.6868	0.7029	0.6595	0.6617	0.6740	0.6684	**0.6881**	0.6827
	2	0.7138	0.6892	0.6995	0.6776	0.6764	0.7082	0.6953	0.6997	0.6892	0.6946
Workload Ratio	**2.5**	0.6974	0.6958	0.6979	0.6995	0.6937	0.7095	0.7064	0.7027	0.7078	0.7228
	3	0.7149	0.7063	0.7095	0.6937	0.7087	0.7251	0.7118	0.7259	0.7031	0.7326
	3.5	0.7079	0.7035	0.7292	0.7086	0.7169	0.7299	0.7115	0.7206	0.7138	0.7265
	4	0.7065	0.7002	0.7271	0.7140	0.7140	0.7227	0.7174	0.7168	0.7219	0.7293
	4.5	0.7037	0.7030	0.7231	0.7212	0.7242	0.7258	0.7159	0.7218	0.7263	0.7252
	5	0.7001	0.7005	0.7329	0.7124	0.7231	0.7289	0.7159	0.7227	0.7258	0.7338

The Antcoba was performed for finding feasible parameters. As shown in experiments, the algorithm generated the best pathway as workload ratio equals 1.5 and release period length equals 4.5. However, the half width of this experiment represented 5.03 days or a 22.73% error in the point estimate 22.1304 days as shown in Figure 6.16.

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximu Val
Delivery Reliability	0.6881	0.06	0.5679	0.7877	0.00	0.86
Lead Time	22.1304	5.03	14.5127	34.0648	11.5788	46.65
On Time Delivery	0.6881	0.06	0.5679	0.7877	0.00	0.86
System Utilization	0.5344	0.03	0.4725	0.5825	0.4495	0.59
Throughput Time	3.5433	1.88	0.5342	7.8783	0.4299	14.31
WorkStation 1 Throughput	53.1921	13.67	24.4093	97.9757	0.00	141.
WorkStation 2 Throughput	2.0121	0.38	1.2618	2.9164	0.00	3.67
WorkStation 3 Throughput	0.9959	0.22	0.6282	1.4122	0.00	2.20
WorkStation 4 Throughput	0.3681	0.06	0.2043	0.4610	0.00	0.74
WorkStation 5 Throughput	85.8677	32.46	35.9433	172.28	0.00	445.
WorkStation 6 Throughput	12.4778	4.50	6.4018	25.1702	0.00	56.66
WorkStation 7 Throughput	75.4974	26.24	34.1800	143.10	0.00	382.
WorkStation 8 Throughput	13.5575	3.26	6.9982	21.9033	0.00	62.60

Figure 6.16 Reports from ten replications

Based on the lead time unit, one day was considered as the base period. To reduce the half width, a number of replications might be adjusted instead of ten replications to $n \cong 10 \times \left(\frac{5.03^2}{0.92^2} \right) = 299$ replications. Hence, three hundred replications were replaced to run the simulation model for updating lead time and delivery reliability. Figure 6.17 displays results from three hundred replications. Moreover, several replications of the simulation model were developed to obtaining a satisfactory internal valid model.

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximu Val
Delivery Reliability	0.6616	< 0.01	0.00	0.8469	0.00	0.90
Lead Time	28.7940	< 0.97	11.9797	68.5240	8.2021	71.79
On Time Delivery	0.6616	< 0.01	0.00	0.8469	0.00	0.90
System Utilization	0.5480	< 0.00	0.4034	0.6932	0.3997	0.72
Throughput Time	6.9827	< 0.59	0.5342	41.6844	0.3504	52.88
WorkStation 1 Throughput	71.3368	< 2.91	15.0759	178.64	0.00	349.
WorkStation 2 Throughput	2.6326	< 0.13	0.6898	8.7412	0.00	13.46
WorkStation 3 Throughput	0.8773	< 0.02	0.5062	1.5697	0.00	2.82
WorkStation 4 Throughput	0.3986	< 0.02	0.2014	1.0263	0.00	1.68
WorkStation 5 Throughput	104.00	< 4.33	24.6735	241.07	0.00	490.
WorkStation 6 Throughput	16.8354	< 1.17	2.3281	76.4115	0.00	135.
WorkStation 7 Throughput	81.0270	< 3.67	22.1434	232.46	0.00	455.
WorkStation 8 Throughput	16.0792	< 1.03	3.5087	50.2558	0.00	83.31

Figure 6.17 Reports from three hundred replications

Figure 6.18 illustrates sample results by applying via Antcoba before applying with three hundred replications of simulated model. After the fifteenth replications, the best value obtained by the hybrid algorithm was 29.22 days for lead time and 68.65% delivery reliability. In addition, workload ratio and release period length related to 2 and 2, respectively as shown in Figure 6.19.

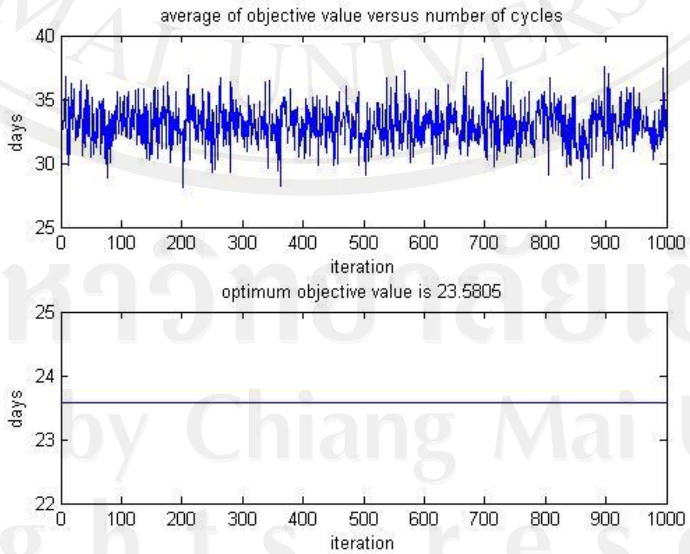


Figure 6.18 Sample results via Antcoba

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximu Val
Delivery Reliability	0.6865	< 0.01	0.3792	0.8513	0.00	0.91
Lead Time	29.2255	< 0.94	13.9951	66.1918	9.5452	73.50
On Time Delivery	0.6865	< 0.01	0.3792	0.8513	0.00	0.91
System Utilization	0.5470	< 0.00	0.3941	0.6731	0.3795	0.68
Throughput Time	7.3006	< 0.61	0.6560	37.6803	0.3643	55.32
WorkStation 1 Throughput	71.7341	< 2.90	15.8502	178.52	0.00	355.
WorkStation 2 Throughput	2.6845	< 0.13	0.7426	7.7479	0.00	13.09
WorkStation 3 Throughput	0.8879	< 0.03	0.3976	2.3573	0.00	3.40
WorkStation 4 Throughput	0.3956	< 0.01	0.1850	1.0248	0.00	1.68
WorkStation 5 Throughput	105.31	< 4.35	27.9698	239.94	0.00	498.
WorkStation 6 Throughput	16.8808	< 1.17	2.2443	71.8614	0.00	129.
WorkStation 7 Throughput	82.3579	< 3.70	24.3466	232.74	0.00	455.
WorkStation 8 Throughput	16.3053	< 1.01	2.6361	63.8147	0.00	95.04

Figure 6.19 Results from workload ratio and release period length relate to 2 and 2

It was generally agreed upon to use the due date of the orders as the priority criterion in the release decision. The proposed algorithm was compared to EDD rule. The half width of EDD represented 1.18 days or a 3.82% error in the point estimate 30.88 days as shown in Figure 6.20.

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Delivery Reliability	0.4306	0.04	0.3635	0.5391	0.00	0.8292
Lead Time	30.8819	1.18	28.3508	33.8015	2.9430	57.2104
On Time Delivery	0.8487	0.02	0.7995	0.8692	0.00	0.9902
System Utilization	0.7965	0.01	0.7636	0.8094	0.6883	0.8142
Throughput Time	35.8903	1.25	33.4770	39.2478	3.4246	66.3654
WorkStation 1 Throughput	280.84	5.36	271.98	290.79	0.00	570.24
WorkStation 2 Throughput	2.8733	0.57	1.8852	4.5096	0.00	5.3487
WorkStation 3 Throughput	0.8329	0.09	0.6831	1.0904	0.00	1.4779
WorkStation 4 Throughput	0.6107	0.06	0.5098	0.7930	0.00	1.1859
WorkStation 5 Throughput	338.45	11.02	314.25	357.56	0.00	716.80
WorkStation 6 Throughput	78.7716	18.05	38.1238	110.36	0.00	204.65
WorkStation 7 Throughput	252.11	10.63	233.99	272.61	0.00	556.60
WorkStation 8 Throughput	71.0022	7.70	58.8105	88.4935	0.00	180.11

Figure 6.20 EDD ten replications

A number of replications might be adjusted instead of ten replications to $n \cong 10 \times \left(\frac{1.18^2}{0.92^2} \right) = 17$ replications. Hence, seventeen replications were replaced to run the simulation model. Results obtained by the EDD algorithm were 30.55 days for lead time and 44.02% delivery reliability as illustrated in Figure 6.21. Comparisons WIP of two approaches are illustrated in Table 6.9. Figure 6.22 shows the comparison of both simulation approaches.

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Delivery Reliability	0.4402	0.03	0.3635	0.5391	0.00	0.8292
Lead Time	30.5550	0.83	27.9740	33.8015	2.9430	57.2104
On Time Delivery	0.8525	0.01	0.7995	0.8740	0.00	0.9902
System Utilization	0.7984	0.01	0.7636	0.8108	0.6883	0.8142
Throughput Time	35.6437	0.84	32.8950	39.2478	3.4246	66.3654
WorkStation 1 Throughput	278.76	4.19	265.82	290.79	0.00	575.27
WorkStation 2 Throughput	2.8301	0.34	1.8852	4.5096	0.00	5.3487
WorkStation 3 Throughput	0.8083	0.05	0.6831	1.0904	0.00	1.4779
WorkStation 4 Throughput	0.6161	0.03	0.5098	0.7930	0.00	1.1859
WorkStation 5 Throughput	333.20	8.04	307.72	357.56	0.00	723.57
WorkStation 6 Throughput	69.6145	12.00	38.1238	110.36	0.00	204.65
WorkStation 7 Throughput	254.60	8.37	230.65	281.22	0.00	561.48
WorkStation 8 Throughput	74.9088	6.98	47.9473	99.26	0.00	187.95

Figure 6.21 EDD seventeen replications

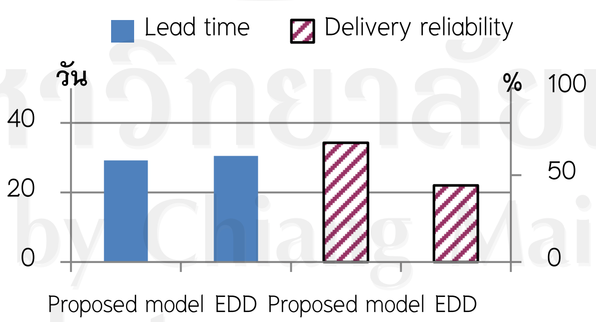


Figure 6.22 Comparison results of the proposed model and EDD

Table 6.9 WIP comparisons of the proposed approach and EDD (EA.)

Workstation	The hybrid algorithm	EDD
Vertical band saw	96.65	6,666.66
Drilling machine	0.55	1.83
Milling machine	0.33	0.14
Computer programming	0.04	0.93
Wire cut EDM machine	431.12	2,871.23
CNC machining center	16.12	64.77
Grinding machine	7.59	326.28
Heat treatment machine	1.58	64.31

6.4 Conclusion

VNM was employed for supporting data in order entry phase of Cobacabana. A number of material flow analysis and product grouping tools were applied for this phase. Next, the effectiveness of Cobacabana, the card-based system for stochastic environments, was explored. An adjusted aggregate load was adopted to translate workload norms into a fixed number of cards. The Cobacabana system focused on controlling throughput times by using a card loop system, release cards, and acceptance cards. The final phase of this study employed the Antcoba algorithm integrating with ARENA for dealing with a model parameter identification issue.

It should be noted that best-case and worst-case performance were investigated in an algorithm analysis. On the one hand, the best-case was proposed in previous Section already On the other hand, if workload ratio and release period length equals were set as 0.5. The planner could not schedule and release production orders. Hence, lead time and delivery reliability were appeared the worst-case performance.

The simulation study for the workload norms and release period lengths was investigated. These factors also replied the sub-question 1. Moreover, the sub-question 2 "Which approach should be suitable to find a job shop scheduling of minimum length for stochastic lean system environments?" was answered by using the hybrid algorithm.