CHAPTER III

CASE STUDY

This chapter discusses the analysis and applications of several project management techniques for the distribution transformer division of PEM. The present production planning and control system are described and then analyzed for further improvement. After that many powerful project management techniques are discussed and applied from the phase of planning to monitoring and control, respectively. Finally all of these applications are linked together as a project-based production planning and control system for the distribution transformer division of PEM. These analysis and applications are taken into account at an appropriate level for realistic working situation. Although each technique is discussed, analyzed and applied in sequence, they must be simultaneously considered in practice.

3.1 Background of Case Study

Precise Electric Manufacturing Co., Ltd. (PEM) was established in 1986 to manufacture a wide range of electrical transmission equipment. Its factories are located at 103/2 Moo 6 Tiwanon Road, Thambol Banmai, Amphur Muang, Pathumthani 12000.

PEM's products can be classified into five groups as follows:

1) Surge Protection Equipment
2) Capacitors for power-factor correction of a.c. power system.
3) Control Systems to control main equipment operation.
4) Instrument Transformers/ Voltage Transformers and Current Transformers
5) Distribution Transformers

The organizational structure of the company can be divided to ten divisions as shown in Figure 3.1.

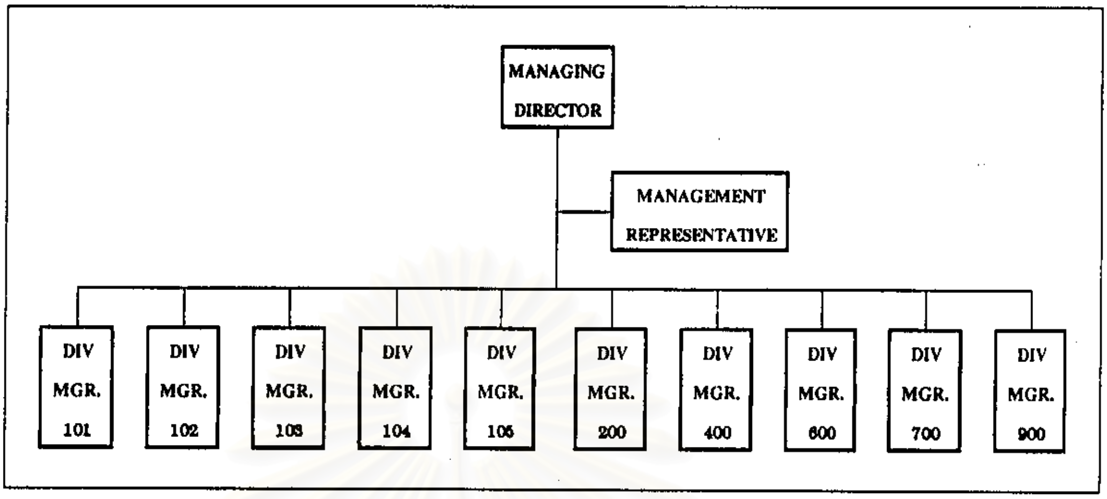


Figure 3.1 *Organizational structure of Precise Electric Manufacturing Co., Ltd.*

DIV. 101	SURGE PROTECTION
DIV. 102	CONTROL and AUTOMATION SYSTEM
DIV. 103	INSTRUMENT TRANSFORMER
DIV. 104	CAPACITOR
DIV. 105	DISTRIBUTION TRANSFORMER
DIV 200	PURCHASING and WAREHOUSE
DIV 400	TECHNOLOGY SUPPORT
DIV 600	ACCOUNTING and FINANCE
DIV 700	HUMAN RESOURCE and ADMINISTRATION
DIV 900	QUALITY ASSURANCE

To conduct this case study, the division of distribution transformer of PEM has been selected, by viewing an order as a manufacturing project. Distribution transformers have received ISO-9002 certification. The customers for the distribution transformers are both oversea and domestic, which include state enterprises and private sectors. Orders from state enterprises are obtained through bidding. While, orders from private sectors and from overseas are directly launched to the company. Lead times to manufacture distribution transformers depend on specifications and order sizes, which may vary from one to 250 units. Generally, the production time may take between two and four months.

The organizational structure of the distribution transformer division is divided into three sections as shown in Figure 3.2. However, it has not production planning and control section.

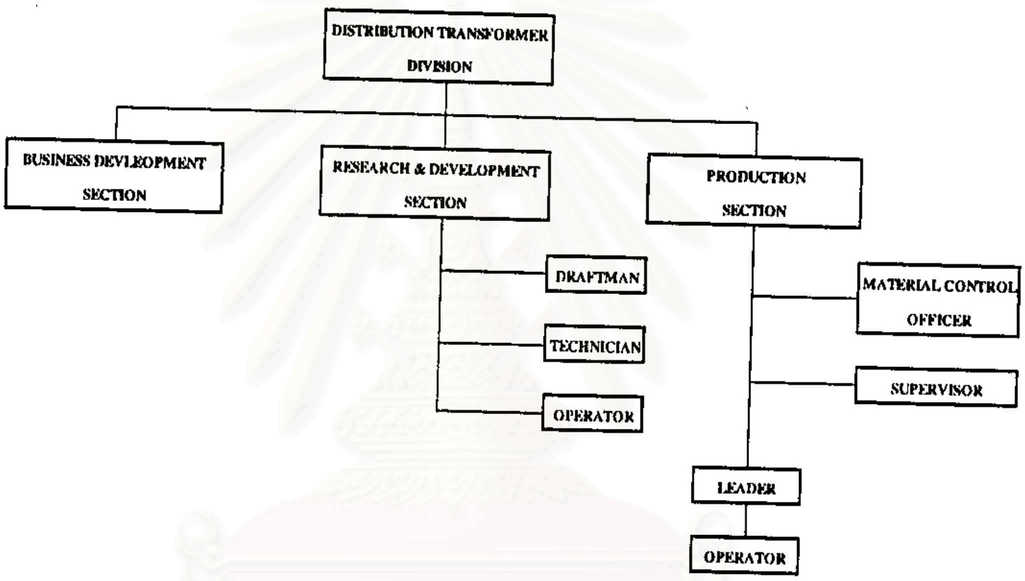


Figure 3.2 Organizational structure of Distribution Transformer Division

Production section of the distribution transformer division can still be divided further into six main sub-sections as shown in Figure 3.3.

To more clearly understand the project-based production planning and control system, the project to manufacture 100 units distribution transformers with specification 250kVA / 22kV, 3 Phase is used to illustrate as an example case. This order must be delivered in two lots, of 50 units each.

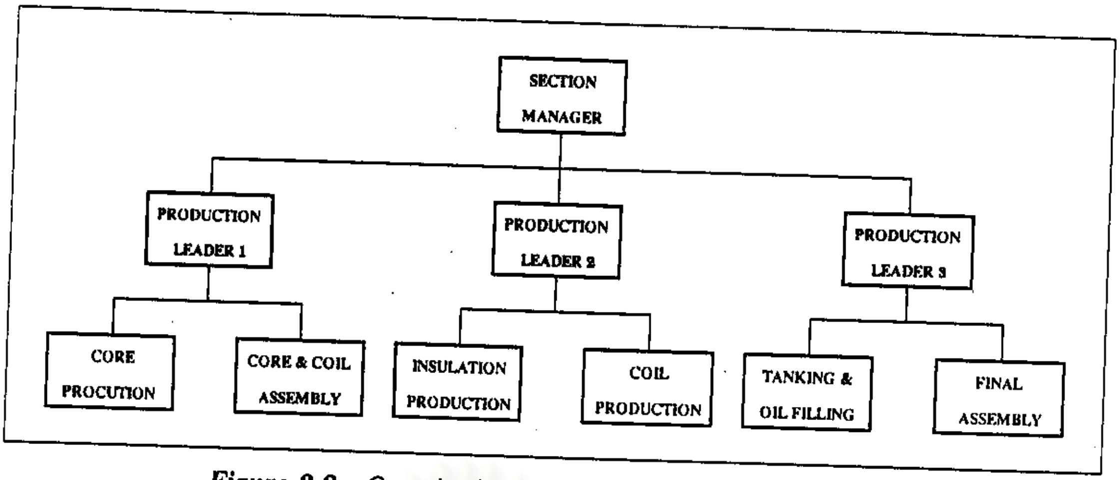


Figure 3.3 *Organizational structure of Production Section*

3.2 Work Breakdown Structure Model

A distribution transformer comprises mainly a core and a coil, or coils, both in an oil-filled tank and other accessories. Operations on an order of distribution transformers commence merely after it is received. The first operation starts with designing the transformers according to the specifications. Then, purchasing orders for required materials are issued. As shown in Figure 3.2, the activities of the production section of the distribution transformer division can be classified to two major groups namely material control and production.

The material control includes material planning and calculation of the required quantity of each item for each order. The production process of a distribution transformer involves a number of activities. However, considering the relationships of these activities, activities duration, required resources, critical points for monitoring and control, the current organizational structure and many other factors, the process can be broken down to nine sub-processes as follows:

Insulation production

Insulation production of distribution transformer manufacturing begins with wrapping copper conductors with insulation papers. This process produces many types of insulations. Many pieces of each type are required for a distribution transformer. Typically, each type of insulations is produced in batch. The major resource of this process requires only workforce.

Low voltage coil winding

Low voltage coil winding process needs many items from the Insulation production process to wind large copper wires around insulated core to be that of low voltage coil. The major resources of this process include low voltage winding machine and workforce.

High voltage coil winding

High voltage winding process uses work from the Low voltage winding process to wind smaller wires over to form high voltage coil. This process requires high voltage winding machines and the workforce as major resources.

Core cutting

The other branches to manufacture distribution transformers begins with cutting various sizes of silicon steel slits, which come in rolls, into small plates. Each size is different in width, length and shape. Each width comprises five different lengths as five items to be assembled into a core frame namely two yokes, two legs and one mid. Due to a number of required core frames, all of these items are produced in large volumes. After that lower yoke of each frame will be punched holes for holding all items together as a frame as shown in Figure 3.4. The major resources of this process include workforce and core cutting machine. In practice, each item is cut in batch in order to reduce set-up time of machines.

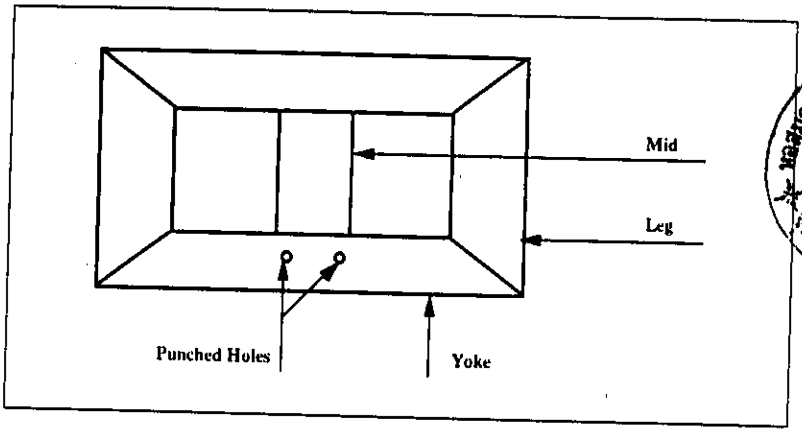


Figure 3.4 *Components of a core frame of a distribution transformer*

Core stacking

Core stacking process assembles and stacks together all items of silicon steels from the Core cutting process on a wooden support, frame by frame to make a completed core. The major resources of this process are stacking table and workforce.

Core and coil assembly

Core and coil assembly process assembles together cores from the Core stacking process and coils from the High voltage coil winding process. This process simply requires workforce as a major resource.

Vacuum and dry

Vacuum and dry process must wait until the number of intermediate products from the Core and coil assembly process equals the maximum capacity of the oven. Then, these intermediate products are heated in the oven for 72 continuous hours. Cost and time of the oven are fixed, independent of the number of units it contains. The oven is only major resource for this process.

Tanking and oil filling

Tanking and oil filling process must wait until the Vacuum and dry process is completed. Then, it starts by placing the assembly into a vacuum tank, which is later filled with oil. This process requires workforce, vacuum bell, and oil filling machine as major resources.

Final assembly

Final assembly process fits the tanks from the Tanking and oil filling process with accessories. The resource of this process is merely workforce.

From all the above processes, the work breakdown structure of distribution transformer manufacturing project can be shown in Figure 3.5.

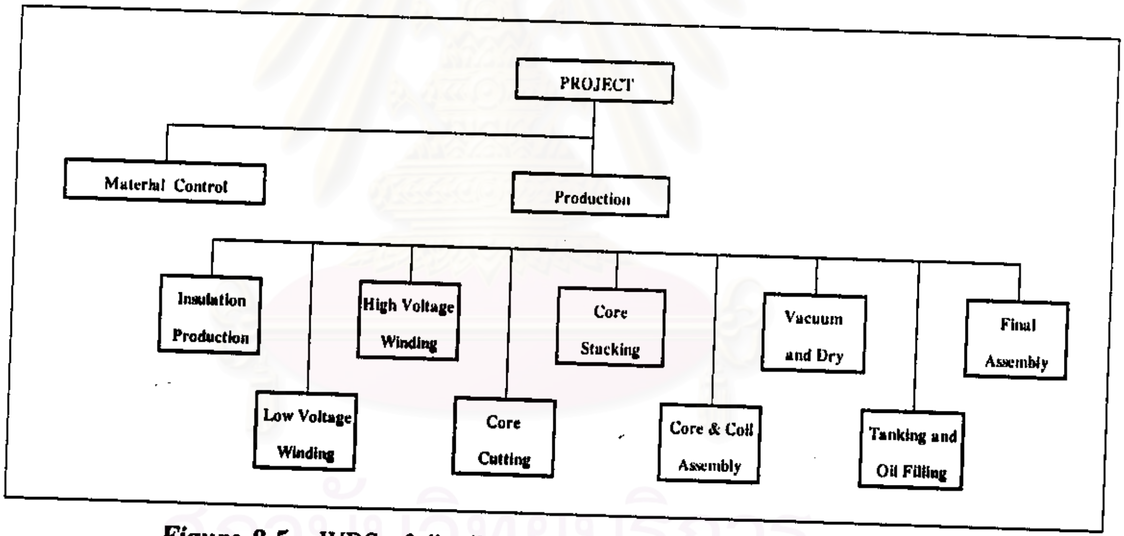


Figure 3.5 WBS of distribution transformer manufacturing project

The shorter but informative descriptions for these processes, which are understood without ambiguity by all employees are Insulation, Core cutting, Core stacking, L.V. winding, H.V. winding, Core & Coil Assembly, Vacuum & dry, Tanking and oil filling, and Final Assembly respectively.

3.3 Expected Resources and Activity Duration Estimates Application

Due to poor data collection system of PEM, there is no reliable information about activity durations from previous projects.

Although these projects are each unique, they still share many similar features. The time estimate for each activity can be estimated with high degree of certainty. Then this time estimate is considered as deterministic estimate. The estimate for each process is made by the most knowledgeable production leaders, who have close experiences on each process and who hold responsibility for its achievement. However, these estimates must be approved by section manager, again, so as to reduce bias.

To get a more accurate estimate, each process duration as repetitive task is not estimated for the whole project of 100 units of distribution transformers. Rather the estimate is broken down for each batch as smaller time consuming elements in order to get a precise time estimate.

The process duration is estimated under all local circumstances in a normal way by normal conditions, normal levels of resources and normal efficiency to get the most realistic times possible. Each process requires a number of resources. However, only critical or major resources are taken into account. According to the sample case study, to manufacture 250 kVA / 22 kV, 3 Phase, the normal resources and activity durations expected for carrying out a batch of 16 units of distribution transformers (as will be discussed in 3.4.1) are classified into processes as shown in Table 3.1 - with the normal working time eight hours per day excepting the oven, which is continuously operated 24 hours a day.

Furthermore, since manufacturing process consists of long series of repetitive operations, which depend on preceding processes. The estimate is considered independently of preceding processes or succeeding processes and it neglects contingencies such as floods, power blackouts, accidents, etc. The estimate for individual process does not take longer because its preceding process delay or materials are not available.

Table 3.1 *Expected resources and task duration estimates for each batch*

Process Name	Duration	Equipments	Workers
Insulation production	*5 Days*	-	*3*
Low voltage coil winding	*8 Days*	*L.V. coil winding machine, 2*	*2*
High voltage coil winding	*4 Days*	*H.V. coil winding machine, 4*	*4*
Core cutting	*7 Days*	*Core cutting machine, 2* *Punching machine, 1*	*4*
Core stacking	*8 Days*	*Stacking table, 3*	*3*
Core and coil assembly	*5 Days*	-	*4*
Vacuum and dry	*72 Hours*	*Oven, 1*	-
Tanking and oil filling	*2 Days*	*Oil purify, 1* *Vacuum bell, 1*	*4*
Final assembly	*3 Days*	-	*2*

3.4 Development of Network Planning Model

Refer to WBS model, a manufacturing project of distribution transformer can be broken down into nine main processes namely Insulation production, Low voltage coil winding, High voltage coil winding, Core cutting, Core stacking, Core and coil assembly, Vacuum and dry, Tanking and oil filling, Final assembly. The primary dependency relationships of these processes can be depicted in the Table 3.2 and Figure 3.6, respectively.

Table 3.2 *The relationships of activities in distribution transformer manufacturing project*

ID	Activity	Predecessors
1	Insulation production	-
2	Low voltage coil winding	1
3	High voltage coil winding	2
4	Core cutting	-
5	Core stacking	4
6	Core and coil assembly	3,5
7	Vacuum and dry	6
8	Tanking and oil filling	7
9	Final assembly	8

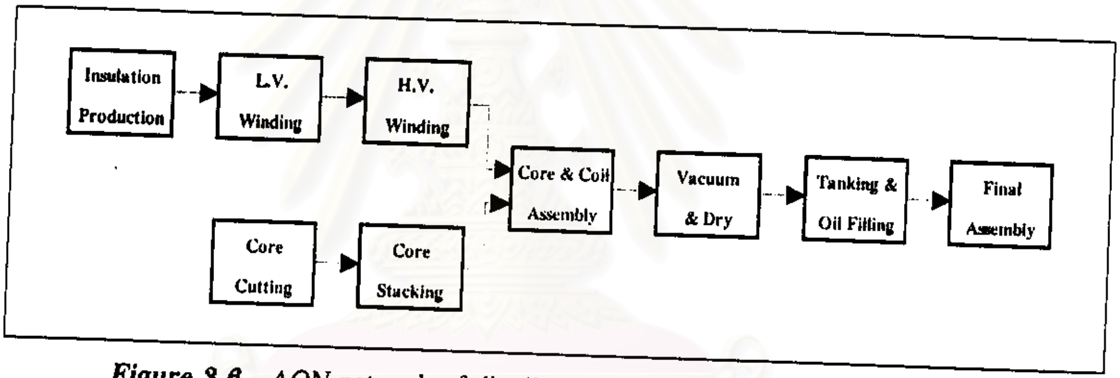


Figure 3.6 *AON network of distribution transformer manufacturing project*

3.4.1 Batch Overlapping Application

The nature of the distribution transformer manufacturing project entails long series of these processes as repetitive tasks, in which many parallel strings of continuing operations can be carried out simultaneously. In practice, it is not necessary for each process to wait for all of its predecessors to be finished before starting. The following process can start after starting it predecessors and waiting for a little bit and then carrying them out in parallel.

First, these repetitive tasks must be viewed as the integration of many sub-projects, in order to allow overlapping work. Building up a plan from smaller parts is more convenient.

Hence, the project of distribution transformer manufacturing can be broken down to many sub-projects or smaller batches with overlapping process as discussed in 2.3.1. With the overlapping approach the second batch does not wait to start until the first batch completes.

As for the batch size, it can range from a single unit to the whole project order size by considering many factors such as processing time, line balance, resource availability and so on. Among all processes of distribution transformer manufacturing, every unit of distribution transformers must pass the Vacuum and dry process. This process is inherently different from the others since the oven, as its single resource, needs to be continuously operated for at least 72 hours without interruption. Cost and time for an oven are fixed regardless of the number of distribution transformers which it contains. Thereby, each time the oven must contain as many distribution transformers as possible to be economical. For this reason, in this process, it is necessary to wait for the number of intermediate distribution transformers from the Core and coil assembly process to equal to the maximum capacity of which the oven can contain at a time.

With this unique feature, the maximum number of distribution transformers which can be contained in the oven at a time is employed as a criterion for the determination of batch size. Refer to the order size of 100 units of 250kVA / 22kV, 3 Phase distribution transformers as the sample case, the oven can at most contain 16 units of this specification at a time. Thus, the batch size of this specification is set at 16 units. With the same concept, batch sizes of other specifications can be determined as shown in Table 3. 3.

Table 3.3 *Batch size of distribution transformer*

Specification	***Batch Size (Units)***
315 kVA / 22 kV.	12
250 kVA / 22 kV.	16
160 kVA / 22 kV.	16
100 kVA / 33 kV.	18
100 kVA / 22 kV.	18
50 kVA / 22 kV.	24

With batch size of 16 units, the order size of 100 units can be broken down to seven batches. The first six full batches consist of 16 units and the last batch consists of merely four units; their summation equals to 100 units of order size.

3.4.2 Ladder Technique Application

Processes have unbalanced durations. For an individual process which consumes less duration than its predecessors, if it starts immediately after its predecessors, there will be interruptions during its operations. The process with interruptions, is easy to plan but difficult to monitor and manage. Therefore, each batch should be divided to show start and finish of each process which it contains. This can be achieved with network planning.

To represent a plan of complex repetitive and overlapping processes, which are dependent upon a continuous flow of processes from other batches, the method of "Ladder Technique" is suitable.

With ladder technique, a process in a batch follows both its previous processes in its batch and its process in immediate previous batch. Thus, the project manager can know when each process of each batch starts and finishes. This is beneficial not only for project monitoring and control but also for resources management - especially, for materials planning.

Examples of the dependency relationship of each task to other tasks with ladder technique application are shown in Figure 3.7.

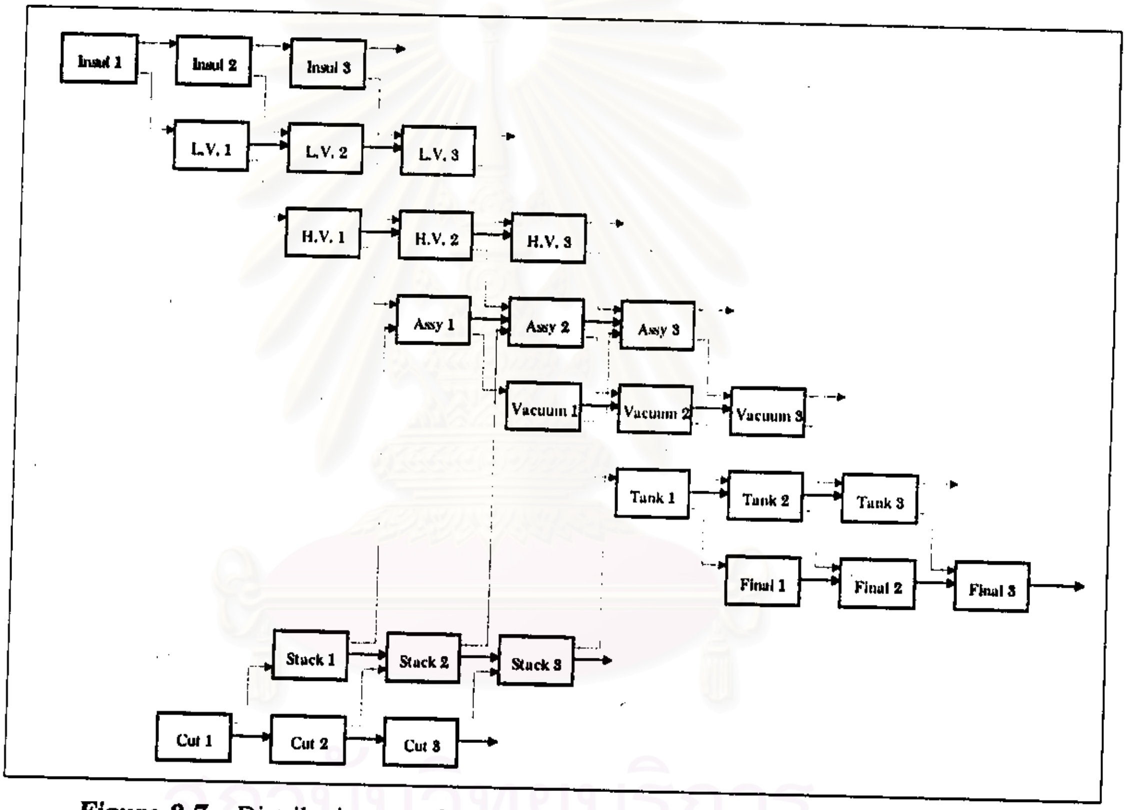


Figure 3.7 *Distribution transformer manufacturing project with ladder technique*

3.4.3 Material Requirement Milestone Application

The traditional planning model of the company can not indicate exactly, what, when and how materials for each process are required. Because it is not divided into smaller batches with starting time for each. Hence, the required date of each material for each process is estimated with allowance time for inaccuracy in the plan. Too much allowance leads to huge inventory while too little allowance leads to materials shortage.

On the other hand, the ladder technique breakdowns project into nine processes and each process is further sub-divided into many smaller batches. With this plan the project manager can know exactly when each batch will be produced and when the materials for each batch are required. Ladder network plan implies the materials requirement then it is used for scheduling materials procurement. For this reason, the materials requirement date for each process is included in the network plan, batch-by-batch, as milestones. This more precise materials requirement schedule in batch promotes Just-In-Time (JIT) delivery and is capable of avoiding materials shortage and huge inventory.

The planned date for manufacturing each batch is employed as the required date for all materials which are needed for that process and is then assigned to its milestone. However, these required dates mean the materials must be prompt for manufacturing process. Therefore, they must be delivered to the company before these required dates to have enough lead time for such process as quality assurance.

In a case where a supplier can not deliver the material on the required date, the milestone of this material must be re-adjusted because the workers and the machines can not work without material. They must wait until it is available. For this reason, the material delivery date of a process determines the start date of that process. It is a prerequisite for the operation. Each batch of materials must be available before its operation can start. Thereby, in ladder network planning, the operation is linked to its material delivery milestone with batch by batch Finish-to-Start (FS) dependency relationship.

Since such process needs many kinds of materials, the date on which the last item to complete the group of materials for that process is received is made the delivery milestone for the process. The dependency relationships of each task and its materials are shown in Figure 3.8. However, economic purchasing arrangements in terms of quantity and time must be considered, also.

3.4.4 Precedence Diagraming Application

Although, the technique of ladder method, which breakdowns the entire project into many smaller batches, allows overlapping operations and leads to shorter project duration. It also can identify the start and finish of each activity. However, within individual batch each activity is still linked with FS relationship. That means, a process can not start until all of its predecessors finish without overlapping between predecessor and successor. While in practice, it is not necessary to wait for a batch of a process to be finished before starting the following process.

For instance, it is not necessary for High voltage coil winding process for the first batch to wait until Low voltage coil winding process for the first batch completes the whole batch to start. The following activity can be started after starting the preceding activity and waiting a bit and then two activities can be carried out in parallel. This allows more overlapping and leads to shorter project duration with better duplication of realistic situations. For this reason, precedence diagraming is employed to represent overlapping in distribution transformer manufacturing process by using three more realistic dependency relationships namely Finish-to-Start (FS), Start-to-Start (SS) and Finish-to-Finish (FF) with lead and lag time. These three dependency relationships are interchangeable and give the same result by changing lead/lag time. However, generally, there is only one relationship which is the easiest to understand and to employ in practice.

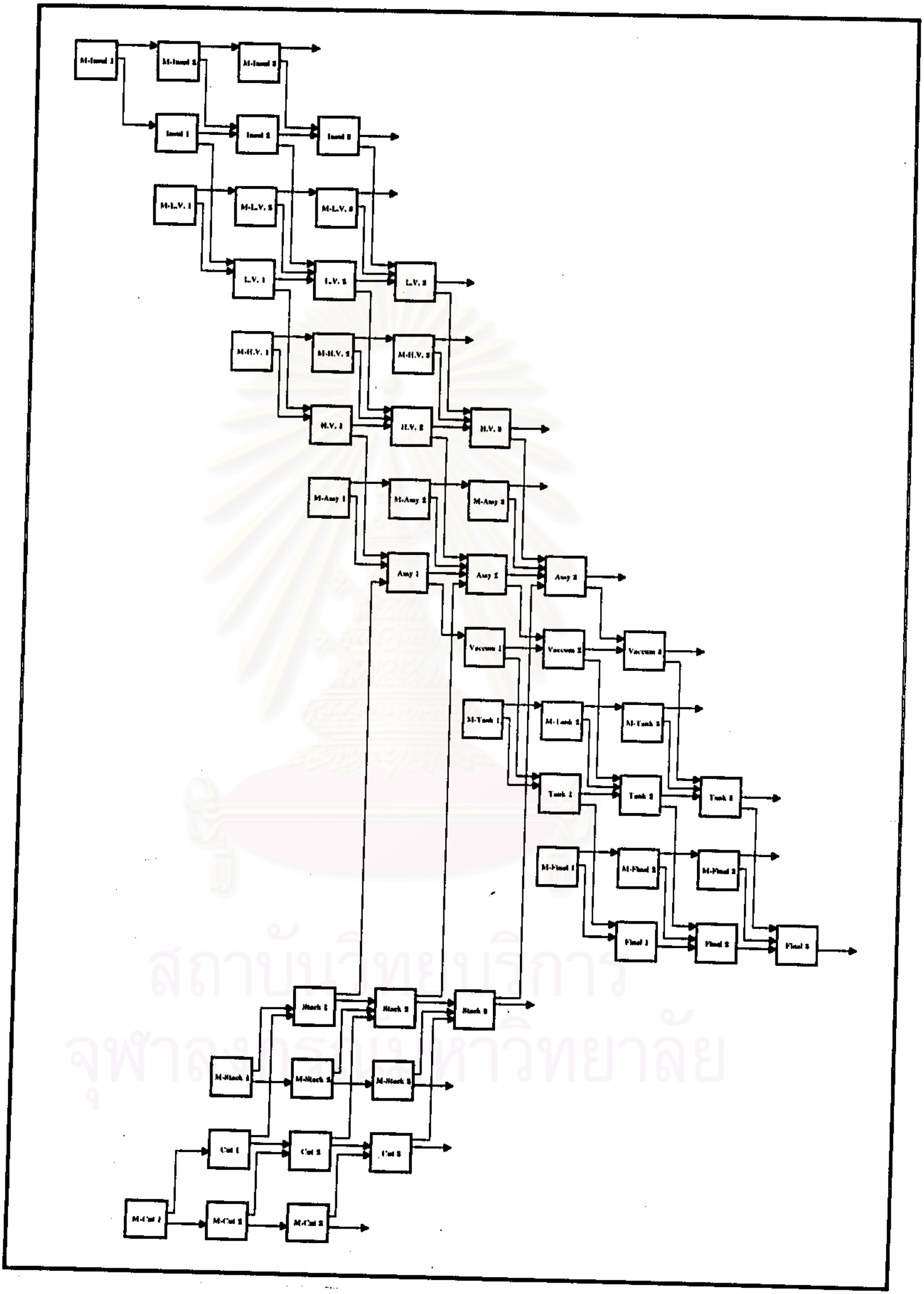


Figure 3.8 *Relationships of operations and their material requirement milestones*

Due to the inflexibility of the minimum lag time, which is discussed in 2.3.3, lag time of one day (SS = 1) is applied as a default lag time for CASE 1, as classified in 2.3.3, where overlap is allowed and the duration of the predecessor is shorter than that of the successor. This lag time is more flexible and easy to plan in practice, since it does not need calculations for processing one unit of preceding activities. With SS = 1, successor can start one day after its predecessors without waiting until preceding processes complete the whole batch.

Similarly, for CASE 2, as classified in 2.3.3, where overlap is allowed and the duration of the predecessor is longer than that of the successor, lag time of one day (FF = 1) is applied. Because it is more flexible and easier for planning. With FF = 1, successor must finish one day after its predecessors.

From these determinations, considering duration of individual task and its predecessors in the project to manufacture 100 units of distribution transformers, specification 250 kVA / 22 kV, 3 Phase as a sample case, the dependency relationships of each process can be assigned as follows:

The duration of the Low voltage coil winding is longer than its predecessor, the Insulation production, then its dependency relationship to the Insulation production is SS = 1.

The duration of the High voltage coil winding is shorter than its predecessor, the Low voltage coil winding, then its dependency relationship to the Low voltage coil winding is FF = 1.

The duration of the Core stacking is longer than its predecessor, the Core cutting, then its dependency relationship to the Core cutting is SS = 1.

The duration of the Final assembly is longer than its predecessor, the Tanking and oil filling, then its dependency relationship to the Tanking and oil filling is SS = 1.

The Core and coil assembly has two predecessors. Its duration is longer than the duration of the High voltage coil winding, then its dependency relationship to the High voltage coil winding is SS = 1. On the other hand, its duration is shorter than duration of the Core stacking, then its dependency relationship to the Core stacking is FF = 1.

For the Vacuum and dry process, the batch size is defined by the maximum number of intermediate distribution transformers which can be heated each time. At this process, it is necessary to wait until full batch from the Core and coil assembly activity is completed before it can start. The Vacuum and dry process can not overlap the Core and coil assembly process. Therefore, this process falls into CASE 3, as classified in 2.3.3, and it is linked to the Core and coil assembly process, with the simple FS constraint without lag time or FS = 0.

Similarly, the Tanking and oil filling process also can not overlap. Because, it must wait until the full batch is heated completely before starting the process. Therefore, the Tanking and oil filling process falls in CASE 3, as classified in 2.3.2 and is linked to the Vacuum and dry process with the simple FS constraint without lag time or FS = 0.

However, the Insulation production and the Core cutting processes must produce a number of items, and each item must be produced in quantity. Only one day of lag time is not enough for starting the following processes. In practice, to allow both processes to produce enough work for their successors, five days lag time is estimated. This estimate is given by the most knowledgeable production leaders - who have close experiences with both processes and hold responsibility for their achievement. This estimate is approved by the section manager again so as to reduce bias.

Furthermore, hammock activities are applied in the network planning model to each batch in order to link every activity in each batch together without specifying the durations. The total duration of these hammock activities is deduced by calculating the timing of all tasks in the batch. Hammock activities can summarize all activities in a batch into one activity, which is useful for milestone reporting to senior management who simply wants to know the important issues at a summary level.

With all above techniques and determinations, the ultimate network planning model was developed as a template on Microsoft Project software. However, each materials requirement milestone in this template must be linked to its operation with SS constraint in order to relate material requirement to its operation. Furthermore, design and shipping activities can be applied in the template, also. The dependency relationships for the template of network planning model in the example case are shown in Table. 3.4.

Table 3.4 *Template of network planning model from Microsoft Project software*

ID	Task Name	Duration	Predecessors
1	Design	3d	
2	**BATCH 1 PRODUCTION**	**47d**	
3	Insulation Material 1	0d	4SS
4	Insulation Production 1	5d	1
5	L.V. Winding Material 1	0d	6SS
6	L.V. Winding 1	8d	4SS+5d
7	H.V. Winding Material 1	0d	8SS
8	H.V. Winding 1	4d	6FF+1d
9	Silicon Steel Slit 1	0d	10SS
10	Core Cutting 1	7d	1
11	Core Stacking Material 1	0d	12SS
12	Core Stacking 1	8d	10SS+5d
13	Accessory for Core & Coil Assembly 1	0d	14SS
14	Core & Coil Assembly 1	5d	8SS+1d,12FF+1d
15	Vacuum & Dry 1	9d	14
16	Oil & Tanking Material 1	0d	17SS
17	Tanking & Oil Filling 1	2d	15
18	Accessory for Final Assembly 1	0d	19SS
19	Final Assembly 1	3d	17SS+1d
20	**BATCH 2 PRODUCTION**	**45d**	
21	Insulation Material 2	0d	3,22SS
22	Insulation Production 2	5d	4
23	L.V. Winding Material 2	0d	5,24SS
24	L.V. Winding 2	8d	6,22SS+1d
25	H.V. Winding Material 2	0d	7,26SS
26	H.V. Winding 2	4d	8,24FF+1d
27	Silicon Steel Slit 2	0d	9,28SS
28	Core Cutting 2	7d	10
29	Core Stacking Material 2	0d	11,30SS
30	Core Stacking 2	8d	12,28SS+1d
31	Accessory for Core & Coil Assembly 2	0d	13,32SS
32	Core & Coil Assembly 2	5d	14,26SS+1d,30FF+1d
33	Vacuum & Dry 2	9d	15,32

Table 3.4 *Template of network planning model from Microsoft Project software (continue)*

ID	Task Name	Duration	Predecessors
34	Oil & Tanking Material 2	0d	16,35SS
35	Tanking & Oil Filling 2	2d	17,33
36	Accessory for Final Assembly 2	0d	18,37SS
37	Final Assembly 2	3d	19,35SS+1d
38	**BATCH 3 PRODUCTION**	**43d**	
39	Insulation Material 3	0d	21,40SS
40	Insulation Production 3	5d	22
41	L.V. Winding Material 3	0d	23,42SS
42	L.V. Winding 3	8d	24,40SS+1d
43	H.V. Winding Material 3	0d	25,44SS
44	H.V. Winding 3	4d	26,42FF+1d
45	Silicon Steel Slit 3	0d	27,46SS
46	Core Cutting 3	7d	28
47	Core Stacking Material 3	0d	29,48SS
48	Core Stacking 3	8d	30,46SS+1d
49	Accessory for Core & Coil Assembly 3	0d	31,50SS
50	Core & Coil Assembly 3	5d	32,44SS+1d,48FF+1d
51	Vacuum & Dry 3	9d	33,50
52	Oil & Tanking Material 3	0d	34,53SS
53	Tanking & Oil Filling 3	2d	35,51
54	Accessory for Final Assembly 3	0d	36,55SS
55	Final Assembly 3	3d	37,53SS+1d
56	**BATCH 4 PRODUCTION**	**41d**	
57	Insulation Material 4	0d	39,58SS
58	Insulation Production 4	5d	40
59	L.V. Winding Material 4	0d	41,60SS
60	L.V. Winding 4	8d	42,58SS+1d
61	H.V. Winding Material 4	0d	43,62SS
62	H.V. Winding 4	4d	44,60FF+1d
63	Silicon Steel Slit 4	0d	45,64SS
64	Core Cutting 4	7d	46
65	Core Stacking Material 4	0d	47,66SS
66	Core Stacking 4	8d	48,64SS+1d

Table 3.4 *Template of network planning model from Microsoft Project software (continue)*

ID	Task Name	Duration	Predecessors
67	Accessory for Core & Coil Assembly 4	0d	49,68SS
68	Core & Coil Assembly 4	5d	50,62SS+1d,66FF+1d
69	Vacuum & Dry 4	9d	51,68
70	Oil & Tanking Material 4	0d	52,71SS
71	Tanking & Oil Filling 4	2d	53,69
72	Accessory for Final Assembly 4	0d	54,73SS
73	Final Assembly 4	3d	55,71SS+1d
74	**BATCH 5 PRODUCTION**	**39d**	
75	Insulation Material 5	0d	57,76SS
76	Insulation Production 5	5d	58
77	L.V. Winding Material 5	0d	59,78SS
78	L.V. Winding 5	8d	60,76SS+1d
79	H.V. Winding Material 5	0d	61,80SS
80	H.V. Winding 5	4d	62,78FF+1d
81	Silicon Steel Slit 5	0d	63,82SS
82	Core Cutting 5	7d	64
83	Core Stacking Material 5	0d	65,84SS
84	Core Stacking 5	8d	66,82SS+1d
85	Accessory for Core & Coil Assembly 5	0d	67,86SS
86	Core & Coil Assembly 5	5d	68,80SS+1d,84FF+1d
87	Vacuum & Dry 5	9d	69,86
88	Oil & Tanking Material 5	0d	70,89SS
89	Tanking & Oil Filling 5	2d	71,87
90	Accessory for Final Assembly 5	0d	72,91SS
91	Final Assembly 5	3d	73,89SS+1d
92	**BATCH 6 PRODUCTION**	**38.13d**	
93	Insulation Material 6	0d	75,94SS
94	Insulation Production 6	5d	76
95	L.V. Winding Material 6	0d	77,96SS
96	L.V. Winding 6	8d	78,94SS+1d
97	H.V. Winding Material 6	0d	79,98SS
98	H.V. Winding 6	4d	80,96FF+1d
99	Silicon Steel Slit 6	0d	81,100SS

Table 8.4 *Template of network planning model from Microsoft Project software (continue)*

ID	Task Name	Duration	Predecessors
100	Core Cutting 6	7d	82
101	Core Stacking Material 6	0d	83,102SS
102	Core Stacking 6	8d	84,100SS+1d
103	Accessory for Core & Coil Assembly 6	0d	85,104SS
104	Core & Coil Assembly 6	5d	86,98SS+1d,102FF+1d
105	Vacuum & Dry 6	9d	87,104
106	Oil & Tanking Material 6	0d	88,107SS
107	Tanking & Oil Filling 6	2d	89,105
108	Accessory for Final Assembly 6	0d	90,109SS
109	Final Assembly 6	3d	91,107SS+1d
110	**BATCH 7 PRODUCTION**	**34d**	
111	Insulation Material 7	0d	93,112SS
112	Insulation Production 7	1.25d	94
113	L.V. Winding Material 7	0d	95,114SS
114	L.V. Winding 7	2d	96,112SS+1d
115	H.V. Winding Material 7	0d	97,116SS
116	H.V. Winding 7	1d	98,114FF+1d
117	Silicon Steel Slit 7	0d	99,118SS
118	Core Cutting 7	1.75d	100
119	Core Stacking Material 7	0d	101,120SS
120	Core Stacking 7	2d	102,118SS+1d
121	Accessory for Core & Coil Assembly 7	0d	103,122SS
122	Core & Coil Assembly 7	1.25d	104,116SS+1d,120FF+1d
123	Vacuum & Dry 7	9d	105,122
124	Oil & Tanking Material 7	0d	106,125SS
125	Tanking & Oil Filling 7	0.5d	107,123
126	Accessory for Final Assembly 7	0d	108,127SS
127	Final Assembly 7	0.75d	109,125SS+1d
128	**Delivery**	**4d**	
129	Delivery Lot 1	2d	
130	Delivery Lot 2	2d	129

3.5 Development of Resource Management Approaches

The traditional planning of PEM is analysed without considering the resource constraints, under the assumption that there will be sufficient resources when they are required. In fact, this situation is seldom the case because of the fixed level of resources. The activities can not be performed if there are inadequate resources. In practice, the feasibility of a plan must be checked with respect to resources available again.

There is a number of resources required to manufacture the distribution transformers. However, only workforce, equipments and materials are considered here.

3.5.1 Material Planning Application

Since the required date for materials for each process can be obtained by the network planning model with materials requirement milestones as discussed earlier. The demand for materials for each process is dependent on the number of finished distribution transformers planned to be produced. While, the quantity for each material to be used to manufacture one unit of product is different. Thus, to control the quantity of materials for each batch process by process and item by item, Bill of Material (BOM) is the primary need. The other information, which are necessary, are scrap rate, in-house inventory, the required safety stock and the status of materials on delivery.

For all of these information the quantity of each material which must be ordered from suppliers batch by batch can be computed. Materials requirement is planned batch by batch by taking into account scrap rate, in-house inventory, schedule receipt and the policy to maintain a level of safety stock of the distribution transformer division. The quantity after each batch consumption must be checked to ensure that it is not below the minimum required stock. If the stock is lower than this level, it must be ordered to replenish.

Although the computational procedure is not too difficult to understand, it consumes a long time and is easy to make mistakes because of a number of materials required. The mistakes always lead to either materials shortage or over demand. Currently, the company employs manual calculation which takes a long time and has a high risk of errors.

For this reason, Material Requirement Schedule (MRS) program was developed to facilitate the computational procedure. MRS program can generate purchase requisition (P/R) of every production centre with little processing time and great accuracy.

For example, BOM and P/R of the Core and coil assembly production centre of the sample case can be generated by MRS program as shown in Table 3.5 and 3.6, respectively. While its computational database is shown in Table 3.7.

Table 3.5 *BOM from MRS program*

BILL OF MATERIAL

CENTER: Core &Coil Assembly
JOB No.: TF002/97
REQUISITION No.: TF502/97
PRODUCT: 250kVA 22kV 3PH
ORDER SIZE: 100 UNITS
BATCH SIZE: 16 UNITS

ITEM	DESCRIPTION OF MATERIAL	CLASS	CODE	COUNT	USAGE / UNIT	SCRAP RATE (%)	REMARK
1	WOODEN ROD dia. 8 x 1000 MM.	A	TF-R-02-0021	PC	9	10	
2	POLYESTER ROD dia. 8 x 250 MM. (bs = 192)	A	TF-R-02-0043	PC	2	12	
3	WOOD SUPPORTING SPACER (FtoC) 4 x 10 x 1000 MM.	A	TF-R-02-0025	PC	9	10	
4	TAP CHANGER HR 711.235 FOR 22 KV 3 PH.	A	TF-R-06-0101	PC	1	8	
5	INSULATION CREPE PAPER 20 MM. (WIDTH)	A	TF-R-06-0112	KG	0.5	10	
6	COPPER LUG FOR CONDUCTER 95 MM2 - M20	B	TF-R-06-0069	PC	4	15	
7	COPPER BAR 3/16" x 1 1/4" , 5 M.	B	TF-R-06-0011	PC	0.64	15	

Table 3.6 *Purchase requisition from MRS program*

PURCHASE REQUISITION

CENTER: Core &Coil Assembly
REQUISITION No.: TF502/97
ORDER SIZE: 100 UNITS
JOB No.: TF002/97
PRODUCT: 250kVA 22kV 3PH
BATCH SIZE: 16 UNITS

ITEM	DESCRIPTION OF MATERIAL	CLASS	CODE	COUNT	USAGE / UNIT	SCRAP RATE (%)	CURRENT STOCK	SAFETY STOCK	TOTAL USE	BATCH No.	1	2	3	4	5	6	7
										DATE	05/23/97	06/02/97	06/11/97	06/21/97	07/01/97	07/12/97	09/20/97
1	WOODEN ROD dia. 8 x 1000 MM.	A	TF-R-02-0021	PC	9	10	120	100	994	Planed Order Release	139	59	159	159	159	159	40
2	POLYESTER ROD dia. 8 x 250 MM. (hs = 192)	A	TF-R-02-0043	PC	2	12	50	50	225	Planed Order Release		22	36	36	36	36	9
3	WOOD SUPPORTING SPACER (FtoC) 4 x 10 x 1000 MM.	A	TF-R-02-0025	PC	9	10	110	100	994	Planed Order Release	149	79	159	159	159	159	40
4	TAP CHANGER HR 711.235 FOR 22 KV 3 PH.	A	TF-R-06-0101	PC	1	8	35	30	113	Planed Order Release	13	18		6	18	18	5
5	INSULATION CREPE PAPER 20 MM. (WIDTH)	A	TF-R-06-0112	KG	0.5	10	20		57	Planed Order Release			7	9	9	9	3
6	COPPER LUG FOR CONDUCTER 95 MM2 - M20	B	TF-R-06-0069	PC	4	15	25	15	463	Planed Order Release	24	74	74	74	74	74	19
7	COPPER BAR 3/16" x 1 1/4" , 5 M.	B	TF-R-06-0011	PC	0.64	15			75	Planed Order Release	12	12	12	12	12	12	3

Table 3.7 *Materials planning database from MRS program*

MATERIAL REQUIREMENT SCHEDULE DATABASE

CENTER	Core &Coil Assembly	JOB No.	TF002/97
REQUISITION No.	TF502/97	PRODUCT	250kVA 22kV 3PH
ORDER SIZE	100 UNITS		
BATCH SIZE	16 UNITS		

ITEM	DESCRIPTION OF MATERIAL	CLASS	CODE	COUNT	USAGE / UNIT	SCRAP RATE (%)	CURRENT STOCK	SAFETY STOCK	TOTAL USE	BATCH No.	1	2	3	4	5	6	7
										REQUIRED DATE	05/23/97	06/02/97	06/11/97	06/21/97	07/01/97	07/12/97	09/20/97
1	WOODEN ROD dia. 8 x 1000 MM.	A	TF-R-02-0021	PC	9	10	120	100	994	Project Requirement	159	159	159	159	159	159	40
										Scheduled Receipts		100					
										Planed Order Release	139	59	159	159	159	159	40
										On Hand	100	100	100	100	100	100	100
2	POLYESTER ROD dia. 8 x 250 MM. (bs = 102)	A	TF-R-02-0043	PC	2	12	50	50	225	Project Requirement	36	36	36	36	36	36	9
										Scheduled Receipts	50						
										Planed Order Release		22	36	36	36	36	9
										On Hand	64	50	50	50	50	50	50
3	WOOD SUPPORTING SPACER (PtoC) 4 x 10 x 1000 MM.	A	TF-R-02-0025	PC	9	10	110	100	994	Project Requirement	159	159	159	159	159	159	40
										Scheduled Receipts		80					
										Planed Order Release	149	79	159	159	159	159	40
										On Hand	100	100	100	100	100	100	100
4	TAP CHANGER HR 711.235 FOR 22 KV 3 PH.	A	TF-R-08-0101	PC	1	8	35	30	113	Project Requirement	18	18	18	18	18	18	5
										Scheduled Receipts			30				
										Planed Order Release	13	18		6	18	18	5
										On Hand	30	30	42	30	30	30	30
5	INSULATION CREPE PAPER 20 MM. (WIDTH)	A	TF-R-06-0112	KG	0.5	10	20		57	Project Requirement	9	9	9	9	9	9	3
										Scheduled Receipts							
										Planed Order Release			7	9	9	9	3
										On Hand	11	2					
6	COPPER LUG FOR CONDUCTER 95 MM2 - M20	B	TF-R-08-0069	PC	4	15	25	15	463	Project Requirement	74	74	74	74	74	74	19
										Scheduled Receipts	40						
										Planed Order Release	24	74	74	74	74	74	19
										On Hand	15	15	15	15	15	15	15
7	COPPER BAR 3/16" x 1 1/4" , 5 M.	B	TF-R-08-0011	PC	0.64	15			75	Project Requirement	12	12	12	12	12	12	3
										Scheduled Receipts							
										Planed Order Release	12	12	12	12	12	12	3
										On Hand							

3.5.2 Heuristic Approaches Application

Since the network planning model is planned on Microsoft Project software, which provides many resource management applications for instance resource calendar, resource histogram, resource levelling and so on.

Therefore, first it is necessary to assign a calendar to every resource. This can be achieved easily by employing company calendar. Company calendar identifies working days and non-working days of the company during the year. Typically, the number of working hours of the company is eight hours a day. Hence for working days of the company, every resource has working time of eight hours a day except for the oven in the Vacuum and dry process. Because the oven must be operated continuously 72 hours per batch of distribution transformers. Hence, the oven as specific resource must be assigned a special calendar, which has 24 working hours a day.

The resource loading histogram in Microsoft Project software can be employed to show loading of individual resource. If there are some overloaded resources, the overloading can be adjusted by resource levelling.

Although, the heuristic approach of resource levelling may not always produce the best solution of resource profile in every case, it at least attempts to seek better solutions. Heuristic approach examines the tasks in that period and allocates the resources sequentially according to some priority rules. In the case where resources are insufficient, activities requiring those resources are delayed until the next period when resources can be re-allocated. However, this activity delay may cause other tasks to become delayed also. Moreover, if this process delays a critical activity, the completion date of project will be extended, and the network planning must be adjusted.

3.6 Production Scheduling Application

To be able to monitor project on day-to-day basis, the network plan must be converted to produce schedule of each process against the time table. This schedule indicates not only when each activity should start and finish but also how many products each process must produce day by day. While, currently, PEM does not set production schedule as daily production target.

Refer to 2.8.2, it is much easier to measure and monitor in term of Equivalent Unit (EU), Therefore, the schedule must be calculated in EU, too. Each process is planned in batch and the estimate is made to get the most realistic time for producing each batch. Therefore, the estimated duration of each process batch by batch can be converted to the most realistic production capacity per day with the following formula:

$$\textit{Production Capacity per Day} = \frac{\textit{Batch Size}}{\textit{Activity Duration for a Batch}}$$

Generally, production capacity per day is the quantity of work which is most likely to be produced in a day. It represents the target which should be set a day. However, the calculation resulted from above the formula always is a decimal number, which is difficult to measure. The fraction of integer represents the work in progress of a unit. When scheduling, work in progress must be neglected and added to the next day production result. For instance, the estimated duration of the Core cutting process in the sample case is seven days for producing a batch of 16 units of intermediate products. Hence,

$$\text{Daily Target} = 16 \div 7 = 2.286 \text{ units.}$$

Then, the schedule can be calculated by neglecting decimal and adding its to production result of next day as shown in Table 3.8.

Table 3.8 *Production target schedule*

Date	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**
Daily Target	2	2	2	3	2	2	3

Production scheduling, detailed project planning, is done on rolling-wave basis. Scheduling is left until it is needed or it is likely to be done before expending the effort on details.

Although the computational process of scheduling is not too difficult to understand, it takes time to do the calculation for every production centre and has high risk of errors, especially for huge order size. Therefore, the Production Schedule (PS) program was developed to facilitate the scheduling computational process with grate accuracy as shown in Table 3.9.

After scheduling with PS program, the result will be set as daily production target for every production centre in Production Monitoring and Control (PMC) program, as will be discussed later.

Table 3.9 Production schedule from PS program

PRODUCTION SCHEDULING PROGRAM

ORDER INFORMATION

PRODUCTION RATE	[illegible]	UNITS PER DAY
ORDER SIZE	[illegible]	UNITS
BATCH SIZE	[illegible]	UNITS PER BATCH

No. OF BATCH

TOTAL BATCH	7	BATCHES
THEN REQUIRE	6	FULL BATCHES
AND LAST BATCH	4	UNITS

PRODUCTION PLANNING FROM MICROSOFT PROJECT PROGRAM

START BATCH	[illegible]	TOTAL BATCH	3
TO	[illegible]	TOTAL UNIT	48

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
ACC. TARGET	3	7	10	14	18	21	25	28	32	36	39	43	46	50	54	57
DAILY TARGET	3	4	3	4	4	3	4	3	4	4	3	4	3	2		

3.7 Development of Monitoring and Control System

As soon as a project is launched, monitoring and control become the dominant function. Without effective control, the project manager has merely little influence over the project. The development of monitoring and control system for the distribution transformer division of PEM is aimed to establish appropriate information system, which can provide required information to make timely decision that will keep project performance as close as possible to the project plan.

3.7.1 Measurement Determination Application

Currently, the measurement and the report for production results of each process are carried out by production leaders on weekly basis. The measurement is attempted in term of Equivalent Unit (EU) but its approach can not reflect the real results, especially the Insulation production and the Core cutting process.

The Insulation production process produces many items for insulation. Moreover, each item is required for many pieces. It is, hence, too difficult for the production leader to measure the results in term of EU. For this reason, he/she reports the result of insulation process by adopting the result of the Low voltage coil winding.

Although this adopting method is easy to measure, the accuracy is not acceptable. Since the Insulation production process is predecessor of the Low voltage coil winding and must be produced in batch. Therefore, it must start before the Low voltage coil winding with rather long lead time of at least five days. In general, a high percentage insulation production is completed before starting the Low voltage coil winding. With the traditional measurement approach, before starting the Low voltage coil winding, the results of the Insulation production process will be reported as zero and will be equal to the Low voltage coil winding results all the time after starting the Low voltage coil winding until they are completed. However, this is impossible because generally the Insulation production process consumes less duration than its successor, the Low voltage coil winding, which logically must finish later.

For this reason, a new measurement approach is needed. The measurement is done at each production centre as a control point or a key point by concentrating on the production result rather than on the intensity of activity. Hence, the measurement is done in terms of EU according to the daily target.

It is easy to measure EU from the process of the Low voltage coil winding, the High voltage coil, the Core stacking, the Core and coil assembly, the Tanking and oil filling, and the Final assembly, respectively. Because these processes work on an intermediate products. Thus, a unit of intermediate product from these processes can be determined as one EU.

The criterion to count one EU is based on the intermediate product which has been finished completely from these processes. For instance, an intermediate product which is finished completely from the Core stacking equals one EU. Error in work in progress assessment will have little overall effect because the project is broken down into nine smaller processes. Therefore, each process contains little work in progress at time. The counting of EU method has an appropriate level of accuracy and it is very easy in practice.

However, the EU measurement for the process of the Insulation production and the Core cutting process is more difficult, because these two processes are the beginning processes, they must produce a number of small items in batches. Furthermore, each item requires a number of pieces for an EU. Refer to the sample case, 250kVA / 22kV, 3 Phase distribution transformers, it requires 29 items of insulation. The required quantity of each item is different as shown in Table 3.10.

Table 3.10 *Items from Insulation production for one unit of distribution transformer*

No.	DESCRIPTION	PIECES / UNIT
1	TAP TUBE (SHORT)	12
2	TAP TUBE (LONG)	12
3	BOLT INS. TUBE	4
4	CYLINDER (10 Turns)	3
5	LV. THPX (4 Turns)	3
6	LV. CHANNEEL	1
7	HV. THPX Lp1 (5 TURNS)	3
8	HV. CHANNEL	1
9	END WINDING INS. (CAP IN)	6
10	END WINDING INS. (CAP OUT)	24
11	HV. END INS.	1
12	INS. STRIP (BIG)	12
13	INS. STRIP (SMALL)	24
14	PLATE FOR CORE CLAMP	3
15	PLATE FOR LV. UP LAYER	3
16	PLATE FOR HV. LEAD OUT	3
17	LV. END INS. (LONG)	42
18	LV. END INS.(SHORT)	42
19	LV. PLATE	6
20	YOKE INSULATION	4
21	PHASE BARRIER	2
22	PLATE FOR DELTA (LONG)	4
23	PLATE FOR DELTA (SHORT)	8
24	RADIAL SPACE (BIG)	36
25	RADIAL SPACE (SAMLL)	72
26	W/J SPACER FOR WINDING	8
27	W/J SPACER FOR CHIM	28
28	W/J SPACER FOR CLAMPING	2
29	CORRUGATED	3
	Total	**372**

Refer to Table 3.10, the Insulation production process must produce 29 items and each item must be produced in batch. Without considering the type or effort on each item, Insulation production process must produce the total of 372 pieces for a unit of the distribution transformer. Therefore, 372 pieces of items from the

Insulation production process, neglecting the type of item, is determined as one EU, under the assumption that each item consumes the same amount of effort.

The criterion to count one EU is the whole 372 pieces without considering type. If there are remainders, they will not be counted, even if the number of the remainders is as high as 371 pieces. The remainders are viewed as work in progress and are added to the production result of the next day. This approach is considered as having an appropriate level of accuracy. Although inaccurate, it is rather consistent. The measurement can be made more accurately by assigning weight for effort of each item or by measuring work in progress but this is not necessary in practice. The more accurate the more complex the measurement is. Besides it is difficult to measure the weight on each item, also.

Similarly, the Core cutting process must produce many sizes of silicon steel slits, which are different in width, length and shape. Each frame of core comprises two yokes, two legs, one mid and punched holes at lower yoke. Due to a large number of frames required for one core, every item must be produced in large volumes. Also, each item must be cut in batches because of the long set up time for cutting machine and punching machine.

The quantity of each item needed for a core of the distribution transformer with specification 250kVA / 22kV, 3 Phase is shown in Table 3.11. Therefore it is necessary to develop an appropriate measurement approach for the Core cutting process.

Table 3.11 *Items from Core cutting process for one unit of distribution transformer*

WIDTH	DESCRIPTION	PIECES / UNIT
105 m.m.	YOKE	204
	LEG	204
	MID	102
	PUNCHING	102
115 m.m.	YOKE	216
	LEG	216
	MID	108
	PUNCHING	108
125 m.m.	YOKE	216
	LEG	216
	MID	108
	PUNCHING	108
135 m.m.	YOKE	400
	LEG	400
	MID	200
	PUNCHING	200
Total		3,108

Similar to the concept of measurement of the Insulation production process, first punching is viewed as an item, therefore the Core cutting process need totally 3,108 pieces without considering types of items, including punching. The criterion to count a EU is the 3,108 pieces without considering type. If there are remainders of the 3,108 pieces, they will not be counted, although they are as high as 3,107 pieces. The remainders will be viewed as work in progress and added to the production of the next day. This approach is considered to be an appropriate level of measurement. It is consistent although it may be inaccurate. The more accuracy the measurement has the more complex it is. Besides weight for effort of each item is approximately the same.

In practice the calculation, in term of EU for the Insulation production and the Core cutting process, by production leaders themselves may be in error. It can be calculated and reported more easily and precisely by the integration of PMC program and the report and data collection system as will be discussed later in 3.7.2.

Measuring EU is applied to only the above eight processes by neglecting the Vacuum and dry process. Because the effort of the Vacuum and dry process is received only from the oven. There is almost no human effort. For each batch the oven will be operating 72 hours continuously without interruption. Besides an oven is a simple machine which has almost never broken down. This process is not critical and should not be taken into account as a control point for monitoring and control. Hence, the actual performance from the Vacuum and dry process is assumed equal to the target during project period and there is no deviation from this process. For this reason, it is not necessary to add work from measuring results from this process.

3.7.2 Report and Data Collection Application

As discussed earlier, information will be collected at the end of each process as a control point or key point. Traditionally, PEM employs the operator's work record method to collect data. Each worker has a responsibility to record what he/she works on a daily basis in the daily production report of ISO-9002 quality system and send to keep at the office. The daily production report of each production centre is shown in Appendix B .

However, these daily production reports are not summarized as a whole or used to track the progress of their process. The production leader of each production centre is responsible to count what his/her workers produce on weekly basis. The result is recorded in the weekly production report as shown in Appendix B. The weekly report of every production centre are sent to the office. Weekly production report is insufficient to control project. It is too late to take corrective actions. Control is best effective if there is still time for corrective actions.

The new data collection is developed by attempting to maintain the current data collection system as much as possible in order to comply to ISO-9002 requirement, to get commitment, and to avoid added works and confusion. Therefore, the current documents of ISO-9002 are adopted and modified.

First with traditional operator's work records, the production leaders are assigned the responsibility to verify daily production reports of his/her workers with additional walk and count method. The results are then summarized on the present form of daily production report and are sent to the office on daily basis. These daily reports are simple and friendly reports. They are single-paged document, which report against defined criteria for control and require simple numerics. They also avoid added work and confusion and allow workers to spend little time to fill in them.

The daily production results of the process of the Low voltage coil winding, the High voltage coil winding, the Core stacking, the Core and coil assembly, the Tanking and oil filling, the Final assembly can be easily measured, collected and reported in term of EU by production leaders as discussed earlier in 3.7.1. Each production leader also has the responsibility of recording target and actual production results on his/her Production Centre Monitoring Board. These Production Centre Monitoring Boards will be discussed later in 3.7.3.

The process of the Core cutting and the Insulation production produce a number of small items, which are too difficult to calculate in term of EU by production leaders; therefore, similar to the traditional method, production leaders have the responsibility to verify what their operators work, items by items, and then summarize on the present daily production report of their processes.

Daily production report from both production centres will be sent to the office. Then, the production results are quite easily and precisely converted into EU with PMC program. After that the EU results will be sent back to the production leader of each process with daily production report, which is newly designed as shown in Table. 3.12. This daily production report is designed as common reports for the Insulation production and the Core cutting production centre. Then each production leader has the responsibility to record this daily production result in term of EU on his/her Production Centre Monitoring Board to allow the workers to know what and how they are doing.

Table 3.12 *Actual production report for Insulation production and Core cutting process*

Actual Production Result

Date ________

☐ **Insulation Production**

☐ **Core Cutting**

Quantity ____________ **EU.**

Reporter ________

After the officer receives all the daily production reports from every production centre, he has a responsibility to key these daily production results into PMC program to automatically calculate the EU result of the Insulation production and the Core cutting production centre and all project monitoring indicators as will be discussed in 3.7.4. Besides, progress of every production centre is automatically calculated and kept in a database, in both numeric and graphic forms. If production leaders dishonestly report his results, it will become obvious at the second or third reporting period.

Furthermore, an officer also is assigned to report all project monitoring indicators on the Project Monitoring Boards in the office to allow executives to monitor the project status as will be discussed later in 3.7.4.

3.7.3 Operation Control Application

Since manufacturing process of the distribution transformer is a repetitive operation, which operates in a series of discrete steps, the work is completed in any one process before intermediate product is passed to the next process.

Therefore, the concept of Line of Balance (LOB) technique is modified to establish the monitoring system to monitor, control and present progress against targets in relation to time and accomplishment during project. The monitoring is determined at each process as a control point except the Vacuum and dry process. Since, the resource of this process is only an oven, there is almost no human effort. The oven which is almost never broken down is operated continuously for 72 hours without stop for one batch of distribution transformers. Thus this process is not critical. The performance of the Vacuum and dry process is assumed equal to target at all time and there is no deviation form this process. For this reason, it is not necessary to increase work in measuring and monitoring of this process in details. However, the performance of the Vacuum and dry process is still monitored and controlled by the network planning model.

Therefore the table is designed to be commonly used by every production centre as shown in Table. 3.13. This monitoring table is used as monitoring and control tools of every production centre. It can be divided into three sections as follows:

The first section compares the daily production target to daily actual production. This section is designed to allow workers to know how much work they must perform each day and whether they can achieve it or not.

The second section compares the cumulative production target to the cumulative actual production. This section is designed to allow workers to know how much work they have performed since beginning of the project compared to the target and how much work is still remained.

The third section is designed to show the difference between daily actual production and daily production target, and the difference between cumulative actual production and cumulative production target. This section is aimed to facilitate workers in seeing at a glance how much work they perform (progress or delay) compared to day by day and cumulative targets.

At each production centre, this table is constructed on a white-board and installed in the work place as Production Centre Monitoring Board in order to allow workers to participate and to improve their morale by showing what they have done and what they must do. Placing monitoring and control as close as possible to the work being controlled with the simple possible mechanism is a good rule to achieve. Furthermore, under the monitoring table on Production Centre Monitoring Board, there is space available for depicting the second section of the table (the cumulative production target and actual product target for that production centre) in the line graph form in order to allow workers to see graphically their progress and trend at a glance.

Besides, this table is developed on Production Monitoring and Control (PMC) program for every production centre as shown in Table 3.14 (only table of the Insulation production centre is shown as an example, here, the other production centres are similar) so as to automatically calculate progress of every centre, keep as database and allow project manager to monitor performance of every production centre at the same time.

All three sections in the monitoring table are graphically depicted also in PMC program as shown in Figure 3.9 to 3.11 (only graphic charts of the Insulation production centre are shown as an example, the other production centres are similar). These graphic comparisons have great benefits for project managers in determining trend.

Keeping original targets of every production centre as baseline in computer database is necessary. Because without database, when the plan is updated to reflect current progress, it will be difficult to calculate variances and control will be lost. However, although the baseline should be maintained constantly as far as possible, it may need to be revised in some situation. For example, if the project becomes significantly delayed, the baseline can not represent a sensible measure for control. Using it is unrealistic and can then actually be demotivating. Hence, it may be necessary to revise the baseline. However, this should be treated as a serious exercise.

Table 3.13 Monitoring and control table

DISTRIBUTION TRANSFORMER DEPARTMENT

Centre ____________________

Job No. ____________________ **Product** ____________________

Quantity ____________________ **Workforce** ____________________

Capacity ____________________ **per Day** **Production Leader** ____________________

Date											
Daily	**Target**										
	Actual										
	Diff.										
Accumulate	**Target**										
	Actual										
	Diff.										

Table 3.14 Monitoring and control table from PMC program

TABLE : INSULATION PRODUCTION

JOB No. : TF 002/97

PRODUCT NAME : 250 kV / 22kV 3 Phases

ORDER SIZE : 100

INSULATION		06/12/1997	06/13/1997	06/16/1997	06/17/1997	06/18/1997	06/19/1997	06/20/1997	06/21/1997	06/23/1997	06/24/1997	06/25/1997	06/26/1997	06/27/1997	06/30/1997	07/01/1997	07/02/1997	07/03/1997	07/04/1997	07/05/1997	07/07/1997	07/08/1997	07/09/1997
DAILY	TARGET		3	3	3	3	4	3	3	3	3	4	3	3	3	3	4	3	3	3	3	4	3
	ACTUAL				2	3	2	4	3	4		4											
ACC.	TARGET		3	6	9	12	16	19	22	25	28	32	35	38	41	44	48	51	54	57	60	64	67
	ACTUAL				2	5	7	11	14	18	18	22											
DIFF.	DAILY		-3	-3	-1		-2	1		1	-3												
	ACC.		-3	-6	-7	-7	-9	-8	-8	-7	-10	-10											

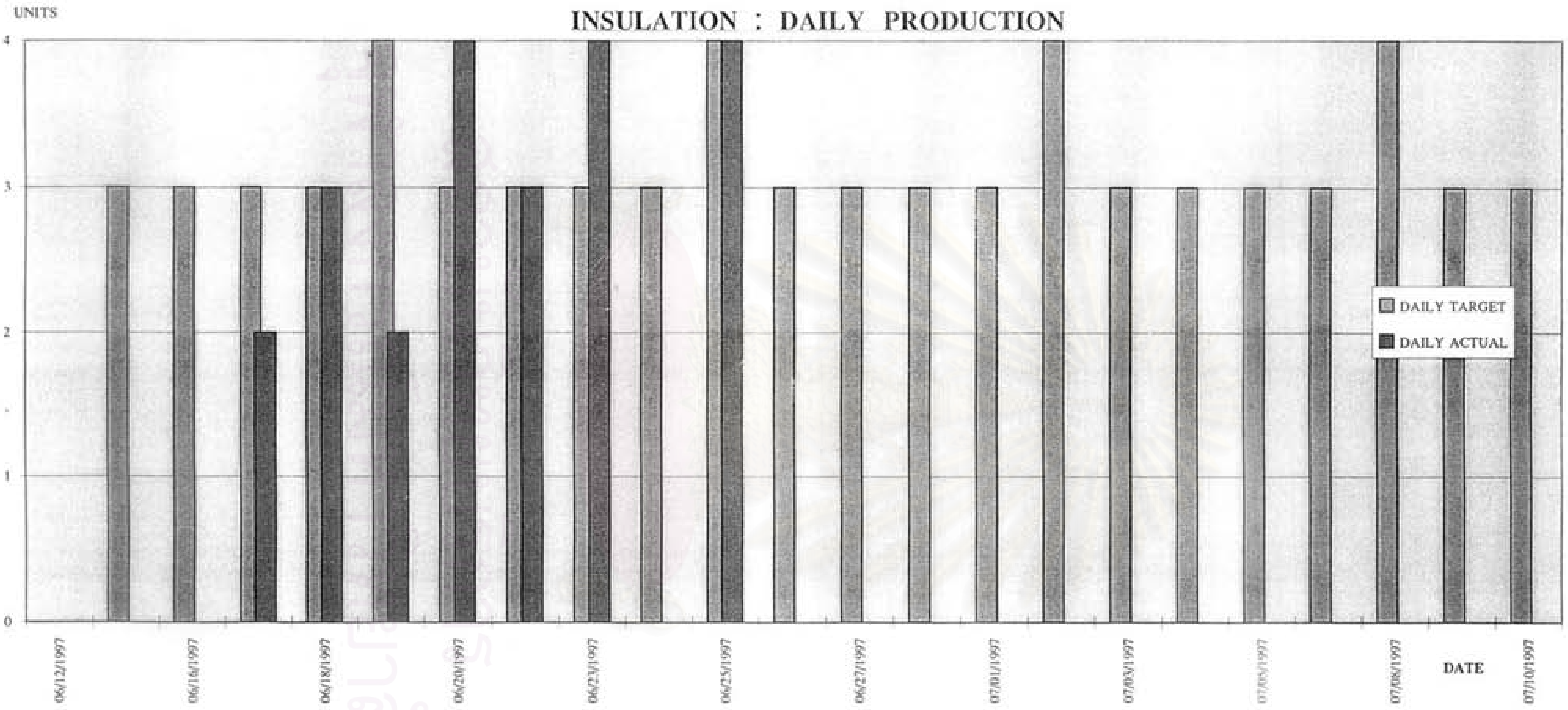


Figure 3.9 *Daily production chart from PMC program*

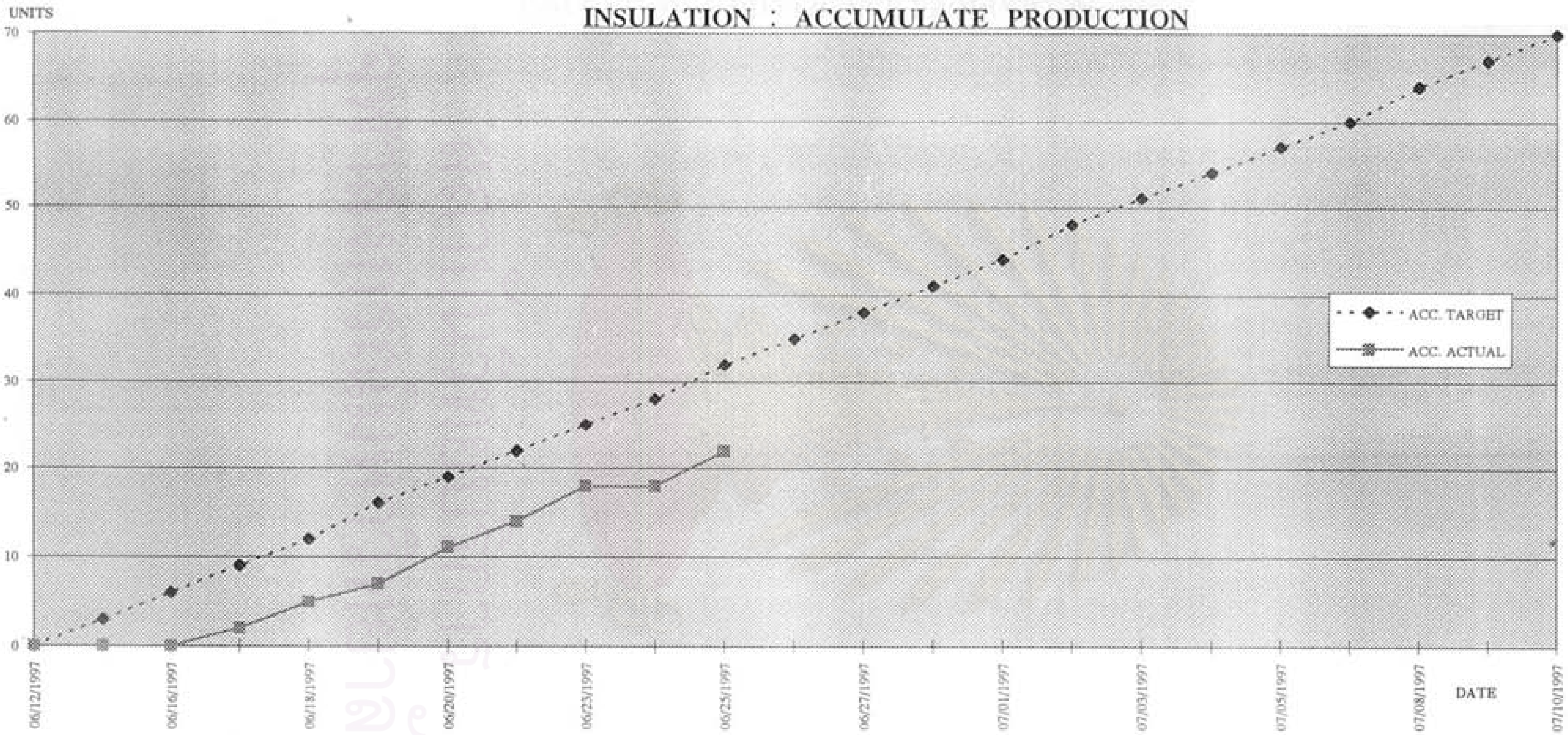


Figure 3.10 *Cumulative production chart from PMC program*

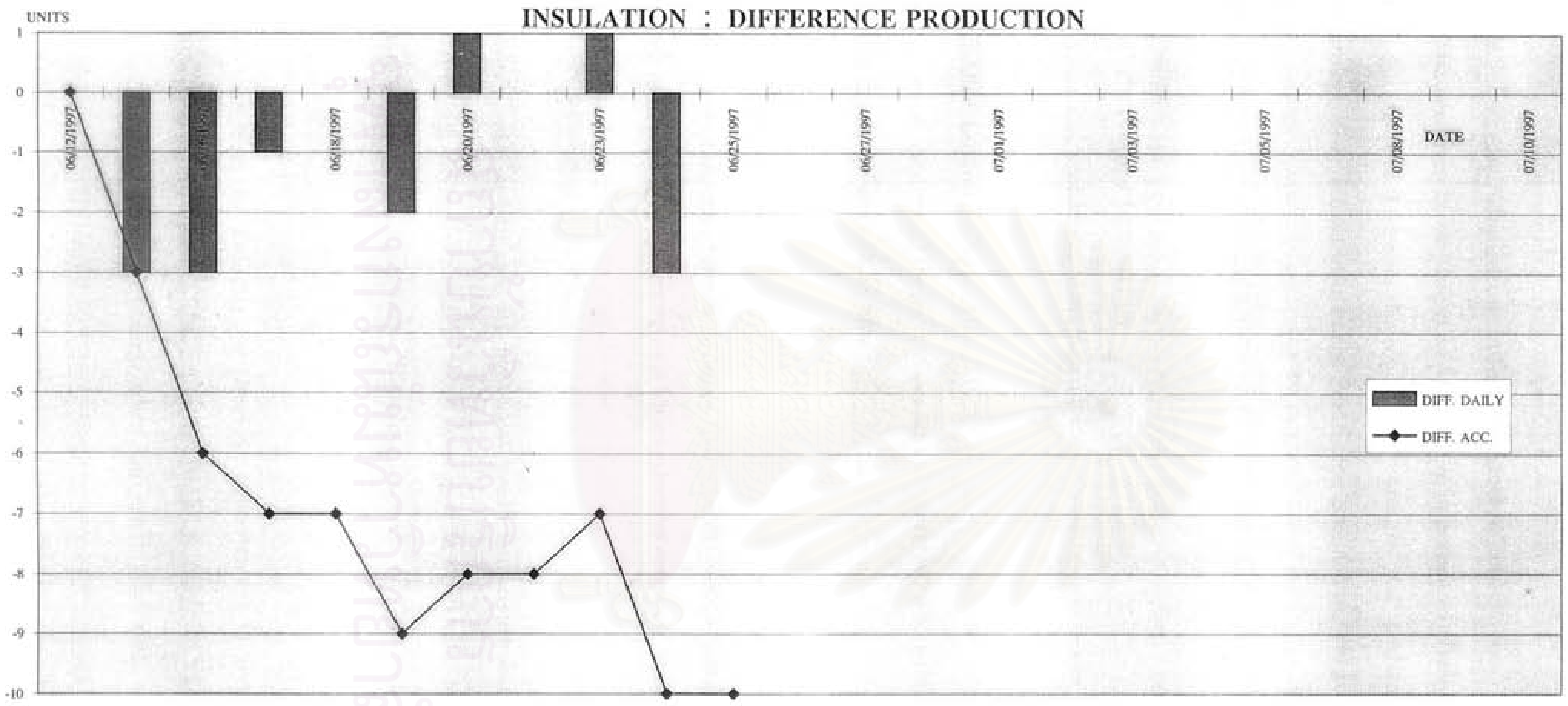


Figure 3.11 *Production difference chart from PMC program*

3.7.4 Project Monitoring Indicators Application

The performance of project in overview is important to allow the executives to know the status of the entire project. To measure the performance of the entire project, four indicators namely Percentage completion, Project performance ratio, Forecasted project duration and Cumulative actual final assembly to delivery contract comparison are developed.

1) Percentage Completion

Since this production planning and control system emphasizes"on-schedule". Hence, percentage completion is modified from the concept of earned value of Cost/Schedule Control System Criteria (C/SCSC) to compare the work value of the physical actual performed with the value of work which should have been performed at any given point in time.

The percentage completion of project can not be measured merely from the finished distribution transformer because the project, which consists of several unbalance processes, always contains a lot of work in progress. Therefore, work in progress from these processes must be assessed also.

Since, the performance of individual production centre has already been measured by the physical amount of work done in term of EU and represented with the operation control application. Therefore, among all percentage completion measurement methods, the concept of the effort accrued and effort remaining is the best for measuring percentage completion. This technique is not only more accurate but also very easy by utilizing the previous measurement in term of EU from operation control application. The error for work in progress assessment is not serious because the project is broken down into many processes, which contain a little work in progress. The percentage completion can be calculated using the following formula:

$$\textit{Percentage Completion} = \frac{\textit{Effort to Date}}{(\textit{Effort to Date} + \textit{Effort Remaining to Date})}$$

- Effort to Date is the cumulative effort, which is put from start to date.
- Effort Remaining to Date is the cumulative effort, which must be put from date to complete project.

Although each process delivers EU, effort which is put into each process is different. Because each process needs different not only types but also amounts of resources. Therefore, each process possesses different proportional effort in each unit of distribution transformer. More effort or more valuable tasks should have a greater effect than the less valuable ones. To more precisely measure percentage completion, weight should be assigned to individual process in accordance to their work. The effort of each process in project can be calculated with the following formula:

$$\textit{Effort to Date of Process } i = \textit{Weight of Process } i \ X \ \textit{Acc. EU to Date of Process } i$$

In this case, since the weight of each process in a distribution transformer is still constant and the EU, which will be delivered, can not be greater than order size, the effort to date can not be greater than total effort. For this reason:

$$\begin{aligned}\textit{Total Effort for a Project} &= \textit{Effort to Date} + \textit{Effort Remaining} \\ &= \Sigma(\textit{Weight of Process } i \ X \ \textit{Order Size})\end{aligned}$$

To monitor and control the project, it is necessary to compare actual percentage completion with target percentage completion. Both actual percentage completion and target percentage completion are based on the same total effort. But the cumulative target effort to date and the cumulative actual effort are different. Both efforts can be calculated via the following formula:

Target Effort to Date=Σ(Weight of Process iX Acc. Target EU to Date of Process i)
Actual Effort to Date=Σ(Weight of Process iX Acc. Actual EU to Date of Process i)

$$\text{Target Percentage Completion to Date} = \frac{\text{Target Effort to Date}}{\text{Total Effort for Project}}$$

$$\text{Actual Percentage Completion to Date} = \frac{\text{Actual Effort to Date}}{\text{Total Effort for Project}}$$

The target percentage completion should be calculated entirely from start to finish of the project by using cumulative target of EU of each process from production schedule and operation control application, as a baseline for comparison to the actual percentage completion.

The percentage completion is applied to measure effort from only eight processes namely the Insulation production, the Low voltage coil winding, the High voltage coil winding, the Core cutting, the Core stacking, the Core and coil assembly, the Tanking and oil filling, the Final assembly. The Vacuum and dry process is neglected because the effort of Vacuum and dry process is received only from an oven, almost without any human effort. The oven, which almost never breakdown, is operated continuously for 72 hours without interruption for each batch. Hence, the actual effort from oven process is assumed equal to target during project and there is no deviation from this process. For this reason, it is not necessary to add work from measuring effort for the Vacuum and dry process.

Manual calculations for percentage completion is very confusing with a large amount of data from every production centre, especially in case of huge project. So the table showed percentage completion was developed on PMC program for automatic calculation and for keeping as baseline database as shown in Table 3.15, and with corresponding graphic chart shown in Figure 3.12.

Keeping original percentage completion target of the whole project as a baseline in computer database is necessary. Without database, when the plan is updated to reflect current progress, it will be difficult to calculate variances, and control will be lost.

Furthermore, to allow executives to see percentage completion of the project at a glance and to determine trend, the percentage completion is graphically depicted on white-board as one of the four Project Monitoring Boards in office, also.

Table 3.15 *Percentage completion and Project performance ratio table from PMC program*

TABLE : PERCENTAGE COMPLETION & PERFORMANCE RATIO

JOB No. : TF 002/97

'RODUCT NAME : 250 kV / 22kV 3 Phases

ORDER SIZE : 100

	06/13/1997	06/16/1997	06/17/1997	06/18/1997	06/19/1997	06/20/1997	06/21/1997	06/23/1997	06/24/1997	06/25/1997	06/26/1997	06/27/1997	06/30/1997	07/01/1997	07/02/1997
ACC. ACTUAL % COMPLETION			0.4%	1.0%	1.6%	2.7%	3.6%	4.9%	5.8%	6.9%					
ACC. TARGET % COMPLETION	0.7%	1.3%	2.0%	2.8%	3.5%	4.2%	5.2%	6.2%	7.2%	8.4%	9.6%	10.6%	11.7%	12.8%	14.0%
PERFORMANCE RATIO			0.196	0.375	0.446	0.633	0.701	0.795	0.798	0.826					
UPPER CONTROL LIMIT	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
LOWER CONTROL LIMIT	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

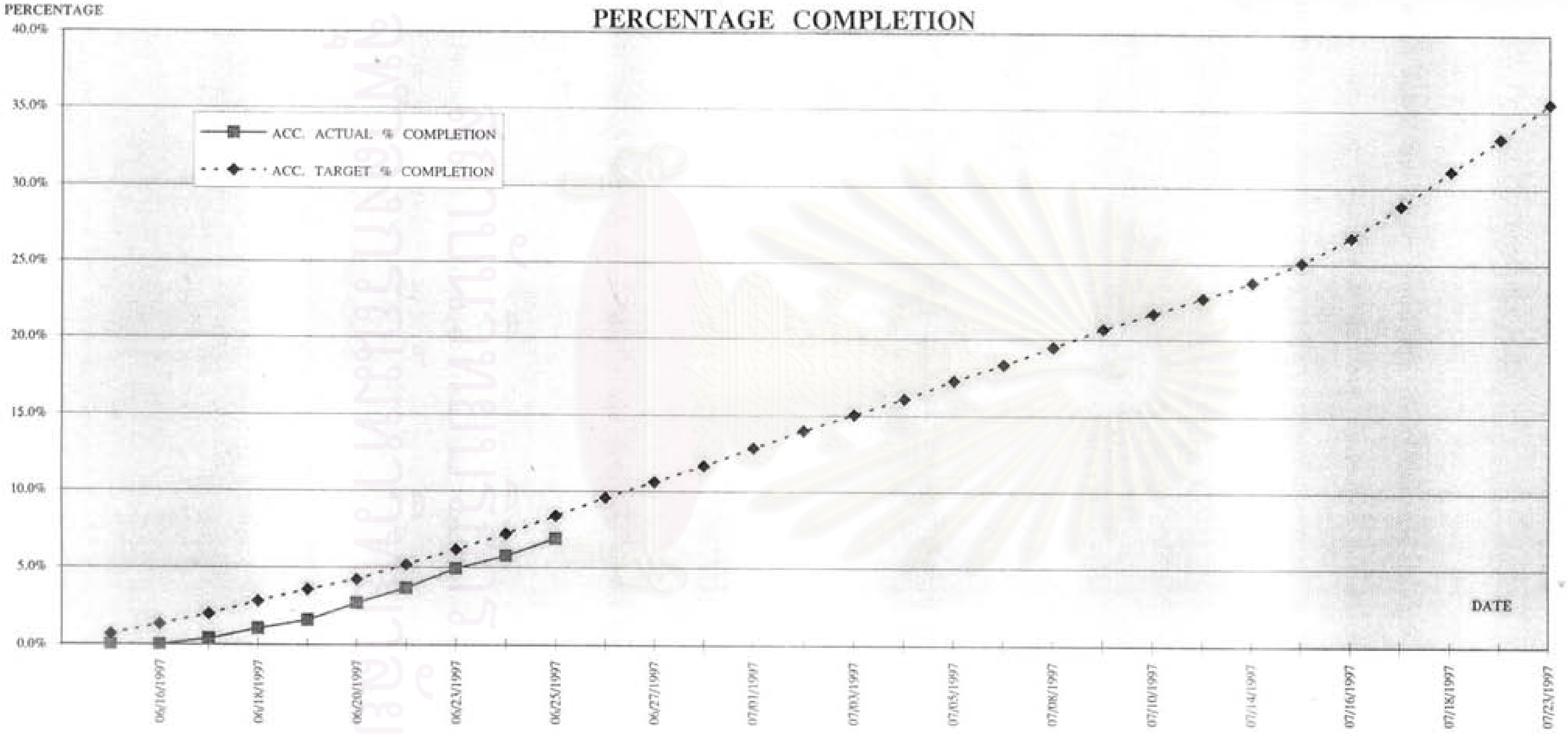


Figure 3.12 *Percentage completion chart from PMC program*

2) Project Performance Ratio

Since the size of project can vary widely with the order size, the variance between actual and target percentage completion has distortion due to the size of project when the project is carried out. To reduce this distortion, performance of entire project is determined by project performance ratio. To avoid added work, the project performance ratio can be calculated quite easily by using information from the percentage completion and following formula:

$$\text{Performance Ratio} = \frac{\text{Actual Percentage Completion to Date}}{\text{Target Percentage Completion to Date}}$$

As an indicator, if the project performance ratio is greater than one, this means the project in overview is ahead schedule.

If project performance ratio equals one means the project in overview is on schedule.

If project performance ratio is less than one means project in overview is behind schedule.

Furthermore, Upper Control Limit (UCL) and Lower Control Limit (LCL) are established as the threshold variance to flag problem areas and to assist in decision making for corrective actions.

LCL is needed obviously because it is a control limit for taking corrective actions when a project is delayed. Moreover, since the task duration is carefully estimated in a case where the project performance ratio is much greater than one, there may be quality problem from accelerated work. Hence UCL is necessary to monitor project, also. With the application of UCL and LCL, when the project performance ratio moves to near either UCL or LCL, the section manager must investigate causes.

Since there is no past information for establishing control limit, primarily UCL and LCL are set at +10% and -10% (1.1 and 0.9), respectively; although, they can be different. Besides both control limits can be changed if there is more information.

A table showing project performance ratio is developed on PMC program for automatic calculation and for keeping as database, by sharing the same table with the performance ratio as shown in Table 3.15. While its graphic chart is shown in Figure 3.13. This database can benefit as historical data for establishing UCL and LCL and also for future projects' reference.

Similarly, the performance ratio is graphically depicted on the white-board which is installed in the office as one of the four of Project Monitoring Boards so as to allow executives to know the status and to see trend of the project performance at a glance too.

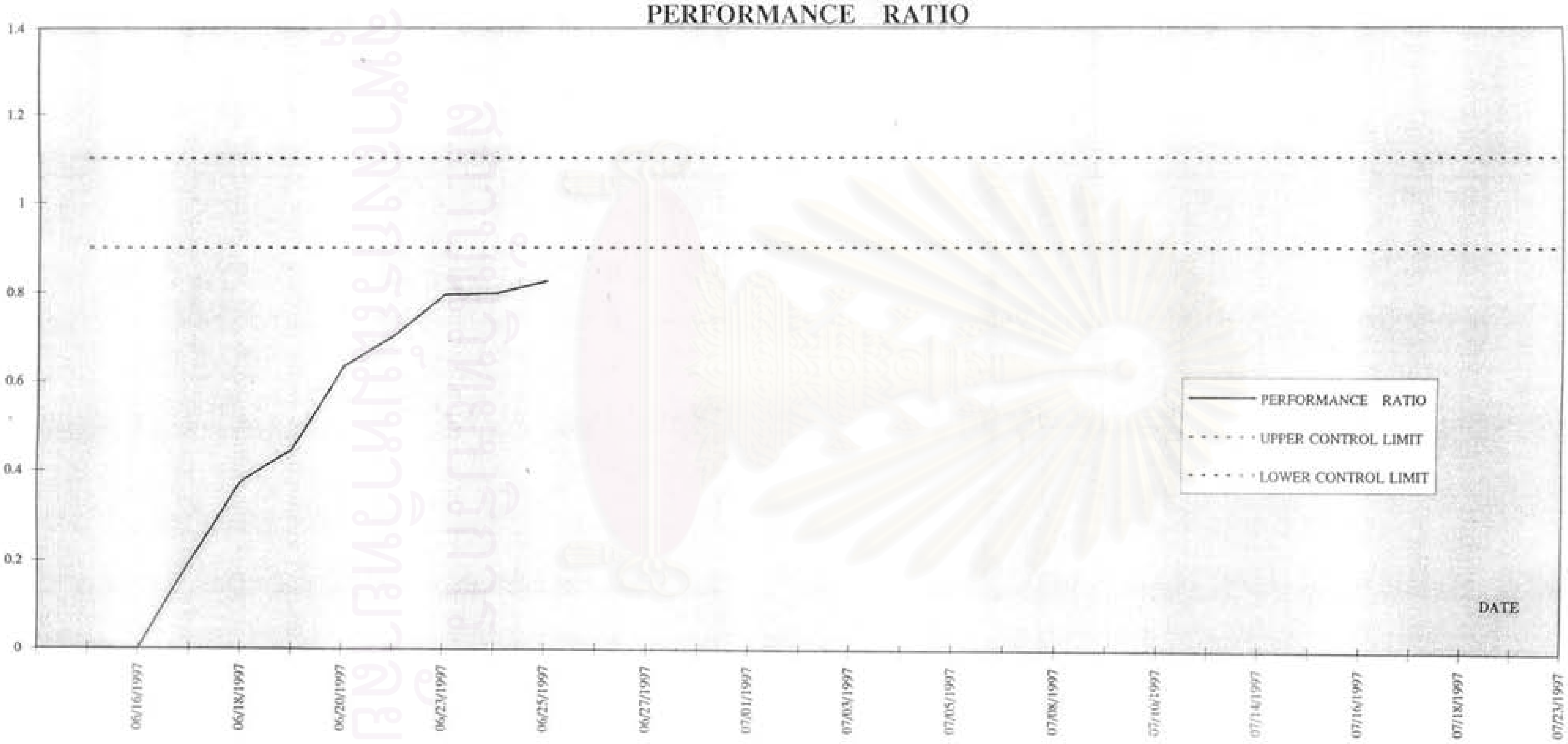


Figure 3.13 *Project performance ratio chart from PMC program*

8) Forecasted Project Duration

Monitoring percentage completion and performance ratio can indicate whether project is on schedule, ahead of schedule or behind schedule. Nevertheless, they can not tell whether the project will complete in time or not. Therefore, forecasting with an early warning to predict the project completion day in comparison to baseline duration is established.

The activity duration of the project is assumed to be rather accurate due to a careful activity duration estimate. Hence, forecasting technique, with the assumption that all remaining activities will be done at baseline schedule, is selected. That means the performance of remaining project will still be the same. With this assumption and to avoid added work, the forecasting can be calculated by using primary information from the percentage completion indicator with the following formula:

Duration at Completion = Baseline Duration Estimate + Schedule Variance to Date

- Schedule Variance to Date is schedule variance between target percentage completion to date and actual percentage completion to date

The duration at completion or the forecasted project duration is compared to original baseline duration estimate. A table showing the forecasted project duration developed on PMC program for automatic calculation and for keeping as database is shown in Table 3.16, with graphic chart as shown in Figure 3.14, respectively. Furthermore, the forecasted project duration indicator is graphically depicted on the white-board as one of four Project Monitoring Boards, which is installed in the office in order to allow executives to determine the trends and to see it at a glance, also.

Table 3.16 Forecasted project duration table from PMC program

TABLE : COMPLETION DAY FORECAST

JOB No. : TF 002/97
PRODUCT NAME : 250 kV / 22kV 3 Phases
ORDER SIZE : 100

	06/13/1997	06/16/1997	06/17/1997	06/18/1997	06/19/1997	06/20/1997	06/21/1997	06/23/1997	06/24/1997	06/25/1997	06/26/1997	06/27/1997	06/30/1997	07/01/1997	07/02/1997	07/03/1997	07/04/1997	07/05/1997
BASED LIND COMPLETION DAY	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
FORECASTED COMPLETION DAY	85	87	88	86	86	86	85	86	85	84								
ACC. CURRENT DEALY	-1	-3	-4	-2	-2	-2	-1	-2	-1									

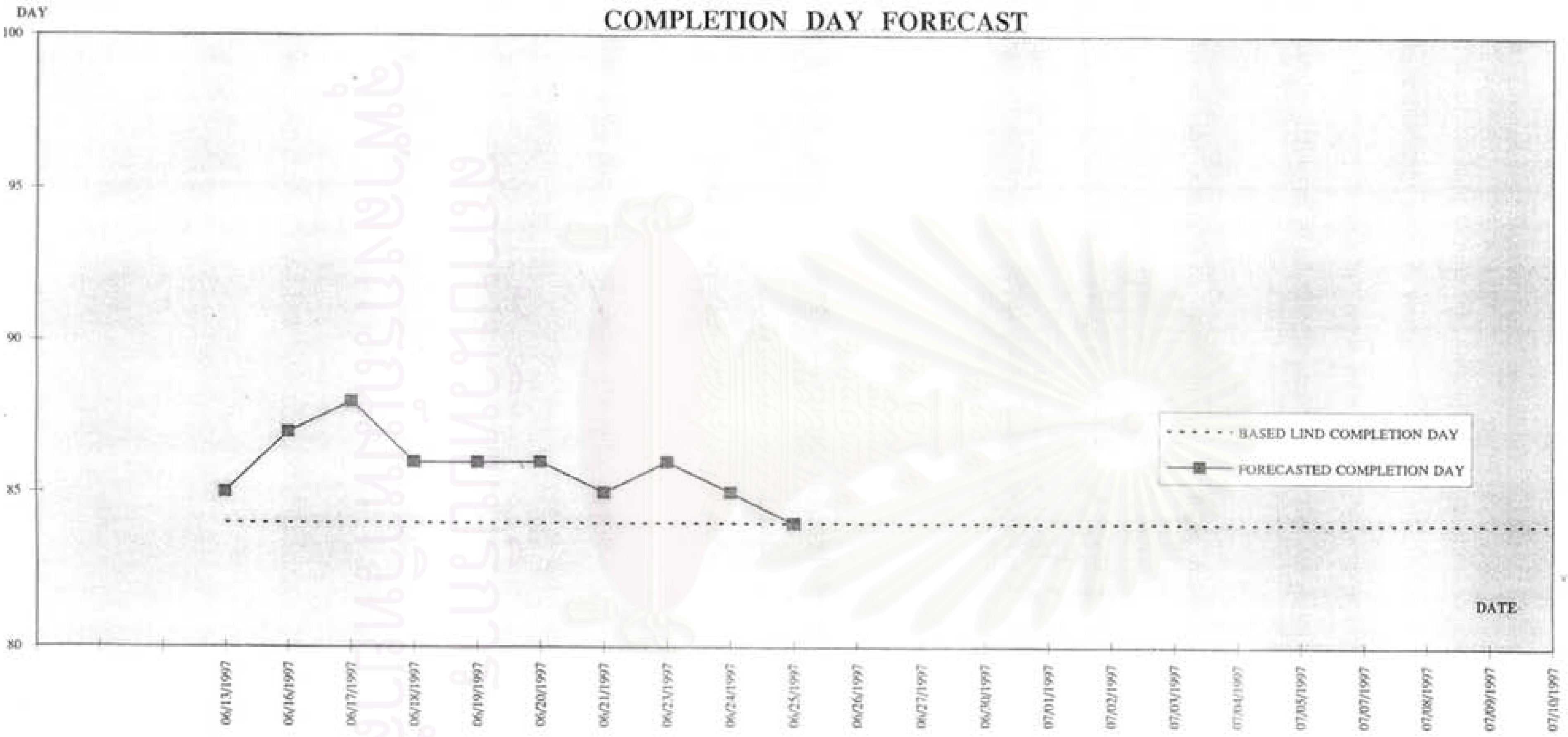


Figure 3.14 *Forecasted project duration chart from PMC program*

4) Cumulative Actual Final assembly to Delivery Contract Comparison

The percentage completion measures the progress of the project by taking into account not only work in progress in each production centre but also the effort put forth. However, it does not show how many distribution transformers have been finished to be delivered to customers according to the delivery contract.

Since, the executives need to know how many finished distribution transformers there are to compare to the delivery contract in order to see the trend of achieving delivery date, generally the delivery is done in batch according to specific time in contract.

Cumulative actual production result of the Final assembly production centre is employed to be compared to the number of required distribution transformers on specific delivery date and is depicted in graphic chart form as one of the four Project Monitoring Boards in the office to allow executives to know the status and trend of project to the delivery date.

Similarly, the table of final assembly production compared to delivery contract is developed on PMC program and is kept as database as shown in Table 3.17, while its graphic chart is presented in Figure 3.15, respectively.

Table 3.17 *Final assembly to delivery contract comparison table from PMC program*

TABLE : FINAL ASSEMBLY & DELIVERY CONTRACT

JOB No. : TF 002/97

RODUCT NAME : 250 kV / 22kV 3 Phase

ORDER SIZE : 100

FINAL ASSY & CONTRACT		08/11/1997	08/13/1997	08/14/1997	08/15/1997	08/16/1997	08/18/1997	08/19/1997	08/20/1997	08/21/1997	08/22/1997	08/25/1997	08/26/1997	08/27/1997	08/28/1997	08/29/1997	08/30/1997	09/01/1997	09/02/1997	09/03/1997	09/04/1997	09/05/1997	09/08/1997	09/09/1997	09/10/1997	09/11/1997
DAILY	TARGET		5	5	6	5	5	6	5	5	6	5	5	6	5	5	6		5	5	6	4				
	ACTUAL	5	6	5	5	4		5	3																	
ACC.	TARGET		5	10	16	21	26	32	37	42	48	53	58	64	69	74	80	80	85	90	96	100	100	100	100	100
	ACTUAL	5	11	16	21	25	25	30	33																	
DIFF.	DAILY	5	1		-1	-1	-5	-1	-2																	
	ACC.	5	6	6	5	4	-1	-2	-4																	
DELIVERY CONTRACT	ACC.													50										100		

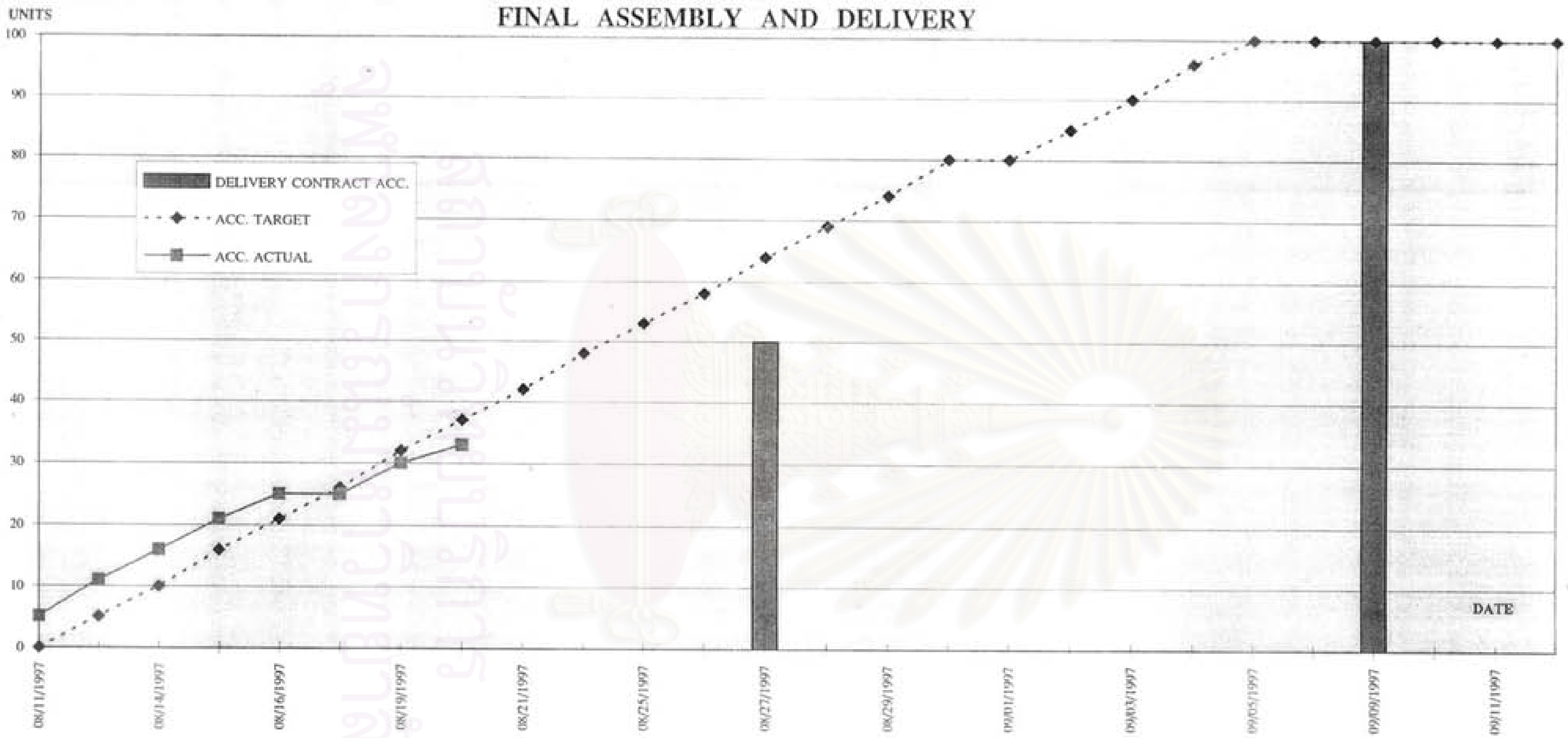


Figure 3.15 Final assembly to delivery contract chart comparison from PMC program

3.8 System Procedure

The cycle of planning-monitoring-controlling is a continuous process until the project is completed. The operation and information flow chart, as shown in Figure 3.16, is created to represent the whole system of project planning and control system. Hence, it is used to briefly illustrate the project-based production planning and control system for distribution transformer of PEM process by process. The manual of developed computer programs is provided in Appendix A.

Project planning process

Project planning process is under the responsibility of section manager. It begins with identifying batch size of the project, estimating activity durations and expected resources for each batch as discussed in 3.3 and 3.4.1, respectively.

Then, the activity duration is analyzed to assign the relationships for each activity according to 3.4.4. After that these relationships with other information such as resources, constraint dates, etc. are put into the templates of Microsoft Project software which have been developed already.

The project master plan will be generated by Microsoft Project software. Considering any constraints such as resources and time - whether there is conflict or not - if the resources are insufficient, the heuristic approaches as discussed in 3.5.2 must be employed. The float along each network path can indicate where certain activity schedule can be moved forward or backward in time without affecting the completions time of the project. The adjustment of time scale to reduce the resources requirements may be possible by consuming some floats on non-critical activities without any project duration extension.

It is convenient to compare the overall project duration with a target or an acceptable time. If the target time is greater than the total project duration, then all activities will have positive floats. Whilst if the target time is less than the total project time, the critical path and possibly some other activities will have negative floats. In this case, it is necessary to take corrective actions such as re-scheduleing more overlapping, starting project earlier, overtime planning, re-allocating resources and so on. Furthermore, the what-if analysis simulation of the software must be utilized as a powerful application in computer program to seek the best plan. The output of project planning process is the project master plan which will be sent to the officer.

Materials Requirement Scheduling Process

After the officer gets the project master plan, refer to 3.4.3 and 3.5.1, the materials milestone of each activity is used with BOM and other materials status information namely scrap rate, in-house inventory, schedule receipt and required safety stock to generate purchase requisition (P/R) for each process, batch by batch, and is sent to purchasing department. In a case where the materials can not be delivered according to materials milestone, the project master plan must be adjusted according the materials available date.

Production Scheduling Process

When getting the final project master plan, both PS program and PMC program are employed together by the officer to schedule daily target of every production centre and every project monitoring indicator on the rolling wave basis according to 3.6. Then these daily targets are kept as database and also published to the production leader of each production centre.

Project Monitoring Boards Set-Up Process

In this process, the officer has the responsibility to set four Project Monitoring Boards on four white-boards, namely Percentage completion, Project performance ratio, Forecasted project duration, and Cumulative actual final assembly to delivery contract comparison as discussed in 3.7.4, by using targets from PMC database. The output of this process is Project Monitoring Boards with targets.

Production Centre Monitoring Boards Set-Up Process

The production leader of each production centre is assigned the responsibility to set-up his/her Production Centre Monitoring Board on a white-board by using targets, which are distributed by the officer according to 3.7.3. Outputs of this process are Production Centre Monitoring Boards with targets of every production centre.

Daily Production Centre Monitoring Boards Up-date Process

When the real production starts, the daily actual production result will be collected and reported by production leader of each production centre on his/her Production Centre Monitoring Board. The daily production reports also are sent to the office. While the production leaders of the Insulation production and the Core cutting production centre must send daily production reports, by item, to the office and wait for the actual production results in term of EU from the officer as discussed in 3.7.2.

Daily Production Monitoring and Control Database Up-Date Process

The officer employs daily actual production results, which are reported from every production centre to up-date PMC database according 3.7.2. The actual production in terms of EU of the Insulation production and the Core cutting production centre will be sent back to its production leader for reporting on his/her Production Centre Monitoring Board.

Daily Project Monitoring Boards Up-date Process

Besides, the officer has the responsibility to up-date all Project Monitoring Boards by using the actual result of every project monitoring indicator, which is calculated by PMC program as discussed in 3.7.2 and 3.7.4.

Project Master Plan Up-date Process

In this process, the actual production result from PMC database will be employed to track project master plan in Microsoft Project software by section manager, generally, on a weekly basis.

Actual and Plan Comparison

For actual and plan comparison, up-to-date project master plan will be used to compare, with its baseline plan and standard. The corrective actions or revised project master plan may be necessary depending on the amount of variances and decision of the section manager.

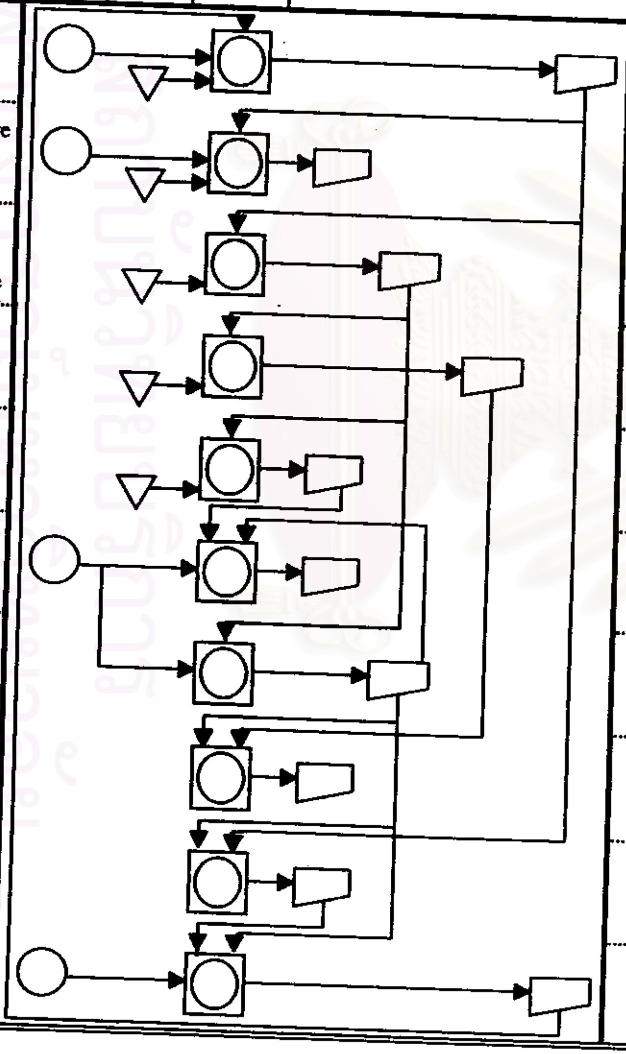
INPUT	EQUIPMENT	INPUT	EQUIP.	PROCESS	OUTPUT	PROCESS NAME	OUTPUT	SEND TO	RESP.
W/A	MS. Project Software					Project Planning	Project Master Plan	Officer	Section Manager
BOM, Material Status	MRS. Software					Materials Requirement Scheduling	Purchase Requisition MRS. Database	Purchasing Department	Officer
--	PS. Software, PMC. Software					Production Scheduling	PMC. Database	Production Leader	Officer
--	White-Board					Project Monitoring Board Set-Up	Project Monitoring Board	--	Officer
--	White-Board					Production Centre Monitoring Board Set-Up	Production Centre Monitoring Board	--	Production Leader
Daily Production Report	--					Daily Production Centre Monitoring Board Up-Date	Up-to-Date Production Centre Monitoring Board	--	Production Leader
--	--					Daily PMC. Database Up-Date	Up-to-Date PMC. Database	--	Officer
--	--					Daily Project Monitoring Board Board Up-Date	Up-to-Date Project Monitoring Board	--	Officer
--	--					Project Master Plan Up-Date	Up-to-Date Project Master Plan	--	Section Manager
--	--					Actual & Target Comparison	Revised Plan, Corrective Actions	--	Section Manager

Figure 3.16 Project-based production planning and control system

3.9 System Testing

The system is tested on a previous order. That order was to manufacture 150 units of 100 kVA / 33 kV, 3 Phase distribution transformers. According to the contract, it must be delivered on March 15, 1997. To avoid delay and penalty, this project was planned to complete two months earlier than the delivery date. It was originally planned to start on October 1, 1996 and to complete on January 15, 1997.

This distribution transformer needs 121 kinds of raw materials or sub-components. The company could not identify exactly when and how much/many each material was required. Purchase requisitions were generated and launched lately. The first purchase requisition was launched on October 1, 1996 - the same day as the starting of the project. For this reason, there was some materials shortage for insulation production, which led to delays in all the following processes. Materials shortage for this project was more serious for tanks and for accessories for final assembly. The company received the last batch of tanks at the end of December 1996. While the last batch of accessories for final assembly was obtained on February 10, 1997.

The production capacities of the Low voltage coil winding and the Core stacking processes were insufficient because they were not managed effectively. Consequently, there were a lot of works in progress at these processes. Frequently, production capacities of both production centres were overloaded; while, sometimes they were idle.

Besides, not only workers but also the management did not know the project status in comparison to the plan because of poor monitoring and control system. Therefore, there was no corrective action taken when actual performance began to deviate from the plan. When the deviation from the plan was significant enough to observe, the section manager and workers rushed through their work. This led to quality problems. Many distribution transformers did not pass the testing process, and must be corrected. This resulted in higher cost and longer time.

Finally, this project was completed on May 4, 1997. It was delayed almost four months compared to the original plan, or almost two months compared to the delivery contract; although, planning had two month allowance for delay. The company was fined and lost its reputation.

When the project is test-planned with the developed project-based production planning and control system, the whole order would be broken down to nine smaller batches. The first eight batches contain 18 units and the last one would contain six units of distribution transformers. According to the plan, the project could have been completed within January 9, 1997 as shown in Table 3.18. The developed system was capable of identifying when each process of each batch should start and finish batch by batch. Therefore, materials requirements, as shown in Table 3.19, could have been planned precisely and quickly. Materials requirements for critical or nearly critical activities could have received special attention and follow up for their delivery in order to avoid materials shortage, which would lead to project delay. In addition, huge inventory could also have been avoided with better timing and lot-sizing of purchase-order placements. Besides, the limited production capacities of the Low voltage coil winding and the Core stacking process could be scheduled and managed more effectively. Hence, both overloaded and idle production capacities could be less.

The critical activities of this project comprised the High voltage coil winding, the Core and coil assembly, the Vacuum and dry activities of the eighth batch and the Vacuum and dry, the Tanking and oil filling, the Final assembly activities of the ninth batch. Hence, in practice these activities and their resources requirements should have received special attention so as to avoid project delays and to crash project duration if necessary. Furthermore, many near-critical activities such as the Low voltage coil winding from the start of the project, the High voltage coil winding and the Core and coil assembly of the ninth batch, the Tanking and oil filling and the Final assembly of the eighth batch and their resources requirement could have been identified and monitored closely as critical activities.

While activities with large floats such as the Insulation production of the last six batches and the Tanking and oil filling and the Final assembly of the first six batches could be used to smooth resource usages by filling gaps in demands in critical path.

The daily-basis monitoring and control system would allow the management to track the project status. Hence, in a case where there was any deviation from baseline plan, corrective measures could be taken earlier and errors from rushed work could be reduced. In this project, when the Low voltage coil winding process, which was a near-critical activity from the start of the project was delayed, it could have been corrected by doing over-time work at early stage of the project. Other benefits from the developed system, especially in the scope of monitoring and control system, will be discussed later in 4.2.

For all of these reasons, the delivery performance of the project to manufacture 150 units of 100 kVA / 33 kV, 3 Phase distribution transformers could have been much better had the project-based production planning and control system been adopted.

Table 3.18 Operation plan

ID	Task Name	Duration	Predecessors	Early Start	Early Finish	Late Start	Late Finish	Free Slack	Total Slack
1	**BATCH 1 PRODUCTION**	**22d**		**01/10/96**	**30/10/96**	**14/10/96**	**09/01/97**	**0d**	**9d**
3	Insulation Production 1	4d		03/10/96	08/10/96	16/10/96	22/10/96	0d	9.6d
5	L.V. Winding 1	7d	3SS+5d	10/10/96	18/10/96	14/10/96	23/10/96	0d	2.6d
7	H.V. Winding 1	3d	5FF+1d	17/10/96	21/10/96	15/11/96	20/11/96	0d	21d
9	Core Cutting 1	6d		01/10/96	08/10/96	14/10/96	21/10/96	0d	9d
11	Core Stacking 1	7d	9SS+5d	08/10/96	16/10/96	14/10/96	22/10/96	0d	4d
13	Core & Coil Assembly 1	4d	7SS+1d,11FF+1d	18/10/96	23/10/96	18/11/96	21/11/96	0d	21d
14	Vacuum & Dry 1	9d	13	23/10/96	26/10/96	10/12/96	13/12/96	0d	35d
16	Tanking & Oil Filling 1	2d	14	28/10/96	29/10/96	17/12/96	19/12/96	0d	36.13d
18	Final Assembly 1	2d	16SS+1d	29/10/96	30/10/96	18/12/96	20/12/96	0d	36.13d
19	**BATCH 2 PRODUCTION**	**22d**		**09/10/96**	**07/11/96**	**22/10/96**	**09/01/97**	**0d**	**9d**
21	Insulation Production 2	4d	3	09/10/96	14/10/96	22/10/96	31/10/96	0d	9.6d
23	L.V. Winding 2	7d	5,21SS+1d	21/10/96	29/10/96	23/10/96	01/11/96	0d	2.6d
25	H.V. Winding 2	3d	7,23FF+1d	28/10/96	30/10/96	21/11/96	26/11/96	0d	18d
27	Core Cutting 2	6d	9	09/10/96	16/10/96	22/10/96	30/10/96	0d	9d
29	Core Stacking 2	7d	11,27SS+1d	17/10/96	25/10/96	23/10/96	31/10/96	0d	4d
31	Core & Coil Assembly 2	4d	13,25SS+1d,29FF+1d	29/10/96	01/11/96	22/11/96	27/11/96	0d	18d
32	Vacuum & Dry 2	9d	14,31	01/11/96	04/11/96	13/12/96	16/12/96	0d	30d

Table 3.18 *Operation plan (continue)*

ID	Task Name	Duration	Predecessors	Early Start	Early Finish	Late Start	Late Finish	Free Slack	Total Slack
34	Tanking & Oil Filling 2	2d	16,32	05/11/96	06/11/96	19/12/96	23/12/96	0d	32.13d
36	Final Assembly 2	2d	18,34SS+1d	06/11/96	07/11/96	20/12/96	24/12/96	0d	32.13d
37	**BATCH 3 PRODUCTION**	**27d**		**15/10/96**	**20/11/96**	**31/10/96**	**09/01/97**	**0d**	**12d**
39	Insulation Production 3	4d	21	15/10/96	18/10/96	31/10/96	11/11/96	0d	12.6d
41	L.V. Winding 3	7d	23,39SS+1d	30/10/96	07/11/96	01/11/96	12/11/96	0d	2.6d
43	H.V. Winding 3	3d	25,41FF+1d	06/11/96	08/11/96	27/11/96	02/12/96	0d	15d
45	Core Cutting 3	6d	27	17/10/96	24/10/96	31/10/96	08/11/96	0d	10d
47	Core Stacking 3	7d	29,45SS+1d	28/10/96	05/11/96	01/11/96	11/11/96	0d	4d
49	Core & Coil Assembly 3	4d	31,43SS+1d,47FF+1d	07/11/96	12/11/96	28/11/96	03/12/96	0d	15d
50	Vacuum & Dry 3	9d	32,49	12/11/96	15/11/96	16/12/96	19/12/96	0d	24d
52	Tanking & Oil Filling 3	2d	34,50	18/11/96	19/11/96	23/12/96	25/12/96	0d	25.13d
54	Final Assembly 3	2d	36,52SS+1d	19/11/96	20/11/96	24/12/96	26/12/96	0d	25.13d
55	**BATCH 4 PRODUCTION**	**28d**		**21/10/96**	**27/11/96**	**11/11/96**	**09/01/97**	**0d**	**15d**
57	Insulation Production 4	4d	39	21/10/96	24/10/96	11/11/96	20/11/96	0d	15.6d
59	L.V. Winding 4	7d	41,57SS+1d	08/11/96	18/11/96	12/11/96	21/11/96	0d	2.6d
61	H.V. Winding 4	3d	43,59FF+1d	15/11/96	19/11/96	03/12/96	06/12/96	0d	13d
63	Core Cutting 4	6d	45	25/10/96	01/11/96	11/11/96	19/11/96	0d	11d
65	Core Stacking 4	7d	47,63SS+1d	06/11/96	14/11/96	12/11/96	20/11/96	0d	4d

Table 3.18 Operation plan (continue)

ID	Task Name	Duration	Predecessors	Early Start	Early Finish	Late Start	Late Finish	Free Slack	Total Slack
67	Core & Coil Assembly 4	4d	49,61SS+1d,65FF+1d	18/11/96	21/11/96	04/12/96	09/12/96	0d	12d
68	Vacuum & Dry 4	9d	50,67	21/11/96	24/11/96	19/12/96	22/12/96	0d	20d
70	Tanking & Oil Filling 4	2d	52,68	25/11/96	26/11/96	25/12/96	27/12/96	0d	22.13d
72	Final Assembly 4	2d	54,70SS+1d	26/11/96	27/11/96	26/12/96	30/12/96	0d	22.13d
73	**BATCH 5 PRODUCTION**	**33d**		**25/10/96**	**10/12/96**	**20/11/96**	**09/01/97**	**0d**	**18d**
75	Insulation Production 5	4d	57	25/10/96	30/10/96	20/11/96	29/11/96	0d	18.6d
77	L.V. Winding 5	7d	59,75SS+1d	19/11/96	27/11/96	21/11/96	02/12/96	0d	2.6d
79	H.V. Winding 5	3d	61,77FF+1d	26/11/96	28/11/96	09/12/96	12/12/96	0d	9d
81	Core Cutting 5	6d	63	04/11/96	11/11/96	20/11/96	28/11/96	0d	12d
83	Core Stacking 5	7d	65,81SS+1d	15/11/96	25/11/96	21/11/96	29/11/96	0d	4d
85	Core & Coil Assembly 5	4d	67,79SS+1d,83FF+1d	27/11/96	02/12/96	10/12/96	13/12/96	0d	9d
86	Vacuum & Dry 5	9d	68,85	02/12/96	05/12/96	22/12/96	25/12/96	0d	14d
88	Tanking & Oil Filling 5	2d	70,86	06/12/96	09/12/96	27/12/96	31/12/96	0d	15.13d
90	Final Assembly 5	2d	72,88SS+1d	09/12/96	10/12/96	30/12/96	02/01/97	0d	15.13d
91	**BATCH 6 PRODUCTION**	**35d**		**31/10/96**	**18/12/96**	**29/11/96**	**09/01/97**	**0d**	**15.83d**
93	Insulation Production 6	4d	75	31/10/96	05/11/96	29/11/96	10/12/96	0d	21.6d
95	L.V. Winding 6	7d	77,93SS+1d	28/11/96	06/12/96	02/12/96	11/12/96	0d	2.6d
97	H.V. Winding 6	3d	79,95FF+1d	05/12/96	09/12/96	13/12/96	18/12/96	0d	6d

Table 3.18 *Operation plan (continue)*

ID	Task Name	Duration	Predecessors	Early Start	Early Finish	Late Start	Late Finish	Free Slack	Total Slack
99	Core Cutting 6	6d	81	12/11/96	19/11/96	29/11/96	09/12/96	0d	13d
101	Core Stacking 6	7d	83,99SS+1d	26/11/96	04/12/96	02/12/96	10/12/96	0d	4d
103	Core & Coil Assembly 6	4d	85,97SS+1d,101FF+1d	06/12/96	11/12/96	16/12/96	19/12/96	0d	6d
104	Vacuum & Dry 6	9d	86,103	11/12/96	14/12/96	25/12/96	28/12/96	0d	10d
106	Tanking & Oil Filling 6	2d	88,104	16/12/96	17/12/96	31/12/96	03/01/97	0d	11.13d
108	Final Assembly 6	2d	90,106SS+1d	17/12/96	18/12/96	02/01/97	04/01/97	0d	11.13d
109	**BATCH 7 PRODUCTION**	**37d**		**06/11/96**	**26/12/96**	**10/12/96**	**09/01/97**	**0d**	**9.82d**
111	Insulation Production 7	4d	93	06/11/96	11/11/96	10/12/96	19/12/96	0d	24.6d
113	L.V. Winding 7	7d	95,111SS+1d	09/12/96	17/12/96	11/12/96	20/12/96	0d	2.6d
115	H.V. Winding 7	3d	97,113FF+1d	16/12/96	18/12/96	19/12/96	24/12/96	0d	3d
117	Core Cutting 7	6d	99	20/11/96	27/11/96	10/12/96	18/12/96	0d	14d
119	Core Stacking 7	7d	101,117SS+1d	05/12/96	13/12/96	11/12/96	19/12/96	0d	4d
121	Core & Coil Assembly 7	4d	103,115SS+1d,119FF+1d	17/12/96	20/12/96	20/12/96	25/12/96	0d	3d
122	Vacuum & Dry 7	9d	104,121	20/12/96	23/12/96	28/12/96	31/12/96	0d	6d
124	Tanking & Oil Filling 7	2d	106,122	24/12/96	25/12/96	03/01/97	06/01/97	0d	7.13d
126	Final Assembly 7	2d	108,124SS+1d	25/12/96	26/12/96	04/01/97	07/01/97	0d	7.13d
127	**BATCH 8 PRODUCTION**	**42d**		**12/11/96**	**08/01/97**	**19/12/96**	**09/01/97**	**0d**	**0.83d**
129	Insulation Production 8	4d	111	12/11/96	15/11/96	19/12/96	04/01/97	0d	27.6d

Table 3.18 *Operation plan (continue)*

ID	Task Name	Duration	Predecessors	Early Start	Early Finish	Late Start	Late Finish	Free Slack	Total Slack
131	L.V. Winding 8	7d	113,129SS+1d	18/12/96	26/12/96	20/12/96	31/12/96	0d	2.6d
133	H.V. Winding 8	3d	115,131FF+1d	25/12/96	27/12/96	25/12/96	02/01/97	0d	0d
135	Core Cutting 8	6d	117	28/11/96	05/12/96	19/12/96	30/12/96	0d	15d
137	Core Stacking 8	7d	119,135SS+1d	16/12/96	24/12/96	20/12/96	30/12/96	0d	4d
139	Core & Coil Assembly 8	4d	121,133SS+1d,137FF+1d	26/12/96	31/12/96	26/12/96	31/12/96	0d	0d
140	Vacuum & Dry 8	9d	122,139	31/12/96	05/01/97	31/12/96	05/01/97	0d	0d
142	Tanking & Oil Filling 8	2d	124,140	06/01/97	07/01/97	06/01/97	08/01/97	0d	0.13d
144	Final Assembly 8	2d	126,142SS+1d	07/01/97	08/01/97	07/01/97	09/01/97	0d	0.13d
145	**BATCH 9 PRODUCTION**	**38.83d**		**18/11/96**	**09/01/97**	**30/12/96**	**09/01/97**	**0d**	**0d**
147	Insulation Production 9	1.4d	129	18/11/96	19/11/96	04/01/97	09/01/97	0d	34.43d
149	L.V. Winding 9	2.4d	131,147SS+1d	27/12/96	31/12/96	06/01/97	08/01/97	0d	6.43d
151	H.V. Winding 9	1d	133,149FF+1d	31/12/96	02/01/97	02/01/97	09/01/97	0d	1.2d
153	Core Cutting 9	2d	135	06/12/96	09/12/96	30/12/96	09/01/97	0d	16.6d
155	Core Stacking 9	2.4d	137,153SS+1d	25/12/96	27/12/96	31/12/96	03/01/97	0d	4.6d
157	Core & Coil Assembly 9	1.4d	139,151SS+1d,155FF+1d	02/01/97	03/01/97	03/01/97	04/01/97	0d	1.2d
158	Vacuum & Dry 9	9d	140,157	05/01/97	08/01/97	05/01/97	08/01/97	0d	0d
160	Tanking & Oil Filling 9	0.7d	142,158	08/01/97	08/01/97	08/01/97	09/01/97	0d	0d
162	Final Assembly 9	0.7d	144,160SS+1d	09/01/97	09/01/97	09/01/97	09/01/97	0d	0d

Table 3.19 *Material requirement milestone plan*

ID	Task Name	Duration	Predecessors	Required Date
1	**BATCH 1 PRODUCTION**	**22d**		**01/10/96**
2	Insulation Material 1	0d	3SS	03/10/96
4	L.V. Winding Material 1	0d	5SS	10/10/96
6	H.V. Winding Material 1	0d	7SS	17/10/96
8	Silicon Steel Slit 1	0d	9SS	01/10/96
10	Core Stacking Material 1	0d	11SS	08/10/96
12	Accessory for Core & Coil Assembly 1	0d	13SS	18/10/96
15	Oil & Tanking Material 1	0d	16SS	28/10/96
17	Accessory for Final Assembly 1	0d	18SS	29/10/96
19	**BATCH 2 PRODUCTION**	**22d**		**09/10/96**
20	Insulation Material 2	0d	2,21SS	09/10/96
22	L.V. Winding Material 2	0d	4,23SS	21/10/96
24	H.V. Winding Material 2	0d	6,25SS	28/10/96
26	Silicon Steel Slit 2	0d	8,27SS	09/10/96
28	Core Stacking Material 2	0d	10,29SS	17/10/96
30	Accessory for Core & Coil Assembly 2	0d	12,31SS	29/10/96
33	Oil & Tanking Material 2	0d	15,34SS	05/11/96
35	Accessory for Final Assembly 2	0d	17,36SS	06/11/96
37	**BATCH 3 PRODUCTION**	**27d**		**15/10/96**
38	Insulation Material 3	0d	20,39SS	15/10/96
40	L.V. Winding Material 3	0d	22,41SS	30/10/96
42	H.V. Winding Material 3	0d	24,43SS	06/11/96
44	Silicon Steel Slit 3	0d	26,45SS	17/10/96
46	Core Stacking Material 3	0d	28,47SS	28/10/96
48	Accessory for Core & Coil Assembly 3	0d	30,49SS	07/11/96
51	Oil & Tanking Material 3	0d	33,52SS	18/11/96
53	Accessory for Final Assembly 3	0d	35,54SS	19/11/96
55	**BATCH 4 PRODUCTION**	**28d**		**21/10/96**
56	Insulation Material 4	0d	38,57SS	21/10/96
58	L.V. Winding Material 4	0d	40,59SS	08/11/96
60	H.V. Winding Material 4	0d	42,61SS	15/11/96
62	Silicon Steel Slit 4	0d	44,63SS	25/10/96
64	Core Stacking Material 4	0d	46,65SS	06/11/96

Table 3.19 *Material requirement milestone plan (continue)*

ID	Task Name	Duration	Predecessors	Required Date
66	Accessory for Core & Coil Assembly 4	0d	48,67SS	18/11/96
69	Oil & Tanking Material 4	0d	51,70SS	25/11/96
71	Accessory for Final Assembly 4	0d	53,72SS	26/11/96
73	**BATCH 5 PRODUCTION**	**33d**		**25/10/96**
74	Insulation Material 5	0d	56,75SS	25/10/96
76	L.V. Winding Material 5	0d	58,77SS	19/11/96
78	H.V. Winding Material 5	0d	60,79SS	26/11/96
80	Silicon Steel Slit 5	0d	62,81SS	04/11/96
82	Core Stacking Material 5	0d	64,83SS	15/11/96
84	Accessory for Core & Coil Assembly 5	0d	66,85SS	27/11/96
87	Oil & Tanking Material 5	0d	69,88SS	06/12/96
89	Accessory for Final Assembly 5	0d	71,90SS	09/12/96
91	**BATCH 6 PRODUCTION**	**35d**		**31/10/96**
92	Insulation Material 6	0d	74,93SS	31/10/96
94	L.V. Winding Material 6	0d	76,95SS	28/11/96
96	H.V. Winding Material 6	0d	78,97SS	05/12/96
98	Silicon Steel Slit 6	0d	80,99SS	12/11/96
100	Core Stacking Material 6	0d	82,101SS	26/11/96
102	Accessory for Core & Coil Assembly 6	0d	84,103SS	06/12/96
105	Oil & Tanking Material 6	0d	87,106SS	16/12/96
107	Accessory for Final Assembly 6	0d	89,108SS	17/12/96
109	**BATCH 7 PRODUCTION**	**37d**		**06/11/96**
110	Insulation Material 7	0d	92,111SS	06/11/96
112	L.V. Winding Material 7	0d	94,113SS	09/12/96
114	H.V. Winding Material 7	0d	96,115SS	16/12/96
116	Silicon Steel Slit 7	0d	98,117SS	20/11/96
118	Core Stacking Material 7	0d	100,119SS	05/12/96
120	Accessory for Core & Coil Assembly 7	0d	102,121SS	17/12/96
123	Oil & Tanking Material 7	0d	105,124SS	24/12/96
125	Accessory for Final Assembly 7	0d	107,126SS	25/12/96
127	**BATCH 8 PRODUCTION**	**42d**		**12/11/96**
128	Insulation Material 8	0d	110,129SS	12/11/96
130	L.V. Winding Material 8	0d	112,131SS	18/12/96

Table 3.19 Material requirement milestone plan (continue)

ID	Task Name	Duration	Predecessors	Required Date
132	H.V. Winding Material 8	0d	114,133SS	25/12/96
134	Silicon Steel Slit 8	0d	116,135SS	28/11/96
136	Core Stacking Material 8	0d	118,137SS	16/12/96
138	Accessory for Core & Coil Assembly 8	0d	120,139SS	26/12/96
141	Oil & Tanking Material 8	0d	123,142SS	06/01/97
143	Accessory for Final Assembly 8	0d	125,144SS	07/01/97
145	**BATCH 9 PRODUCTION**	**38.83d**		**18/11/96**
146	Insulation Material 9	0d	128,147SS	18/11/96
148	L.V. Winding Material 9	0d	130,149SS	27/12/96
150	H.V. Winding Material 9	0d	132,151SS	31/12/96
152	Silicon Steel Slit 9	0d	134,153SS	06/12/96
154	Core Stacking Material 9	0d	136,155SS	25/12/96
156	Accessory for Core & Coil Assembly 9	0d	138,157SS	02/01/97
159	Oil & Tanking Material 9	0d	141,160SS	08/01/97
161	Accessory for Final Assembly 9	0d	143,162SS	09/01/97