Chapter IV

Development of Decision Support System for Maintenance Planning

4-1 Methodology

The methodology in developing the decision support system for maintenance planning is categorized into 3 stages as follows:

(1) The definition stage: collecting data and knowledge for building the DSS.

(2) The design stage: designing and building the DSS architecture.

(3) The implementation stage: building the DSS application and evaluating the system.

4-2 Definition Stage

In the definition stage, the data and knowledge involved with the decision making process in maintenance planning are collected. The knowledge regarding maintenance planning and scheduling is gathered by interviewing from the experts. These experts are the manager and the maintenance supervisor who have experience in maintenance of printing machinery. The knowledge is also based on procedures in planning and scheduling of maintenance recommended by Duffuaa et al (1998) in chapter 3. The data and knowledge in maintenance planning and scheduling are used for constructing a model of the decision process in the DSS. Three main phases of maintenance planning and scheduling are presented by the chart in figure 4.1.

Figure 4.1 Maintenance Planning and Scheduling Phases.

From the figure 4.1, the process of maintenance planning and scheduling is categorized into three phases. At the beginning, the maintenance policies are selected, while the preventive tasks are identified in order to optimize the costs and performance of the machine. Then, the selected tasks are set into the maintenance plan and schedule. Finally, after these tasks are performed following the plan, the results of these tasks will be reported and summarized for improving the maintenance plan and work performance.

At the first phase, the effects and costs of the machine failure will be considered with the costs of preventive maintenance in order to select the suitable preventive tasks for the maintenance plan. By applying the IDEF0 technique, the process can be decomposed into four sub-processes. These are the analysis of the failure data, the identification of the preventive task, the comparison of preventive tasks and failures, and the creation of the job list sub-processes. These sub-processes are presented in the figure 4.2.

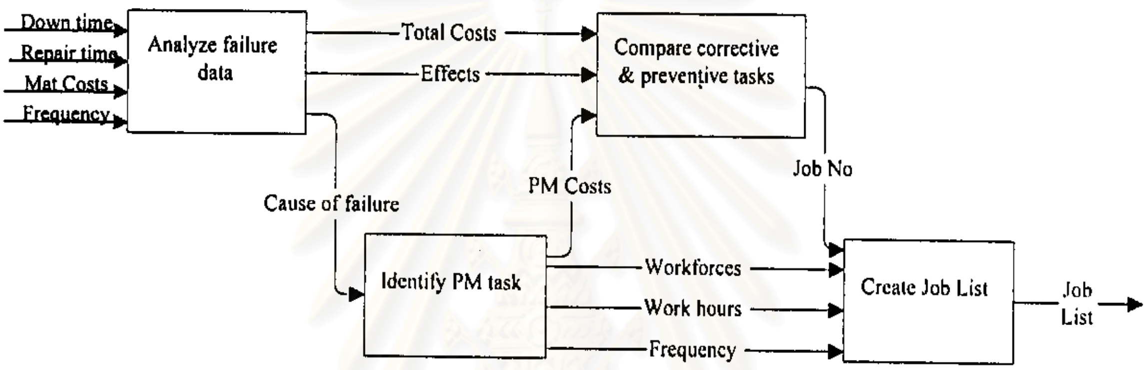

Figure 4.2 Process in Selecting Maintenance Policy and Preventive Tasks.

From the chart in figure 4.2, the failure data, such as downtime, repair time, and material costs, are determined by the analysis of the failure data sub-process. The outputs of this sub-process are the failure effects, the costs, and the cause of failure. The cause of failure is used in the sub-process of identifying the preventive maintenance tasks. The costs of preventive maintenance from this sub-process will be compared with the breakdown costs in the comparison sub-process. The comparison of the maintenance costs is considered with the effects of the machine failures. The output of this sub-process is the recommended maintenance tasks for planning and scheduling. According to the process, the decision model for selecting maintenance policy can be defined as follows:

In the figure 4.3, the decision model starts from considering the effects of machine failure. For the machine failures that effect to the safety of work, the preventive tasks related to these failures will be added into the job list for the maintenance planning. For the failures that do not effect to the safety, the costs of preventive task related to those failures will be compared with the costs of machine breakdown. The preventive tasks that have lower costs than the machine breakdown will be selected in order to minimize the overall costs. The rest of the machine failures that are not related with the selected tasks will be corrected by the corrective maintenance.

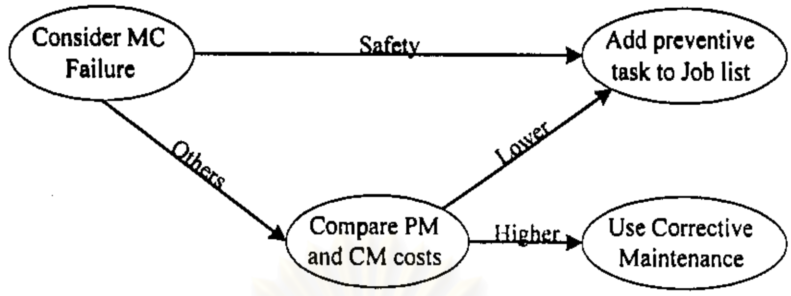

Figure 4.3 Decision Model for Selecting Maintenance Policy.

In the phase of setting the maintenance plan, the preventive job list defined from the first phase is used for determining the primary or yearly maintenance plan. The primary or yearly plan is the long-term plan. It is used as a guideline for setting the more accurate plan. Since the production plan for printing can be determined for only in the short period, the data of production schedule are not used in this phase. The process in setting the maintenance plan is presented in figure 4.4.

Figure 4.4 Process in Setting Maintenance Plan.

From the figure 4.4, the process in setting the maintenance plan composes of the categorizing and the scheduling of the maintenance task sub-processes. The preventive job number and frequency are used as the input in the categorizing sub-process. The preventive tasks are categorized by the frequency to perform the task. They can be classified into four groups: every month, every 3 months, every 6 months, and every year. After categorizing the preventive tasks into different groups, the groups of maintenance tasks, the related information, and the available date are used in the scheduling sub-process. The output result of this sub-process is the yearly maintenance plan. The decision model for setting the maintenance plan can be defined in figure 4.5.

According to the model in figure 4.5, the groups of maintenance tasks categorized by the different frequencies are scheduled to perform on the specific

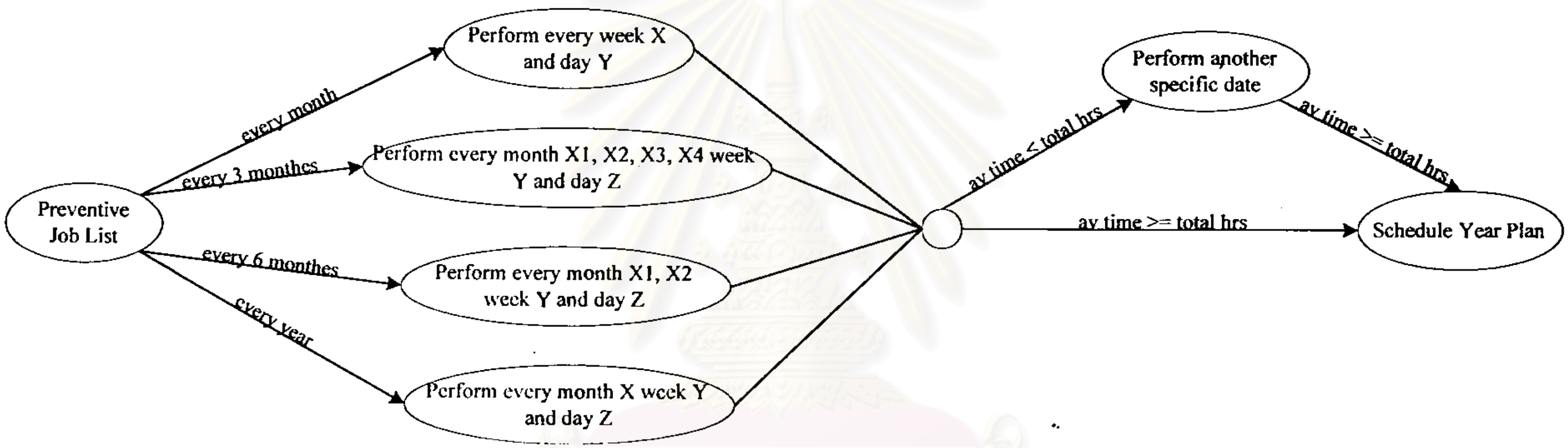

Figure 4.5 Decision model for setting maintenance plan

dates. These dates are specified for the groups of preventive tasks with the different frequencies by the users. The maintenance tasks that are scheduled on the same specific date will be put into the maintenance plan, unless the total work hours of those tasks are less than the available time of the specific date. The maintenance tasks that their work hours exceed the available hours of the specific date will be rescheduled to another date. After all of the maintenance tasks are scheduled to the specified date, they will be summarized into the maintenance plan.

For the last phase, the processes in performing and summarizing the maintenance plan are presented as in figure 4.6. This process is consisted of three sub-processes. These are the comparison of the maintenance and production plans, the rescheduling of the maintenance plan, and the performing of the maintenance plan sub-processes. The primary or yearly maintenance and production plans are the inputs of the comparison sub-process. In this sub-process, the dates to perform the scheduled maintenance tasks are compared with the dates to perform the production tasks. The outputs of this sub-process are the weekly maintenance plan that matches the production schedule and the maintenance backlog 1. The weekly maintenance plan and backlog are considered with the available time in the rescheduling sub-process. This sub-process has functions in updating and improving the maintenance plan to be more accurate and to match the production schedule. After rescheduling the plan, the maintenance tasks will be performed. The maintenance work orders and descriptions are used in the performing sub-process. The results from performing the maintenance tasks are reported in order to evaluate the work performance, while the unfinished maintenance jobs are listed in the backlog 2. This backlog is used to reschedule the maintenance plan.

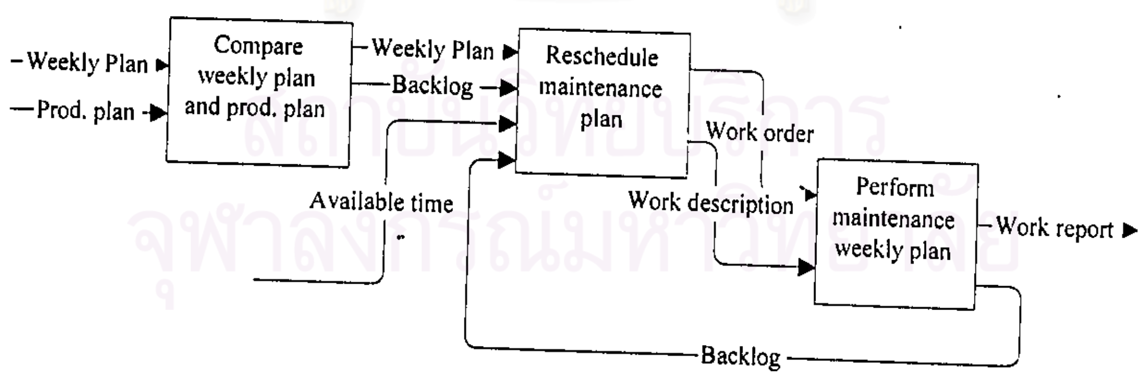

Figure 4.6 Processes in Performing and Summarizing Maintenance Plan.

According to the decision model for maintenance planning and scheduling in figure 4.7, the primary or yearly maintenance and production plans are considered. The dates to perform the preventive maintenance tasks are

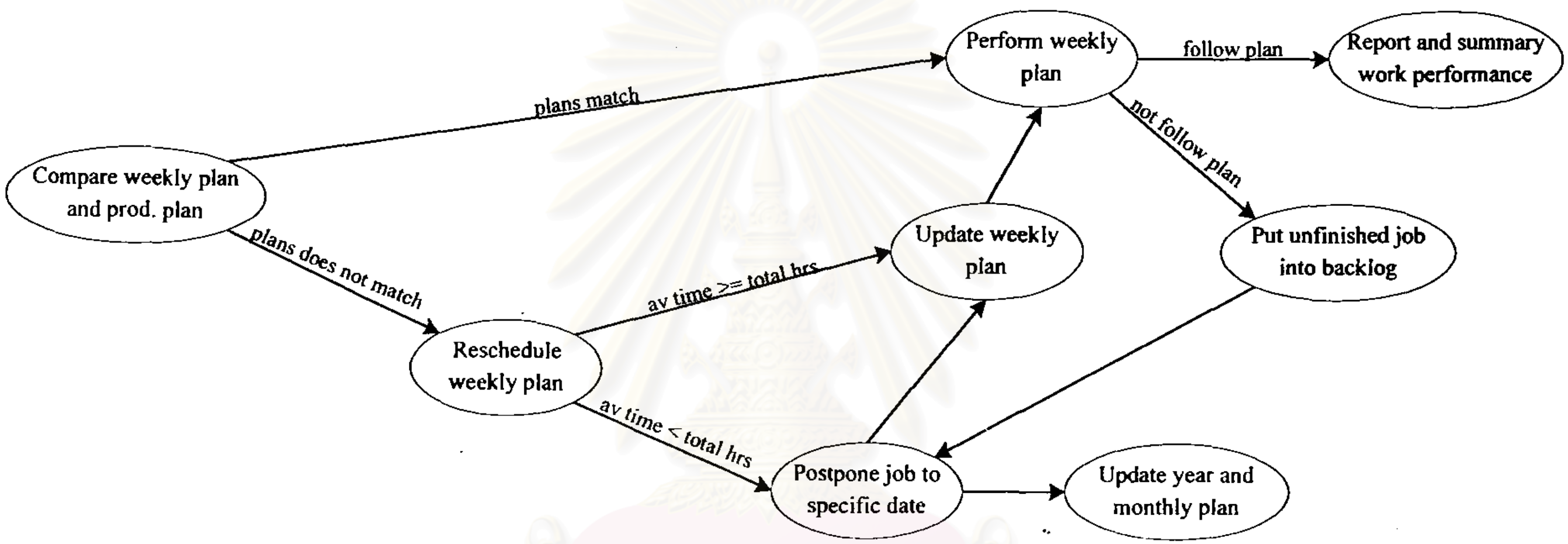

Figure 4.7 Decision model for maintenance planning and scheduling

considered with the dates in the production plan. The maintenance tasks that cannot be performed due to the production schedule will be rescheduled to another dates. After rescheduling the maintenance tasks, they will be performed following the updated plan. The unfinished tasks from maintenance plan are listed into the backlog for rescheduling, while the finished tasks are reported and summarized to evaluate the work performance.

4-3 <u>Design Stage</u>

In the design stage, the DSS architecture is built. The data required for the decision model in the definition stage are collected for building the database in the DSS architecture. These data come from the failure history records of the machine and the machine maintenance and troubleshooting manual. The structure and relationships of data will be discussed later in the section 4-3-3. The architecture of Decision Support System for Maintenance Planning (DSMP) is composed of four major components. These are the dialog or user interface, the knowledge base, the data, and the model components. The architecture of DSMP is presented in figure 4.8.

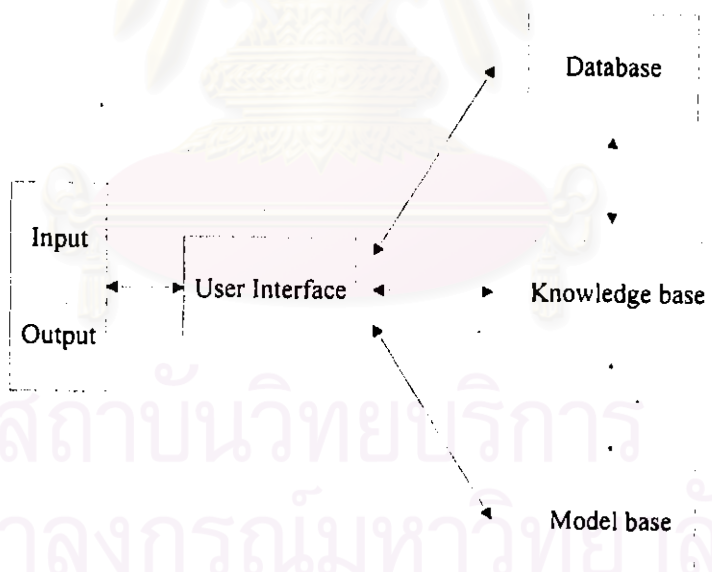

Figure 4.8 Architecture of DSMP.

4-3-1 <u>Dialog Component</u>

The dialog or user interface component in the DSMP is used for recording the input information to the system. It allows the users to direct the system. It is used to present the output information to support the decision. The users can direct the system by using the command buttons in the system menu. The input information for analysis can be recorded through the designed forms in the menu, while the results of analysis are reported in the tables. The dialog component in the DSMP is consisted of the main menu, the sub-menus, the forms, and the commands for directing the system. In the DSMP main menu, there are various sub-menus and commands for browsing into the forms and executing the programs as the following.

(1) Input menu: for recording and correcting the input information.

- *Job list form*: contains the information of preventive tasks.
- *Machine list form*: contains the information of the machines in the plant.
- *Machine failure history form*: contains the failure data of each machine.
- *Subcontractor form*: contains the information of the subcontractors.
- *Work report form*: contains the daily report of the maintenance works.
- *Relationship form*: contains the relationships between the corrective and preventive maintenance tasks.

(2) Machine failure history command: presents the past machine failure data to the users by providing the questioning form to query the types of machine.

(3) Maintenance costs menu: consists of 4 commands that are related to the maintenance costs.

- *Preventive maintenance costs command*: for calculating the PM costs.
- *Breakdown maintenance costs command*: for calculating the CM costs.
- *Costs relationships command*: for comparing the costs of PM and CM.
- *Job recommendation command*: for suggesting the suitable PM tasks.

(4) Frequency model menu: provides the commands for determining the optimal frequency to perform the PM tasks.

- *Parameter form*: for recording the parameters of the frequency model.
- *Frequency model command*: for optimizing the frequency of the preventive tasks.

(5) Year plan menu: contains 5 commands for setting the maintenance year plan.

- *Work calendar command*: for presenting the work dates of each year.
- *Year plan parameter form*: for recording the data in setting the year plan.
- *Setting plan command*: for processing the maintenance year plan.
- *Year plan command*: for presenting the maintenance year plan to the users.
- *Yearly report command*: presenting the yearly report of the maintenance work to the users.

(6) Monthly plan command: presents the monthly plan of the maintenance works to the users by providing the questioning form to query the specific month.

(7) Weekly plan menu: contains 5 commands for setting the maintenance weekly plan.

- *Production plan command*: for presenting the weekly production plan.
- *Production plan form*: for recording the data of the production plan.
- *Setting plan command*: for processing the maintenance weekly plan.
- *Weekly plan command*: for presenting the maintenance weekly plan.
- *Weekly report command*: presenting the weekly report of the maintenance work to the users.

(8) Maintenance index menu: contains 4 commands for determining the maintenance indexes to measure the maintenance performance.

- *Machine availability command*: for calculating the availability of the machine.
- *Mean time between failure command*: for calculating the average time of each type of failure that occurs in the machine.
- *Mean time to repair command*: for calculating the average time used in repairing the machine for each type of failure.
- *Overtime hour command*: for calculating the number of overtime due to the machine failure in the specific range of time.

4-3-2 Knowledge base Component

The knowledge base component in the DSMP is built from the decision models defined in the definition stage. The main functions of the knowledge base in this system can be categorized into three parts. Theses are to recommend for the preventive maintenance jobs, to schedule the maintenance plan, and to update and summarize the maintenance plan and works. According to these functions, the procedures of the knowledge base in the DSMP can be described as follows:

Recommending the preventive tasks: According to the decision model in figure 4.3, the procedures in identifying the preventive tasks for the maintenance plan are presented as followings:

- Consider the effects of the machine failures classified by safety, production, quality, and environment.
- If the machine failures effect to safety, recommend the related preventive jobs of these failures to perform in the maintenance plan.
- If the machine failures effect to the others, consider the costs of machine breakdown and the costs of preventive tasks related with those failures.
- If the costs of preventive tasks related to failures are lower than the costs of failures, recommend these preventive tasks to perform in the maintenance plan.

Scheduling the maintenance plan: The procedures for scheduling the preventive maintenance plan referred to the decision model in figure 4.5 are described as follows:

- List the available days and hours for performing the maintenance tasks.
- Consider and classify the preventive jobs by the frequency or the interval time to perform the task from the preventive job list.
- Specify a day, a week and a month to perform the task for each group of the preventive jobs with the different frequencies.
- Consider the workforces and work hours required performing each job.
- Calculate the total cumulative work hours required for the jobs with the same frequency.

- If the cumulative hours of the job are less than the available hours of the specific date, schedule the preventive job to the specific date.
- Identify the other dates to perform the rest of preventive tasks from the available day list.
- Recalculate the cumulative work hours for the jobs that are not scheduled.
- Schedule the rest of jobs to the new specific dates.
- Calculate and update the available hours of the dates in the available day list.

Updating and summarizing the maintenance plan and works: From the decision model in figure 4.7, the procedures in updating and summarizing the maintenance plan and works are presented as follows:

- Identify the weekly production plan.
- Compare the weekly production plan with the weekly maintenance plan.
- If the sum of the production hours and the maintenance work hours is higher than the available hours of the specific date, remove the jobs that cause the excess hours from the maintenance schedule into the backlog.
- Identify the date to perform the preventive tasks from the available day list.
- Reschedule the preventive jobs in the backlog to the new specific dates.
- Update and summarize the maintenance plan.
- Estimate the expected costs of the preventive tasks in the maintenance plan.
- Identify the maintenance work orders.
- Perform the preventive maintenance tasks.
- Report the work results and the number of the unfinished tasks.
- List the unfinished tasks into the backlog.
- If there is any backlog task, identify the date to perform the backlog tasks from the available day list.
- Schedule the backlog tasks to the new specific dates.
- Calculate the actual costs of maintenance.
- Summarize the performance of the maintenance work and compare the actual maintenance costs with the expected costs.

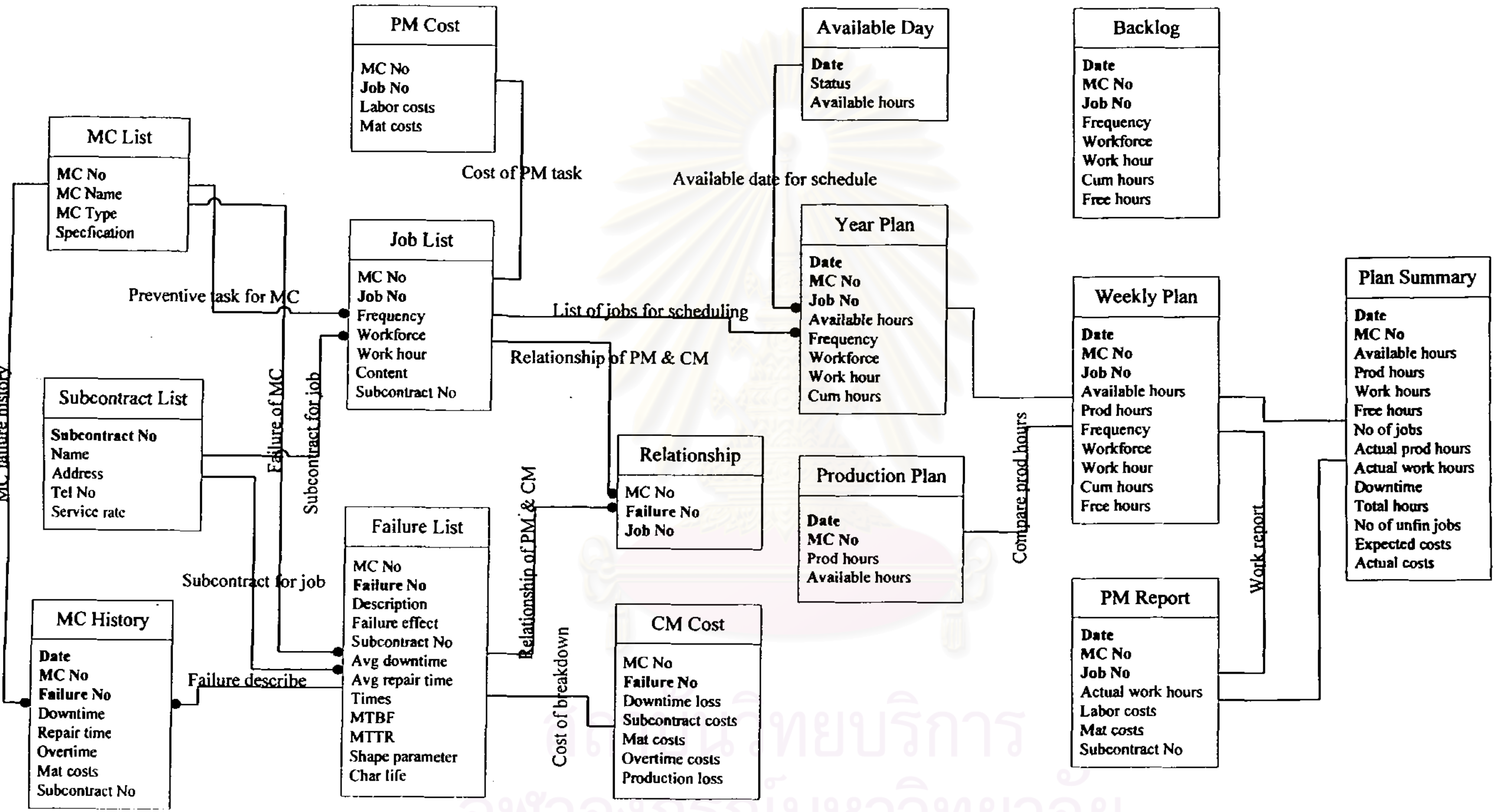

Figure 4.9 Main Structure of DSMP Database

4-3-3 Data Component

The data component in the DSMP is composed of the database and the database management system. The database is built from the group of data tables that are related in the relational form. These data tables store the data and information used in the DSMP. The data in the DSMP database can be classified into three types: the input, the in-process, and the output data. The input data files store the data from the users. The are used for the processing and analysis activities. The in-process data is the data that is analyzed and processed by the programs or models into the temporary form. These data are stored in the table files for the further analysis. The output data are the analysis results from the DSMP programs. They are stored in the table files for presenting to the users. The main structure of the DSMP database is defined as in the figure 4.9.

According to the figure 4.9, the data of the machine, the preventive tasks. and the machine failures are used for setting the maintenance plan and determining the maintenance parameters and indexes. These data are stored in the data files. The MC list data file contains the data of the machine in the operation. These data are used for identifying the machine in the maintenance activities. The data of the preventive tasks and the machine failures are stored in the job list and the failure list data file respectively. These data are used to describe the characteristics of the preventive tasks and the machine failures. They are the contents of the tasks, the work hours and workforces required, the frequency to perform, the mean time between failures, and etc.

The machine, the preventive task, and the failure data are used with the other related data for planning and scheduling maintenance tasks. These data are the subcontractor data, the machine failure history data, the maintenance cost data, and the relationship of the preventive task and the machine failure data. The subcontractor data are stored in the subcontract list data file. This file is related with the job list and the failure list file. It describes the information of subcontractors who are responsible for the preventive tasks or the machine failures. The machine failure history data in the MC history file relate the MC list file with the failure list file. They present the records of failures that occur to the machine.

The data of the maintenance costs in the PM cost and the CM cost data files are used to present the costs of the preventive tasks and the machine failures. These data will be used for calculating the expected maintenance costs in the maintenance planning. The relationship of the preventive task and the machine failure data in the relationship file are used to relate the preventive task with the machine failure. By using the data of the preventive task, the machine failure, the maintenance costs, and the relationship, the suitable preventive tasks for the maintenance planning can be identified.

The preventive task data in the job list file are used with the available date data for scheduling the yearly maintenance plan. The maintenance plan data are stored in the year plan file. The important data in the year plan file are the dates to perform the tasks and the information regarding the preventive tasks. The year plan data will be compared with the production plan data in the production plan file for scheduling the more accurate plan in the weekly plan file. The data in the weekly plan file will be used to order the preventive tasks. The data of the unfinished task are stored in the backlog data file. These data will be used for reschedule the maintenance plan. The weekly plan data are also related with the work report data in the PM report file. The data of weekly plan will be compared with the work report data for summarizing the maintenance plan. The actual data in the PM report file, such as work hours, workforces, and maintenance costs, are compared with the expected data in the weekly plan file. These data are summarized in the plan summary data file.

From the structure of the DSMP database, the table files for storing the maintenance data are created. The database is consisted of 38 table files for storing the input, the in-process, and the output data. The list of tables and their functions is presented in the table 4.1. The table files in the DSMP database can be classified into three groups. These are the input, the in-process, and the output tables. The types of data stored in the input tables are the task contents. the machine, the descriptions of failure, the frequency, and the subcontractor details. These types of data are used for analysis and processing into the maintenance plan, the costs, and the performance measurement indexes. The example of the input table is the job list table. This table contains the information of the preventive tasks. In the job list table, the details of preventive tasks, such as the job number, the job description, the frequency, the workforces. and the work hours, are stored to use for scheduling the maintenance tasks.

Some data processing processes in the DSMP, such as the maintenance scheduling, compose of many steps. The input data of these processes may be analyzed and changed into the in-process format. The input data are changed into the easier format for processing into the output results. This type of data is kept in the in-process table file. The example of the in-process table is the year plan1 table file. This table stores the information of all maintenance tasks and the available work date. By identifying the specific date and the frequency, the data in the year plan1 table are used to query the maintenance tasks for setting the maintenance schedule.

Table 4.1: List of tables in DSMP database.

Table name	Function
available_day	store data of work days for scheduling maintenance plan.
available_day2	store in process data of work days for scheduling maintenance plan.
avg_labor_rate	store data of average labor rate for calculating maintenance costs.
avg_rev_rate	store data of average revenue rate for calculating opportunity loss.
backlog	store in process data of maintenance tasks that need to be rescheduled.
backlog2	store data of unfinished maintenance tasks for reschedule.
calendar	store date data of a specific year for identifying work days.
cm_cost	store costs of machine breakdown for each type of failure.
failure_effect	store list of effects from machine failures.
failure_list	store information of machine failures
input	store data of specific date to perform maintenance tasks of different frequencies.
input_hrs	store specific hour identified by users to perform maintenance tasks in each day.
interval	store frequency and expected costs of maintenance calculated by optimal model.
job_list	store information of preventive maintenance tasks.
mc_availability	store percent availability of machine within specific range of time.
mc_history	store information of failure records of machine.
mc_history_query	store machine number for specifying the query machine failure history records.
mc_index_query	store range dates that users specify for calculating maintenance index of machine.
mc_list	store information of machine.
mc_overtime	store percent machine overtime due to failure within specific range of time.
monthly_plan	store information of preventive maintenance plan of specific month.
parameter	store optimal frequency of maintenance task calculated by optimal model.
pm_cost	store costs of preventive maintenance tasks.
pm_report	store information report of preventive tasks that are performed.
present_month	store month that users specify for query monthly maintenance plan.
present_year	store year that users specify for query list of work days.
prod_plan_week	store information of weekly production plan.
relationship	store relationship information between machine failures and preventive tasks.
subcontract	strore information of subcontractors.
sum_week_plan	store information of weekly summary of maintenance works.
sum_year_plan	store information of yearly summary of maintenance works.
today_date	store date that users specify for updating daily maintenance report information.
weekly_plan	store information of weekly maintenance plan.
weekly_plan1	store in process information of weekly maintenance plan.
wk_performance	store statistical information of preventive maintenance tasks.
year_plan	store information of yearly maintenance plan.
year_plan1	store in process information of yearly maintenance plan.
year_plan3	store in process information of yearly maintenance plan.

After the data are analyzed and processed into the desired results, the output data will be stored in the output table for presenting to the users. These data are the maintenance plan, the maintenance costs, the frequency, and the performance indexes. The example of the output table is the year plan table that stores the data of the yearly maintenance plan.

In the DSMP database, there are many tables that are related. The relations of these tables are created by the store of the same information between the tables. For example, the job list and the machine list tables are related by storing the data of the machine number. The relations of the tables are presented in the structure of the DSMP database in figure 4.9.

The database management system of the DSMP is applied by using the database management engine of the application program available in the market. In the DSMP, the Visual FoxPro database management engine is applied.

4-3-4 Model Component

The model component in the DSMP is consisted of the models for analyzing the data and information. These models have the functions in calculating and optimizing data. They are used to find the specific values for supporting the decisions. In the DSMP, the models used for the data analysis are composed of the maintenance costs models, the optimal frequency maintenance model, the shape and characteristic life parameter model, and the maintenance index models.

Maintenance Cost Model is consisted of the models for determining the costs of preventive maintenance and machine breakdown. In the DSMP, these maintenance costs are defined as follows:

PM cost = PM labor cost + PM material cost

where,

PM labor cost = labor rate per hour × workforces × work hours

or for subcontract = service rate per hour × work hours

Breakdown or CM cost = downtime loss + material cost + subcontract-
-cost + production loss

where,

Downtime loss	=	labor rate per hour × workforces × downtime
Subcontract cost	=	service rate per hour × repair time
Production loss	=	revenue rate per hour × downtime

Optimal frequency maintenance model is used to determine the appropriate frequency for each preventive maintenance task. According to the section 3-4. the optimal preventive maintenance models developed by Duffuaa et al (1998) are applied in the DSMP. Since the complex printing machinery is composed of many parts, the appropriate maintenance policy for the printing machinery is the policy II (see section 3-4.). In the policy II, referred to Barlow and Hunter (1960), the maintenance task schedule is fixed. This reduces the complexity in rescheduling the maintenance tasks every time that the failure occurs. As a result, the policy II should be appropriate, especially for the complex equipment with the high number of parts, such as the printing machinery.

In order to apply the optimal preventive maintenance model developed by Duffuaa et al (1998), the probability density function of the machine failure needs to be determined. The Weibull distribution is widely used to describe the characteristic of failure of the equipment. The examples of equipment parts applied by this distribution are the ball bearings, the motors, and etc. In the DSMP, the Weibull distribution is used to describe the failures of printing machinery parts. The functions and parameters related to the Weibull distribution are presented as follows:

The probability density function of the Weibull distribution is

$$f(t) = \beta \eta^{-\beta} t^{\beta-1} \exp[-(t/\eta)^{\beta}] \qquad \text{for} \quad t > 0$$

The distribution function is defined as

$$F(t) = 1 - \exp[-(t/\eta)^{\beta}] \qquad \text{for} \quad t > 0$$

The failure rate function is given as

$$r(t) = \beta\eta^{-1}(t/\eta)^{\beta-1}$$

where β is the shape parameter and η is the characteristic life of the Weibull distribution.

According to the optimal maintenance model of the policy II in section 3-4, the model to determine the expected costs of maintenance per unit time is defined as:

$$UEC(t_p) = \frac{C_p + C_f H(t_p)}{t_p}$$

where,

$$H(t_p) = \int r(t)dt$$

For the Weibull distribution,

$$H(t_p) = \int \beta\eta^{-1}(t/\eta)^{\beta-1}dt$$
$$= (t_p/\eta)^{\beta}$$

Thus,

$$UEC(t_p) = \frac{C_p + C_f (t_p/\eta)^{\beta}}{t_p}$$

By applying the trial and error technique, t_p or the interval time to perform the maintenance task at the minimum expected costs per unit is defined. As a result, the optimal frequency for the maintenance task can be identified to a decision-maker.

The problem for determining the optimum frequency for the maintenance task is the difficulty to identify the parameters for the model. While the costs of preventive and corrective maintenance can be calculated from the maintenance cost model, the shape parameter and the characteristic life of the Weibull distribution are defined by the failure information through the analysis models discussed as following.

Shape and characteristic life parameter model is used to estimate the values of the shape parameter and the characteristic life in the Weibull distribution for using in the optimal frequency maintenance model. According to Nelson (1982), the equations for estimating the shape parameter and the characteristic life are presented as follows:

$$\beta = \frac{\pi^2}{\sqrt{6}\,\sigma}$$

and $\eta = \exp[\mu + \gamma (\sqrt{6}/\pi)\, \sigma]$

where μ and σ is the mean and the standard deviation of time to failure of the equipment.

and $\gamma = 0.5772157...$

Maintenance index models are used to find the index values for measuring the maintenance performance. The maintenance indexes used for the performance measurement in the DSMP are the availability of machine, the mean time between failure, the mean time to repair, and the production overtime due to machine failures. The formulas for these maintenance indexes, referred to Duffuaa et al (1998) are defined as:

$$\text{Machine Availability} = \frac{\text{Scheduled production time} - \text{Downtime}}{\text{Scheduled production time}}$$

$$\text{Mean time between failures} = \frac{\text{Scheduled production time} - \text{Downtime}}{\text{Number of failures}}$$

$$\text{Mean time to repair} = \frac{\text{Downtime delays from failures}}{\text{Number of failures}}$$

$$\text{Overtime due to failures} = \frac{\text{Overtime hours worked} \times 100}{\text{Total hours worked}}$$

Table 4.2: List of models and formulas in the DSMP programs.

	Model name	Formula
1	PM Cost	PM labor cost + PM material cost
2	PM labor cost	labor rate per hour x workforces x work hours
3	Subcontract cost	service rate per hour x work hours
4	CM cost	downtime loss + material cost + subcontract cost + production loss
5	Downtime loss	labor rate per hour x workforces x downtime
6	Production loss	revenue rate per hour x downtime
7	Expected maintenance costs per unit	Cp + Cf (tp/n)^b
	for the policy II [UEC(tp)]	tp
8	Shape parameter (b)	(pi^2) / (sqrt(6) x sigma)
9	Characteristic life (n)	exp[mean + {gamma x [sqrt(6)/pi] x sigma}
10	Gamma	0.5772157...
11	Machine Availability	(scheduled production time – downtime) / scheduled production time

	Model name	Formula
12	Mean time between failures	(scheduled production time – downtime) / number of failures
13	Mean time to repair	downtime delays from failures / number of failures
14	Overtime due to failures	(overtime hours worked x 100) / total hours worked

4-4 Implementation Stage

In the implementation stage, the system designed in the definition stage is built into the application software. The DSMP software is developed under the Visual FoxPro software. The Visual FoxPro software provides the abilities for the users to create the database and to develop the application software. Unlike the popular software, such as the Access, the Visual FoxPro is more flexible to create the programs for the system. The programs that require the abilities to calculate the complex math models can be written by using the Visual FoxPro language. While the Access has the limits to calculate the very complex math models, it needs to link with the software like the Visual Basic for building the programs and application. This causes the difficulties in developing the system software, since it needs to build on the two developing software.

In order to build the DSMP, the dialog component of the system is created from the menu, the form, and the command tools. The structure of the dialog component is built as described in the section 4-3-1. The data component is created by building the data tables in the database structure from the Visual FoxPro database designer. These tables are used to store the data for analyzing in the knowledge base and the model base and for supporting the decision of users. The relationships between the tables are linked by the primary key attributes and the foreign key attributes of the data tables. The knowledge base and the model components of the system are built from the program codes. These codes are written with the Visual FoxPro and SQL languages. The dialog component, the database structure, and the program source codes of the DSMP software are presented in the system manual in the appendix A.

Steps for developing the DSMP software are described as follows:

(1) Create the data tables and the database.

(2) Write the knowledge base and the model base programs.

(3) Design the menus, commands and forms for creating the user interface.

(4) Input the data and information into the database.

(5) Test by executing the programs.

(6) Correct the program errors.

In the DSMP, the knowledge base and the model base are created from the program codes. The list of names and functions of the programs in the DSMP software are defined as the followings.

- *Primary_plan*: contains the knowledge base and the program for setting the primary or yearly maintenance plan.
- *Monthly_plan*: contains the program for query the maintenance monthly plan from the year plan.
- *Weekly_plan and Weekly_plan2*: contains the knowledge base, the models and the program for scheduling the weekly maintenance tasks. They are used to calculate the expected costs of preventive maintenance and to update the maintenance plan.
- *Report, Report2 and Report3*: contains the knowledge base, the models and the program for rescheduling and updating the maintenance plan. They are also used to summarize the maintenance work performance and to calculate and compare the actual costs of maintenance with the expected costs.
- *Update_failure_list*: contains the models for updating and calculating the machine failure information and the machine failure history.
- *Bd_cost_summary*: contains the models for calculating and summarizing the costs of machine breakdown in each year.
- *Pm_cost*: contains the knowledge base and the models for defining the costs of each preventive maintenance job.
- *Cm_cost*: contains the knowledge base and the models for defining the costs of corrective maintenance for each type of failure.
- *Interval_model*: contains the knowledge base and the models for identifying the parameters for the optimal frequency maintenance model. It is used to optimize the frequency of each maintenance task.
- *Mc_availability*: contains the model for calculating the availability of the machine to evaluate the maintenance performance.
- *Mc_overtime*: contains the model for calculating the number of machine overtime hours due to failures.