COMPUTER AIDED COST ESTIMATION OF STEEL STRUCTURES
A CASE STUDY OF OPERATIONAL APPROACH

by

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ABSTRACT

An arrangement has been set up between the University of British Columbia and an industrial firm ,Coast Steel Fabricators, to investigate the topic of computer cost estimation of steel structures. The objective of this research is to computerize the current cost estimating process of Coast Steel Fabricators and investigate a method of generating the labour hour variables used by the estimating program. This research has made the following contributions: A computer estimating program was developed using the operational approach and a method was investigated to generate the labour hour variables required by the computer estimating program. The unique arrangement between this study and the industrial firm has proven to be successful. Coast Steel Fabricators updrated their estimating process and achieved a higher efficiency. The author was given hands-on experience and free access of the data files throughout the study.

The computer cost estimating program is written in Basic and runs under the MAI-Four computer system. The program is menu-driven to allow the users to:

1. store labour hour variables;
2. enter inputs from take-offs;
3. compute the labour hours and material weights; and
4. calculate the labour cost, material cost and total cost.

Coast Steel Fabricators reported that the computer cost estimating program has reduced the overall estimating time

by 30%.

The labour hour variables are defined as the time for each operation. As these variables are vital to the computer estimating program, a method has been developed to obtain these variables by collecting shop data at a global level through an information system. The global shop data will then be analyzed by the technique of Multiple Linear Regression (MLR) using a spreadsheet program (Lotus 1-2-3). An optimun size of 200 observations was recommended to give a monthly average. The program is also menu-driven to allow the users to:

1. convert global shop data into piece files;
2. sort the piece file into component files;
3. perform MLR analysis on the component file to obtain the labour hour variables; and
4. plot the standard error of each labour hour variable.

The labour hour variables will serve as a powerful tool for time studies in case of the start-up of a new fabrication plant and will provide feedback to the cost estimation program of an ongoing fabricator.

Since the applications are written in the Basic and spreadsheet environments, programs can be easily customized for use by a number of steel fabricators.

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Chapter 1

INTRODUCTION

New general strategies have recently been investigated at U.B.C. and the possibility of developing a computerized estimation program for steel structures exists [1] [2]. Early results from these research programs were promising and invited an implementation of these findings into the workplace. A local steel fabricator, Coast Steel Fabricators Ltd.,was trying to upgrade their estimating process to take advantage of the new strategies and computer technologies. This research included a case study of computer aided estimation using an operational approach. The study was composed of two parts. In the first part, a computer estimating program was developed on a mini-computer in Basic. This program has been completed and was put to use as a daily operation tool in the estimating department. The computer estimating program has reduced the total estimating time by 30%.

The second part of the research project was concerned with the generation of the labour hour variables used in the estimating program at the fabricating shop. These variables are needed to calculate the labour hours and thus the labour cost. They are important because they reflect the performance of the fabricating shop. Several approaches of collecting global shop data have been investigated for different levels of shop management. The global shop data were reduced by multiple linear regression utilizing a program written in Lotus 123 macro language. The global shop data served as feedback for the estimating program as well as a database for efficiency, coverage and learning curve studies [3]. Finally, this project showed that future research should be directed towards the development of a mechanism which simplifies the process of data retrieval from shop drawings.

Chapter 2

COMPUTER ESTIMATING PROGRAM

A computer estimating program has been written in Basic language for the "MAI-Four" computer system. Recently, a utility program was added to handle file storage and deletion. The estimating program is menu-driven allowing the access of four major sub-programs. Their functions are:

1. storage of the labour hour variables;
2. input of take-off sheets;
3. computation of the labour hours and material weights; and
4. calculation of the labour costs, material costs and total costs.

To run the computer estimating program, details of the drawings must be first recorded on the take-off sheets and then entered into the computer. A hardcopy of the entries, known as the take-off summary, will be issued by the estimating program. The take-off summary is similar to the page by page summary shown in figure 4.1 except that the "WEIGHT", "HOURS", and the bottom part are missing. Note that each line on the take-off summary will represent a structural member and the operations associated with it. The take-off summary is checked and then used as the input data file for the computer estimating program which calculates the material weights and the labour hours of the required operations. The results are summarized by the page by page summary. The values under the "WEIGHT" and "HOURS" headings in figure 2.1 are the calculated weights and the labour hours. The bottom part gives the total number of operations and the corresponding time of performing them. The results of the page by page summary will then be sorted in terms of activity, description, and shape to give the labour grouping, material grouping and material summary. Finally, the unit material costs, wages, overhead and profit are entered to give the total cost. Because of the agreement with Coast Steel Fabricators, further details of the computer estimating program cannot be discussed to protect their trade secrets.

The approach used in the computer estimating program is known as the operational approach. Costs of steel structures were previously calculated by estimating the weight and multiplying it by a cost factor [4]. This was accurate when labour costs were relatively low. However, with the increasing importance of labour costs on total costs and the availability of new technologies for handling the massive data associated with labour costs, an advanced approach can be employed for steel structure estimation.

In general, the total cost is composed of the material, labour, equipment and overhead [1]. The material cost can be found by summing up the products of the individual material weights and the corresponding material costs. The costs for equipment and overhead are fixed costs and can be taken as a percentage of the total of the variable costs of material and labour. Labour costs are the most difficult items to estimate. Different operations require different amounts of labour time. However, the basic operations such as shearing, punching, drilling, etc. are relatively fixed. The key to estimating labour hours lies in the identification of these common operations for each structural component and the proper application of known labour hour variables. This approach is known as the operational approach.

On the other hand, Leung [2] has suggested general formulas to cover all operations for all components, for example, a general formula for drilling is

$$DR = n\{T_s + \sum_{i=1}^{n} (T_a)_i + t_d*N_h + t_c*N_h\}/N$$

where $n = \frac{N}{N_s}$ and $\frac{N}{N_s}$ is integer division

DR = time for operation (i.e. drilling)

T_s = setup time

T_a = alignment time

t_d = drilling time per hole

N_h = number of holes

t_c = time to center one punch hole

N = number of identical members

N_s = maximum number of plates in a stack.

The advantage of the formula method is that only a small set of labour hour variables are needed to cover the operations of all components. The disadvantage is that since the formula does not cover all the parameters, this method may not give good results for some components. However, if each operation on a given component is treated as a single independent unit, the labour costs can be derived using these units. The advantage of this single unit method is that each unit will best reflect the operation on an individual component and hence gives a more accurate labour hour estimate. A full set of all labour hour variables must be obtained in order to perform the estimation.

In the reported project, both methods are used to complement each other. The single unit method will be used as the basic mechanism of the computer estimating program. However, if an individual labour hour variable is not available, the formula method is used to obtain it and then store it in the appropriate data file. A full set of labour formulas have been compiled by the estimating department through their studies in the fabricating shop. Figure 2.2 shows how the two methods are used together. In general, the formula method is used for the start-up fabrication period when there are virtually no previous records of labour hour variables. It can also be used in a design office for cost optimization. The single unit method is more often used when a manufacturer already possesses a large data base of the labour hour variables. Methods of retrieving these labour hour variables will be discussed later.

The computer estimating program has been tested substantially and was put into use for over a year. The management of Coast Steel reported that it has reduced their total estimation time by 30%. With higher efficiency, the estimating department was observed to be able to maintain their service with a smaller staff. The computer estimating program has become an indispensible tool and was readily accepted by all the estimators. The computer estimating program not only relieved their workload but also allowed additional analysis which was not performed before. For example, when an estimator identified an area where saving could be made, he suggested a structural equivalent to it. Because of the calculations involved, only one structural equivalent could be considered. However, with the computer estimating program, a variety of versions can be considered to determine which produces the greatest saving.

Since all of the estimators are graduates of Universities or technical institutes, they are more willing to accept changes. They welcome hi-tech and think the use of a computer will enchance their work. Hence, the first part of this research , the cost estimating program, was completed on schedule. Continual feedback and advice was given by the estimators which contributed to the success of the estimating program. On the other hand, management from the shop seem to have a lower academic background and are more reluctant to accept changes. They think the current system is adequate and dislike the computer. Because of the lack of interest shown by the shop management, the second part of this research was behind schedule. Input from the shop management was minimal and most of the research was done through observations by the author in the shop. Thus the findings of the labour hour variables cannot be tested and verified in the shop.

The arrangement between this study and the industrial firm can be summarized in figure 2.3. The author provides technical support to Coast Steel in computerizing their estimating process and in researching other estimating issues. In return, Coast Steel allows access to their data file and contributes some financial and facility support. The key to such an arrangement lies in a common interest. Since both parties are interested in the topic of cost estimating of steel structures, efforts can be co-ordinated and results will be shared. However, since the industrial firm is only interested in the work they are doing, they may ignore other studies. The student must collect as much research data as possible while he is still working on areas the firm is interested in. Care should also be taken as to what material must be disclosed or withheld to protect the trade secrets of the industrial firm.

FILE NAME= SAMPLE	COAST STEEL FABRICATOR	DATE: 08/15/84
DIVISION : 0 * NORMAL *	PAGE BY PAGE SUMMARY	PAGE: 1

PAGE /LINE	QTY	DESCRIPTION	SH	W/LB	LENGTH	WEIGHT (LB)	CODE	IN-LINE OPERATIONS A	B	C	D	E	F	G	ADDITIONAL OPERATIONS H /LB	I	J	K	L	M	N	O	P	HOURS
								CUT	BEV CUT	PRE CUT	COP	PUN HOL	DRI HOL	SID	END PLS	STI	GUS	EXT END	CLP	CON PCS	STB	BRG	EX	
1/1	1	16	W	40	30	1200	2	1	0	0	2	24	0	3	0	0	0	0	0	0	0	0	0	2.2
1/2	1	21	W	55	25	1375	2	1	0	2	0	10	0	1	0	0	0	0	0	0	0	0	0	1.6
1/3	1	18	W	55	21.5	1183	2	1	2	0	0	0	4	1.5	0	0	0	0	0	0	0	0	0	1.6
1/4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/5	3	6X3/8	PL	0	.8	19	2A	3	0	0	0	18	0	1	3	0	0	0	0	0	0	0	0	2
1/6	4	3.5X1/2	PL	0	1.3	28	2A	4	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	2
1/7	1	18X1/2	PL	0	2.5	77	2A	1	0	0	0	4	0	1	0	0	1	0	0	0	0	0	0	1.1
1/8	1	6X1/2	PL	0	2.8	29	2A	1	0	0	0	5	0	1	0	0	0	1	0	0	0	0	0	1
1/9	2	3X3X1/4	L	4.9	.5	4	2A	2	0	0	0	4	0	1	0	0	0	0	2	0	0	0	0	.8
1/10	1	4X4X1/4	L	6.6	15	99	2A	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1.5
1/11	2	8	C	11.5	1.5	34	2A	2	0	0	2	4	0	1	0	0	0	0	0	0	2	0	0	1.9
1/12	1	10X1	PL	0	1.3	43	2A	1	0	0	0	0	4	.1	0	0	0	0	0	0	0	1	0	1.3
1/13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/14	24	3/4 NELSON	SP	.5	.3	12	2A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1/15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TOTAL WEIGHT= 4102 TOTAL HOURS= 18

	CODE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	HOURS
OPS	2	3	2	2	2	34	4		0	0	0	0	0	0	0	0	0	0
HOURS	2	1.7	.6	.3	.3	1.9	.5		0	0	0	0	0	0	0	0	0	5.4
OPS	2A	15	0	0	2	38	4		3	4	1	1	2	1	2	1	1	0
HOURS	2A	1.9	0	0	.4	.7	.4		1.5	1.8	.9	.8	.6	1.2	1	.7	1	12.6

CODE= 2 PCS= 3 TOTAL HOURS= 18

Figure 2.1 The Page by Page Summary

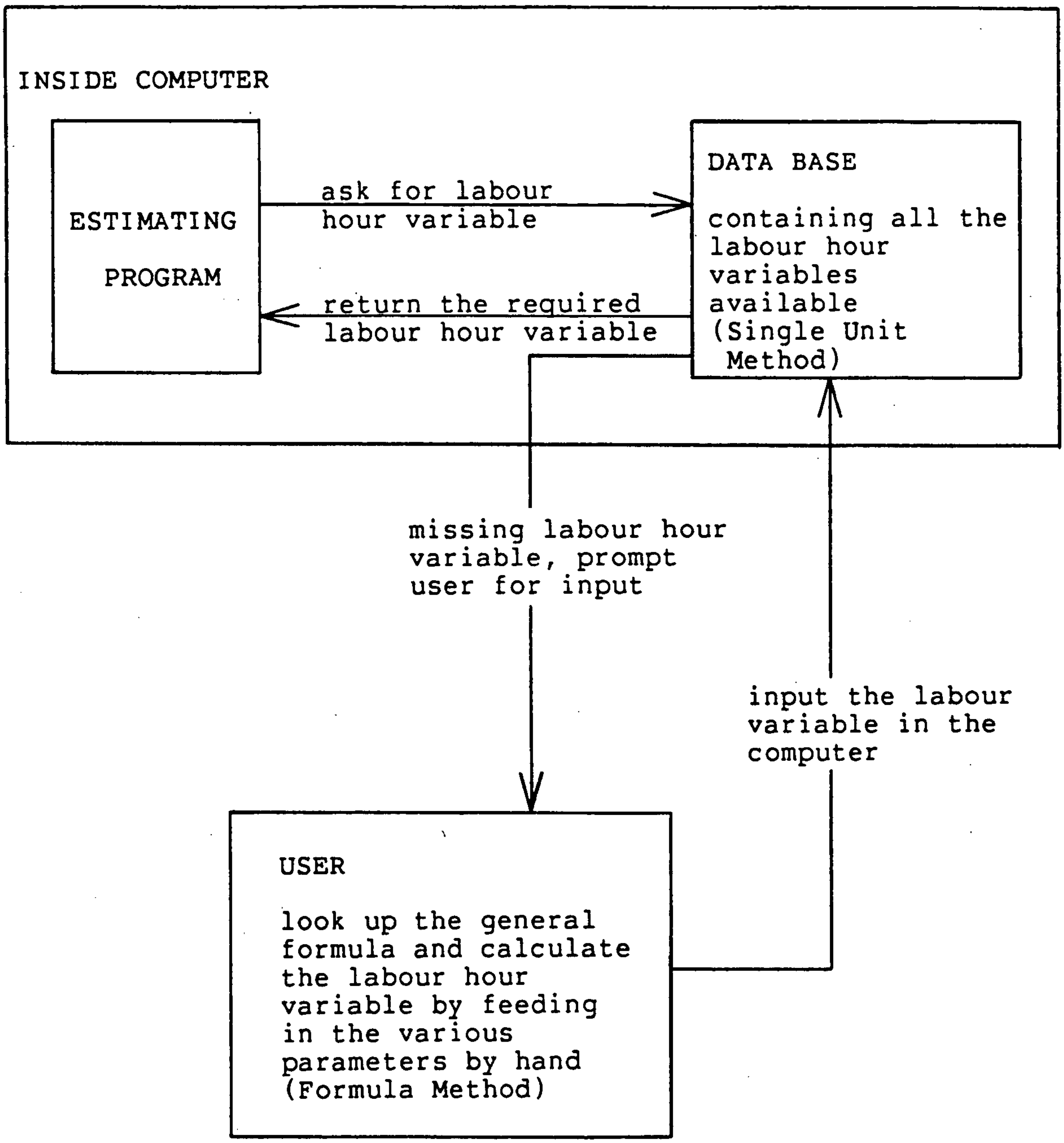


Figure 2.2 The Formula and Single Unit Methods of Retrieving Labour Hour Variables

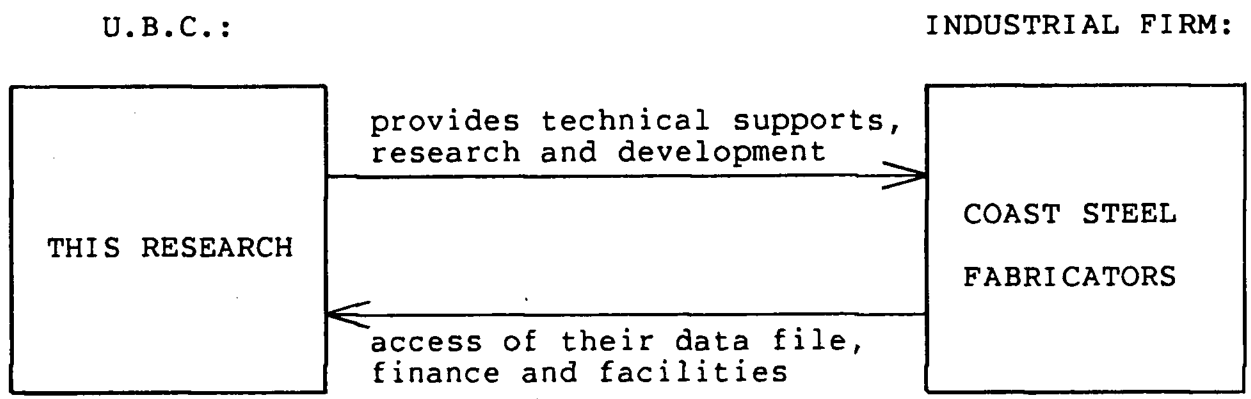


Figure 2.3 The Relationship Between This Research and the Industrial Firm

Chapter 3

LABOUR HOUR VARIABLES

3.1 INTRODUCTION

Labour hour variables are used in the operational approach. The objective is to find a method to obtain these variables. This will be discussed in the following chapters. Multiple linear regression is used to analyze the global shop data to give the labour hour variables. The analysis is done on a micro-computer spreadsheet (Lotus 1-2-3) using macro programming technique. The standard error of each labour hour variable will be plotted to show the precision of the the analysis.

In this case study, four approaches of collecting shop data have been examined (figure 3.1). Only the first three approaches are investigated in detail. The last approach which involves a fundamental change of the fabricating shop management will only be discussed as a theoretical option.

3.2 CURRENT SHOP PRACTICE AND GLOBAL SHOP DATA

Currently, in the case of Coast Steel Fabricators, materials are handled by material bills and the job sequences are scheduled by the route cards (figure 3.2). The labour hours are recorded in the time cards in such a manner that no labour hour variable can be obtained directly without some sorting. In general, the workers record their time on a basis of classification which separates all components into beams, columns, frames, etc. instead of component basis such as W150X27, L75X75X6, etc. For example, a worker records 2 hours under the classification of "beam" together with the drawing numbers instead of breaking the 2 hours into individual operations on different components such as 1 hour on sawing W150X27 and 1 hour on punching 20 holes on PL8.

The current system of shop monitoring is adequate as long as the fabricator is interested in the total labour hours and individual labour hours under each classification. However, these shop records are not the global shop data required for the determination of the labour hour variables. Formerly, time studies had to be used to determine the labour hour variables. In fact the current labour hour variables used in the computer estimating program were found by time studies. However, it seems to be more efficient to collect the global shop data and analyze the data to obtain the performance of the individual worker and his production.

The global shop data are just combinations of local shop data. The local or particular shop data are the labour hour variables that are to be found. The global shop data are the sum or observation of several local data, for example, the total time for shearing and punching of a 10 mm plate is "global shop data" whereas the individual time to shear and time to punch are the "local shop data", i.e. the labour hour variables. Multiple linear regression is then used to calculate the local shop data, i.e. labour hour variables from the global shop data (figure 3.3). These labour hour variables can be used to update the computer estimating program. If both the estimating department and the shop management have adopted the same information system for the labour operations, these values can be used directly in the computer estimating program. Unfortunately, the shop management has classified all the additional operations shown in figure 2.1 in terms of weld and fit. However, other in-line operations are used by both departments. Thus, most of the labour hour variables are compatible while a small portion of them will require experience to interpolate. Because of the time constraint of this research, a linkage program has not yet been developed.

3.3 COLLECTING GLOBAL SHOP DATA, APPROACH #1

"Raw" shop data must be carefully studied and sorted into global shop data. Studies and sorting are required because in the current job set-up the workers do not record enough information on the time card. For instance, the workers never record what type of operation they have done on the time card. Moreover, they sometimes even forget to put down the drawing numbers. Hence, a detailed study of the period of operation and sequence of job flow must be made in order to assign global shop data for certain operations (figure 3.4).

Assume that the global shop data on contract 5441 and drawings 11, 14, 17 are to be found. From the time cards of figure 3.4, worker number 9 and 12 have spent 0.75 hour and 1 hour at 7 a.m. respectively. Worker number 25 who is the last one working on these drawings has spent 4.0 hours at 1 p.m. However, what they actually did is not known since they do not put down the kind of operation they have performed. To see what kind of operations are required in these drawings, the route card should be checked. The route card has indicated that saw, drill and fit on W150X24 plus angle shear and punch on L75X75X10 should be performed. From the route card and the time cards, one can conclude that a set of operations have been performed and a set of times are observed in performing the operations. However, the relationship between these two individual sets of operations and times is not clear. Also the number of the operations is not known yet. To find it, the actual drawings should be referenced to give the exact number of each operation, for example, there are 3 angle shears and 6 punches on L75X75X10. The job sequence indicates that both the saw and angle shear must be performed first and independently, followed by the drill and finally fit. This sequence of job flow is usually indicated by the arrangement of the operation columns on the route card. From experience, angle shear and punch are performed together and drill and fit are handled together by the fitter. The general practice in the shop dictates that certain workers will usually perform the same sort of operation all the time. Worker number 9, 12 and 25 are known as the shear man, saw man and fitter respectively. Hence, one can deduce the global shop data from the raw shop data through a detailed study and sorting. These global shop data are summarized by the last box in figure 3.4.

In general, this approach is poorly suited to obtain global shop data as it involves extensive fabrication knowledge, effort and patience. Also, since experience plays a major role in this approach, it will be difficult to implement into a computer program. However, the advantage of this approach is that relatively fewer raw shop data are needed to deduce the global shop data which are also easier to analyze. For instance, one can correctly conclude that the labour hour variable for sawing W150X24 is 1/3 hour.

3.4 COLLECTING GLOBAL SHOP DATA, APPROACH #2

The second approach also uses the raw shop data with a simple sorting routine. All hours referring to the same drawings on the time cards will be added to give the individual total hours on the same drawings. Figure 3.5 shows that the individual hours on each time card are not particular important. Rather the sum of these hours for the same drawings is needed to be assigned to a number of operations. No deduction, logic or experience is required to find the global shop data. The magnitude of the operations on drawings 11, 14 and 17 can be obtained by referencing the individual drawings. The operations are then summed up to give the left hand side of the equation shown in figure 3.5. The total hours corresponding to each drawing will be the right hand side of the equation. This equation represents the global shop data.

The results between the first and second approaches are summarized in figure 3.6. One can easily see that the global shop data generated by the second approach is fairly complicated and more raw shop data are needed. Nevertheless, more raw shop data can be easily obtained with the use of older records. The complicated equations of this approach do not represent a major obstacle because they are readily solved by the computer. Thus, if a fabricator does not want to change his monitoring system, the second approach is recommended because the procedure can be implemented into a computer program to produce the labour hour variables.

3.5 COLLECTING GLOBAL SHOP DATA, APPROACH #3

A third possibility requires a slight deviation from the current shop practice but results in a much better information system for collecting global shop data. Operations on the route cards should be quantified. The route card alone will give the RHS of the global equation without referencing the drawings. The workers must circle the operations on the route card and report the time they spent on the operation. Now the hours inside the circle will give the LHS of the global equation. Therefore, global shop data will appear on the route cards and will then be entered into the computer for the analytical analysis. Figure 3.7 shows an example of this approach.

Since the daily hours of the individual worker can be summed from these route cards, the time cards are no longer needed. So basically, the workers themselves are actually spending less time on work reports than before (Approach #1 and #2). There may be an increased work load on the management as the operations must be quantified on the route cards. The entry of route card information will replace that of the time card. Hence, the extra effort is only minimal. As the raw shop data are formulated in an appropriate way, all of them will become the global shop data. Little sorting is required to compile these global shop data for MLR analysis. Moreover, these global shop data can also be used for accounting, forecasting, controlling and scheduling purposes.

3.6 COLLECTING GLOBAL SHOP DATA, APPROACH #4

The fourth approach is an ideal approach of collecting global shop data. Forde [1] has proposed control stations at critical shop locations such that the time at which a job passes through these stations can be recorded. The duration between two subsequent work stations will represent the time taken for a certain operation, i.e. the RHS of the global equation. With the job sequence being known, this duration of time can be assigned to that operation representing the LHS of the global equation. Hence, a global equation will be set up and will represent global shop data. The mechanism behind the fourth approach is very similar to that of the third approach. The difference between them is that the fourth approach is fully automatic while the third approach depends on human input. Berry [5] suggests that pre-encoded media such as bar-codes and magnetic strip devices be used to collect the shop data. The fourth approach utilizes sensing devices to register the flow and time of a job in the shop. A scheme of the fourth approach is shown in figure 3.8. Not only will the daily workload of both workers and management be reduced but also unnecessary human error during data entry will be eliminated. The information from the drawings is still taken-off by the shop management and entered into the computer. The computer records all this information and issue the most optimal route cards. The computer selects the optimal material to be used and instructs the worker to put an indicator on it. Once the material is brought into the shop, an entry time is recorded by a sensing device such as the bar code detector located at the entrance. Some operations are performed to this material, and when finished the material will be passed on to other workers for the next operation. When the material is passed from one location to another, the worker number together with the material information are registered and the time of occurrence is again recorded. The sequence is repeated until the finished component leaves the shop and the exit time is recorded.

Once the system is set up, the workers will soon be unaware of the fact that their performance is continuously monitored. Since little human input is involved, errors or misinformation will be reduced. However, this ideal approach may involve changes in the current shop practice and the installation of the sensing hardware. A case study of this approach is proposed for the future.

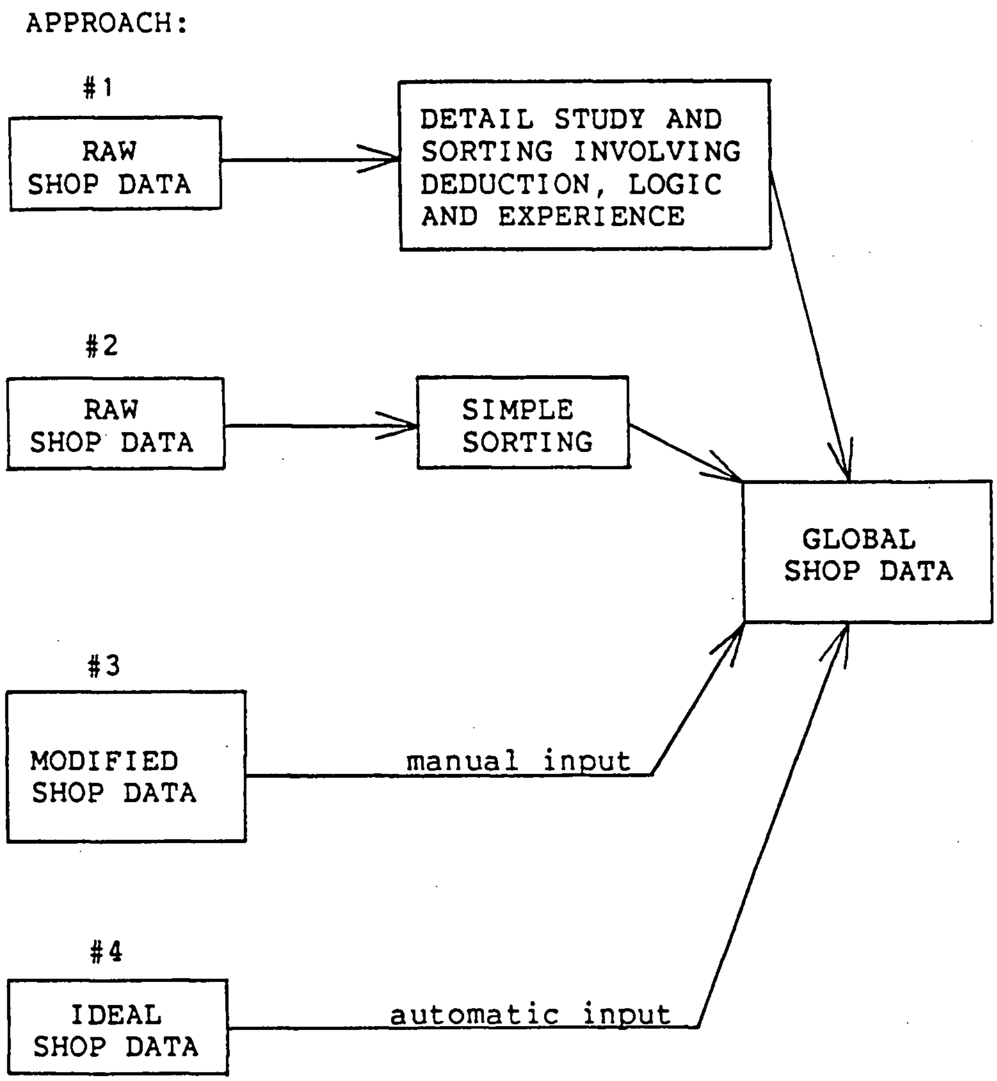
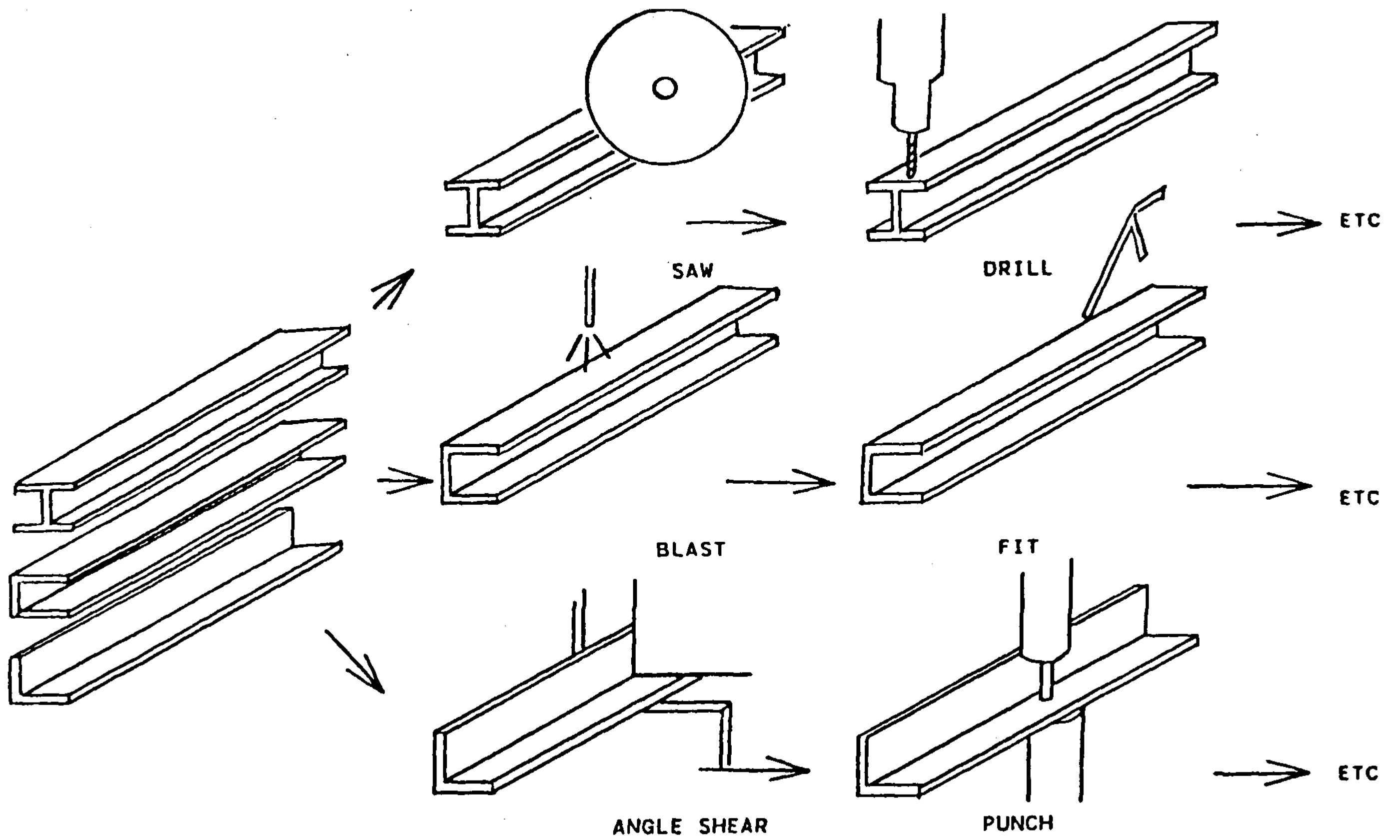


Figure 3.1 Four Approaches of Collecting Shop Data



MATERIAL BILL

Descr.	Qty.	Cut/M
W150X27	1	12
C200X21	1	3
L75X75X6	1	5

ROUTE CARD

Contract:
Drawings:

		OPERATIONS:				
Q	Descr.	L.sh	Punch	Saw	...	Fit
1	W150X27			X	X	X
1	C200X21				X	X
1	L75X75X6	X	X			X

Figure 3.2 Material Bill and Route Card

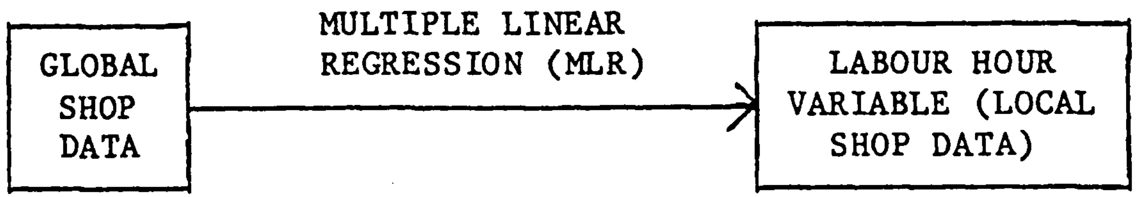


Figure 3.3 Global and Local Shop Data

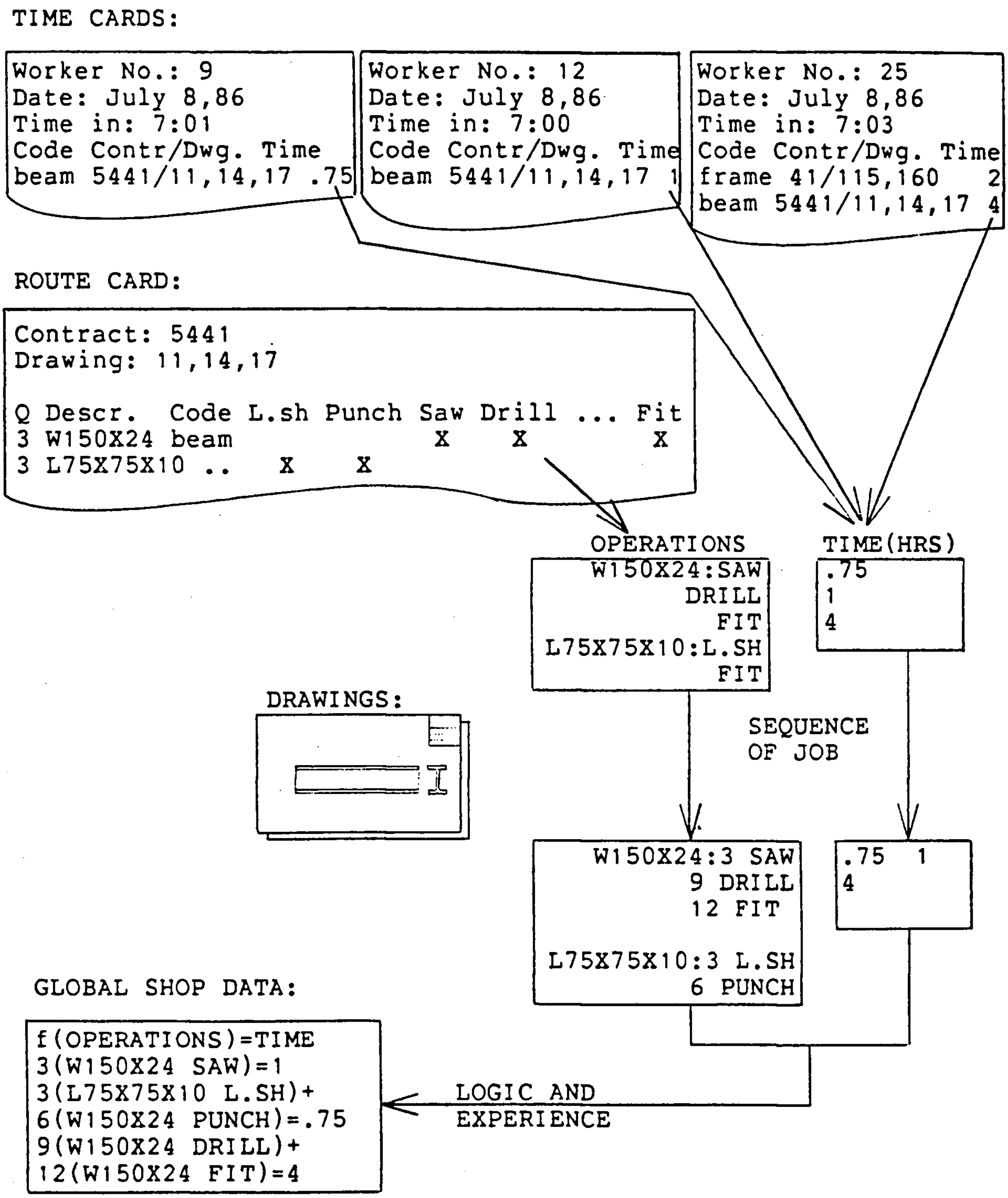


Figure 3.4 An Example of Approach #1

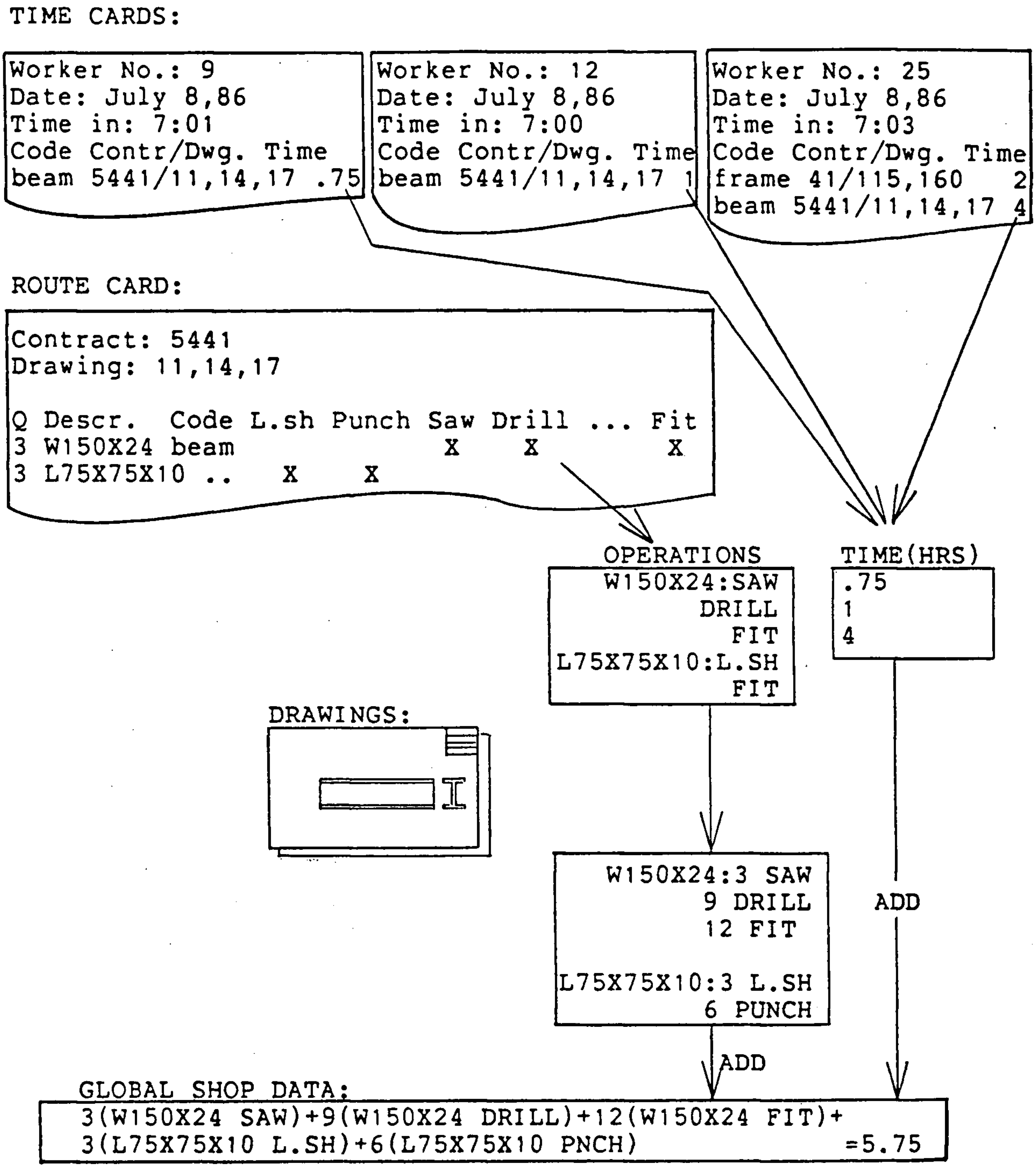


Figure 3.5 An Example of Approach #2

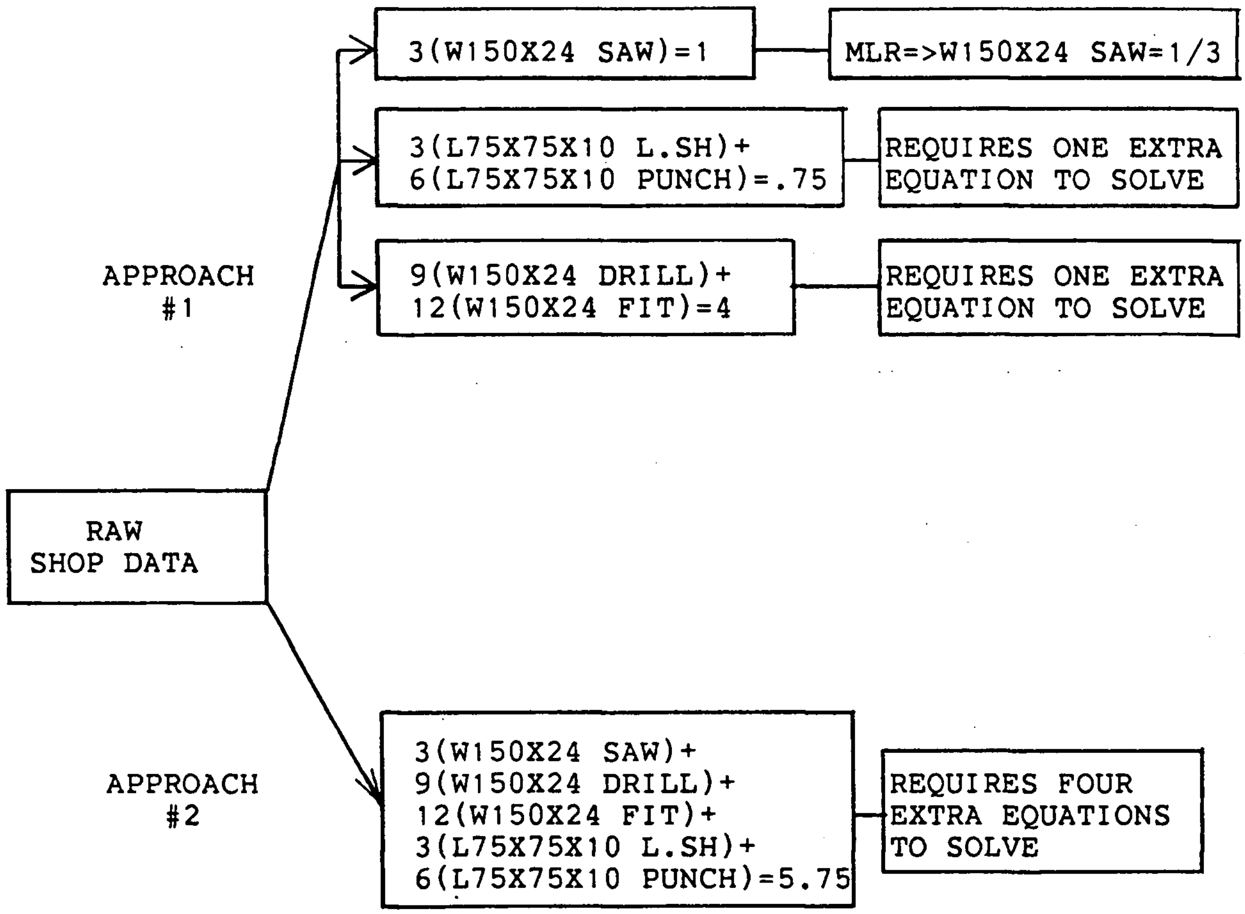
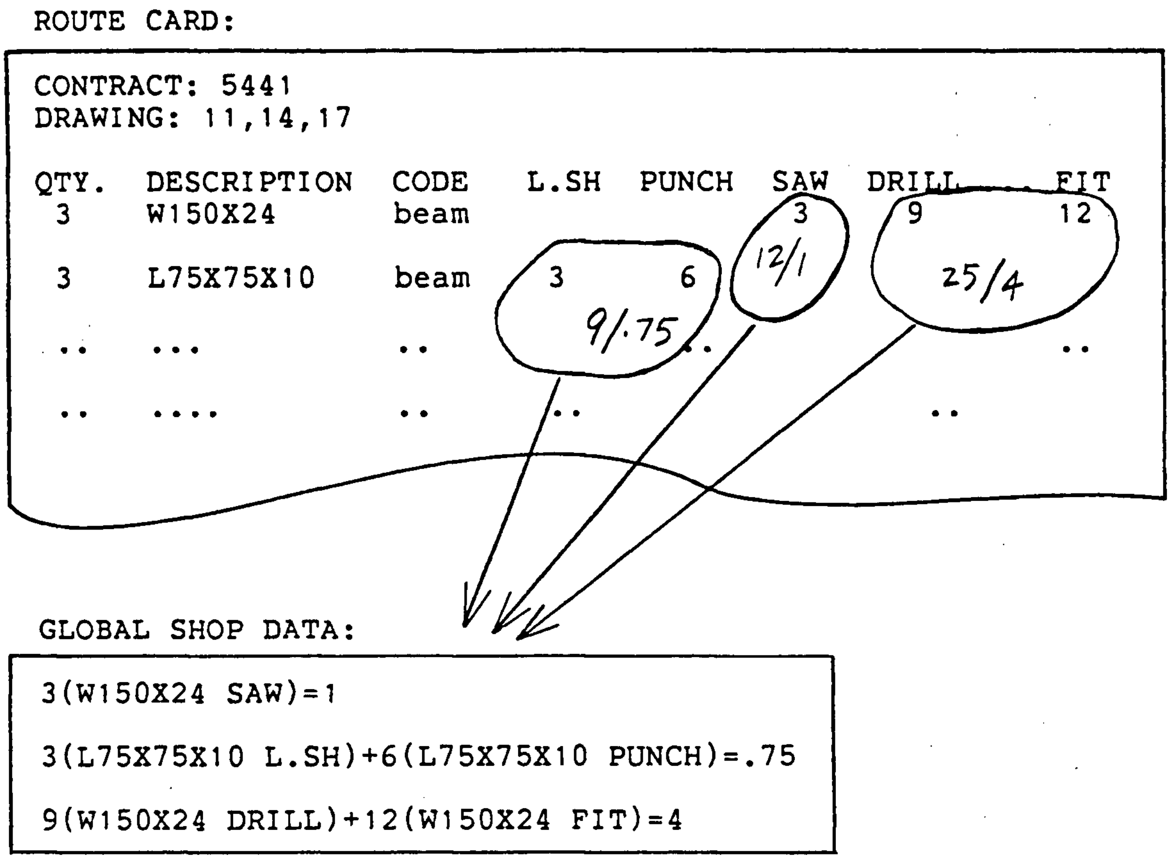


Figure 3.6 A Comparison of Approach #1 and #2



Note: 9/.75 => Worker no./Hours spent

Figure 3.7 An Example of Approach #3

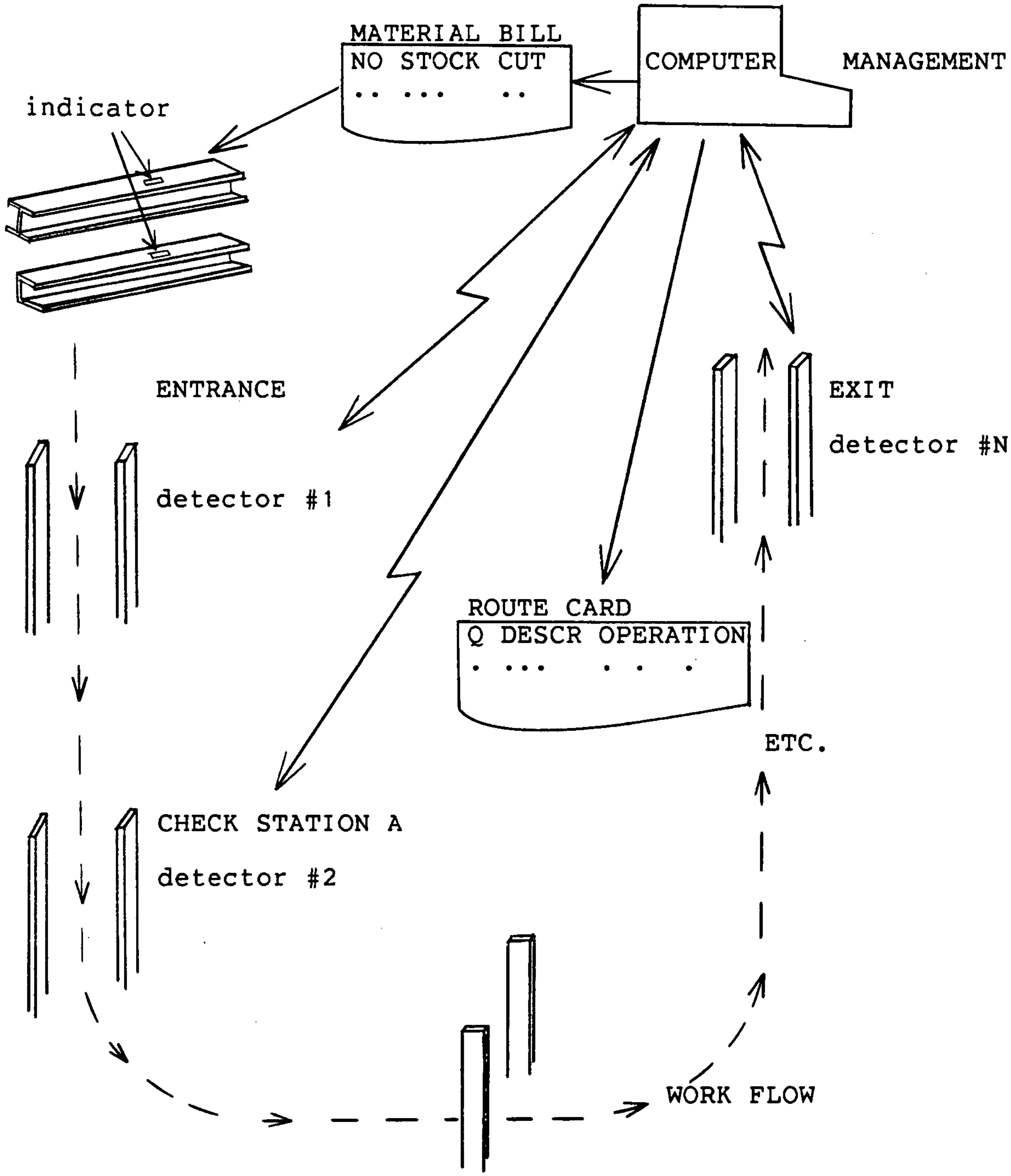


Figure 3.8 A Scheme of Approach #4

Chapter 4

SORTING AND MULTIPLE LINEAR REGRESSION ON LOTUS 123

4.1 INTRODUCTION

The previously described computer cost estimating program in chapter two was written in Basic language. This limited the availability, ease of use, compatibility and flexibility of the program. In order to improve on these points, an analytical program has been developed using the current most popular high level programming language, Lotus 1-2-3 and its macro feature [6]. This macro program consists of the conversion, sorting, analyzing and plotting routines. The conversion routine converts global shop data into files consisting of the same number of component pieces up to a maximum of two pieces. The sorting routine sorts the global shop data into files containing the same component. Subsequently the global shop data of the same component are analyzed and reduced to local shop data i.e. labour hour variables through Multiple Linear Regression (MLR). Finally the labour hour variables are analyzed and their standard errors are graphed by the plotting routine. The graph will indicate to the users the accuracy of the labour hour variables derived. The macro program is menu-driven and resembles the Lotus 1-2-3 menu. The opening menu will start automatically but can also be accessed from the regular Lotus 1-2-3 spreadsheet.

4.2 LOTUS 1-2-3 ENVIRONMENT

The reasons for switching the programming environment from Basic to Lotus 1-2-3 macro language are availability, ease of use, compatibility and flexibility. "Lotus 1-2-3" is currently the most popular business software package on the market. The macro program developed is composed of short program routines which can be easily copied and assembled for other purposes. Since each macro program routine is independent, the user can just implement the ones which fits his needs.

The compatibility of certain software on different computer hardware is always a problem. Even the most popular Basic language has compatibility problem on different computer hardwares. For instance, some adjustments must be made to adapt the cost estimating program to the IBM personal computer as previously described software is designed for the Mai-Four Basic system. Moreover, programs written in IBM PC's Basic language may not run even on other IBM compatible computers. Lotus 1-2-3 is a more common environment than Basic. Almost all business micro-computers are able to run Lotus 1-2-3. The macro program will reside inside Lotus 1-2-3, and the compatibility of the macro program is definitely not a problem. Thus more users can take advantage of the results of this research project.

The flexibility associated with macro programming will allow users to customize the macro program to best fit their needs. The effect of each command will be displaced on the screen such that the user can always follow and debug the macro programs. Input and output are taken care of by Lotus 1-2-3. The users can expand and improve the existing program and can create accounting, forecasting and scheduling program routines which share the same global shop data.

4.3 LOTUS 1-2-3 MACRO PROGRAM

The macro program is designed for Lotus 1-2-3 release 2 and runs on the IBM PC with 512 K memory and DOS 2.1. The program developed is composed of four main parts; namely the conversion, sorting, analyzing and plotting routines. Each routine is a worksheet itself which contains its own menus and macro commands. These worksheets are inter-connected by the opening menu as shown in figure 4.1 [7]. There are two ways to select an item from the menu. The first way is to point to a menu item by moving the arrow key on the numerical pad to highlight the item and then pressing the "return" key. The second way is to type the first letter of the menu item [8]. The program is menu-driven such that the user can perform all the operations just by pointing or typing the menu items, for example, when the "plot" item is selected, the plot worksheet will be automatically retrieved and the subsequent menu will prompt the users for next selection. The inter-connection is obtained by using the auto-execute macro "\0" which will be automatically invoked once the worksheet is loaded. Hence, the macro program will appear as a complete program eventhough it is composed of four worksheets. On the other hand, the macro program can be used as an advanced feature to the regular Lotus menus and functions. Since the opening menu can also be accessed from the spreadsheet by holding the "ALT" key while pressing the "M" key, the user is free to use the feature of the macro program even when he is working on something other than the MLR analysis. Moreover, the user can combine other menus with the opening menu to increase productivity.

Worksheet design and data format are very important to the macro program. A good worksheet design enhances the readability and organization of the program. With Lotus 1-2-3 release 2, there is more freedom in designing the worksheet without regard to space because only the individual loaded cells are saved in random access memory. In the macro program routines, the input data always starts at the upper left hand side of the worksheet i.e. the home position and the output data are placed either at cell A1000 or cell A2000. The menus and macro commands are programmed at cell BA1 and the help messages are written at cell CA1. Since the format of the input data file will affect the workability of the program, the data should be examined more closely. In figure 4.2, the global shop data file shown is a typical input data file. Note that the global shop data are arbitrarily derived and do not necessary reflect the shop performance of Coast Steel Fabricators Limited. These data are used only to illustrate the fuctions and procedures of the macro program. The field names of the global shop data are described as follows. Column A refers to the contract number and the drawing number. Column B refers to the individual worker. Column C indicates the number of different pieces used to create one structural member. This number is either one or two since the member piece is temporarily restricted to two at most. There are two reasons for this restriction. Firstly, Lotus 1-2-3 will only allow file names to be eight characters long. Thus it will be very difficult to keep track of the different component files of more than two members. For instance, the PL10PL16W200X22 and PL10PL16W610X113 will have the same file name eventhough the third piece is different. A method to correct this limitation is to develop a system of numerical names to represent all the combination of different members, for example, number 12345678 will represent PL10PL16W200X22 and number 23456789 will represent PL10PL16W610X113. Since there are 100,000,000 numbers available, a full range of different members can be represented. Next, Lotus 1-2-3 will only allow thirty-two fields in the /DATA QUERY function. An addition of the third member will increase the total number of fields above the thirty-two limit as there are thirteen operations for each member. A way to overcome this limitation is not to use the /DATA QUERY function but use the /DATA SORT function instead. However, such a switch will drastically retard the power and speed of the conversion routine because it takes several SORT functions to emulate one QUERY function. Such a trade-off is not justified at present because Lotus 1-2-3 may well remove such a limitation in the future. Column D means the total number of members used, e.g. if there are 2 PL8 and 3 W150X24, PIECE=2 and QTY=2+3=5. Column E means the description of the member e.g. PL8. In case of a double piece such as PL8 and PL10, the description will be PL8PL10. No space is allowed between the two names PL8 and PL10 because this description will be used later as a worksheet file name and Lotus will not permit any space in a file name. Also, since Lotus will only take the first eight characters as a file name, attention must be paid to ensure each description has the first eight characters distinct. For example, PL8W610X113 and PL8W610X217 will have the same file name as they both have PL8W610X in their first eight characters. The user can change the later description as P8W610X217 or PL8W610217 to distinish it from PL8W610X113. Columns F to AE are the operations performed for the member(s). The first thirteen operations refer to the first member in case of a double piece and these operations will be the only operations for a single piece. Similarly, the next thirteen operations will refer to the second member of the double piece. The thirteen operations are the template, layout, angle shear, plate shear, punch, burn, saw, drill, line punch, bend, fit, weld and clip respectively. Finally, column AF is the total hours spent on all those operations together. The position of the fields are important but their size will not affect the workability of the macro program. In other words, the user can change the size of all the columns but should not change their order.

To copy the macro program, the user should run the Lotus 1-2-3 release 2 system disk and start typing the menus ,macro commands and help messages on the appropriate locations as indicated in the individual routines. For the novice user of Lotus 1-2-3, any book on the market such as the Lotus 1-2-3 manual [8] and the Using Lotus 1-2-3 [9] should give enough guidance to the user. The menus and macro commands are located at cell BA1 and the help messages at cell CA1. Note that an apostrophe must be typed before the the slash, backslash, formula and numerical labels. Once these menus and macros are copied, the user should move the cursor to cell BA1. The column BA contains the range names of the menus and macros and must be activated by using /RANGE NAME LABEL RIGHT [7]. The user will then be prompted for the range and he can move the pointer to cover all the range names on column BA. These menus and macros can be tested by pressing "ALT" "M" to see if the range names are activated. Since the macro program has assumed the four individual worksheets to be MASTER, SORT, ANALYZE and PLOT. The corresponding menus and macros must be saved under these four file names, i.e. the converting, sorting, analyzing and plotting routines should be saved under the file names of master, sort, analyze and plot respectively. The user should also copy the global data file to test the macro program.

4.3.1 CONVERSION ROUTINE

The conversion routine which can be accessed through the opening menu will convert the master global data file into piece files (figure 4.3). The maximum number of different components of each record is temporarily limited to two. To start the conversion routine, the user should load the "MASTER" worksheet into Lotus spreadsheet by the /FILE RETRIEVE function. Remember that the conversion routine is saved as the MASTER file as described in the previous section. Once the file is retrieved, the opening menu will automatically appear and prompt the user for a menu item. When the conversion item is chosen, the next menu will ask the user to name an input data file such as the global data file to be converted. Then the next menu will prompt the user for the choice of output files. Either a single or double file is allowed. If the single item is selected, the macro program will convert the single piece records of the input data file into an output file called "SINGLE". Likewise, the "DOUBLE" output file will be converted by grouping the double piece records in the input data file. Figures 4.4 and 4.5 show the results of the conversion routine on the global shop data file.

The conversion routine uses the /DATA QUERY function to manipulate the data. The input data are assumed to be at the upper left corner of the spreadsheet. The output of the single piece records will be placed at cell A1000 while those of the double piece records will be put at cell A2000. In figure 4.6, the conversion routine starts with an auto-execute macro at cell BA1. Note that the range name for it is "\0" which is "backslash zero". The auto-execute macro will be executed once the "MASTER" worksheet is loaded and invokes the menu MENU0 which is located at cell BA5. Cell BA3 shows another macro "\M" which can be accessed by typing "ALT" "M". This macro will again invoke the menu MENU0. There are six menu items in MENU0. They are the convert, sort, analyze, plot, Lotus 123 and help. The row at BB6 will further describe the functions of the menu items as shown in figure 4.1. The next row i.e. BB7 to BG7 is the commands being executed when the item is chosen. If the convert item is selected, the command /xmMENU1~ will invoke the next menu MENU1. Similarly, when the sort, analyze or plot is chosen, the individual worksheet will be retrieved by the /fr command. The Lotus 123 item will exit the macro program to the regular spreadsheet. Finally, the help item will move the screen to cell CA1 to give user more information about the program as shown in figure 4.7. Note that the messages should be typed as long labels occupying the column CA only. MENU1 is another menu which will ask the user to input a data file such as the global shop data file. The command /fcce{?}~ will combine the input data file at the "home" position of the worksheet and the next command /xmCONVERT~ will invoke the next menu CONVERT located below. There are three items in the CONVERT menu. The cells below the single and double items are "Convert to single piece data file" and "Convert to double piece data file" respectively. The commands /xgSINGLE~ and /xgDOUBLE~ will invoke the macros SINGLE located at cell BA20 and DOUBLE located at cell BA33 respectively.

The macro SINGLE will set the ouput fields at cell A1000 by copying the input data fields. Next, the criterion range is set at cells AT1 and AT2. The criterion field is PIECE and the criterion is one. Only the columns A to S are used as the input range because the single piece records are shorter than the double piece records. When all the input, output and criterion ranges are set, the data will be extracted. Finally, the last field of the output will be replaced by the "HOURS" and the output file is saved under the name of "SINGLE". The macro will return the opening menu when the commands are fully executed. Similarly, the macro DOUBLE will convert the input data file into double piece data file in the same fashion. Note that the column BB contains the macro commands while the column BE holds the comments of those commands.

4.3.2 <u>SORTING ROUTINE</u>

The sorting routine sorts the piece file into files containing components of the same description. For instance, the sorting program will sort the single piece file into files containing one component only such as PL8, W150X24, etc as shown in figure 4.8. If there are more than one component such as the double piece files, the description of these data files will be a combination of the components with the component names in ascending order, e.g. PL8W150X24 as a description.

The purpose of the conversion and sorting routines is to reduce the master data file into smaller files that contain the same unknowns. It is very inefficient to solve 1000 equations with 1000 unknowns if the same problem can be converted and sorted into 100 sets of 10 equations with 10 unknowns. It is easier to solve a 10X10 matrix and the result is more accurate. Since there is no relationship between any two individual single piece members, say PL8 and W150X24, the equations are independent. In other words, the system of equations can be decoupled. Note that double piece data are treated as individual structural members and hence are also independent. For example, PL8W150X24 by itself should give the labour hour variables for both PL8 and W150X24 if enough data are collected. It seems that work has been repeated in determining the labour hour variables. The reason for that is sometimes a particular member, such as a small angle, is attached to other members to form a double piece member. The labour hour variables for this member can only be determined through the double piece data. Meanwhile, for some other members, such as the large channels and I-shapes, the single piece data will be easier to obtain. A logical way to convert the master data file is to group the data according to the number of different members it contained. The converted data files will then be further sorted by the descriptions of the members. Hence, there are eventually many small data files which contain only a few unknowns. Such a reduced data file will become the input files for MLR analysis.

Figure 4.9 shows a listing of the sorting routine. A close look at this listing indicates that there are many similarities between the conversion and sorting routines. However, the help messages are quite different as seen in figure 4.10. The sorting macro located at cell BA15 also use /DATA QUERY function for data manipulation, but a few tricks have been added. First, the output files are no longer limited to single and double only and the description of the member(s) must be used to name the output files. This has been achieved by copying the description at cell E2 to the range name DESCRIP at BA28. Next, the program must keep track of the descriptions used. Since data are usally mixed in the input file, the efficiency of the sorting routine will be greatly reduced if the used records are sorted over and over again. Such a redundancy is avoided by deleting the the used records as shown in cell BB30 i.e. the /dqddq~ command. Finally, the program will check if all the records have been used by the command /xi(C2=0)~/xmMENU20~ at cell BB15.

4.3.3 MLR ROUTINE

With each component file, one can perform the MLR analysis to obtain the labour hour variables. The theory and algorithm of the MLR analysis will be discussed in the next chapter. Figures 4.11 and 4.12 show the listing and the help messages of the MLR routine. Remember that this routine should be saved under the file name "ANALYZE" as required by the macro program. The MLR routine can be divided into two parts. The first part which starts from cell BB15 to BB40 is concerned with the deletion of the empty "operation" columns. The first thirty entries of each operation will be summed. If the sum is zero, the column is said to be empty and is deleted. Note that the deletion is done from the last operation i.e. column AE to the first one i.e. column F because the other way round will result in some empty columns not being summed and hence not being deleted. The second part of the MLR routine is of course concerned with the regression itself. The regression is done by using the /DATA REGRESSION function. Since this function only allows sixteen independent variables, the maximum operation columns must be less than or equal to sixteen after the empty columns are deleted. This requirement will usually be fulfilled as each member will have a only few operations. No member will have all thirteen operations because some operations are in conflict; for example, a member can either be punched or drilled but not both. In cell BB45, the intercept is forced to be zero by the command /iz. The intercept or the set-up time as in the case of this study is assumed to be zero because the program would like to distribute the set-up time into the labour hour variables rather than having an explicit set-up time. The reason is that the explicit set-up time will be true for certain combinations of operations say saw, drill and fit, but will not be applicable for other combinations of operations such as saw, drill and weld. Such a problem can be avoided if the set-up time is distributed into the labour hour variables.

4.3.4 PLOTTING ROUTINE

The plotting routine calculates the relative standard error for each labour hour variable in terms of percentage. The routine will then display the relative standard errors in a bar chart and the absolute standard error on top of the labour hour variables in a stacked bar chart. These graphs should help management to pin-point places where attention is needed. Figures 4.13 and 4.14 show the listing and help messages of the plotting routine. The commands at cells BB12 to BB20 will calculate the relative standard error by dividing the absolute standard error by the coefficient i.e. the labour hour variable. The macro REL at cell BA26 will plot a bar chart showing the relative standard error as shown in figures 4.15 to 4.17. The standard error indicates the degree of precision in quantitative terms [10]. Similarly, the macro ABS at cell BA38 will plot a stacked bar chart showing the absolute standard errors on top of the labour hour variables.

Figures 4.15 to 4.17 are the results of the plotting routine on the component files C200X15, PL8 and W150X24. The upper right hand panel shows the component file data after the empty columns are deleted. The panel right below it gives the results of the MLR analysis. The individual items of the MLR output are described as follows. The "Constant" term at cell A1001 refers to the set-up time as mentioned before. The next item below it refers to the standard error of the dependent variable i.e. the total hours. The "R squared" term at cell A1003 refers to the coefficient of determination. The "No. of Observations" term means the the number of records being used. In general, the larger the number of observations, the better the result. Since it is not practical to have an infinite number of observations, a monthly average should be adequate. Assuming ten records per day and twenty days a month, 200 observations should give meaningful labour hour variables. The next item refers to the degree of freedom of the system of equations. The X coefficients at cell A1007 are the labour hour variables which are the objective of the macro program. Their standard errors are listed right below them. The units of the standard error and the labour hour variables are hours. Since the labour hour variables are of different magnitudes, their standard errors are quite difficult to compare. To overcome this, the relative standard errors are computed in terms of percentage alone to give a better picture of the precision of the variables. The bar and stacked bar charts of figures 4.15 to 4.17 should the help management to evaluate shop performance. Figure 4.18 and 4.19 give the results of the component files PL8PL10 and PL10W610X113. Since there are less observations than unknowns, no solution can be found. Note that the number of observations must be greater than the number of unknowns in order to have a solution.

```
A1:
Convert   Sort   Analyze   Plot   Lotus123   Help
Convert master global data file into piece files
   A     B     C     D     E     F     G
```

```
A1:
Convert   Sort   Analyze   Plot   Lotus123   Help
Sort piece data file into component data files
   A     B     C     D     E     F     G
```

```
A1:
Convert   Sort   Analyze   Plot   Lotus123   Help
Analyze user specified component data file
   A     B     C     D     E     F     G
```

```
A1:
Convert   Sort   Analyze   Plot   Lotus123   Help
Plot the residual error
   A     B     C     D     E     F     G
```

```
A1:
Convert   Sort   Analyze   Plot   Lotus123   Help
Exit to Lotus 123
   A     B     C     D     E     F     G
```

```
A1:
Convert   Sort   Analyze   Plot   Lotus123   Help
Help menu
   A     B     C     D     E     F     G
```

Figure 4.1 The Opening Menu

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
1	CONTR-DWG	MAN	PIEC	QTY	DESCRIPTION	1TEM	1LAY	1LSH	1PSH	1PUN	1BUR	1SAW	1DRI	1LIN	1BEN	1FIT	1WEL	1CLI	2TEM	2LAY	2LSH	2PSH	2PUN	2BUR	2SAW	2DRI	2LIN	2BEN	2FIT	2WEL	2CLI	HOURS
2	5432-50	7	1	2	W150X24	0	0	0	0	0	0	4	32	0	0	0	0	0	1.5													
3	5432-58	21	1	4	PL8	0	32	0	0	24	0	0	0	0	0	0	0	0	2.25													
4	5432-58	14	1	4	PL8	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5													
5	5432-46	7	1	4	W150X24	0	0	0	0	0	0	0	8	0	0	44	0	0	8													
6	5432-17	29	1	4	PL8	0	0	0	0	24	0	0	0	0	0	0	0	0	1.25													
7	5432-17	29	1	4	PL8	0	0	0	0	0	0	0	0	0	0	16	0	0	1.75													
8	5445-2	9	1	4	C200X15	0	0	0	0	0	8	0	0	0	0	0	0	0	1													
9	5445-2	21	1	4	C200X15	0	0	0	0	0	6	0	16	0	0	0	0	0	3													
10	5432-9	7	1	6	W150X24	0	0	0	0	0	12	0	68	0	0	24	0	0	12													
11	5432-40	14	1	7	W150X24	0	0	0	0	0	0	0	212	0	0	72	0	0	12													
12	5432-36	29	1	3	W150X24	0	0	0	0	0	6	0	0	0	0	0	0	0	8													
13	5432-60	22	2	14	PL8PL10	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	3.5
14	5432-5	7	1	5	W150X24	0	0	0	0	0	0	0	0	0	0	92	0	0	8													
15	5432-51	29	1	4	PL8	0	0	0	0	12	0	0	0	0	0	0	0	0	1.5													
16	5442-23	12	2	16	PL10W610X113	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	12
17	5442-4	14	2	3	PL10W610X113	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3
18	5432-9	22	2	92	PL8PL10	0	0	0	56	0	0	0	0	0	0	0	0	56	0	0	0	56	0	0	0	0	0	0	0	0	64	7
19	5436-601	2	2	20	PL8PL10	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	40	32	0	0	0	0	0	0	0	0	3.5
20	5442-34	14	2	6	PL10W610X113	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	7.25
21	5436-513	9	1	7	C200X15	0	0	0	0	0	6	0	16	0	0	16	0	0	4.25													
22	5432-51	29	1	4	PL8	0	0	0	0	0	0	0	0	0	0	16	0	0	1.75													
23	5432-56	22	1	56	PL8	0	0	0	112	0	0	0	0	0	0	0	0	0	5													
24	5442-6	21	2	5	PL8PL10	0	0	0	6	8	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	2.75
25	5436-513'	29	1	6	C200X15	0	0	0	0	0	6	0	16	0	0	32	0	0	6													
26	5432-31	29	1	4	PL8	0	0	0	24	0	0	0	0	0	0	0	0	0	1.5													
27	5432-31	29	1	4	PL8	0	0	0	0	0	0	0	0	0	0	16	0	0	1.5													
28	5442-37	21	1	4	C200X15	0	0	0	0	0	4	0	4	0	0	0	0	0	3													
29	5442-33	23	1	8	C200X15	0	0	0	0	0	8	0	52	0	0	0	0	0	6													
30	5442-63	25	2	3	PL8PL10	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1

Figure 4.2 The Global Data File

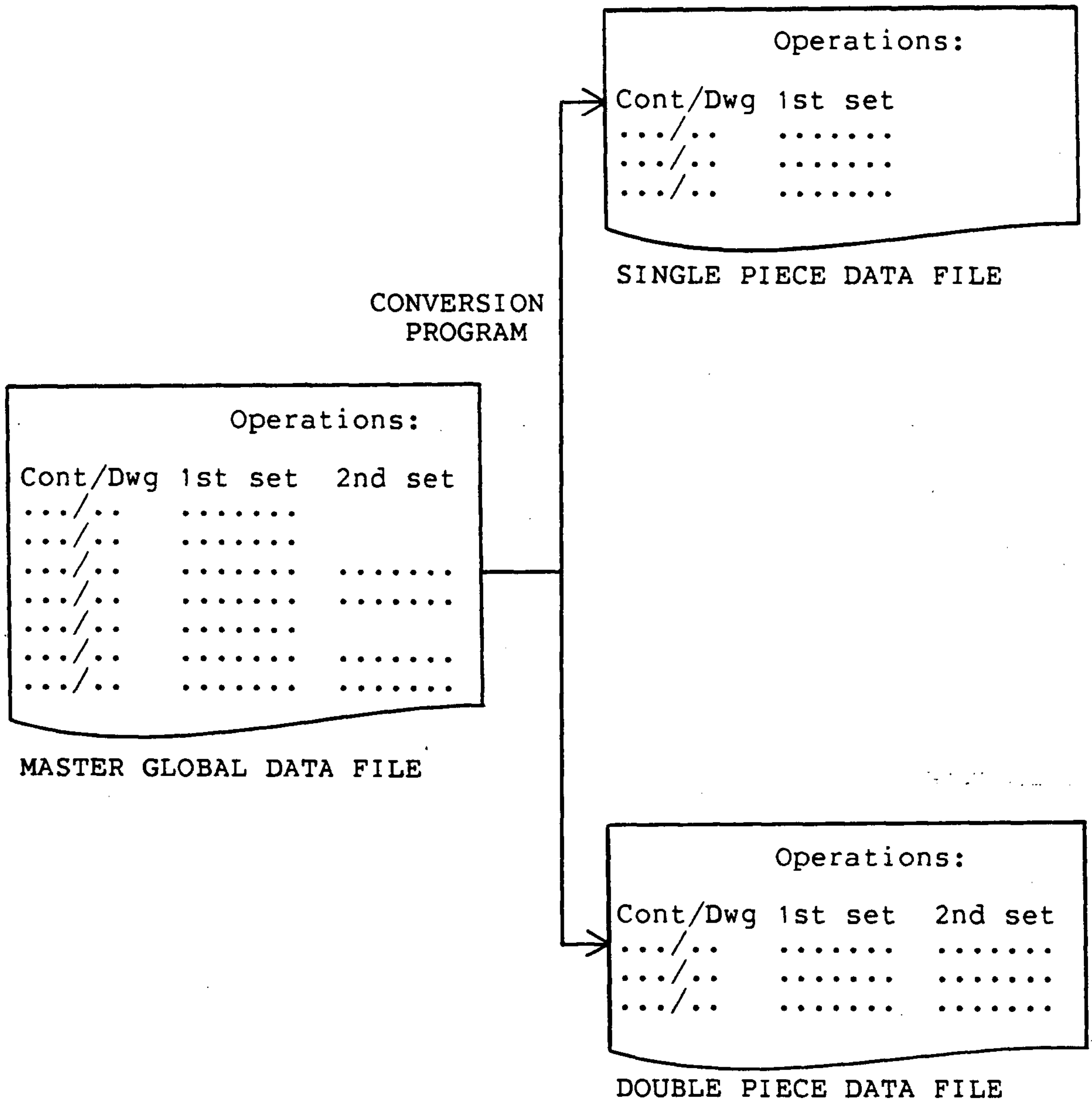


Figure 4.3 The Function of the Conversion Routine

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	CONTR-DWG	MAN	PIEC	QTY	DESCRIPTION	1TEM	1LAY	1LSH	1PSH	1PUN	1BUR	1SAW	1DRI	1LIN	1BEN	1FIT	1WEL	1CLI	HOURS
2	5432-50	7	1	2	W150X24	0	0	0	0	0	0	4	32	0	0	0	0	0	1.5
3	5432-58	21	1	4	PL8	0	32	0	0	24	0	0	0	0	0	0	0	0	2.25
4	5432-58	14	1	4	PL8	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5
5	5432-46	7	1	4	W150X24	0	0	0	0	0	0	0	8	0	0	44	0	0	8
6	5432-17	29	1	4	PL8	0	0	0	0	24	0	0	0	0	0	0	0	0	1.25
7	5432-17	29	1	4	PL8	0	0	0	0	0	0	0	0	0	0	16	0	0	1.75
8	5445-2	9	1	4	C200X15	0	0	0	0	0	8	0	0	0	0	0	0	0	1
9	5445-2	21	1	4	C200X15	0	0	0	0	0	6	0	16	0	0	0	0	0	3
10	5432-9	7	1	6	W150X24	0	0	0	0	0	12	0	68	0	0	24	0	0	12
11	5432-40	14	1	7	W150X24	0	0	0	0	0	0	0	212	0	0	72	0	0	12
12	5432-36	29	1	3	W150X24	0	0	0	0	0	6	0	0	0	0	0	0	0	8
13	5432-5	7	1	5	W150X24	0	0	0	0	0	0	0	0	0	0	92	0	0	8
14	5432-51	29	1	4	PL8	0	0	0	0	12	0	0	0	0	0	0	0	0	1.5
15	5436-513	9	1	7	C200X15	0	0	0	0	0	6	0	16	0	0	16	0	0	4.25
16	5432-51	29	1	4	PL8	0	0	0	0	0	0	0	0	0	0	16	0	0	1.75
17	5432-56	22	1	56	PL8	0	0	0	112	0	0	0	0	0	0	0	0	0	5
18	5436-513'	29	1	6	C200X15	0	0	0	0	0	6	0	16	0	0	32	0	0	6
19	5432-31	29	1	4	PL8	0	0	0	24	0	0	0	0	0	0	0	0	0	1.5
20	5432-31	29	1	4	PL8	0	0	0	0	0	0	0	0	0	0	16	0	0	1.5
21	5442-37	21	1	4	C200X15	0	0	0	0	0	4	0	4	0	0	0	0	0	3
22	5442-33	23	1	8	C200X15	0	0	0	0	0	8	0	52	0	0	0	0	0	6

Figure 4.4 An Example of the Single Piece Data File

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
1	CONTR-DWG	MAN	PIEC	QTY	DESCRIPTION	1TEM	1LAY	1LSH	1PSH	1PUN	1BUR	1SAW	1DRI	1LIN	1BEN	1FIT	1WEL	1CLI	2TEM	2LAY	2LSH	2PSH	2PUN	2BUR	2SAW	2DRI	2LIN	2BEN	2FIT	2WEL	2CLI	HOURS
2	5432-60	22	2	14	PL8PL10	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	3.5
3	5442-23	12	2	16	PL10W610X113	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	12
4	5442-4	14	2	3	PL10W610X113	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3
5	5432-9	22	2	92	PL8PL10	0	0	0	56	0	0	0	0	0	0	0	0	56	0	0	0	56	0	0	0	0	0	0	0	0	64	7
6	5436-601	2	2	20	PL8PL10	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	40	32	0	0	0	0	0	0	0	0	3.5
7	5442-34	14	2	6	PL10W610X113	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	7.25
8	5442-6	21	2	5	PL8PL10	0	0	0	6	8	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	2.75
9	5442-63	25	2	3	PL8PL10	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1

Note: These shop data are arbitrarily derived and do not necessary reflect the shop performance of Coast Steel Fabricators Ltd.

Figure 4.5 An Example of the Double Piece Data File

```
        BA      BB        BC        BD        BE        BF        BG
 1      \0      /xmMENU0~
 2
 3      \M      /xmMENU0~
 4
 5      MENU0   Convert   Sort      Analyze   Plot      Lotus123  Help
 6              Convert masSort piece Analyze comPlot residuExit to LotHelp menu
 7              /xmMENU1~ /frSORT~  /frANALYZE~/frSORT~ /xq     {goto}CA1~
 8                                                                /xmMENU0~
 9      MENU1   Data file?
10              Hit return to continue
11              {home}
12              /fcce{?}~
13              /xmCONVERT~
14
15      CONVERT Single    Double    Help
16              Convert to Convert to Help menu
17              /xgSINGLE~ /xgDOUBLE~ {goto}CA34~
18                                  /xmCONVERT~
19
20      SINGLE  /cA1..S1~A1000~               set: output field at A1000
21              /cC1..C1~AT1~                      criteria range at AT1..AT2
22              {goto}AT2~1~                  copy 1 to AT2
23              {goto}S1~{end}{down}~         anchor at the lower right corner
24              /dqri..{home}~                data querry: input range
25              cAT1..AT2~                                criteria range
26              oA1000..S1900~eq                          output range
27              {goto}S1000~                  go to 2TEMP
28              HOURS~                        replace 2TEMP with HOURS
29              /fxvSINGLE~                   file extract: SINGLE
30              A1000..S1900~r{esc}                         extract range
31              /xmMENU0~                     back to MENU0~
32
33      DOUBLE  /cA1..AF1~A2000~              set: output field at A2000
34              /cC1..C1~AT1~                      criteria range at AT1..AT2
35              {goto}AT2~2~                  copy 2 to AT2
36              /dqri{home}{end}{down}..      data querry: input range
37              {home}{end}{right}~
38              cAT1..AT2~                                criteria range
39              oA2000..AT2900~eq                         output range
40              /fxvDOUBLE~                   file extract: DOUBLE
41              A2000..AT2900~r{esc}                        extract range
42              /xmMENU0~                     back to MENU0~
```

Figure 4.6 The Menus and Macros of the Conversion Routine

```
CA
HELP 0 :

OPENING MENU -- Can be accessed from Lotus spreadsheet by holding "ALT"
                key while pressing "M"

EXIT MENU ----- By choosing "Lotus 123" option or hitting "ESC"

TO START ------ You should have prepared a data file which have the
                same format as the GLOBAL data file resided in this disk.

GLOBAL DATA --- The global data file contains fields:
                CONTR-DWG = Contract-Drawings
                MAN = Labour number
                PIECE = No. of different members
                QTY = Total number of members
                DESCRIPTION = Description of the member(s)
                1OPERATION = Refers to the first member
                2OPERATION = Refers to the second members
                OPERATION = Labour operation performed on the member
                TEM = Template
                LAY = Layout
                LSH = Angle Shear
                PSH = Plate shear
                PUN = Punch
                BUR = Burn cut
                SAW = Saw
                DRI = Drill
                LIN = Line punch
                BEN = Bend
                FIT = Fitting
                WEL = Welding
                CLI = Clipping
                HOURS = Time to perform the operation
HELP 1:

CONVERT ------- Converting the GLOBAL data file into SINGLE and
                DOUBLE data files

DATA FILE ----- Enter the name of the data file to be converted

SINGLE -------- Single file is a file generated from the global data
                file which contains data with ONE type of member only

DOUBLE -------- Double file is a file generated from the global data
                file which contains data with TWO types of members only


                    I---- SINGLE ------ SORT ------ ANALYZE ------ PLOT
                    I
PATH:   MASTER ----I
                    I
                    I---- DOUBLE ------ SORT ------ ANALYZE ------ PLOT
```

Figure 4.7 The Help Messages of the Conversion Routine

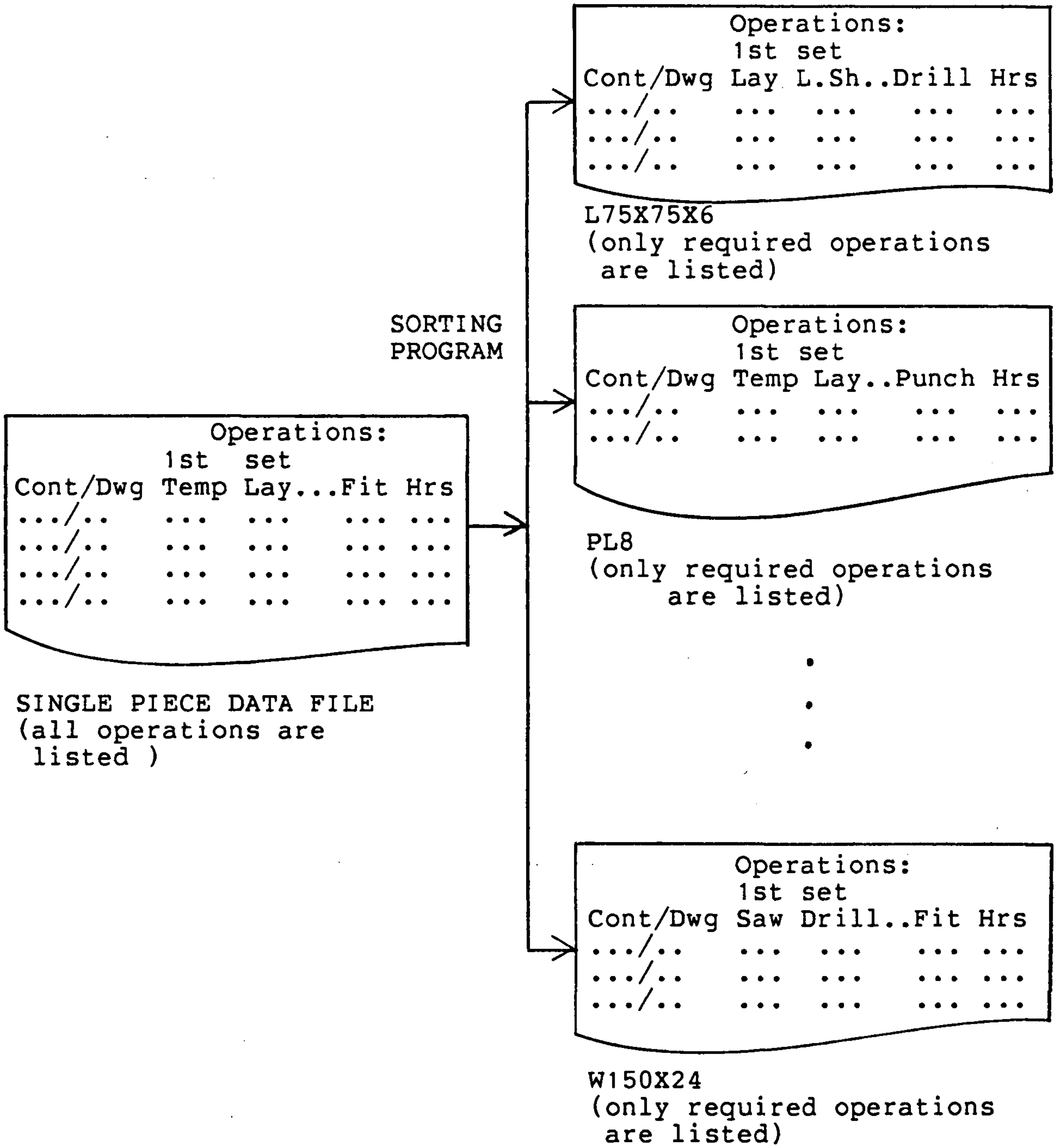


Figure 4.8 The Function of the Sorting Routine

```
        BA        BB         BC         BD         BE         BF         BG
  1     \0        /xmMENU21~
  2
  3     \M        /xmMENU20~
  4
  5     MENU20    Convert    Sort       Analyze    Plot       Lotus123   Help
  6               Convert masSort piece Analyze comPlot residuExit to LotHelp menu
  7               /frMASTER~ /xmMENU21~ /frANALYZE~/frPLOT~   /xq        {goto}CA1~
  8                                                                      /xmMENU20~
  9     MENU21    Data file?
 10               Hit return to continue
 11               {home}
 12               /fcce{?}~
 13               /xgSORT~
 14
 15     SORT      /xi(C2=0)~/xmMENU20~             if C2 = 0, end loop and MENU20
 16               {HOME}/cA1..AF1~A1000~           copy output fields at A1000
 17               {GOTO}E1~                        go to description
 18               /c..{END}{DOWN}~AT1~             copy description to column E
 19               {goto}E2~                        go to description
 20               /cE2~DESCRIP~                    copy description into DESCRIP
 21               /dqi{HOME}                       data querry: input range
 22               ..{END}{RIGHT}{END}{DOWN}~
 23               cAT1..AT2~                                  criteria range
 24               oA1000..AF2000~                             output range
 25               eq                                          extract; quit
 26               {GOTO}A1000~                     go to output range
 27               /fxv                             file extract by DESCRIPtion
 28     DESCRIP
 29               ~A1000..AF2000~r{esc}            extract range
 30               /dqddq~                          delete the extracted records
 31               /xgSORT~                         start the loop again
```

Figure 4.9 The Menus and Macros of the Sorting Routine

```
CA
HELP 20:

SORT --------- Sort the SINGLE or DOUBLE data file into component
               files containing the same type of member(s) only

PURPOSE ------ The purpose of the CONVERT and SORT routines is to
               reduce the global shop data into smaller and simpler
               files containing the same type of members.
               It is more efficient to solve a 100 sets of 10x10 matrix
               than to solve a 1000 x1000 matrix.

METHOD ------- The DATA QUERRY function is used to sort the piece file.
               The first description of the data records (i.e. entry E2)
               is used as the CRITERIA to EXTRACT the records out.
               These records will become a data file themselves by the
               FILE XTRACT function. The extracted records will be deleted
               by the DATA QUERRY DELETE function. Thus the next criteria
               will be replaced by a new one and the process repeats
               again untill all the records are extracted.
               The QTY (i.e. entry C2) is used to determine the end
               of the loop.

ERROR -------- One of the possible errors is the component file
               may have already existed from previous run.
               Hence, the user should rename existed component files
               with a different names.

OPENING MENU - can be accessed from Lotus spreadsheet by holding "ALT"
               key while pressing "M"

FIELDS ------- There are a max. of 32 fields in DATA QUERRY
```

Figure 4.10 The Help Messages of the Sorting Routine

```
          BA        BB         BC         BD         BE         BF         BG
 1        \0        /xmMENU31~
 2
 3        \M        /xmMENU30~
 4
 5        MENU30    Convert    Sort       Analyze    Plot       Lotus123   Help
 6                  Convert masSort piece Analyze comPlot residuExit to LotHelp menu
 7                  /frMASTER~ /frSORT~   /xmMENU31~ /frPLOT~   /xq        {goto}CA1~
 8                                                                         /xmMENU30~
 9        MENU31    Data file?
10                  Hit return to continue
11                  {home}
12                  /fcce{?}~
13                  /xgDELETE~
14
15        DELETE    /xi@SUM(AE1..AE30)<=0~/wdcAE1~   delete empty columns:
16                  /xi@SUM(AD1..AD30)<=0~/wdcAD1~
17                  /xi@SUM(AC1..AC30)<=0~/wdcAC1~   use @SUM function to check
18                  /xi@SUM(AB1..AB30)<=0~/wdcAB1~   if the column is empty
19                  /xi@SUM(AA1..AA30)<=0~/wdcAA1~
20                  /xi@SUM(Z1..Z30)<=0~/wdcZ1~      if yes, delete column
21                  /xi@SUM(Y1..Y30)<=0~/wdcY1~      if no, check the next one
22                  /xi@SUM(X1..X30)<=0~/wdcX1~      on the left
23                  /xi@SUM(W1..W30)<=0~/wdcW1~
24                  /xi@SUM(V1..V30)<=0~/wdcV1~      note the deleting starts from
25                  /xi@SUM(U1..U30)<=0~/wdcU1~      the right end and proceed to
26                  /xi@SUM(T1..T30)<=0~/wdcT1~      the left
27                  /xi@SUM(S1..S30)<=0~/wdcS1~
28                  /xi@SUM(R1..R30)<=0~/wdcR1~
29                  /xi@SUM(Q1..Q30)<=0~/wdcQ1~
30                  /xi@SUM(P1..P30)<=0~/wdcP1~
31                  /xi@SUM(O1..O30)<=0~/wdcO1~
32                  /xi@SUM(N1..N30)<=0~/wdcN1~
33                  /xi@SUM(M1..M30)<=0~/wdcM1~
34                  /xi@SUM(L1..L30)<=0~/wdcL1~
35                  /xi@SUM(K1..K30)<=0~/wdcK1~
36                  /xi@SUM(J1..J30)<=0~/wdcJ1~
37                  /xi@SUM(I1..I30)<=0~/wdcI1~
38                  /xi@SUM(H1..H30)<=0~/wdcH1~
39                  /xi@SUM(G1..G30)<=0~/wdcG1~
40                  /xi@SUM(F1..F30)<=0~/wdcF1~
41                  {goto}F2~
42                  /drrx..{end}{right}              go to the first operation
43                  {left}{end}{down}~               DATA REGRESSION RESET X-range
44                  y{end}{right}..{end}{down}~                            Y-range
45                  oA1000~izg                                             Output;go
46                  {goto}A1000~                     go to OUTPUT range
47                  /cE2~DESCRIP~                    copy description into DESCRIP
48                  /fXV                             FILE EXTRACT VALUE
49        DESCRIP                                    description as file name
50                  ~A1..AT1500~r{esc}               extract RANGE
51                  /xmMENU30~                       back to MENU30
```

Figure 4.11 The Menus and Macros of the Analyzing Routine

```
CA
HELP 30:

ANALYZE ------- The ANALYZE routine is composed of two parts.
                The first part is to delete the empty columns which if
                present will screw up the sebsequent MLR analysis.
                The second part is to perform the MULTIPLE LINEAR
                REGRESSION (MLR) by using the DATA REGRESSION function
                provided by the new release of Lotus 1-2-3 Version2.

DELETE -------- The empty columns are deleted by the WORKSHEET DELETE
                COLUMN function. The @SUM statistic function is used to
                determine if the columns contain zero entries. It is
                very important to delete these empty columns (empty
                column refers to the column with all the entries = 0
                under a particular operation) because a deleted file
                will mean a small matrix to be solved and also the
                algorithm of the present MLR function will not work
                if empty columns are present.

MLR ----------- Multiple linear regression will be performed on
                the data file with the following RANGES:
                X-RANGE = The operation range
                Y-RANGE = The hour range
                OUTPUT-RANGE = The result of the MLR analysis and
                will be located at cell A1000

OPENING MENU -- can be accessed from Lotus spreadsheet by holding "ALT"
                key while pressing "M"

OPERATIONS ---- There are a max. of 16 operation columns
```

Figure 4.12 The Help Messages of the Analyzing Routine

```
        BA        BB         BC         BD          BE         BF         BG
1       \0        /xmMENU41~
2
3       \M        /xmMENU40~
4
5       MENU40    Convert    Sort       Analyze     Plot       Lotus123   Help
6                 Convert masSort piece Analyze compPlot residuExit to LotHelp menu
7                 /frMASTER~ /frSORT~   /frANALYZE~ /xmMENU41~ /xq~       {goto}CA1~
8                                                                         /xmMENU40~
9       MENU41    Data file?
10                Hit return to continue
11                {home}/fcce{?}~                   data file to be plotted
12                {goto}A1000~                      go to MLR output range
13                {goto}C1008~                      go to STD. ERR of Coef.
14                /c..{end}{right}~                 copy this row of data
15                {down}~{down}                     into the row below it
16                +{up}/{up}{up}*100~               % ERROR = ERROR/VALUE
17                /c~..{end}{right}~
18                {goto}A1009~                      put a field name for
19                % Std. Error of Coef.~            this % ERROR row
20                /xmMENU42~
21
22      MENU42    Relative R.Absolute R.Menu        Lotus123   Help
23                Plot relatiPlot absoluBack to openExit to LotHelp menu
24                /xgREL~    /xgABS~    /xmMENU40~  /xq~       {goto}CA1~/xmMENU42~
25
26      REL       /cE2~DESCRI1~                     copy the description to x-range
27                {goto}C1009~/grgtb                graph reset graph type bar
28                a..{end}{right}~                  A-range
29                ola% STD. ERROR~                  A-legend
30                tfBAR CHART SHOWING % STD. ERROR~ title first
31                tx
32      DESCRI1                                     title X-axis = description
33                ~tyPERCENTAGE~                    title y-axis
34                qxF1~x..{end}{right}{left}~v      quit; x-range = operations; view
35                ncBAR~q~                          name create
36                /xmMENU42~                        back to MENU42
37
38      ABS       /cE2~DESCRI2~                     copy the description to x-range
39                {goto}C1007~/grgts                graph reset graph type stack
40                a..{end}{right}~                  A-range
41                b{down}                           B-range
42                ..{end}{right}~
43                olaLABOUR HOUR~                   A-legend
44                lbABS. STD. ERROR~                B-legend
45                tfSTACK BAR SHOWING ABS. STD. ERROR~
46                tx                                title first
47      DESCRI2                                     title X-axis = description
48                ~tyHOURS~                         title y-axis
49                qxF1~x..{end}{right}{left}~v      quit; x-range = operations; view
50                ncSTACK~q~                        name create
51                /xmMENU42~                        back to MENU42
```

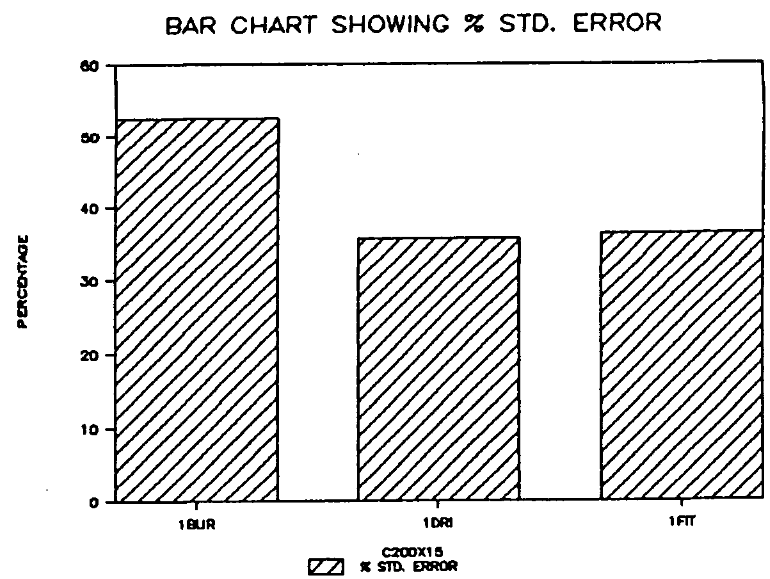
Figure 4.13 The Menus and Macros of the Plotting Routine

```
CA
HELP 40:

PLOT ---------- There are two ways to see the distributions of the
                results. The % graph shows how the STANDARD ERRORS of
                coefficients (i.e. LABOUR HOUR VARIABLES) vary in terms
                of percentage alone. The STACK graph shows the ABS.
                STD. ERRORS on top of the COEFFICIENTS (i.e. LABOUR
                HOUR VARIABLES). These graphs should help the
                management to pin-point places where attention is neede.

GRAPHS -------- The graphs are named as BAR and STACK respectively.
                Since these graphs are not saved explicitly, the user
                must use GRAPH NAME USE SAVE to save them permanently

HARDCOPY ------ a hardcopy of the observed graphs can be obtained
                by using the Lotus Printgraph on graph files

OPENING MENU -- Can be accessed from the Lotus spreadsheet by holding "ALT"
                key while pressing "M"
```

Figure 4.14 The Help Messages of the Plotting Routine

	A	B	C	D	E	F	G	H	I
1	CONTR-DWG	MAN	PIEC	QTY	DESCRIPTION	1BUR	1DRI	1FIT	HOURS
2	5445-2	9	1	4	C200X15	8	0	0	1
3	5445-2	21	1	4	C200X15	6	16	0	3
4	5436-513	9	1	7	C200X15	6	16	16	4.25
5	5436-513'	29	1	6	C200X15	6	16	32	6
6	5442-37	21	1	4	C200X15	4	4	0	3
7	5442-33	23	1	8	C200X15	8	52	0	6

	A	B	C	D	E
1000		Regression Output:			
1001	Constant				0
1002	Std Err of Y Est				1.136750
1003	R Squared				0.795632
1004	No. of Observations				6
1005	Degrees of Freedom				3
1006					
1007	X Coefficient(s)		0.230052	0.083943	0.100996
1008	Std Err of Coef.		0.120980	0.030084	0.036905
1009	% Std. Error of Coef.		52.58817	35.83920	36.54103



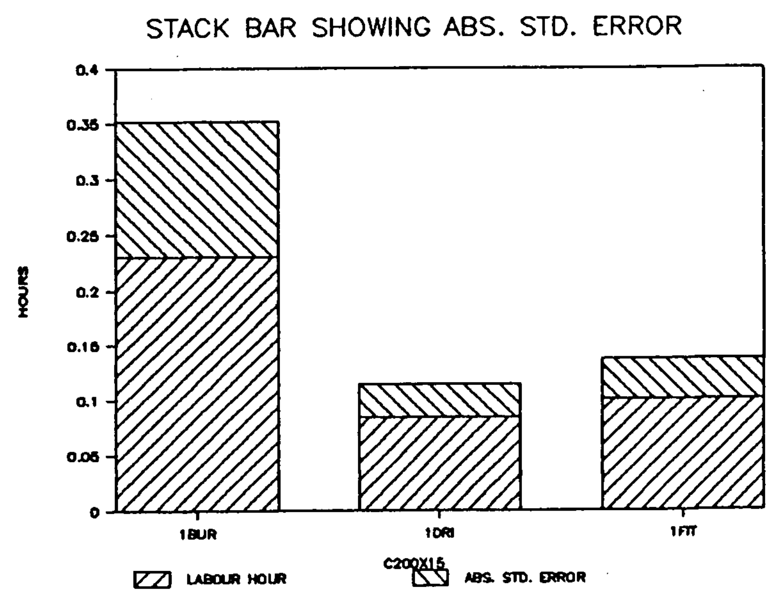
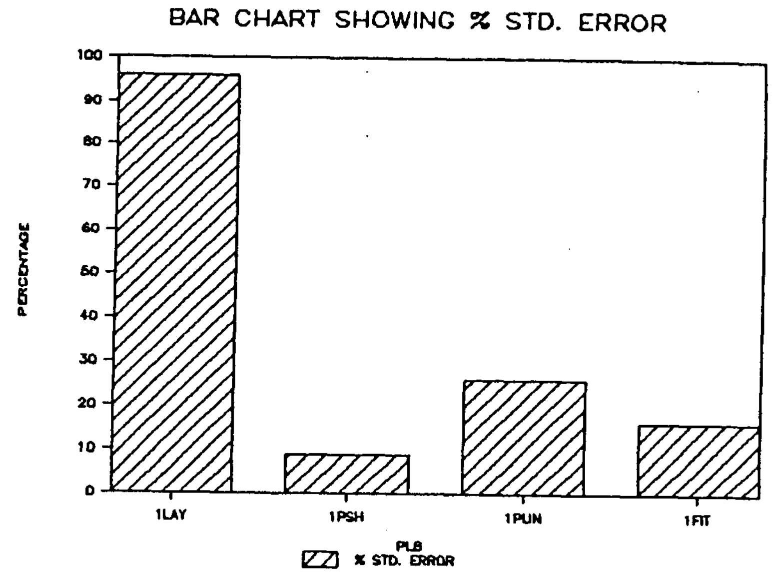


Figure 4.15 The Results of the C200X15 Component File

	A	B	C	D	E	F	G	H	I	J
1	CONTR-DWG	MAN	PIEC	QTY	DESCRIPTION	1LAY	1PSH	1PUN	1FIT	HOURS
2	5432-58	21	1	4	PL8	32	0	24	0	2.25
3	5432-58	14	1	4	PL8	0	0	0	0	0.5
4	5432-17	29	1	4	PL8	0	0	24	0	1.25
5	5432-17	29	1	4	PL8	0	0	0	16	1.75
6	5432-51	29	1	4	PL8	0	0	12	0	1.5
7	5432-51	29	1	4	PL8	0	0	0	16	1.75
8	5432-56	22	1	56	PL8	0	112	0	0	5
9	5432-31	29	1	4	PL8	0	24	0	0	1.5
10	5432-31	29	1	4	PL8	0	0	0	16	1.5

	A	B	C	D	E	F
1000		Regression Output:				
1001	Constant			0		
1002	Std Err of Y Est			0.464709		
1003	R Squared			0.914567		
1004	No. of Observations			9		
1005	Degrees of Freedom			5		
1006						
1007	X Coefficient(s)		0.020312	0.045426	0.066666	0.104166
1008	Std Err of Coef.		0.019483	0.004057	0.017318	0.016768
1009	% Std. Error of Coef.		95.91903	8.931051	25.97807	16.09802



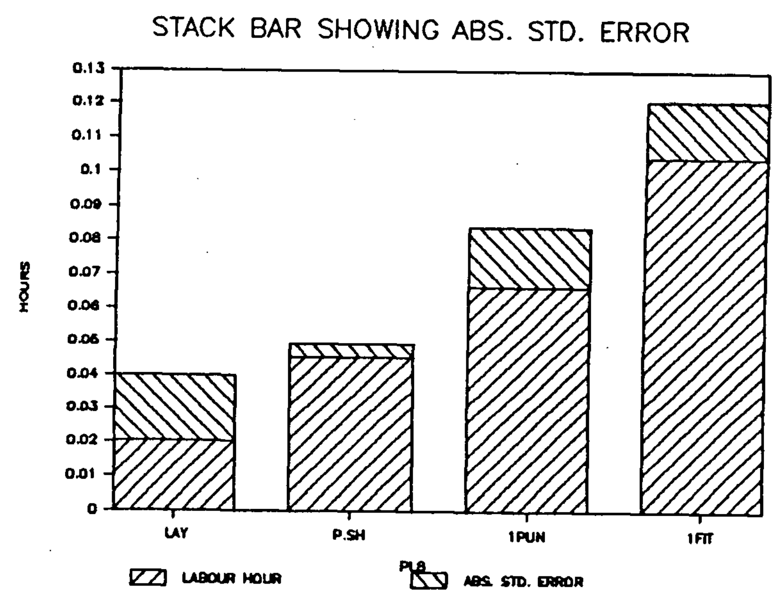
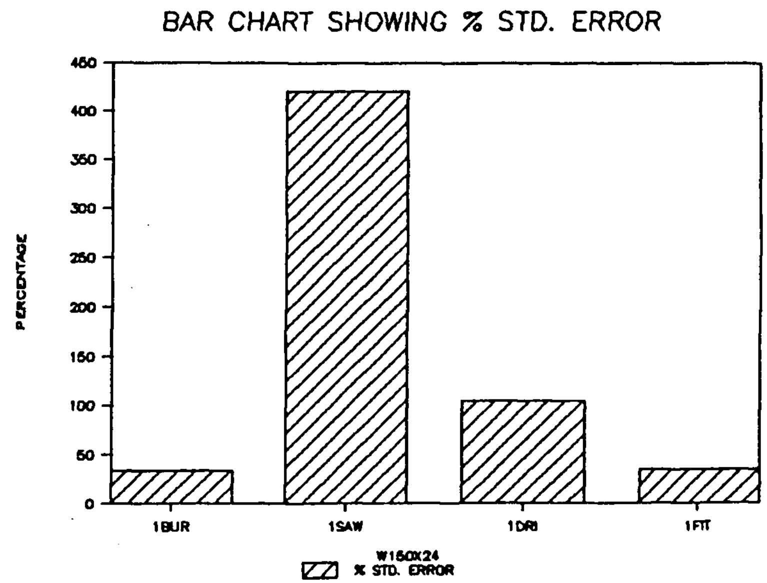


Figure 4.16 The Results of the PL8 Component File

	A	B	C	D	E	F	G	H	I	J
1	CONTR-DWG	MAN	PIEC	QTY	DESCRIPTION	1BUR	1SAW	1DRI	1FIT	HOURS
2	5432-50	7	1	2	W150X24	0	4	32	0	1.5
3	5432-46	7	1	4	W150X24	0	0	8	44	8
4	5432-9	7	1	6	W150X24	12	0	68	24	12
5	5432-40	14	1	7	W150X24	0	0	212	72	12
6	5432-36	29	1	3	W150X24	6	0	0	0	8
7	5432-5	7	1	5	W150X24	0	0	0	92	8

	A	B	C	D	E	F
1000		Regression Output:				
1001	Constant			0		
1002	Std Err of Y Est			3.571181		
1003	R Squared			0.654731		
1004	No. of Observations			6		
1005	Degrees of Freedom			2		
1006						
1007	X Coefficient(s)		0.811904	0.216078	0.019865	0.102941
1008	Std Err of Coef.		0.276692	0.908033	0.020706	0.035419
1009	% Std. Error of Coef.		34.07945	420.2331	104.2375	34.40709



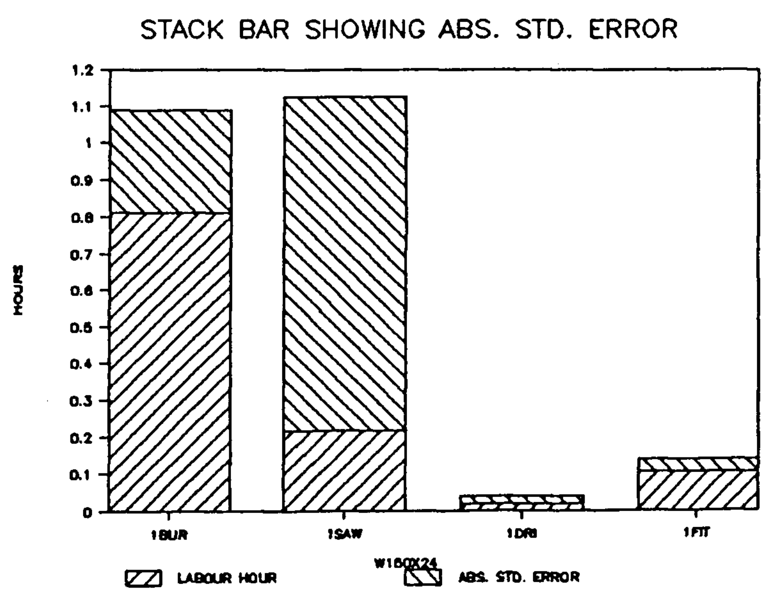


Figure 4.17 The Results of the W150X24 Component File

	A	B	C	D	E	F	G	H	I	J	K	L
1	CONTR-DWG	MAN	PIEC	QTY	DESCRIPTION	1PSH	1PUN	1CLI	2PSH	2PUN	2CLI	HOURS
2	5432-60	22	2	14	PL8PL10	20	0	0	8	0	0	3.5
3	5432-9	22	2	92	PL8PL10	56	0	56	56	0	64	7
4	5436-601	2	2	20	PL8PL10	24	0	0	40	32	0	3.5
5	5442-6	21	2	5	PL8PL10	6	8	0	4	4	0	2.75
6	5442-63	25	2	3	PL8PL10	3	3	0	1	0	0	1

Error message from Lotus:

Too few observations for number of variables

Figure 4.18 The Results of the PL8PL10 Component File

	A	B	C	D	E	F	G	H	I
1	CONTR-DWG	MAN	PIEC	QTY	DESCRIPTION	1PSH	1PUN	2BUR	HOURS
2	5442-23	12	2	16	PL10W610X113	0	14	2	12
3	5442-4	14	2	3	PL10W610X113	2	0	1	3
4	5442-34	14	2	6	PL10W610X113	0	8	1	7.25

Error message from Lotus:

Too few observation for number of variables

Figure 4.19 The Results of the PL10W610X113 Component File

Chapter 5

THEORY OF MLR

5.1 SYSTEM OF EQUATIONS

In order to evaluate the labour hour variables, a system of algebraic equations $A\underline{x} = \underline{b}$ must be solved. The matrix A represents the set of operations done on a particular piece of a component in different observations. The vector $\underline{x}$ represents the labour hour variables that are being determined, and $\underline{b}$ is the time the worker has spent on the operations contained in matrix A. An example of a system of algebraic equations from the fabricating shop is illustrated by figure 5.1. The system $A\underline{x} = \underline{b}$ will have an exact solution if the number of independent equations equals the number of unknowns. But in general, for a real case, there will be more equations than unknowns because a large number of equations will be observed in the fabricating shop for the relatively fewer operations. When a system $A\underline{x} = \underline{b}$ has more equations than unknowns, the system is said to be inconsistent. Inconsistency means that there probably does not exist a vector $\underline{x}$ that perfectly fits the data $\underline{b}$, or, in other words, the vector $\underline{b}$ probably will not be a combination of the columns of A.

5.2 REGRESSION ANALYSIS

Inconsistency is a common phenomenon for the global shop data as the time of performing the same operation on a particular piece will fluctuate slightly from day to day for the same worker and greatly between different workers. For example, worker A may take 2 to 3 minutes to drill a hole on C200X21 while worker B may take 4 to 5 minutes to do the same job. Thus, it does not make sense to expect an exact solution $\underline{x}$. Rather an approximate solution $\bar{\underline{x}}$, which represents the best estimate of the labour hour variables, should be used. Multiple Linear Regression (MLR) is used to give this average solution $\bar{\underline{x}}$. The error between the actual observed time and the approximate time is $E = ||A\bar{\underline{x}}-\underline{b}||$ which is the absolute distance between the vectors $\underline{b}$ and $A\bar{\underline{x}}$. The objective of the MLR is to minimize $E = ||A\bar{\underline{x}}-\underline{b}||$. A number of methods can be used to achieve this minimization and the least squares fit has been chosen. Strang [11] has shown that minimizing E is equivalent to finding the projection $A\bar{\underline{x}}$ which is closest to $\underline{b}$ in the column space. From the geometry of figure 5.2, the residual error vector $(A\bar{\underline{x}}-\underline{b})$ must be perpendicular to the column space. Since the column space can be represented by any vector $A\underline{y}$, $A\underline{y}$ must be perpendicular to $(A\bar{\underline{x}}-\underline{b})$ or

$$(A\underline{y})^T (A\bar{\underline{x}}-\underline{b}) = 0 \qquad \text{property of orthogonality}$$

$$\underline{y}^T (A^T A\bar{\underline{x}}-A^T\underline{b}) = 0 \qquad A^T = \text{transpose of } A$$

Normal equation

Hence, the approximate solution $\bar{\underline{x}}$ must satisfy the normal equation $A^T A\bar{\underline{x}} - A^T \underline{b} = 0$ or $A^T A\bar{\underline{x}} = A^T \underline{b}$ for E to be minimum. Note that the vectors $\bar{\underline{x}}$ and $\underline{x}$ are different in the sense that $\bar{\underline{x}}$ is the best approximate of $\underline{x}$ which gives the vector $A\bar{\underline{x}}$ closest to $\underline{b}$. Hence, residual error $E = ||A\bar{\underline{x}} - \underline{b}||$ will be present unless it is a perfect fit.

5.3 ALGORITHM OF MLR

The algorithm of MLR Macro program sets up the normal equation first and then solves the equation for $\bar{\underline{x}}$.

$$\text{Normal equation: } A^T A\bar{\underline{x}} - A^T \underline{b} = 0$$

$$A^T A\bar{\underline{x}} = A^T \underline{b}$$

$$[A]^T\ [A]\ \bar{\underline{x}} = [A]^T\ \underline{b}$$

In the computer, we can store A and $\underline{b}$ together with their products after pre-multiplication by A^T for efficiency of data storage, i.e.

$$[A]^T\ [A \mid \underline{b}] = [A^T A \mid A^T \underline{b}]$$

Once the normal equation has been computed, we can reduce the LHS matrix to the identity matrix and the corresponding RHS will give the average solution $\bar{\underline{x}}$.

$$[A^TA]\,\bar{\underline{x}} = A^T\underline{b}$$

$$\Big|\ \text{row operation}$$

$$[I]\,\bar{\underline{x}} = \bar{\underline{x}}$$

The necessary and sufficient requirement for matrix A^TA to be reducible to the identity matrix is that there are non-zero pivots along the diagonal. If no non-zero pivot can be found along a column, the matrix is singular and has no unique solution. Hence, part of the algorithm for testing the existence of a solution is to find if there is a non-zero pivot along each column. Once the identity matrix has been computed, the corresponding RHS vector will be the approximate solution $\bar{\underline{x}}$ (figure 5.3).

OBSERVATIONS OF A TYPICAL COMPONENT
FROM A FABRICATION SHOP:

							HOURS
2 SAW	+	8 DRILL				=	8
4 SAW	+	2 DRILL	+	10 FIT		=	10
1 SAW	+	2 DRILL	+	2 FIT		=	5
3 SAW			+	12 FIT		=	9
6 SAW	+	8 DRILL	+	20 FIT		=	21

$$\begin{pmatrix} 2 & 8 & 0 \\ 4 & 2 & 10 \\ 1 & 2 & 2 \\ 3 & 0 & 12 \\ 6 & 8 & 20 \end{pmatrix} \begin{pmatrix} \text{SAW} \\ \text{DRILL} \\ \text{FIT} \end{pmatrix} = \begin{pmatrix} 8 \\ 10 \\ 5 \\ 9 \\ 21 \end{pmatrix}$$

$$A \quad x \quad = \quad b$$

where $A = \begin{pmatrix} 2 & 8 & 0 \\ 4 & 2 & 10 \\ 1 & 2 & 2 \\ 3 & 0 & 12 \\ 6 & 8 & 20 \end{pmatrix}$ $x = \begin{pmatrix} \text{SAW} \\ \text{DRILL} \\ \text{FIT} \end{pmatrix}$ $b = \begin{pmatrix} 8 \\ 10 \\ 5 \\ 9 \\ 21 \end{pmatrix}$

Figure 5.1 A System of Algebraic Equations

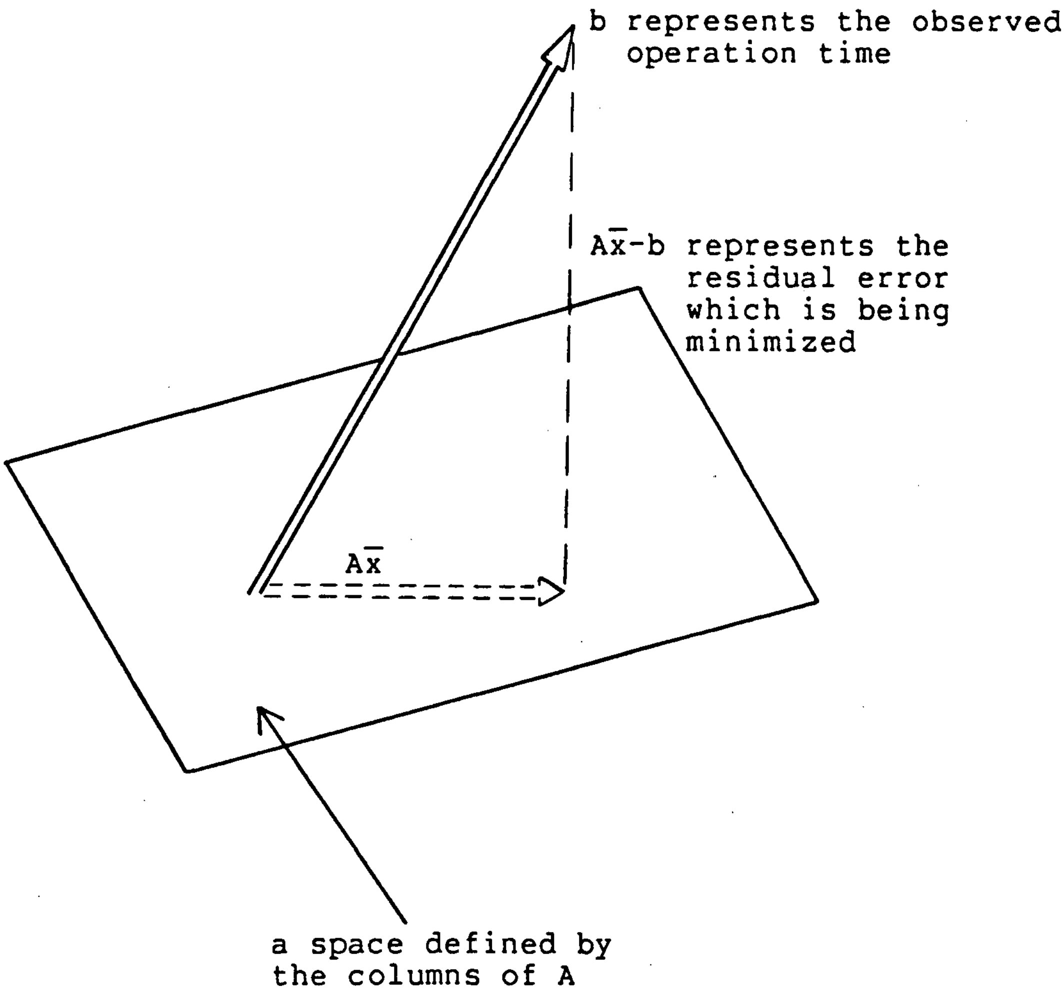


Figure 5.2 A Graphical Illustration Showing the Minimization of the Residual Error

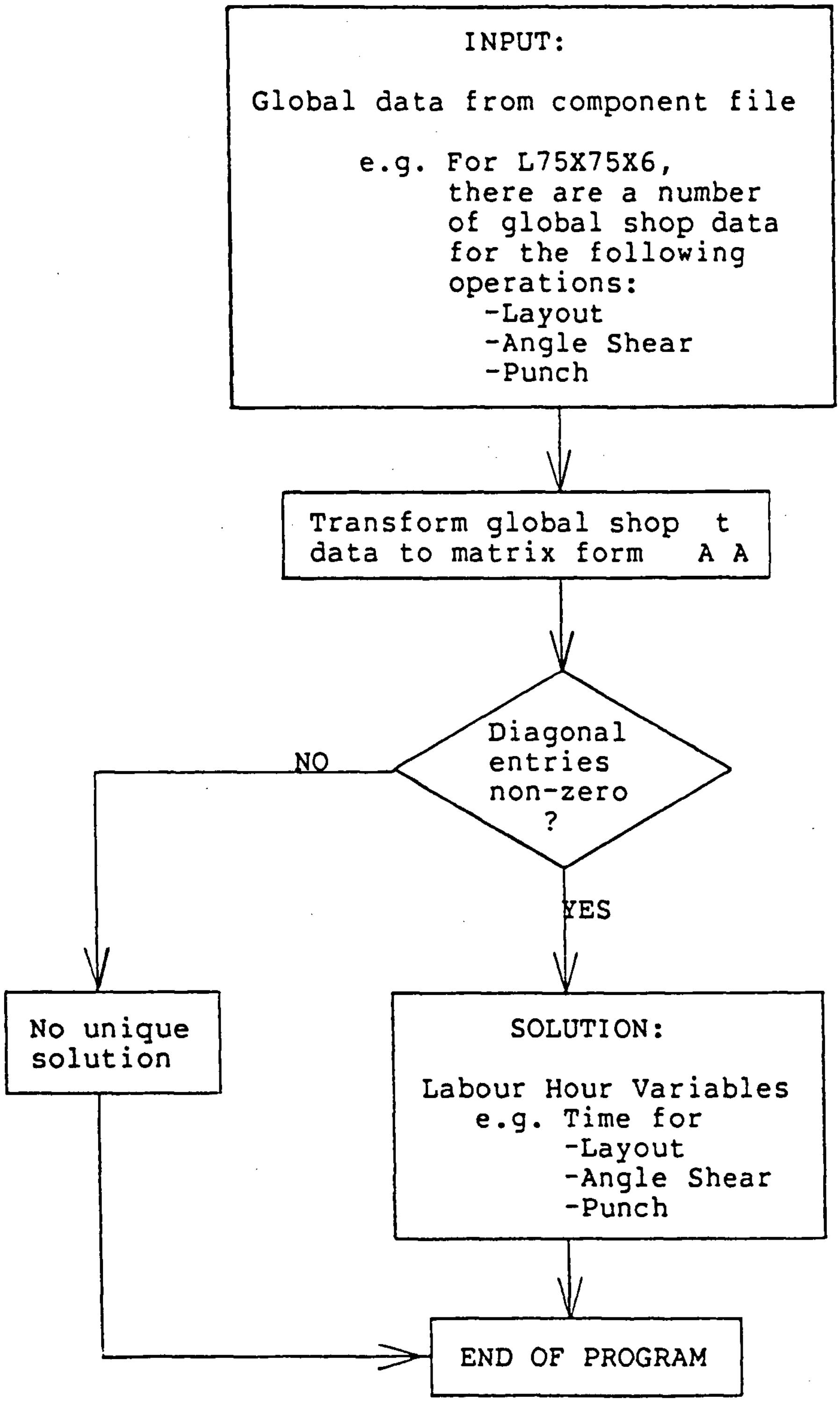


Figure 5.3 A Flow Chart for the MLR Aanalysis

Chapter 6

CONCLUSIONS

1. A computer program on cost estimation which quickly and accurately performs all the calculations, sortings and statistics required has been developed utilizing the program BASIC language. The management of Coast Steel Fabricators Ltd. has found that such a program has reduced their total estimating time by 30%.
2. A procedure has been developed to obtain the labour hour variables used in estimating. In the case of the start-up of a new fabrication plant, this procedure will serve as a powerful tool for time studies of the various labour operations. For continuous operation of a fabrication plant, this procedure will provide feedback and update the labour hour variables used in the estimating program.
3. This project concluded that the earlier research was successful and brought in real application in the estimation of steel structures. This research project is a continuation of the two previous ones done at U.B.C. by Y.C. Leung [2] and Bruce Forde [1]. The operational approach used is a modification of the one proposed by Y.C. Leung. The idea of Multiple Linear Regression on cost estimation was introduced by Bruce Forde but a different algorithm was used.
4. The Lotus 1-2-3 macro programming is proven to be superior in analyzing the labour hour variables. The

work on labour hour variables was done using Lotus 1-2-3 and its macro capability. There was a change of the computer environment. The earlier cost estimating program was developed under the Basic language environment but the later labour hour analysis utilized the Lotus 1-2-3 environment. The main reasons for that are availability, ease of use, compatibility and flexibility. Lotus 123 itself is fairly easy to use and the macro program will run on a variety of computers. The flexibility of the macro program will allow users to modify or adjust the program to best fit their needs.

5. From the study of the current cost estimation process, the management concluded that the input of drawings is the most time consuming part. The management advised that future research on the direct input of drawings should be investigated. Currently, drawing data are first transferred to take-off sheets and then typed into the computer. A new method should be developed to speed up this process. The new approach should take advantage of the technology of computer aided drafting and computer graphics.

6. Results from this case study can be helpful to other steel fabricators or even other manufacturers.

Chapter 7

FUTURE RESEARCH

7.1 COMPUTER COST ESTIMATION PROGRAM ON LOTUS 1-2-3 SPREADSHEET

A flow chart and an example give guidance for future research. Figure 7.1 shows a flow chart of how the computer cost estimating program should be implemented in the Lotus 1-2-3 spreadsheet environment. The macro program to be developed should be menu-driven to lead the users for the subsequent take-off, material, computation and final summary menus. Each subsequent menu will further lead the users to perform the required work. The future macro program should connect the individual files together and include a HELP menu to give users on-line assistance. An example of the various menus can be seen in figure 7.2. These flow chart and example, together with the user manual of the computer cost estimating program, should give enough guidelines for a rewrite of the program on a spreadsheet environment.

7.2 INPUT FROM DRAWINGS

A fast and efficient method of entering data from drawings into the computer should be developed because this is now the most time consuming part of the whole estimating process. Currently, information is manually transferred from drawings onto take-off sheets and then typed into the computer. Both steps are slow and contain the possibility of unnecessary errors. Future research should investigate a method of inputting this information in a single step instead of two.

The latest technology in computer graphics should also be considered in the new investigation. There are new hardware devices such as the image reader [12] and the drum-scanner [13] which can trace diagrams on drawings. Given the suitable harware and software, information can be transferred from drawings to the computer in a much better way. Figure 7.3 shows a scheme of this method. Technology in computer aided drawing should also be considered in developing the inputting method. Nowadays, many drawings are drawn by computer and information on the drawings already exists in the form of a data base [14] [15]. Figure 7.4 indicates this method.

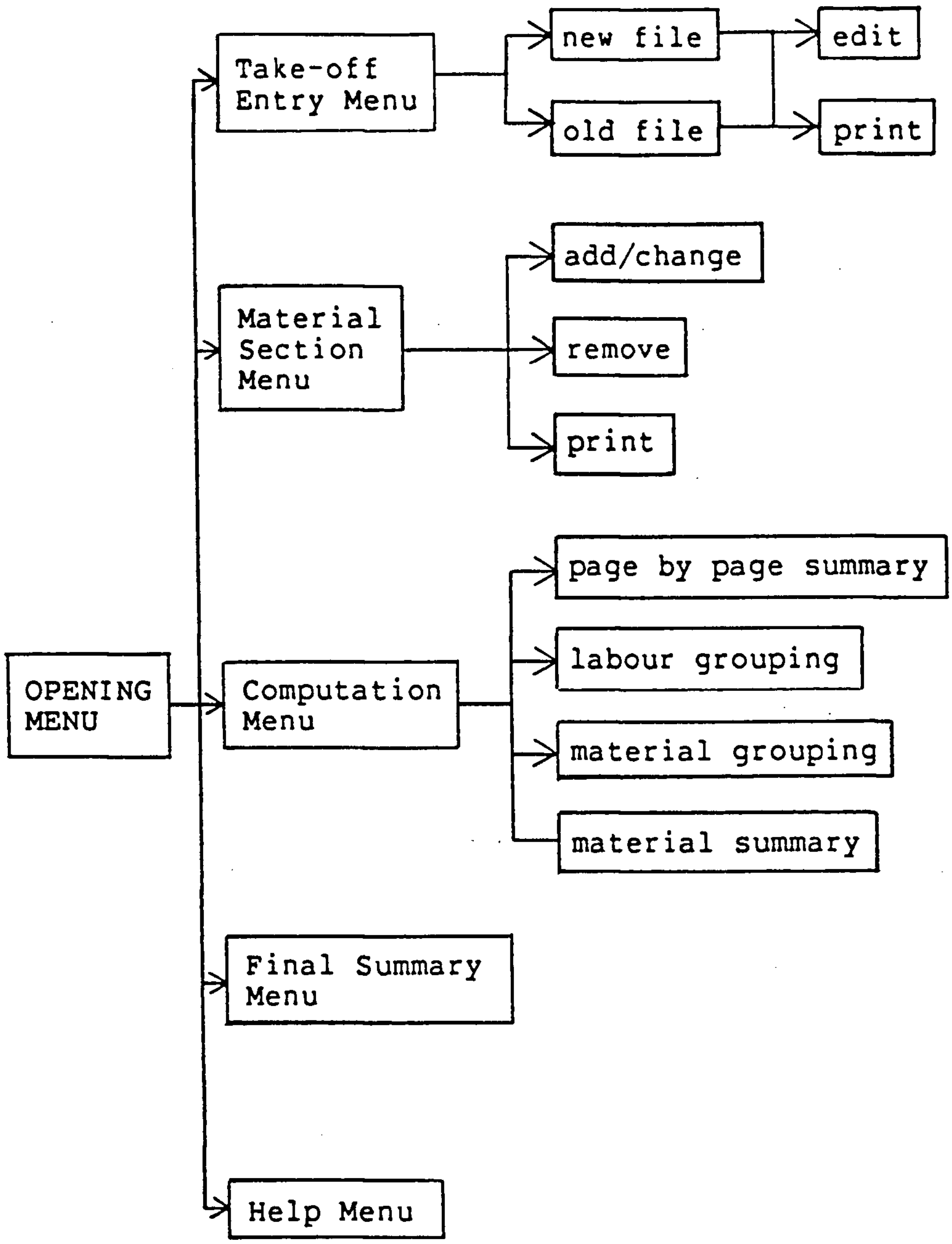


Figure 7.1 A Flow Chart for Computer Cost Estimating Program in Lotus 123

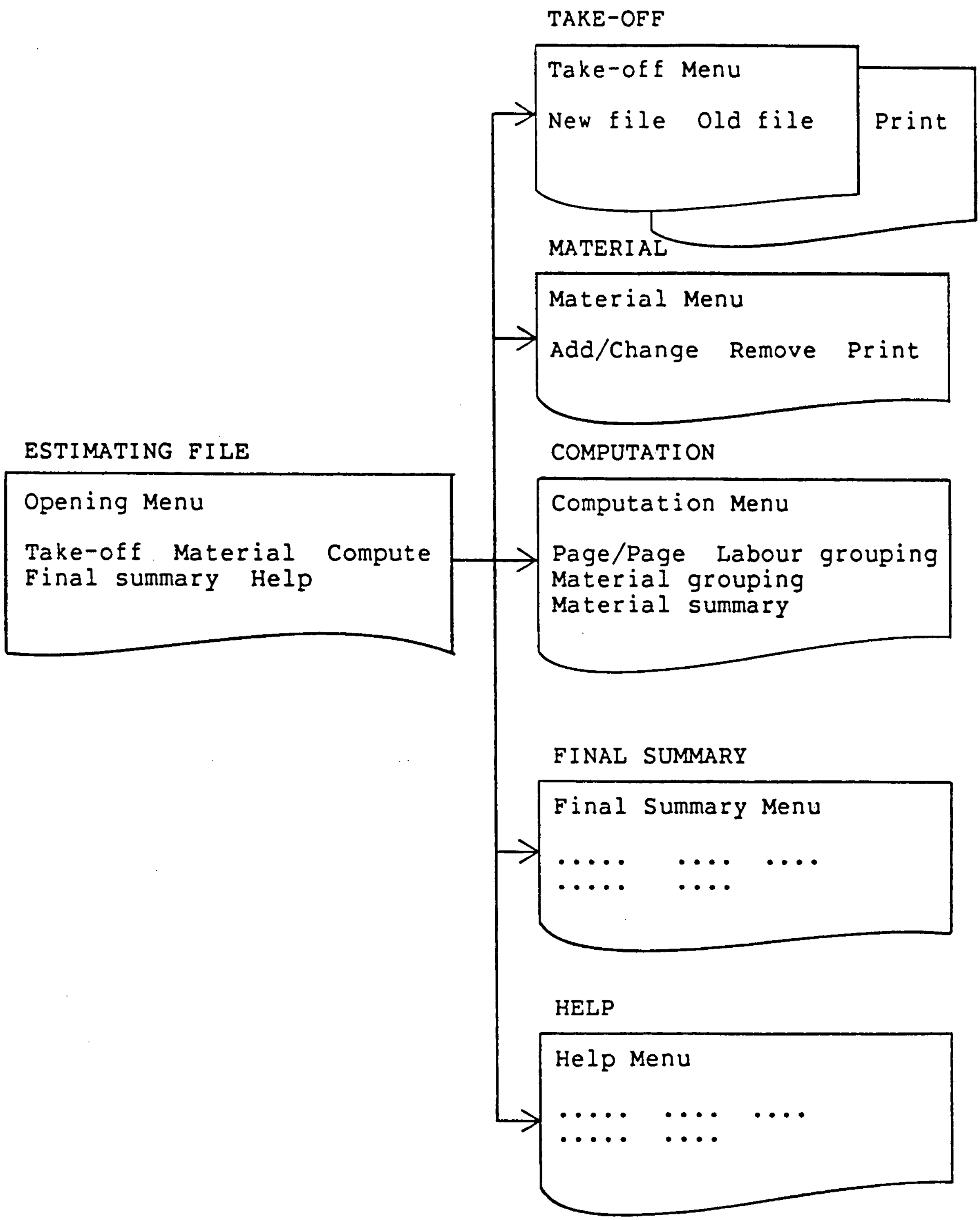


Figure 7.2 An Example Showing the Spreadsheets and Menu

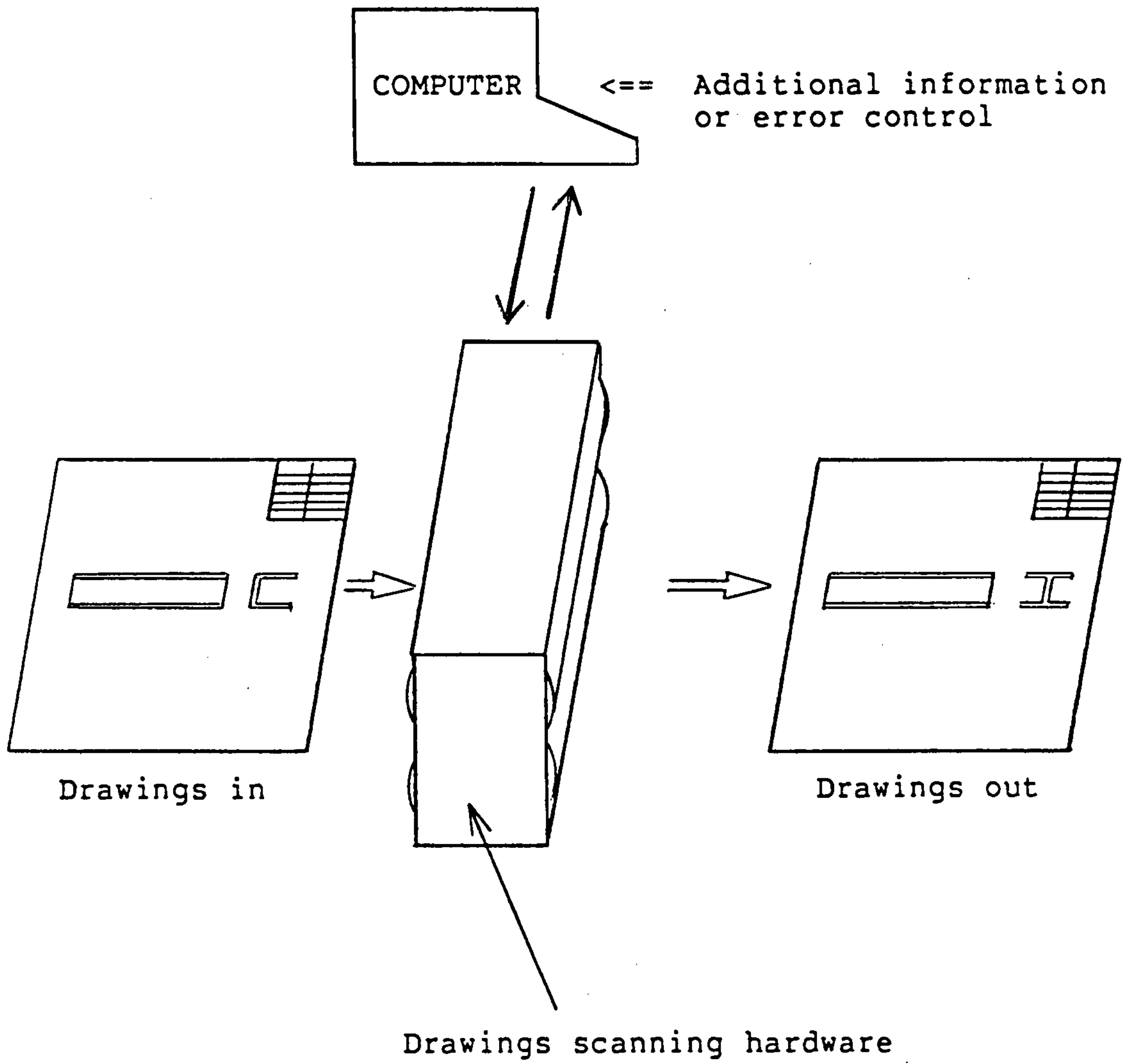


Figure 7.3 A Scheme of Utilizing Computer Graphics

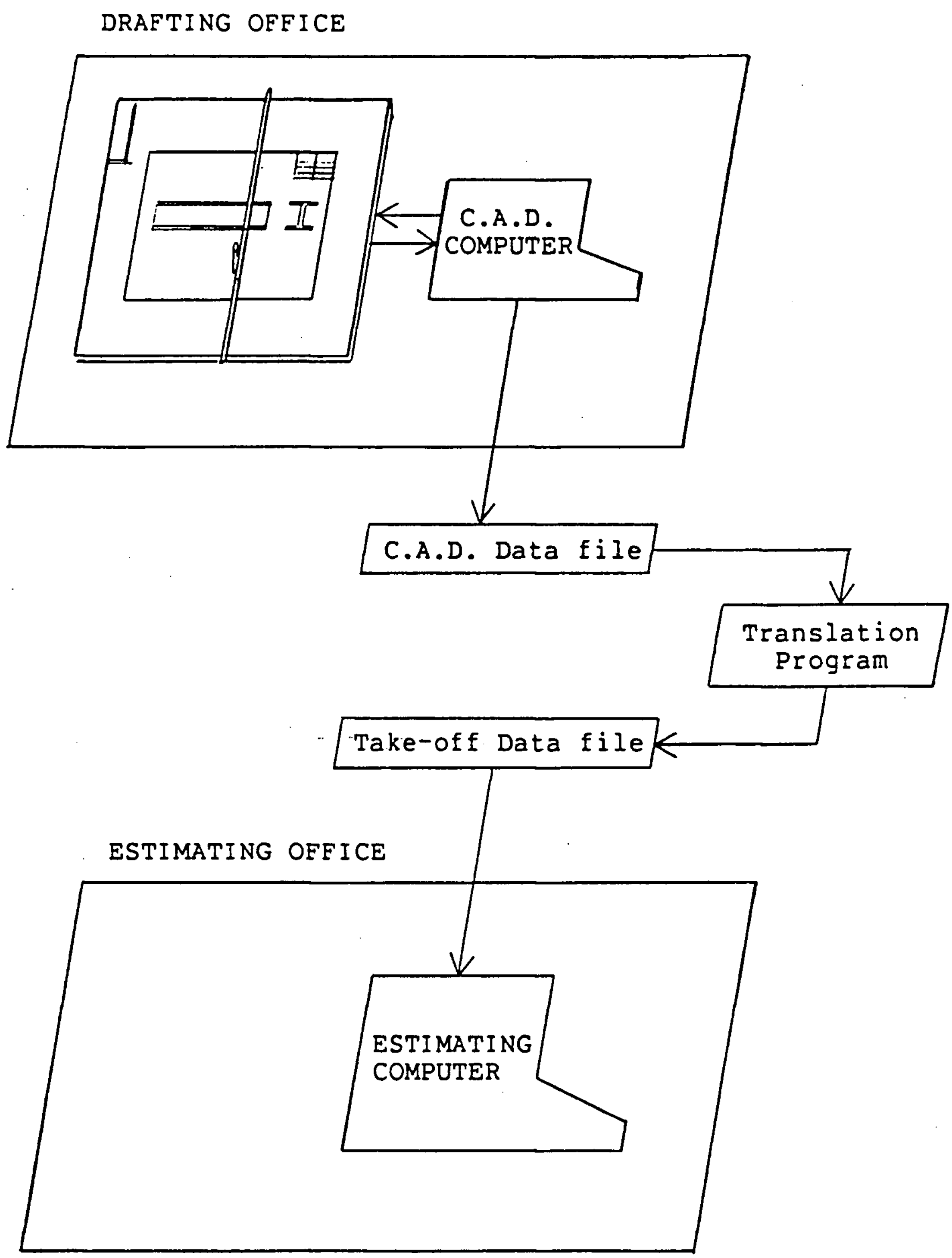


Figure 7.4 A Scheme Utilizing C.A.D. Technology

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APPENDIX

A computer diskette is appended to show the macro programs on labour hour variables. This diskette contains the worksheet data files and must be used with the system diskette of Lotus 1-2-3 Release 2. The user should make a copy of the appended diskette and works with the backup copy. Note that no protective tape should be placed on the backup diskette in running the program. To start the macro program, the user should use /FILE RETRIEVE to load the "MASTER" file into the Lotus spreadsheet. Once loaded, the opening menu will automatically appear and it can also be accessed by pressing "ALT" "M" after the user has left the menu. To exit from the macro program, one should use either the "Lotus 123" menu item or the "ESC" key. There is a HELP menu to assist the user for the various functions offered by the macro program.

The user manual and the listings of the cost estimating program can be obtained through the author or his supervisor Dr.S.F. Stiemer.