GENERATION AND EVALUATION OF ASSEMBLY SEQUENCE ALTERNATIVES

by

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B.M.E., General Motors Institute

(1983)

SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS OF THE

DEGREE OF

MASTER OF SCIENCE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

February 1987

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November, 1986

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Submitted to the Department of Mechanical Engineering
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ABSTRACT

The overall influence of an assembly sequence is far reaching, impacting aspects such as assembly system design, final product quality, and unit cost. The determination of assembly sequence has long been dependent on the knowledge and expertise of the manufacturing engineer. In an effort to provide better analysis tools to the Simultaneous or Concurrent Engineering approach to the product development process, the generation and evaluation of product assembly sequences was studied. Prior diagrammatic representations and methods of generating alternative assembly sequences are presented. They are shown to be incapable of representing all possible assembly sequences for a given product and also unable to represent some of the mechanical precedence constraints imposed by physical part geometry.

A new, algorithmic method, called liaison sequence analysis [Bourjault, 1984], of determining and representing all mechanical precedence constraints, as well as generating all possible assembly sequences, is discussed. A simplified technique [De Fazio and Whitney] which is based on Bourjault's method is also presented. Several modifications to the basic structure of liaison sequence analysis are offered in this thesis, so as to permit the inclusion of non-assembly tasks, such as functional test, part fixturing, and inspection, which frequently occur on the assembly line.

The criteria and considerations, both the qualitative and quantitative aspects, encountered in the selection of candidate assembly sequences are addressed. The generation technique and selection criteria are applied to the assembly of two unique products, the steering column subassembly and engine dress components. The impact of different assembly sequences on unit assembly cost and assembly system configuration is evaluated using ASDP, an Assembly System Design Computer Program developed at the Charles Stark Draper Laboratory, Inc. [Gustavson, 1986]. The results show that key assembly sequence characteristics, such as resource utilization, grouping of common operations, and minimum non-value added labor, can result in as much as a twenty percent unit assembly cost advantage of one sequence over another. These results are consistent over both products and a variety of assembly resources, such as manual operators, fixed and programmable automation.

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ACKNOWLEDGEMENTS

First of all, I would like to express my sincere gratitude to my academic advisor, Dr. Daniel E. Whitney, for his invaluable support and guidance throughout the development of this thesis. His professional insights and genuine interest in teaching made this an outstanding learning experience.

I would also like to thank Mr. Richard Gustavson and Dr. Thomas De Fazio, staff members at the Charles Stark Draper Laboratory, for their assistance in the application of the tools and techniques they have developed.

My appreciation is extended to the managers and engineers at General Motors Corporation, namely Messrs. Len Boerma, Don Downie, Doug Dulyea, Bill Hanna, and Don Lukins, for providing this outstanding academic and professional opportunity.

It is also appropriate to thank my friends at the Draper Laboratory as well as MIT, especially George Mitroka, Tim Roggenkamp, Ron Nitschke, Maggie Urbank, Brian Jacobs, Tom Kurfess, Matt Brown, and countless others, who made even the most difficult times more bearable.

Finally, I wish to extend my sincere gratitude to my family, friends, and particularly my parents back home in Fowler, Michigan. Their confidence and support eased the rather trying transition back into the academic world.

This work was funded by the National Science Foundation under Grant No. DMC-8417949.

Charles J. Klein

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1.0 INTRODUCTION

1.1 TOPIC BACKGROUND

Recent losses in market share and profit margins have pressured many manufacturers to reevaluate all aspects of their production methods in an effort to reduce product cost and increase their market competitiveness. One organizational approach recently employed by industry is simultaneous engineering. Utilizing various analysis tools, the product design and manufacturing staffs work together and develop design and production plans concurrently rather than separately. By working through several design iterations, the goal of simultaneous engineering is to optimize both product function and its ability to be manufactured at the lowest cost.

One analysis tool used in the reduction of overall assembly costs, Design for Assembly, is receiving growing support from industry. The analysis methods of Design for Assembly, such as the Hitachi method or those by Boothroyd and Dewhurst, provide a systematic procedure for the analysis of a product's design features with the goal of reducing assembly and part handling costs.

The major thrust of these analysis techniques is aimed at the design phase of the product development process. The Design for Assembly analysis encourages the designer to evaluate potential design changes or alternative designs in light of their impact on assembly or part handling. A summarized list of design guidelines is provided below:

1. Minimize the number of parts.
2. Ensure that the product has a suitable base part on which to build the assembly.
3. Ensure that the base part has features that will enable it to be readily located in a stable position in the horizontal plane.

4. If possible, design the product so that it can be built up in layer fashion, each part being assembled from above and positively located so that there is no tendency for it to move under the action of the horizontal forces during the machine index period.
5. Try to facilitate assembly by providing chamfers or tapers which will help guide and position the parts in the correct position.
6. Avoid expensive and time consuming fastening operations, such as screwing soldering, and so on.

The simultaneous engineering team must also develop and define the required assembly system and methods for alternative product designs. as well as evaluate specific design aspects for their impact on manufacturing cost. It is the role of the engineering group to establish the assembly sequence, processes, and machines which will meet production volume requirements at lowest cost. The product design information is used to create the sequence alternatives. A product with a relatively small number of parts to be assembled, say six or seven, can give rise to a surprisingly large number of potential assembly sequences. The selection of assembly sequence can greatly influence many aspects of the manufacturing system, such as labor efficiency, ability to automate, final product quality or reject rate, and unit assembly cost. The generation of assembly sequence alternatives is done in a largely unstructured manner and is highly dependent on the expertise and knowledge. Because of the undefined and subjective nature of the generation of assembly sequences and the subsequent sequence selection process, very few planning aids exist for the analysis of assembly.

1.2 PRIOR PLANNING AIDS

Process planning is defined as "that function within a manufacturing facility that establishes which machining processes and parameters are to be used (as well as the machines capable of performing these processes) to convert (machine) a piece part from its initial form to its final form"[1]. Process planning aids to date have been devoted almost entirely to machining operations. The planning methods employed are of two types, variant and generative.

The variant planning approach uses similarity of components to retrieve existing process plans. The plan retrieval method is based on the grouping of parts into families. Components are first coded and then input into a part family search. A standard plan is retrieved for a particular family of parts. The standard plan must then be modified by the manufacturing engineer to suit the design requirements of the specific part. There are no limitations as to the detail level that can exist in a set of standard plans, though they must contain at least a sequence of fabrication steps or operations. Variant systems reduce, but do not eliminate, the human effort required to develop new process plans. Since the variant approach consists of retrieving previous solutions, it has have the inherent disadvantage of privileging old solutions rather than developing new, more appropriate solutions.

The second type of planning system, called generative process planning, is defined as "a system that synthesizes process information in order to create a process plan for a new component automatically"[2]. By using decision logic, a generative process planner can define the required operations and operation sequence for the component being planned. No standard plans are stored as in the variant planning approach so new components are planned as easily as an existing component. Despite their obvious advantages, generative planners are more difficult to

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[1]Chang, T-C, and Wysk, R.A., An Introduction to Automated Process Planning Systems, (Prentice-Hall, Englewood, N.J., 1985), p. 25
[2]Ibid, p.39

implement, and thus far have shown limited capability. Again, they have focussed exclusively on machining processes, and are restricted in the part complexity they can comprehend. The most promising of the generative process planning systems is GARI [Descotte and Latombe 1985], which utilizes an expert knowledge base to iteratively create an "optimum" machining plan.

While a great deal of effort has been expended in the development of process planning for machining applications, as well as in the analysis of Design for Assembly, information regarding the generation and selection of assembly sequences is a virtually untapped area. Planning aids for assembly have centered on distribution of work load or line balance of the assembly line. Computer programs, such as CALB [Illinois Institute of Technology, 1972] (Computer Aided Line Balance) and Nulisp [Smith 1979], utilize assembly operation time and a diagrammatic representation of assembly, primarily the precedence diagram, to determine an optimal assembly line balance. These planning aids do not consider other assembly sequence selection criteria, such as tooling requirements, tool changes, and ability to automate certain tasks, which can also have a significant impact on product assembly costs.

1.3 THESIS OBJECTIVE

The primary objective of this thesis is to address the apparent lack of structure and knowledge in the generation and selection of assembly sequences. The planning for assembly can be divided into two parts. The first part addresses the generation of the viable sequence alternatives. The information required to generate the physically possible sequences consists primarily of critical geometric information and other assembly requirements, such as the need for test or inspection. This information is specific to the product being assembled. Once the sequence alternatives have been enumerated, selection of an assembly sequence, which results in the least cost assembly system, is the next step. This process has long been dependent on the knowledge and expertise of the manufacturing engineer. The objective of this second part of the thesis is to identify the knowledge and sequence attributes which are most desirable and cost beneficial.

1.4 THESIS ORGANIZATION

In order to communicate the stated objectives of this thesis in a thorough and organized manner, it will be presented in the following format. Chapter 2 will review frequently used diagrammatic representations of assemblies. It will present their limitations as well as their current application by manufacturing engineers. Chapter 3 will present a new and more structured method of generating all possible assembly sequences, which was introduced by Alain Bourjault in 1984. A modification of Bourjault's method will also be discussed. The extension of the new generation technique to assembly activities other than mechanical part to part mating will be addressed in Chapter 4, and several examples will be used to clarify the application. Chapter 5 will discuss the issues and knowledge associated with the evaluation and selection of alternative assembly sequences, and their impact on product assembly cost. Chapter 6 will apply the identified selection criteria to several examples and using ASDP [Gustavson 1985], an assembly system planning aid, will evaluate their impact on product assembly cost. Finally, Chapter 7 will present the summarized conclusions and recommendations of this thesis.

2.0 PRIOR DIAGRAMMATIC REPRESENTATIONS OF ASSEMBLY

Several different diagrammatic representations of assembly have been employed by manufacturing engineers to assist in the determination of assembly sequences. The three methods of representation which will be presented in this chapter are:

1. Connection Matrix
2. Precedence Diagram
3. Parts Tree

Of the three techniques, the precedence diagram is the most widely used by manufacturing engineers. This chapter will also address the advantages and limitations of each of the three methods and will conclude with discussion of their typical application as planning aids.

2.1 CONNECTION MATRIX

The connection matrix is the most simplistic representation of assembly and provides little information regarding valid assembly sequences. The connection matrix does provide information about the presence or absence of a relationship between parts, and is easily generated from product assembly drawings. Three extreme examples are shown in Figure 2.1 on the following page.

It is obvious from these examples that construction of the matrix is accomplished by numbering each of the parts and placing the numbers on the vertical and horizontal axes of the matrix. Entries are made in the matrix locations where contact or a connection exists between parts. For example, in item B of Figure 2.1, entries are made in locations (1,2), (1,3), (1,4), and (1,5), as

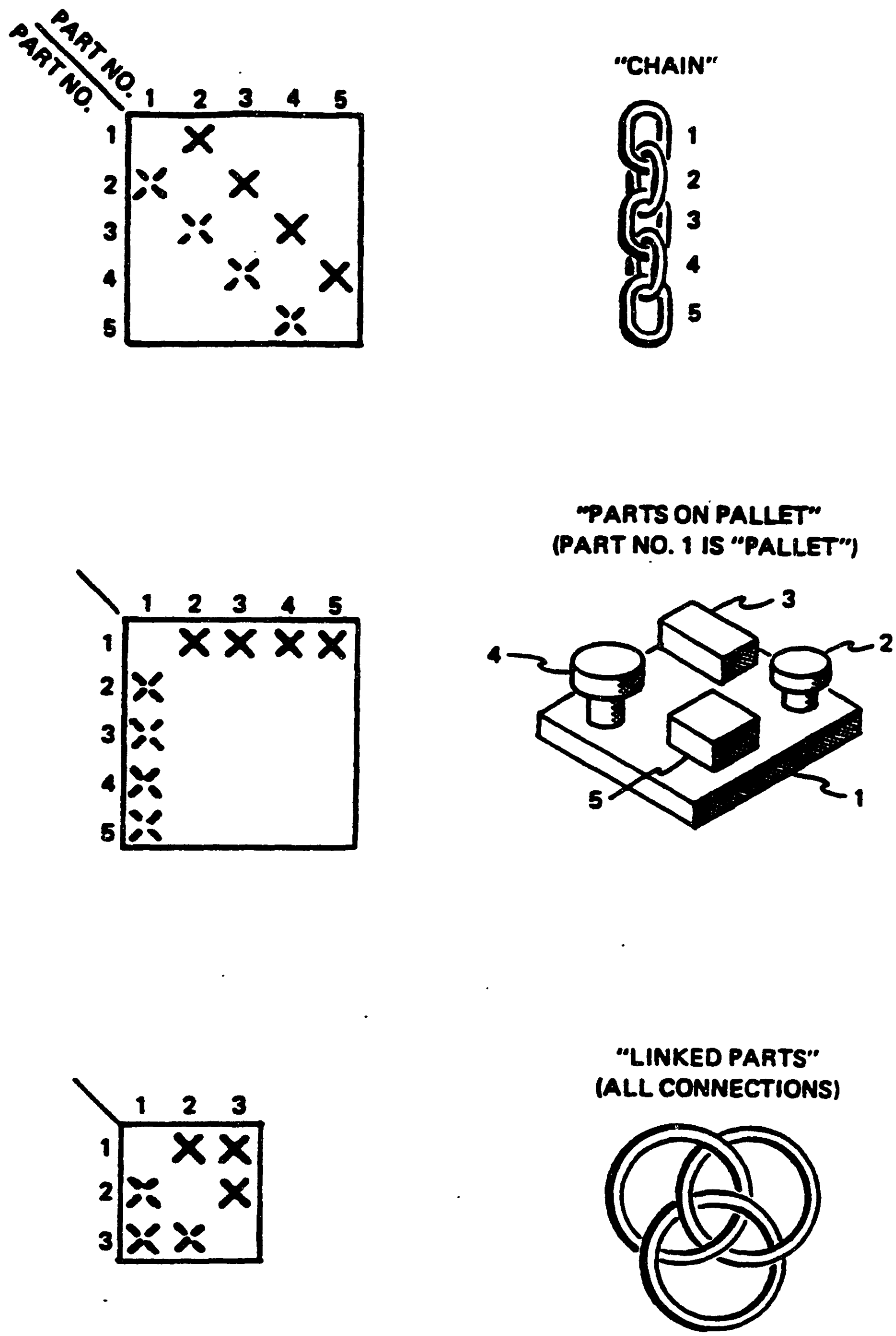


Figure 2.1: Connection Matrix Examples

Source: Draper Report, R-1643

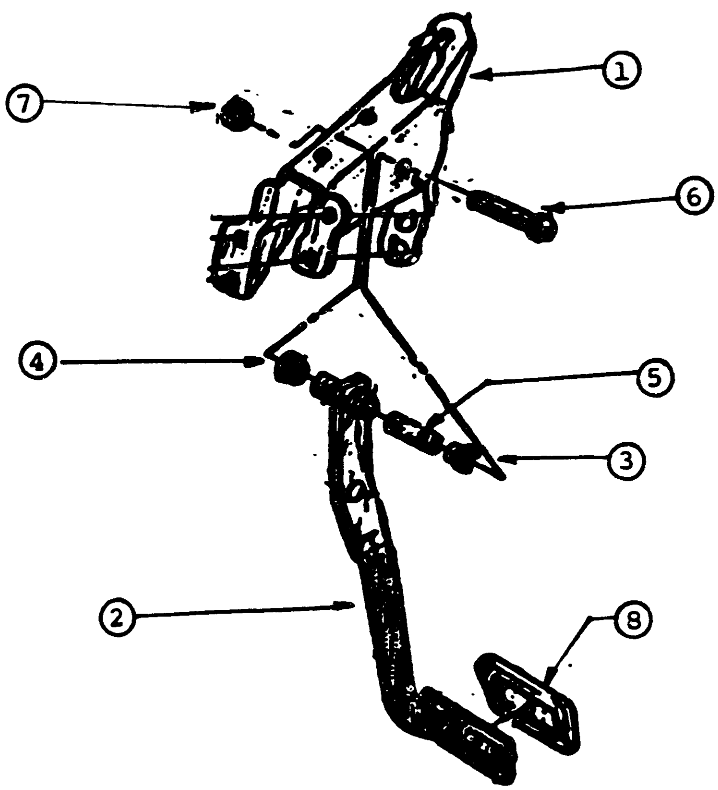
contact exists between those parts. No contact between parts results in no matrix entry. It is worthy to note that the connection matrix is necessarily symmetric about its diagonal, and therefore all information could be represented with only half the matrix.

One extension to the connection matrix is to use two unique matrix entries in order to differentiate between simple contact between parts and a physical connection. Figure 2.2 applies the two entry method to the brake pedal subassembly. Again, the method of construction is very simple. Information regarding part to part contact or connection is also easily extracted from a product assembly drawing.

2.1.1 Advantages and Limitations

The most obvious advantage of the connection matrix is its simplicity. It requires minimal knowledge to create, however it is this same simplicity that limits its usefulness. From the connection matrix, a series of assembly sequences may be generated, as all the connections or matrix entries must be completed to assemble the product. In fact, it can generate more sequences than may be physically possible. The connection matrix does not contain any precedence information, such as part interferences that can constrain the possible orderings of parts. For example, on the brake pedal subassembly, any sequence which begins with the connection of parts 6 and 7, the nut and bolt, is not a valid sequence as the bolt must pass through the bracket, pedal, spacer, and bushings before the nut to bolt connection can be made.

Despite this shortcoming, the connection matrix does provide insight into one aspect of assembly, that being the selection of a "base" part. A base part is typically viewed as the first part in the assembly sequence, and has other components assembled to it. Candidate base parts are those parts which have a



PART NUMBER

PART NUMBER	1	2	3	4	5	6	7	8
1			O	O		O	O	
2			X		O	O		X
3	O	X				O		
4	O				X	O		
5		O		X		O		
6	O	O	O	O	O		X	
7	O					X		X
8		X					X	

PART KEY
1-- BRACKET ASM.
2-- PEDAL ASM.
3-- LH BUSHING
4-- RH BUSHING
5-- SPACER
6-- BOLT
7-- NUT
8-- PAD

O = contact
X = connection

Figure 2.2: Brake Pedal Assembly Drawing and Connection Matrix

high degree of connectivity to other parts. This information can be extracted directly from the connection matrix, though it provides no information about the ability to fixture or jig the base part.

2.2 PRECEDENCE DIAGRAM

As mentioned previously, the precedence diagram is used extensively by manufacturing engineers for assembly analysis. Its use in applications is presented in Section 2.4. Despite its frequent use in industry since the late 1950's, no structured or rigorously defined method exists for the construction of the diagram.

Development of the precedence diagram begins with a listing of the assembly work elements, that is, all the minimum rational elements or operations required to complete the product assembly. An element listing for the steering column subassembly is provided in Table 1.

ELEMENT NO.	ELEMENT DESCRIPTION
1	PLACE COLUMN IN FIXTURE
2	PAINT COLUMN
3	STEERING WHEEL AND NUT TO COLUMN
4	SUPPORT BRACKET AND TWO BOLTS TO COLUMN
5	SECURE TWO BOLTS
6	FINGER START ONE BOLT TO COLUMN
7	FINGER START ONE BOLT TO COLUMN
8	SECURE ONE BRACKET BOLT
9	SECURE ONE BRACKET BOLT
10	FEEL FOR BRACKET SECURENESS
11	INSTALL TILT LEVER TO COLUMN
12	INSTALL TURN/CRUISE LEVER TO COLUMN
13	INSTALL HAZARD KNOB TO COLUMN
14	SECURE STEERING WHEEL NUT
15	INSTALL RETAINER CLIP TO COLUMN
16	INSPECT FOR PRESENCE OF RETAINER CLIP
17	PUSH ON HORN PAD
18	SECURE TWO SCREWS TO HORN PAD
19	FEEL FOR SECURENESS OF HORN PAD
20	ELECTRICAL TEST
21	ASSEMBLY COMPLETE

Table 1: Steering Column Subassembly Work Elements

The assembly drawing for the steering column is shown in Figure 2.3. Minimum rational elements are defined as "indivisible elements of work or natural minimum units beyond which minimum assembly work cannot be defined rationally"[3]. This allows the practitioner to tailor the element listing to the specific assembly or product being analyzed.

The next step in the construction of the precedence diagram is the selection of work elements that can be performed first. Typically, this involves fixturing of a major component, such as a frame, at the start of the assembly line. This component is often referred to as the "base" part, discussed in the previous section. For example, in the case of the steering column subassembly, the best candidate first element is element 1, place column assembly into fixture, because of its high degree of connectivity with the other components.

The candidate first element or elements, each represented by a numbered node, are placed to the left of the diagram. Then, for each element remaining on the element listing, the question is asked " Are all the elements which must precede this element already entered on the diagram?" Again, referring to the steering column, element 1 is placed to the left. The elements which have element 1 as their only predecessor are elements 2 and 4. These two elements are placed to the right of element 1 on the diagram (See Figure 2.4), and lines are drawn from the element 1 node to nodes 2 and 4. This notation indicates that element 1 must be done before element 2 or element 4 may be done. To carry this example one step further, the elements which may be completed after element 2, the paint operation, are elements 3, 11 ,12, and 13. The levers and steering wheel operations must be preceded by paint so as to prevent paint overspray onto these parts. The complete diagram is shown in Figure 2.4.

[3]Prenting, T.O. and Battaglin, R.M., "The Precedence Diagram: A Tool for Analysis in Assembly Line Balancing," Journal of Industrial Engineering Vol. XV, No. 4, P. 210, July-August, 1964

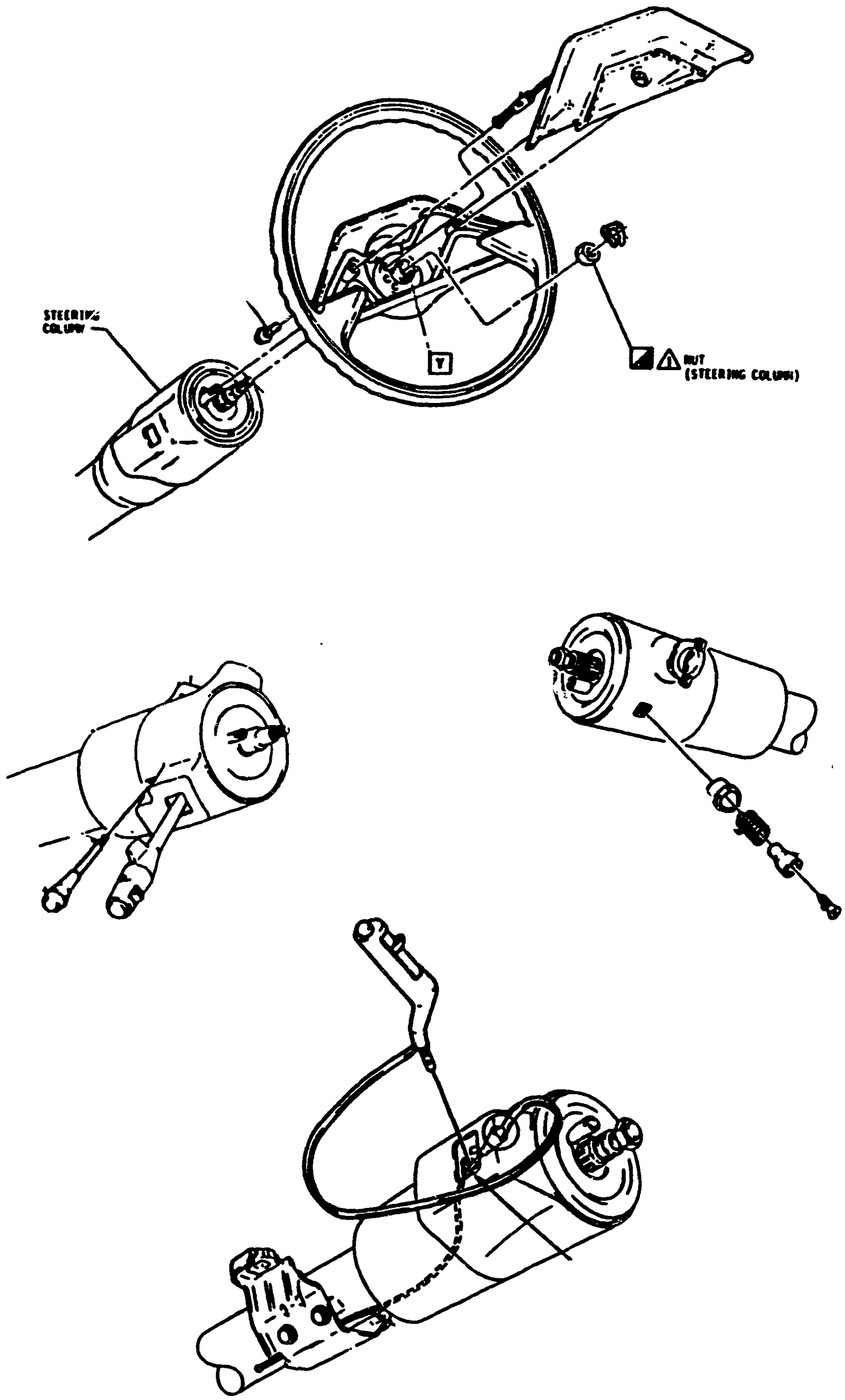


Figure 2.3: Steering Column Assembly Drawings

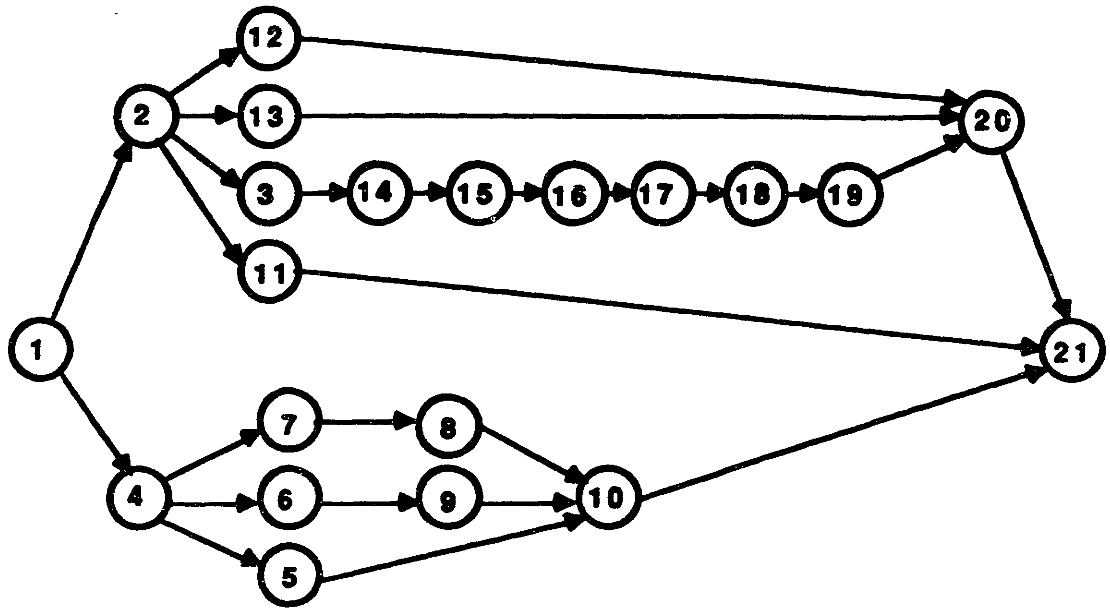


Figure 2.4: Steering Column Precedence Diagram

The diagram is read from left to right and no element may be completed until all its immediate predecessors are done. For example, element 20 may not be done until elements 12, 13, and 19 have been done.

Several extensions to the precedence diagram are offered by Prenting and Battaglin [1964]. They discuss the incorporation of aspects such as on-line subassembly, facility restrictions, and artificial restrictions. This is accomplished by incorporating coded information, regarding positional information about operator-product or operator-line relationships, to each node on the diagram. The incorporation of this information and its application by manufacturing engineers is addressed in Section 2.4.

2.2.1 Advantages and Limitations

The precedence diagram contains information that can not be extracted from the connection matrix discussed earlier in this Chapter. First of all, the precedence diagram uses operational level detail about the assembly rather than simple contact or connection information. Second, it also addresses the restrictions on the possible ordering of assembly. While the connection matrix provides no information about the valid sequences of the contacts or connections, the nodal relations in the precedence diagram constrain the allowable sequences of assembly.

The precedence diagram, however, is not without its shortcomings, which can be placed into two categories, lack of structure in diagram creation and lack of uniqueness. The first addresses the lack of a formal structure or algorithmic nature in the development of the precedence diagram. It is frequently discussed and applied, but its creation or development is seldom described. The ability to construct a precedence diagram for a particular assembly is assumed. The most detailed discussion of the precedence diagram is done by Prenting and Battaglin. Still, there is no algorithmic basis for the creation of the precedence diagram.

The second shortcoming is that the precedence diagram is not a unique representation of the assembly. In other words, one precedence diagram does not represent all possible or physically realizable assembly sequences for a given product. Once a base or first part has been selected, many of the assembly sequences are eliminated. This evaluative step severely constrains the number of assembly sequences the diagram can represent, as there are often several parts which could be first in the assembly sequence. Thus, it takes several individual precedence diagrams to represent all possible sequences for a product. There are also several assembly constraints that the precedence diagram simply cannot represent. These constraints involve specific combinations of precedence relations between elements. Examples of this limitation are provided by De Fazio and Whitney [1986].

2.3 PARTS TREE

The third diagrammatic representation of assembly is the parts tree. It differs from the previously discussed graphical representations in both the method of construction and the information it contains. The construction of the parts tree begins after a candidate assembly sequence has been already been determined. The parts tree is typically used to identify problem areas with a potential assembly sequence as well as point out possible solutions to the problems. Parts are represented as branches and junctions or nodes constitute the marriage or joining of parts. Two examples will assist in clarifying their construction.

Figure 2.5, on the following page, shows a very simple parts tree consisting of the assembly of four individual parts. The assembly sequence has already been determined to be part A first, followed by part B, part C and part D respectively. The diagram is read from left to right with part A being the first branch. The first assembly operation is the assembly of part A to part B. This is represented by a node connecting the branches of parts A and B. The succeeding node connects the branches of parts A and B, which have already been mated, and the branch extending to part C. Finally, the assembly is completed by the addition of part D to the subassembly consisting of parts A, B, and C.

The parts tree for a more complex product, that being an automobile alternator, is shown in Figure 2.6. Several alternative assembly sequences were identified for the alternator and parts trees were drawn for each. This parts tree was constructed by Whitney [1979] for an assembly analysis of the product. As in the previous example, the nodes or branch junctions represent the joining of parts. The fan spacer, fan, pulley, lockwasher, and nut are assembled in order much like the simpler example. It is at this point that the two examples differ. The front housing, bearing, retainer, and short screws are assembled in order,

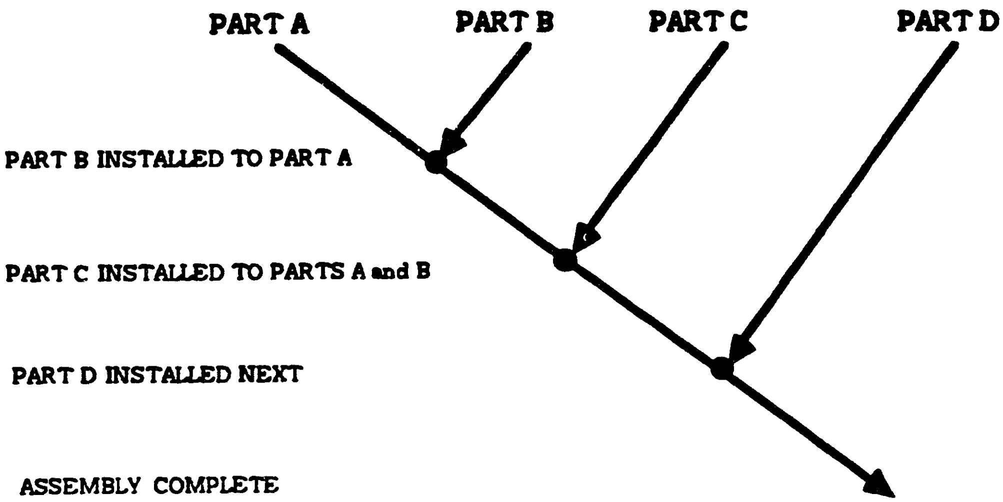


Figure 2.5: Simple Parts Tree

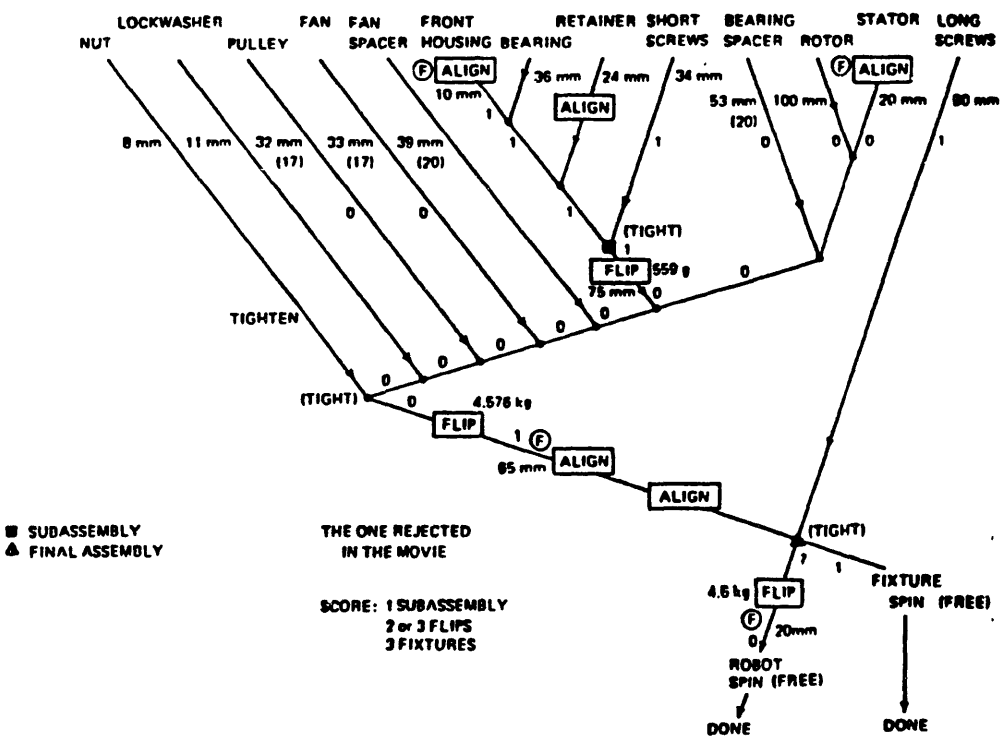


Figure 2.6: Parts Tree Representation of a Subassembly

Source: Draper Report, R-996

but as a separate subassembly. These are highlighted in Figure 2.6. This entire subassembly is then mated to the other components. The remainder of this parts tree is quite straight forward.

Thus, the parts tree can graphically represent a wide variety of assembly orders, including those which utilize subassemblies. Beyond the simple graphical representation of branches and nodes, additional information regarding in process part orientation, fixturing requirements, and the interaction of automation with the assembly can be included. The incorporation and application of this supplemental detail by manufacturing engineers will be discussed in Section 2.4.

2.3.1 Advantages and Limitations

The parts tree is yet another graphical representation of assembly, and, for a given product, there can be many parts trees. The primary disadvantage of parts trees is that they express only one possible assembly sequence per diagram. The assembly sequence must be determined prior to the construction of the diagram, thus it does not represent the available choices of assembly order.

Though they express only one of many possible assembly sequences for a given product, parts trees are a convenient and compact representation of a particular assembly sequence. They allow the manufacturing engineer to easily visualize the order of assembly. When provided with supplemental detail, parts trees are a useful tool for comparing several alternative sequences.

2.4 APPLICATION OF DIAGRAMMATIC REPRESENTATIONS

Diagrammatic representations of assembly have seen extensive application by manufacturing engineers in the planning of production assembly systems. Two of the three representations described in this chapter, namely the parts tree and the precedence diagram, are frequently employed. The third diagrammatic representation, the connection matrix, has not been usefully applied by industry. This is primarily due to the limited information that can be extracted from the matrix. Assembly sequences may be generated directly from the connection matrix, however it can not be determined if these are physically realizable sequences.

The parts tree has been usefully applied as an assembly planning tool. Several alternative assembly sequences for a product are determined and placed into the skeletal branch and node network, discussed in the previous section. The application of the parts tree is in three basic areas, sequence problem identification, problem resolution, and final sequence selection.

From the skeletal form, supplemental detail or information about the assembly requirements is selectively placed on the nodes and branches of the diagram. There are no restrictions as to the type of detail which can be added. Examples include part fixturing, part orientation for assembly, part insertion depth, subassemblies, or required automation motions. Several of these are shown in Figure 2.7 on the following page.

The supplemental information is useful in identifying a variety of problems or inefficiencies in a potential sequence. In the area of problem identification, the parts tree can be of assistance in pointing out specific design problems which may aid the assembly process. Other judgement criteria are also applied as to the cycle time, special tooling, non-assembly operations, and fixturing requirements of each sequence. Useful subassemblies are easily recognized from the parts tree. Finally, based on the specific judgement criteria, the manufacturing engineer selects the best candidate sequence. For example, in the case of the automobile alternator shown in Figure 2.7, Whitney uncovered a more desirable assembly sequence after several iterations. The parts tree was utilized to identify several design changes which reduced overall parts count, but did not affect product function. Finally, a candidate sequence was selected among several valid parts trees, which required no assembly reorientations and required only one direction for part insertion.

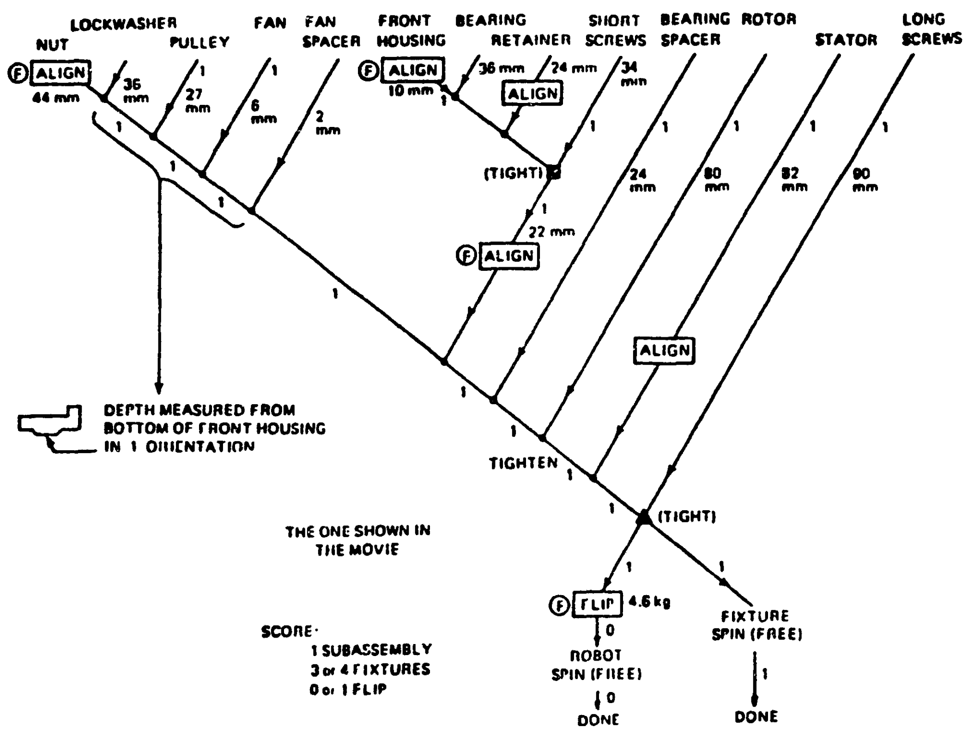


Figure 2.7: Detailed Parts Tree Representation

Source: CSDL Report R-996, 1979

Again, the part tree is applied after several valid alternative assembly sequences have already been determined. The basic structure of part branches and nodes is created for each sequence, and then supplemented with other pertinent information. The manufacturing engineer utilizes this completed diagram to identify areas for potential design changes. After all design iterations are done, the parts tree is a useful tool for the comparison to other candidate sequences. Finally, based on the judgement criteria applied, a fina' assembly sequence is selected.

By far, the most frequently applied diagrammatic representation of assembly is the precedence diagram. It is used almost exclusively as a line balancing tool. In order to accomplish this task, the basic network of nodes and arrows, described in Section 2.2, is supplemented with three types of information: assembly time for each element or node, facility restrictions, and operator-part restrictions. Assembly time consists of the total time duration required to complete an element in the element listing and is typically expressed in hundredths of a minute. Facility restrictions are limitations placed on certain elements which require their completion be done in a specific station or series of stations. For example, the location of a particular machine or test station may require that a specific element be done only in several selected stations. Finally, operator-part limitations, also known as positional restrictions, are associated with access restrictions for particular elements. For example, a restriction may be characterized as "front of assembly" meaning that the specific work element may be performed by an operator only on the front of the assembly. By the same token, work content that is done on the rear of the assembly will not be assigned to the same station.

The computer planning aids which employ precedence diagrams, such as CALB (Computer Aided Line Balance), require that both the precedence information as well as the supplemental information be entered in a usable format. The necessary information for each element is codified. The information for each node or element consists of its immediate predecessors, those elements which must precede its completion, assembly time, positional restrictions, and facility restrictions. Immediate predecessors are represented by their node number from the element listing and assembly time given hundredths of a minute. The other information is coded by a letter, such as F, for positional restrictions, and by a series of station numbers in the case of facility restrictions. Finally, maximum station cycle time is supplied.

CALB iterates through the sequence alternatives in search of the sequence which provides the most efficient use of labor and a minimum amount of idle time for the entire assembly system, yet does not violate the positional or facility constraints provided by the user. Line balancing is discussed in detail by Polk [1985]. The program output is an element listing or work content for each assembly station.

While the solution provided by the computer line balancing aids provides a solution with a minimum amount of system unbalance time, the method does have several shortcomings. First of all, line balance is primarily suited to assembly systems consisting of manual work stations only. In this case, the minimum manpower results in the lowest unit assembly cost. The planning aids do not account for the non value added work content which results from selecting a particular sequence alternative, such as frequent tool changes or additional walk time. Also, consideration of other judgement criteria, such as part orientations, ability to automate, accessibility, or special tooling requirements are not included. In an effort to overcome these shortcomings, the manufacturing engineer typically rearranges the work content after the line balance program has been run in order to accommodate the other considerations.

3.0 LIAISON SEQUENCE ANALYSIS

The previous chapter presented three graphical representations of assembly that have been frequently applied by manufacturing engineers. The most popular technique, the precedence diagram, is used extensively as a line balancing tool with several computer aids being available. As mentioned earlier, there is no one unique precedence diagram for a particular assembly, and therefore it cannot, in general, represent all possible assembly sequences. The result is that an efficient alternative sequence may be overlooked. This chapter will present a new technique, introduced by Bourjault, that generates all possible assembly for a particular product. The beauty of the approach is that it is entirely algorithmic, and reduces to a series of yes and no questions. The response to each question is supplied by the engineer based on knowledge of the geometric relationships between parts. The second part of this chapter will present a modification of this technique offered by De Fazio and Whitney, which reduces the number of questions required to properly define assembly precedence constraints, yet keeps the algorithmic nature of the technique.

3.1 BOURJAULT METHOD

Alain Bourjault, in his PhD. thesis [1984], presents a method of generating all possible assembly sequences for any given assembly. Utilizing the information from an assembly drawing or a parts list, the method begins by creating a graphical representation of the assembly. Each individual part is identified by a node and its accompanying part name. Bourjault completes the assembly representational network, called a liaison diagram, by establishing arcs or liaisons between nodes (parts) which have a physical relationship to one another. The example used by Bourjault, the assembly of a ball point pen, is shown in Figure 3.1.

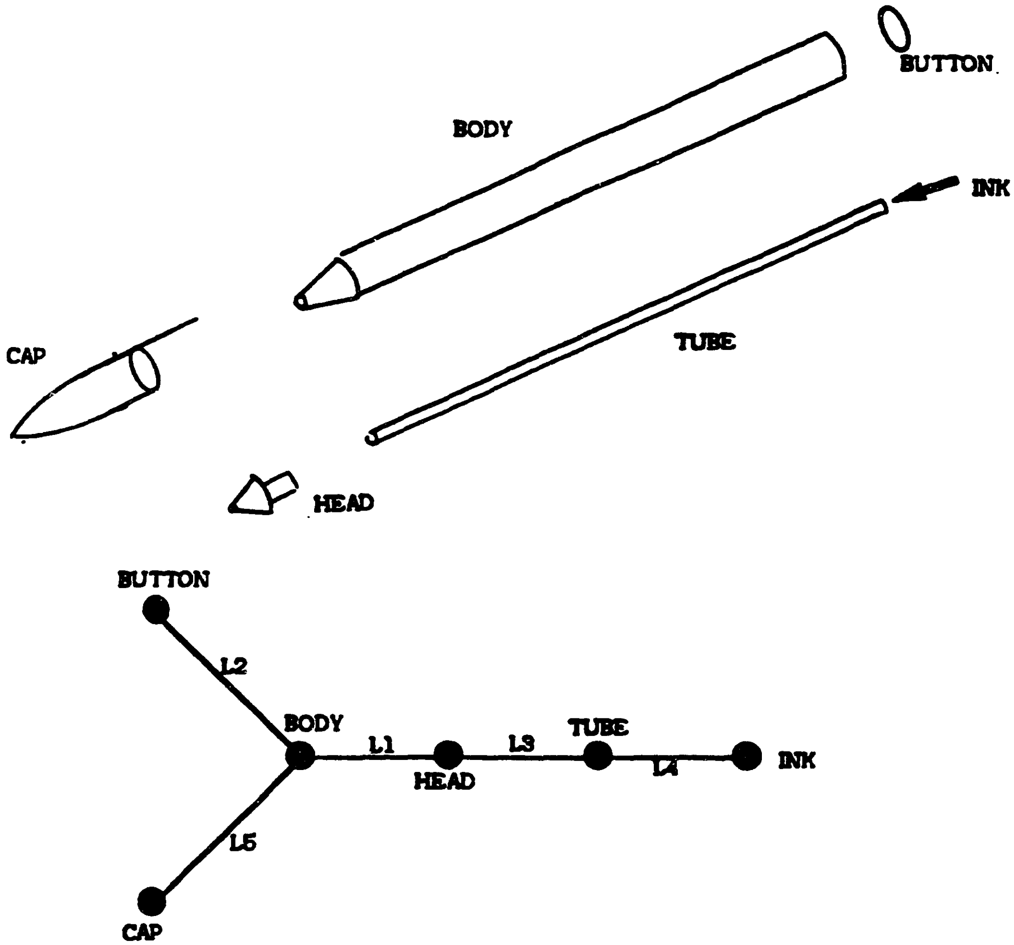


Figure 3.1: Ball Point Pen Example

Source: Alain Bourjault, 1984

Examples of liaisons include physical part to part contact or connection, interference fit between parts, or pass through without touching, such as a bolt passing through a hole. Each liaison is assigned a number for reference use later in the generation process. Much of this information can be extracted from a connection matrix, discussed in Section 2.1, however the definition of what constitutes a liaison is not made explicit by Bourjault. The application of liaisons is flexible and can be tailored by the engineer to meet specific needs of the assembly under study.

In the method described by Bourjault, component assembly is viewed as the sequential completion of the liaisons between parts. The next step in the approach is the development of rules which describe the possible states of assembly. The rules or precedence constraints are the result of a series of questions about each of the liaisons described in the liaison diagram.

Bourjault exhaustively determines the forbidden orders or partial orders of assembly by a series of questions which are structured in modules. The response to each of the questions is either a "yes " or "no", and this response dictates what subsequent action must be taken. The questions used in this technique are of two basic types:

Question 1: Is it true that liaison L(i) can be established if liaisons (L(j), L(k)) have already been established?

Question 2: Is it true that liaison L(i) can be established if liaisons (L(j), L(k)) have not already been established?

The liaison grouping (L(j), L(k)) is referred to as the "body" of the question. The body can consist of a single liaison or a group of liaisons. The flow chart for the question and answer process is shown in Figure 3.2. The first level of questions addresses only pairs of liaisons, and precedes the questions in the individual modules. A "no" response to a question asked in the first level results in the omission of the liaison from the body of the question in Module 1. Thus, Module 1 will contain (L-1) liaisons in the body of the question, unless a "no" response is obtained from the first level of questions. In that case, the body of the question in Module 1 will have (L-1-No. of "no" responses) liaisons.

The response to a question in Module 1 dictates that one of two types of action be taken. A "no" response in Module 1 means that a precedence rule or constraint for the assembly may be written. A "yes" response dictates that the

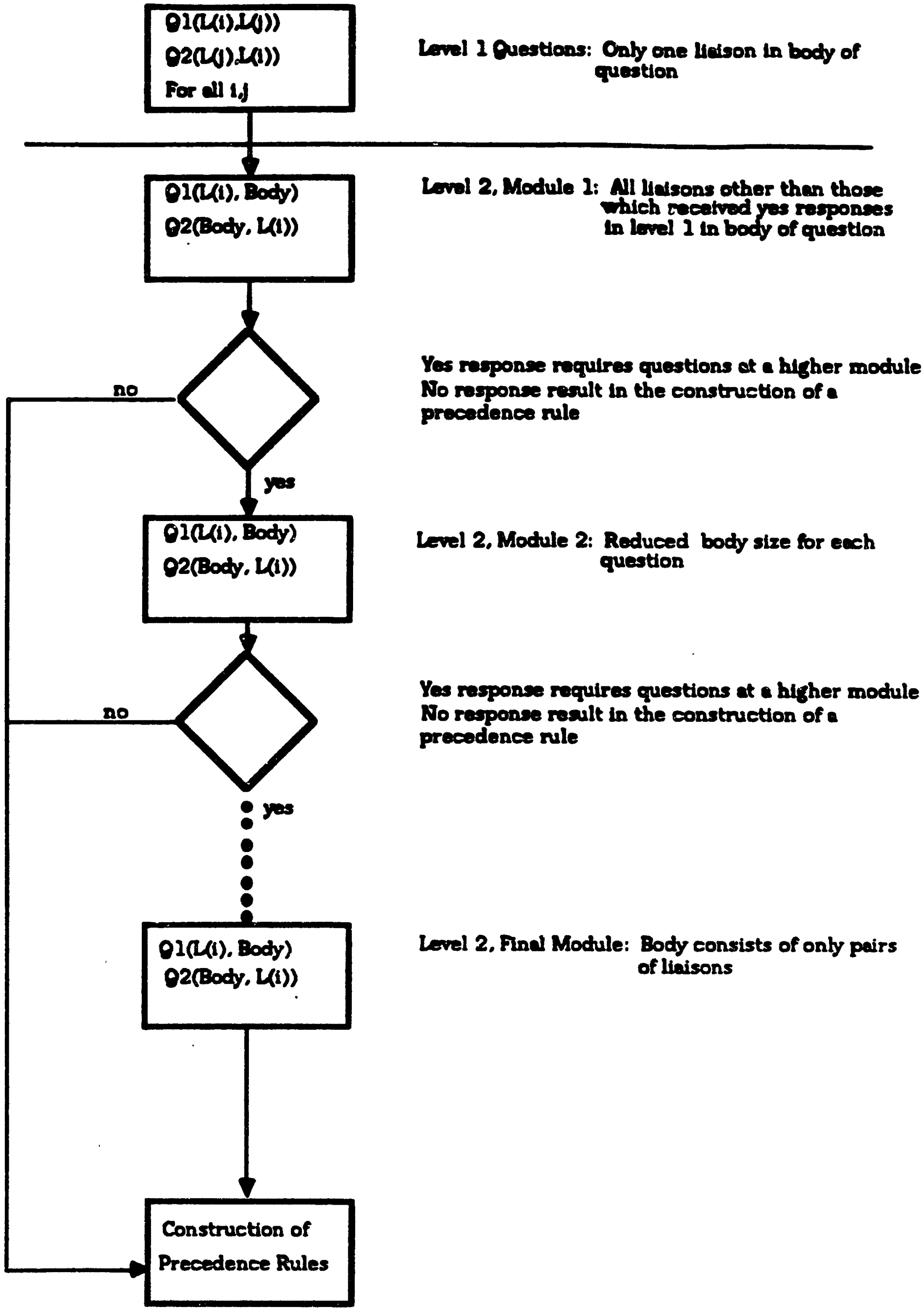


Figure 3.2: Question and Answer Flow Chart

questioning progress to the next module, which will have a reduced number of liaisons in its body. This process continues until either no further questions are required, because only precedence constraints result from the questions, or the body of the higher order module reduces to a question regarding just a pair of liaisons.

Once the precedence constraints have been determined, Bourjault generates the valid assembly sequences. They are represented in terms of an inverted tree which describes the possible orders of assembly. The origin for the inverted tree is a state of disassembly, or in other words, a state where no liaisons have been completed. The next level contains the liaisons which may be completed first. In the case of the ball point pen, they are liaisons 1, 2, and 3. The next level consists of the liaisons which may follow those identified as first. This process is continued until all liaisons have been completed. The complete inverted tree representing all possible sequences for the ball point pen is shown in Figure 3.3.

3.1.1 Advantages and Limitations

Clearly, the real strength of the assembly sequence enumeration technique is its rigor. The format and order of the questions guarantee that all interaction and precedence constraints between liaisons are identified. Once all precedence constraints have been defined, enumeration of alternative assembly sequences is also a very straight forward process.

It is the rigor of the question and answer portion of Bourjault's technique that makes its application on assemblies with large parts counts both cumbersome and tedious. If L is allowed to denote the number of liaisons, the number of questions resulting from the first level is:

$$\text{First Level Questions} = 2L^2$$

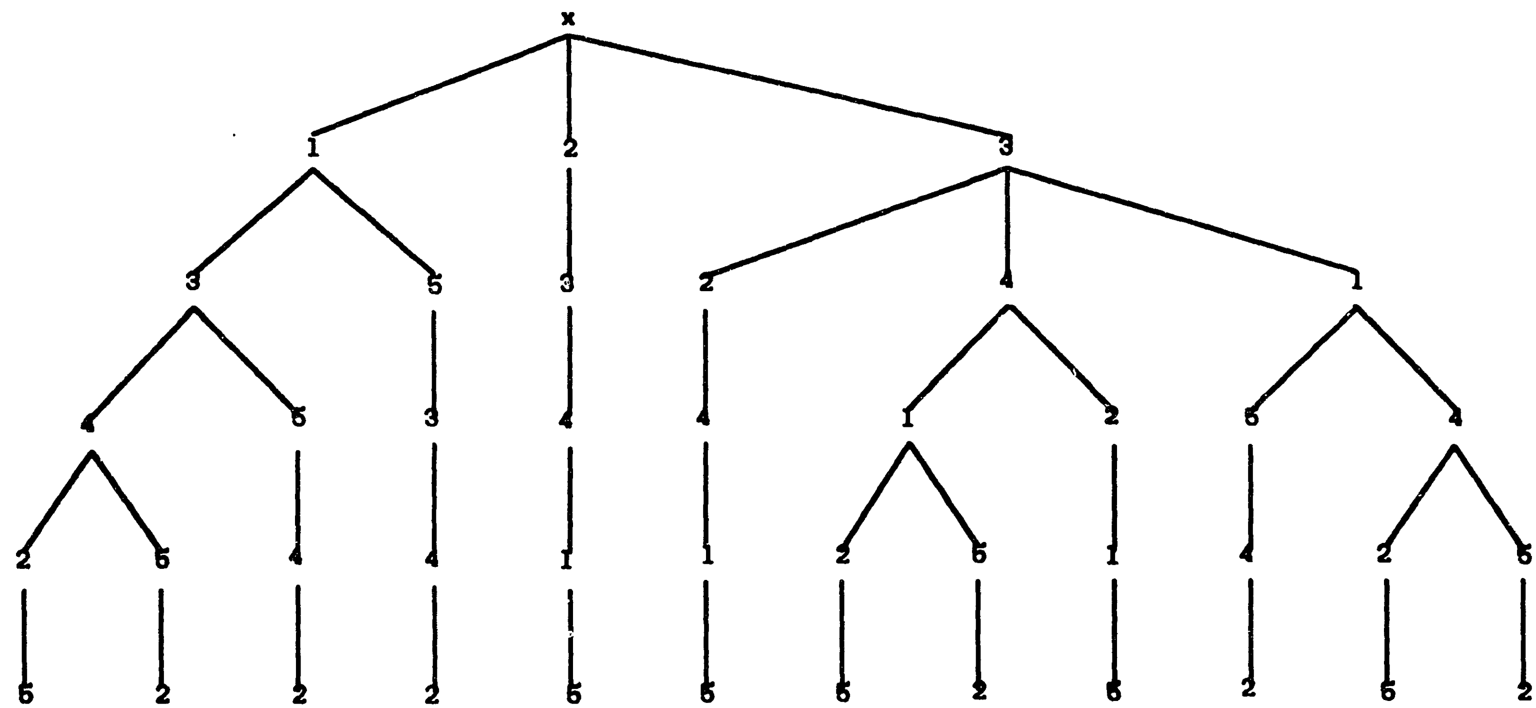


Figure 3.3: Inverted Tree Representation of Assembly
Source: Alain Bourjault, 1984

The first level defines precedence relations between each pair of liaisons and is the same for any assembly. The number of questions required in second level varies with the responses at the first level, i.e., all "no" responses in Module 1 complete the definition of the precedence constraints, "yes" responses require additional questions at Module 2. Therefore, the minimum number of questions required in Module 1 is:

$$\text{Minimum Module 1 Questions} = 2L$$

The limiting case for the number of questions required to define the assembly is dependant on the question responses in Modules 1 through L, but cannot exceed:

$$\text{Maximum Number of Questions} = L2^{L}$$

Thus, the number of questions, required to properly specify all precedence constraints in the method presented by Bourjault is:

$$2L^{2} + 2L \leq \text{Questions Required} \leq L2^{L}$$

Table 2, on the following page, exemplifies how quickly question count grows with liaison count. Though Bourjault's method is algorithmic and forces the practitioner to evaluate all possible interactions between pairs and groups of liaisons, it has limited application on more complex assemblies of perhaps seven or more liaisons, because of the required number of questions.

3.2 SIMPLIFIED GENERATION OF ASSEMBLY SEQUENCES

Though the sequence generation technique presented by Bourjault is both well structured and rigorous, the sheer volume of questions required to properly define the precedence relations between mates prohibits its application on assemblies with large part counts. De Fazio and Whitney [1986] have modified the question and answer portion of Bourjault's method in order to reduce the number of questions.

	Number of Questions	
Liaisons	Minimum	Maximum
4	40	64
5	60	160
6	84	384
7	112	896
8	144	2048
9	180	4608
10	220	10240
11	264	22528
12	312	49152
13	364	106496
14	420	229376
15	480	491520

Table 2: Minimum-Maximum Liaison Question Count

Source: T. L. De Fazio, Internal Draper Memo, May 1986

The simplified technique also begins with a graphical network of nodes and liaisons, representing parts and relationships between parts respectively. As in the method shown by Bourjault, nodes are labeled with their appropriate part name and liaisons are assigned a number. It is at this point that the simplified generation method departs from that of Bourjault.

The revision, which permits a reduced set of questions, is the modification or rephrasing of the questions pertaining to the liaisons. The questions are of two forms:

For all liaisons i= 1 to n

Question 1: What liaison or liaisons must be established before liaison L(i) can be established?

Question 2: What liaison or liaisons must not be established so that liaison L(i) can be established?

It should be clear that the response to these questions is no longer a "yes" or "no". Instead, the response is directly expressed as a precedence constraint between either a pair of liaisons or between an individual liaison and a group of liaisons. The response is represented as a set of Boolean Algebra expressions such as those shown below:

Answer 1: (L8 and L2) > L1

Answer 2: L1 > L5

These expressions are read as, both liaison 2 and liaison 8 must be established before liaison 1 can be established. Similarly, the second expression is read as, liaison 1 must precede or be established before liaison 5 can be established. The individual responses can then be combined into one diagram which describes the precedence relationships for the entire assembly. Two examples will be used to help clarify the application of the modified technique. The first example is that of the ball point pen discussed in the previous section, and the second example is of the steering column subassembly introduced in Section 2.2.

As in the technique described by Bourjault, the assembly is characterized by a network of nodes and liaisons. The liaison diagram for the ball point pen is repeated in Figure 3.4. The next step in the generation process is the determination of the precedence constraints derived from the responses to the modified questions. The definition of these constraints begins on the following page.

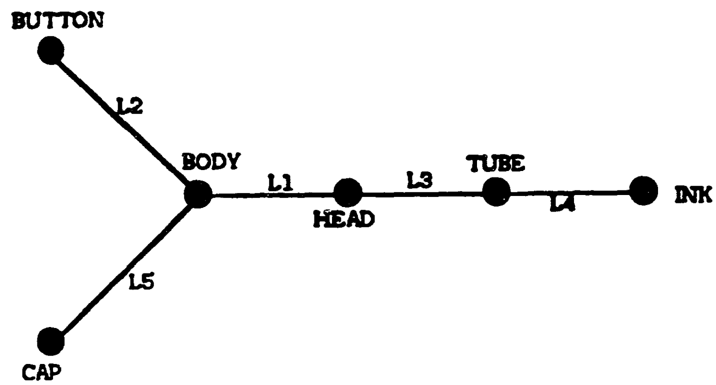


Figure 3.4: Ball Point Pen Liaison Diagram

Source: Alain Bourjault, 1984

Question 1: What liaison or liaisons must be established before liaison L(i) can be established?

Response:	i= 1	No liaison must be established before liaison 1	(R1)
	i= 2	No liaison must be established before liaison 2	(R2)
	i= 1	No liaison must be established before liaison 3	(R3)
	i= 4	L3 > L4, Head to tube must precede ink into tube	(R4)
	i= 5	L1 > L5, Head to body must precede cap to body	(R5)

Question 2: What liaison or liaisons must not be established so that liaison L(i) can be established?

Response:	i= 1	L1 > L5, identical constraint to that above	(R6)
	i= 2	No liaison must be unestablished so L2 may be done	(R7)

i= 3 L3 > (L1 and L2) Note: This notation means that L3 must be established before both liaisons 1 and 2 are established. L3 does not have to precede them individually. (R8)

i= 4 L4 > (L1 and L2) Note: Similar to the constraint described above. The ink cannot be put into the tube if <u>both</u> the head is on the body, and the button is on the body. (R9)

i= 5 No liaison need be unestablished so that L5 can be done. (R10)

Two comments are worthy of noting before continuing with this example. First, it is necessary to clarify the meaning of the third and fourth responses to question 2. The Boolean expression L3 > (L1 and L2) means the head to tube must be done prior to the completion of both the head to body and the button to body liaisons. Liaison 3 can be done as long as one or both liaisons 1 and 2 are incomplete. Second, the combination of responses R4 and R9 eliminates the need to express response R8 as a separate precedence constraint. Response R4 requires L3 to precede L4 and response R9 requires L4 to be completed before both L1 and L2 are done, so L3 necessarily precedes L1 and L2. The complete set of precedence constraints for this assembly is shown below:

L3 > L4 > (L1 and L2)

L1 > L5

The final step in the process is to generate the valid assembly sequences based on the stated precedence constraints. It begins by determining which liaisons may be established first, or in other words are unprecedented. In the case of the ball point pen, the candidate first liaisons are L1, L2, and L3. While Bourjault uses an inverted tree to describe all possible assembly orders, De Fazio and Whitney employ a more compact notation, which treats assembly as a series of state transitions starting with a completely disassembled product and concluding with one that is fully assembled. At the first level of the state-space diagram are states showing the completion of liaisons 1, 2, and 3. (See Figure 3.5). The next step is to determine the next attainable state of assembly. This is accomplished by evaluating which liaisons may follow each of the first assembly states. For example, once liaison L1 has been established, the next liaisons which may be completed are liaisons L3 and L5. For liaison L2, only L3 can be the next liaison completed as L1 cannot be done until L4 has been done. Completing the second level of the diagram, liaison L3 may be followed by either L1, L2, or L4. The completed state space representation of valid assembly sequences is shown in Figure 3.5. An acceptable sequence is any path originating at the disassembled state and ending at the bottom where all liaisons have been completed.

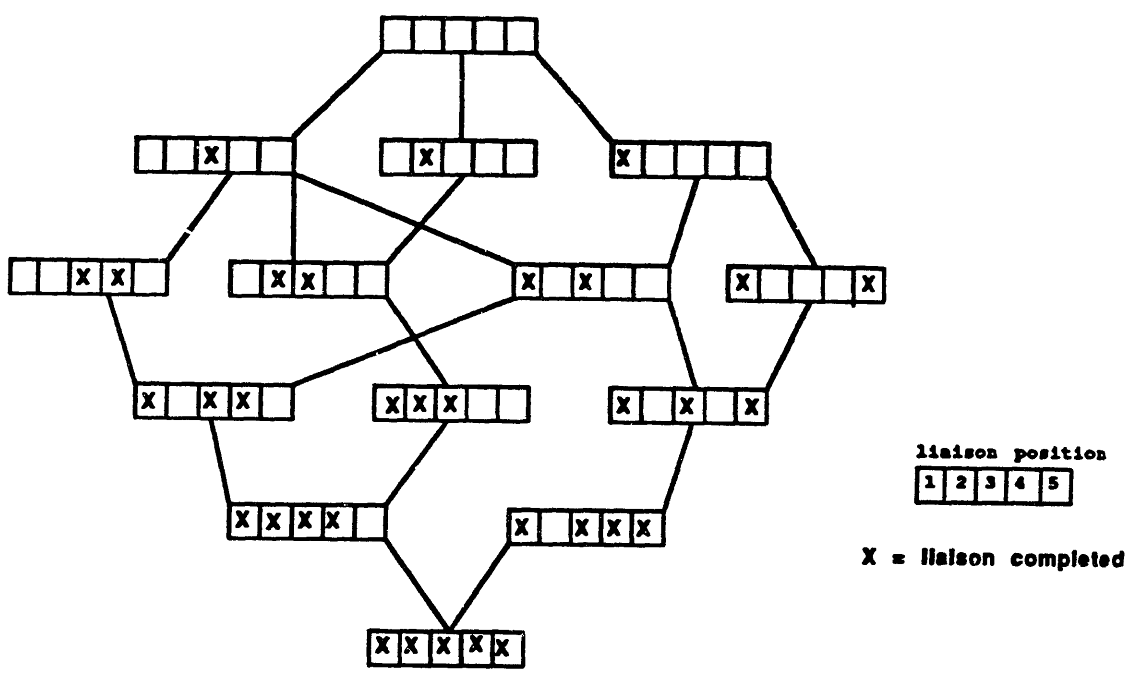


Figure 3.5: State-Space Representation of Assembly

Source: T. L. De Fazio, Internal Draper Memo, May 1986

The second example, the steering column subassembly, is taken from production of the 1985 GM20. The liaison diagram, shown in Figure 3.6, consists of 12 nodes and 15 liaisons, as the four bolts used to attach the bracket to the column assembly are represented by a single node. The determination of the assembly precedence constraints by the algorithmic question and answer process follows:

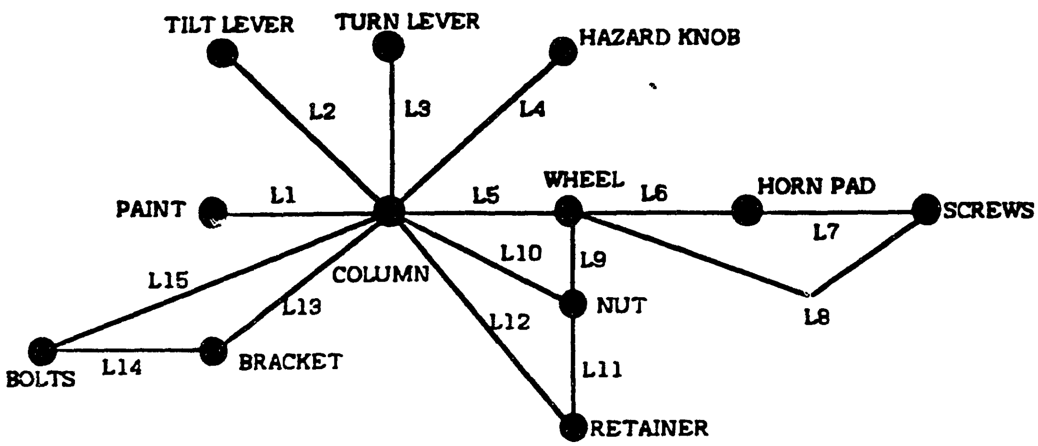


Figure 3.6: Steering Column Subassembly Liaison Diagram

Question 1: What liaison or liaisons must be established before liaison L(i) can be established?

i= 1 No liaison must be established before liaison 1

i= 2 L1 > L2

i= 3 L1 > L3

i= 4 L1 > L4

i= 5 L1 > L5

i= 6 L9 > L6

L11 > L6

i= 7 L6 > L7

i= 8 No liaison must be completed before liaison L8

i= 9 L5 > L9

i= 10 L5 > L10

i= 11 (L9 and L10) > L11

i= 12 (L9 and L10) > L12

i= 13 No liaison must be completed before liaison L13

i= 14 No liaison must be completed before liaison L14

i= 15 (L13 and L14) > L15

Question 2: What liaison or liaisons must not be established so that liaison L(i) can be established?

i= 1 L1 >L2 Note: This is to assure adequate paint coverage.

L1 > L3

L1 > L4

L1 > L5

i= 2 No liaison need be unestablished so that liaison 2 can be done

i= 3 No liaison need be unestablished so that liaison 3 can be done

i= 4 No liaison need be unestablished so that liaison 4 can be done

i= 5 L5 > L10

L5 > L12

i= 6 L6 > L7

i= 7 No liaison must be unestablished so that liaison 7 can be done

i= 8 No liaison must be unestablished so that liaison 8 can be done

i= 9 L9 > L6

L9 > (L5 and L12)

i= 10 L10 > L12

L10 > (L5 and L6)

i= 11 L11 > (L6 and L9)

i= 12 L12 > (L5 and L6)

i= 13 L13 > L15

i= 14 L14 > L15

i= 15 No liaison must be unestablished so that liaison 15 can be done

These sequence constraints are summarized in Figure 3.7, on the following page. The generation process from this diagram is identical to the method discussed for the ball point pen. Upon inspection of this diagram, there are two points worth noting. First of all, this diagram identifies three parts, namely the column, bracket, or bolts as candidate first or base parts. These parts are associated with candidate first liaisons. This exemplifies the increased strength of this method of generating sequences over that of the precedence diagram. It would require several precedence diagrams to describe all the valid assembly sequences for this product, each originating from a different base part (See Section 2.2).

The second item worth noting deals with the topology of the graphical liaison diagram. Referring again to Figure 3.6, the diagram shows several "closed loops" of liaisons, like those between the column, bracket, and bolt nodes. The point worth noting is that the completion of two of the three liaisons in this loop implies that the third liaison must have also been completed. For example, if liaison L13, bolts to bracket is completed first, and then liaison L14 is completed, it is necessarily true that liaison L15 has been completed simultaneously with L14 This is dictated by the physical relationship of the parts.

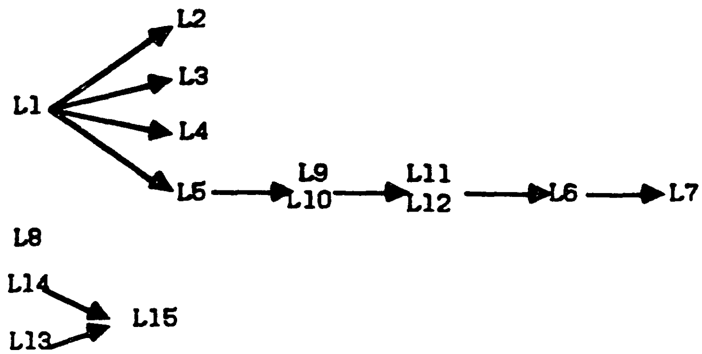


Figure 3.7: Summary of Steering Column Subassembly Precedence Constraints

3.2.1 Advantages and Limitations

The clear advantage of the simplified assembly sequence generation method over that presented by Bourjault is the reduced question set required to define precedence relations. For all assemblies analyzed by the simplified technique the question count is 2L, where L is the number of liaisons in the graphical representation. In the case of the steering column assembly, it required exactly 30 questions, where by the other technique, a minimum of 480 questions would have been required. It is also important to note that while the questions have been modified, the simplified technique maintains its algorithmic nature.

It could be said that, while the question set has been reduced, the response to the modified questions is much more complex or difficult. In fact, the information or knowledge required to answer either the modified question set or those presented by Bourjault is the same. The thought process used by the engineer or assembly planner is very similar to the questions of the simplified technique.

De Fazio and Whitney also offer a more compact notation of the allowable assembly states. Bourjault employs an inverted tree to describe the attainable assembly orders. While both are easily generated from the liaison precedence diagram, the state-space representation is better suited to the evaluation of the alternative assembly sequences. This aspect is discussed in detail by De Fazio and Whitney .

Finally, the simplified technique for generating assembly sequences shares a shortcoming with the technique introduced by Bourjault. That shortcoming deals with the level of detail and information provided about the assembly sequence. The liaisons are established for parts which have a "functional" relationship to one another. There are, however, many assembly line activities that are not simple part to part mates, typically associated with the establishment of a liaison between parts. Assembly activities, including fastener operations which consist of loose assemble and secure operations, are not adequately defined in the liaison graphical representation scheme. Other tasks, such as inspection and functional test, also play an important role in the selection of alternative assembly sequences. The incorporation of these and other types of operations will be addressed in Chapter 4.

4.0 EXTENSION OF LIAISON SEQUENCE ANALYSIS

The previous chapter introduced two methods of generating all valid assembly sequences for a given product. Each of the techniques, that by Bourjault and the simplified generation technique, address only part to part mates or liaisons. There are, however, many activities or operations which occur on the assembly line that do not include part placement, and therefore do not fit directly into the liaison representational method. This chapter will address the extension of the liaison sequence technique to tasks other than the previously discussed part to part liaisons. The chapter is presented in three sections. The first section discusses prior classifications schemes applied to individual parts, and introduces assembly task classifications offered by other sources. It also presents an alternative classification of assembly tasks based on a survey conducted on the 1985/86 GM20 Steering Column, Instrument Panel, and Engine Dress Area. The second section of this chapter presents a method of incorporating assembly operations, other than part to part liaisons, into the liaison representational scheme. Finally, examples are drawn from industrial applications to clarify several complex cases.

4.1 ASSEMBLY LINE TASK CLASSIFICATION

4.1.1 Prior Part Classification Techniques

Classification or taxonomy has been widely practiced on specific applications of industrial work. Classification is the process in which items are separated into groups based on the existence or absence of characteristic attributes. The majority of effort has focussed on the classification of individual or piece-parts in order to gain insight into part manufacturing and parts feeding requirements. At the root of these classification applications is a coding scheme, which define key geometric and supplementary part attributes.

Several coding systems have been applied to the area of part manufacturing and machining. One of the first was introduced by Optiz [1967, 1970] and utilizes a nine digit code (See Figure 4.1). The first five digits provide geometric information about the part shape, symmetry, and other dimensionless characteristics. The final four digits or the supplementary code provide dimensional, tolerance, and material detail. The part information provided by the Optiz code gives clear indications as to the machine resources, tooling, feed speed, and machining time required to manufacture the specific part.

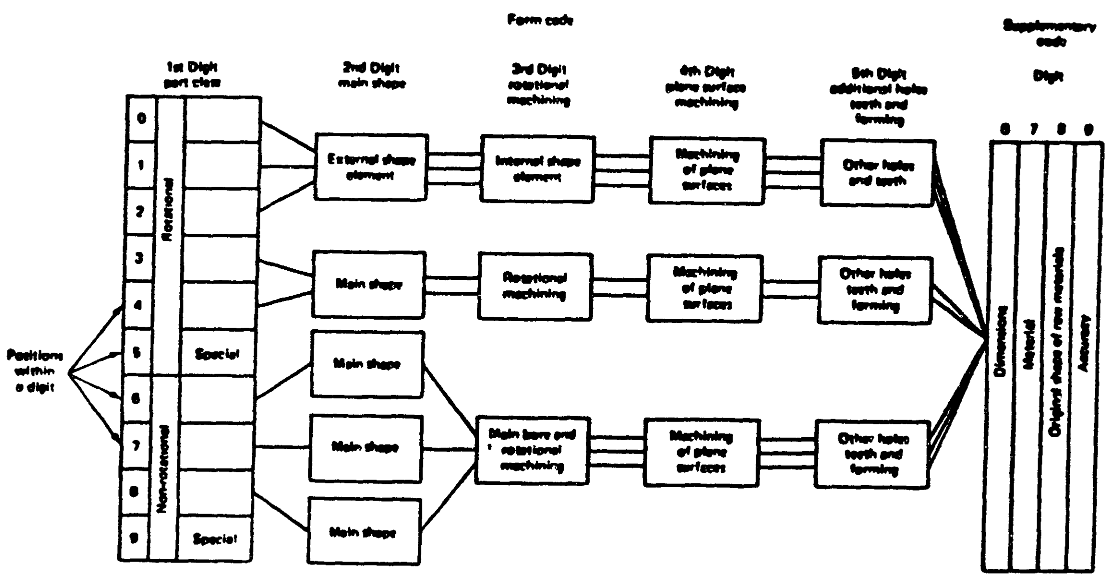


Figure 4.1: Optiz Coding and Classification System

Source: H. Optiz, A Classification System to Describe Workpieces, 1970

Another coding system, KK-3 [Japan Society for the Promotion of Machine Industry 1980] is a general purpose classification and coding system. Parts classified are primarily metal cutting and grinding components. KK-3 employs a 21 digit code and, as a result, can represent more detail than the Optiz code. The first digit classifies the general function of the component while the second digit provides additional functional detail. KK-3 classifies parts as rotational and nonrotational, and unlike the Optiz code, includes some information about the kinds of noncutting processes that are required. Figure 4.2 shows the complete code structure for the KK-3 system.

Digit	Items	(Rotational components)	
1	Parts name	General classification	
2		Detail classification	
3	Materials	General classification	
4		Detail classification	
5	Chief dimensions	Length	
6		Diameter	
7	Primary shapes and ratio of major dimensions		
8	Shape details and kinds of processes	External surface	External surface and outer primary shape
9			Concentric screw threaded parts
10			Functional cut-off parts
11			Extraordinary shaped parts
12			Forming
13			Cylindrical surface
14		Internal surface	Internal primary shape
15			Internal curved surface
16			Internal flat surface and cylindrical surface
17		End surface	
18		Nonconcentric holes	Regularly located holes
19			Special holes
20		Noncutting process	
21	Accuracy		

Figure: KK-3 Coding and Classification Structure

Source: Japan Society for the promotion of Machine Industry, 1980

While several other classification schemes have been employed to parts machining applications, classification has also been applied to the area of individual part handling. The most notable scheme for part feeding is that offered by Seth and Boothroyd [1982]. Separate classifications are employed to describe automatic handling and manual handling. In the case of automatic handling, the three digit code is used to express part attributes. The first digit defines basic part shape as either rotational, triangular and square prismatic, or rectangular. The second and third digits provide additional detail about the shape of the part.

4.1.2 Prior Assembly Task Classifications

As evidenced by the discussion of the previous section, the work regarding classification and codification has centered, almost exclusively, on two major areas, individual part machining and part feeding. One major obstacle in applying codification techniques to assembly is that assembly deals with a number of components in contrast to machining and parts feeding which deals specifically with an individual part. Complications arise because the parameters required to accurately describe assembly are dependent on initial part orientation and order or sequence of assembly. These complications inhibit the use of coding techniques to match parts, assembly tasks, and assembly machines.

Despite these obstacles, the classification of assembly tasks into several groups has been undertaken by several sources. The goal of this classification effort is to provide insight into the assembly requirements of a particular product, such as the assembly devices required and the necessary directions of insertion. A simplistic classification scheme [Buda and Svoboda 1980] is shown in Figure 4.3. Tasks are classified into two major categories, joining and supplementary operations. While this categorization is far from exhaustive, it does identify assembly tasks or operations that are not specifically associated with part mating or joining.

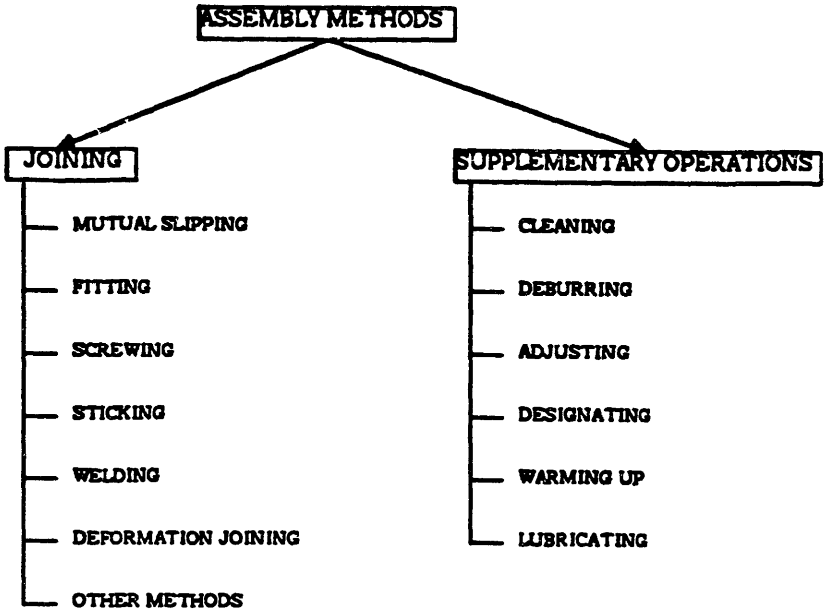


Figure 4.3: Assembly Methods Classification

Source: Buda and Svoboda, 1980

Kondoleon [1976] conducted an assembly analysis of several diverse products in order to determine the assembly tasks and principle insertion directions required to complete the product assembly. The products evaluated by Kondoleon are listed in Table 4.1. The assembly tasks were grouped into the following categories:

A. Simple Insertion

B. Stage Insertion/Push and Twist

C. Multiple Insertion/Alignment

D. Insert Peg and Retainer

E. Screws

F. Force Fit

G. Remove Locating Pin

H. Part Reorientation

I. Provide Temporary Support

J. Crimp Sheet Metal

K. Provide Temporary Support

L. Weld or Solder

M. Test Operation

PRODUCT NAME	NO. OF PIECE PARTS
TIMER COVER	7
TIMER CASE AND FINAL ASSEMBLY	18
REFRIGERATOR COMPRESSOR	26
BIKE BRAKE	15
TRANSFORMER ELECTRIC BUSHING	6
END CAP ASSEMBLIES FOR SMALL INDUCTION MOTORS	29
INDUCTION MOTOR MAIN BODY AND FINAL ASSEMBLY	21
JIGSAW	58
TOASTER OVEN	41
AUTOMOBILE ALTERNATOR	17

Table 3: Products Analyzed for Product Statistics

Source: A. Kondoleon, 1976

A complete listing of the task categories used by Kondoleon, accompanied by visual aids, are shown in Figure 4.4 on the following page. The assembly analysis conducted by Kondoleon identified not only assembly operations, but also showed that certain directions of insertion were dominant. The direction of assembly has implications for the design and selection of assembly machines, however the direction of assembly varies with selection of base part and assembly sequence. It is because of this that no codification scheme exists to assist in the selection of assembly machinery.

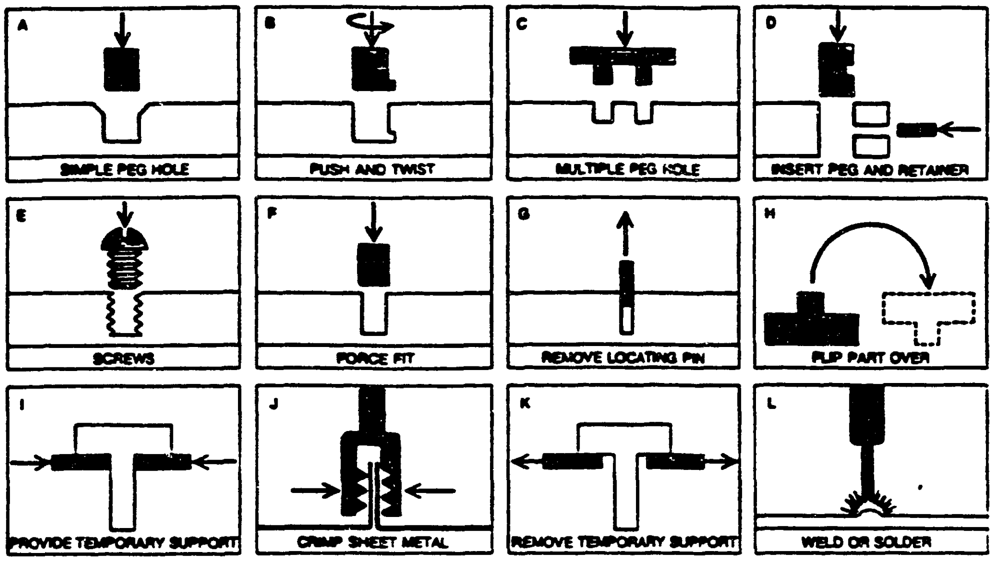


Figure 4.4: Typical Manufacturing Tasks

Source: Draper Report R-1643

4.1.3 Rational Element Level Task Classification

The assembly line task survey conducted on major subassemblies of the 1985/86 GM20 vehicle identified several activities not covered by the categories presented by Kondoleon. A different classification scheme is offered here, which views tasks in terms of their minimum rational elements (discussed in Section 2.2). Tasks are placed into one of two major categories, part assembly tasks and non-assembly operations. Each of the major headings has several subgroups, which further define the elemental detail of an assembly operation. The categorization scheme is shown in Figure 4.5.

Four subgroups are identified under the part mating heading. This is done with the liaison graphical representation in mind. Further description of the four part mating grouping is presented with examples.

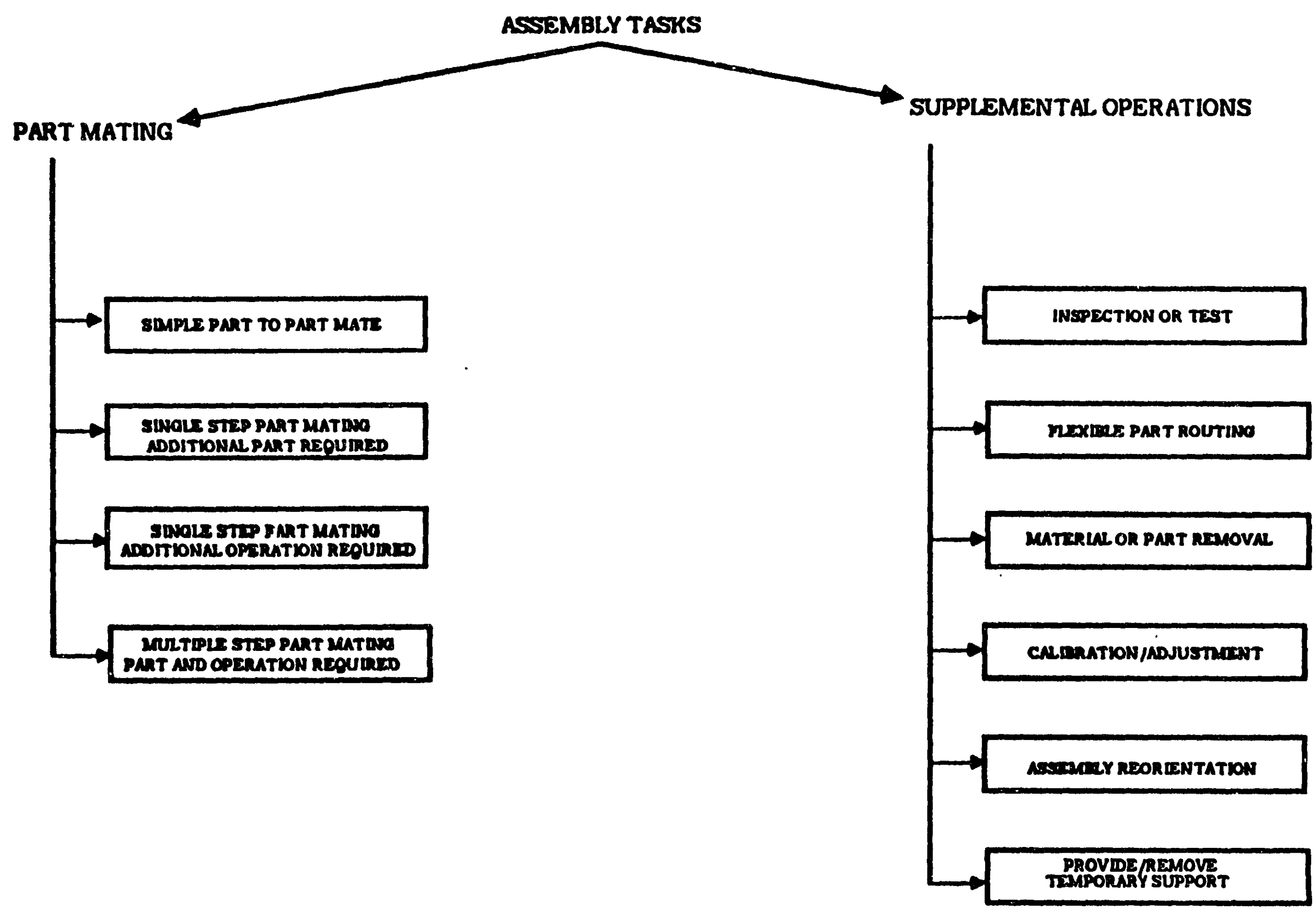


FIGURE 4.5: ELEMENT LEVEL TASK CLASSIFICATION

A. Simple Part to Part Mate-- single step connection between parts. Examples include force fit, peg in hole, and paint

B. Single Step Part Mating, Additional Part Required-- additional part required to secure. Example tasks include staples, rivets, solder, and liquid adhesive

C. Single Step Part Mating, Additional Operation Required-- parts placed together, an additional operation is required to secure. Representative tasks include spot weld and sheet metal crimp

D. Multiple Step Part Mating, Additional Part and Operation Required-- Parts can be loose assembled (semi-stable) and completed with a secure operation. Often associated with fastener operations

The other major heading, non-assembly operations, includes tasks that are not directly associated with part placement or part mating. Additional detail regarding these subgroups follows:

E. Inspection and Test-- evaluation of completed operations. Examples include visual presence check, torque check, and electrical test

F. Flexible Part Routing-- changing or establishing the shape of a flexible part prior to being secured. Tasks include routing electrical harnesses and fluid hoses

G. Material or Part Removal--removal of protective shipping material, cut or drill operations, and part removal or disassembly

H. Calibration/Adjustment-- required set-up after installation. Examples include headlamp aim or shim placement

I. Fluid Fill

J. Assembly Reorientation

K. Provide/Remove Temporary Support-- fixturing required for locating or temporary part stability

This listing of supplemental tasks do not fit directly into the liaison representational scheme as they do not have specific nodes associated with them. The inclusion of these tasks is presented in the following section.

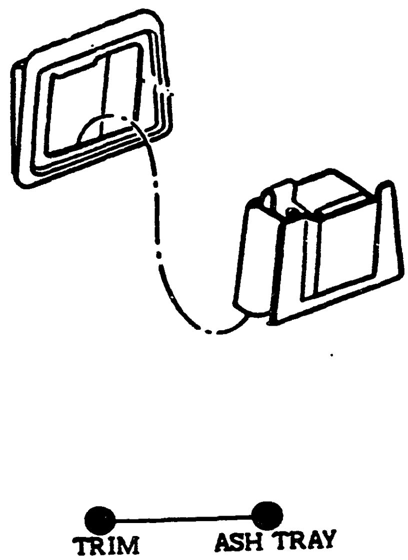
4.2 INCORPORATION OF OPERATIONS INTO LIAISON SEQUENCE ANALYSIS

The procedure for generating assembly sequences which consist of part to part liaisons, discussed in Chapter 3, is well defined. Each part is represented by a node and a physical relationship between parts establishes a liaison or arc between the nodes. In practice, assembly consists of many operations, like those presented in the previous section, other than part placement or simple part mating. The inclusion of these operations make the liaison sequence generation technique more applicable and robust.

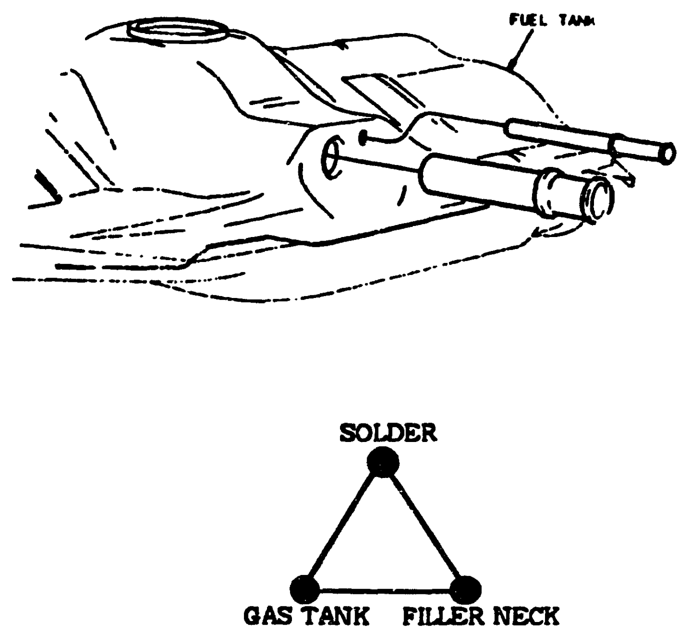
The additional operation requirements come from two sources. The first source is additional element level detail regarding part mating tasks, like that described in section 4.1.3. The second source is the listing of supplemental assembly information, such as test and inspection requirements or flexible part routing that apply to specific components.

4.2.1 Supplemental Part Mating Detail

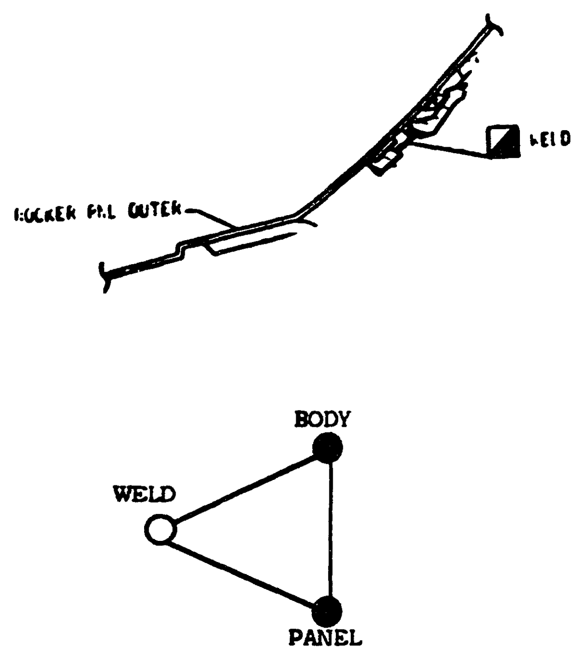
The representation of part mating tasks A and B, namely simple part to part mating and part mating with an additional part required is defined in Section 3.1. Examples of each task type are shown in Figure 4.6. In each case, parts are represented by nodes and the liaison represents the relationship or operation required to mate the parts. Part mating tasks C and D, single step part mating



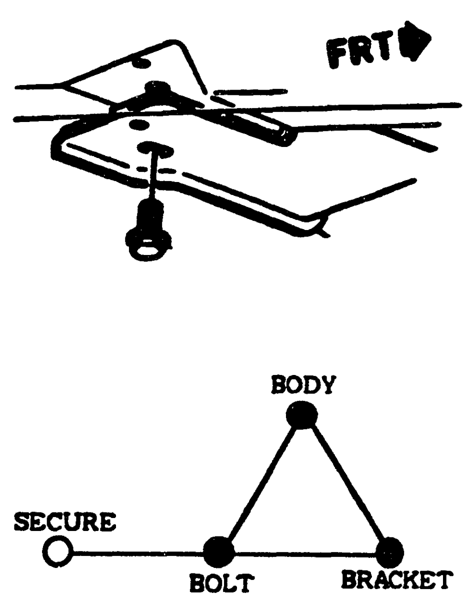
Example a: Simple Part Mating



Example b: Single Step Part Mating
Additional Part Required



Example c: Single Step Part Mating
Additional Operation Required



Example d: Multiple Step Part Mating

Figure 4.6: Graphical Representations of Part Mating Detail

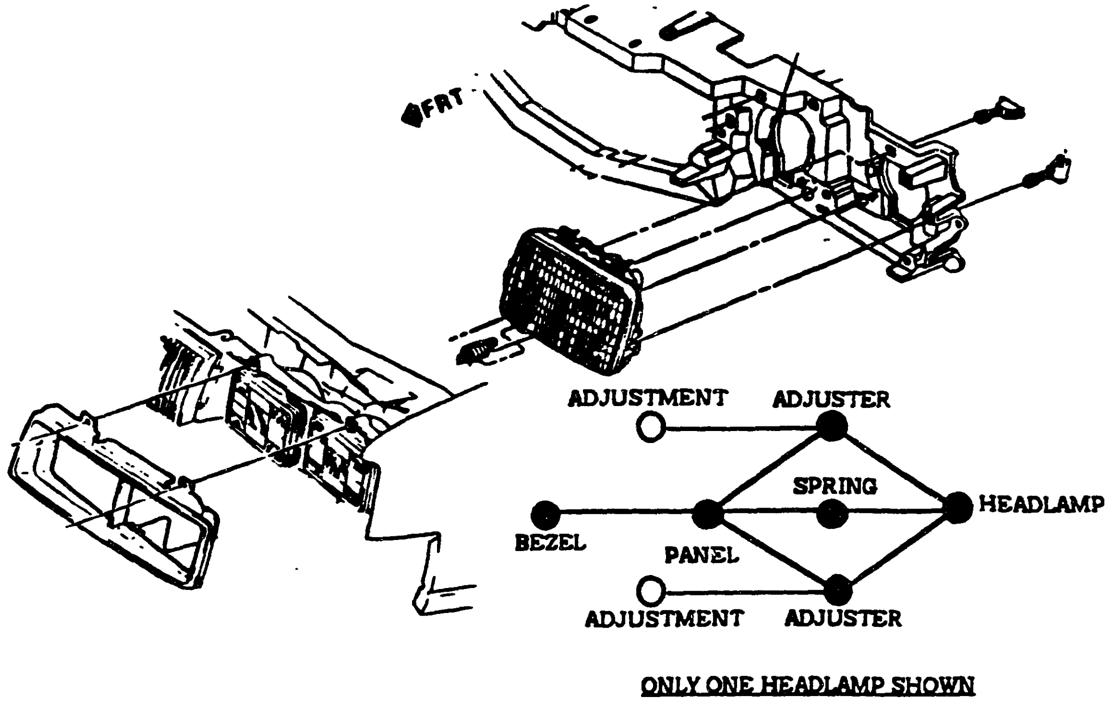
with an additional operation required and multiple step part mating, have operations that can be rationally separated from the physical mating of the two parts. These tasks require special representation to fit into liaison representational scheme.

Examples of each task type C and D are shown in Figure 4.6 with their assembly drawing and graphical representation. The most obvious approach to this problem is to create a "phantom" node for operations such as the spot weld or fastener secure. For example, in Figure 4.6d, one liaison is thought of as "establish part liaison", while the other liaison associated with the "phantom" node can be referred to as "establish tightness liaison".

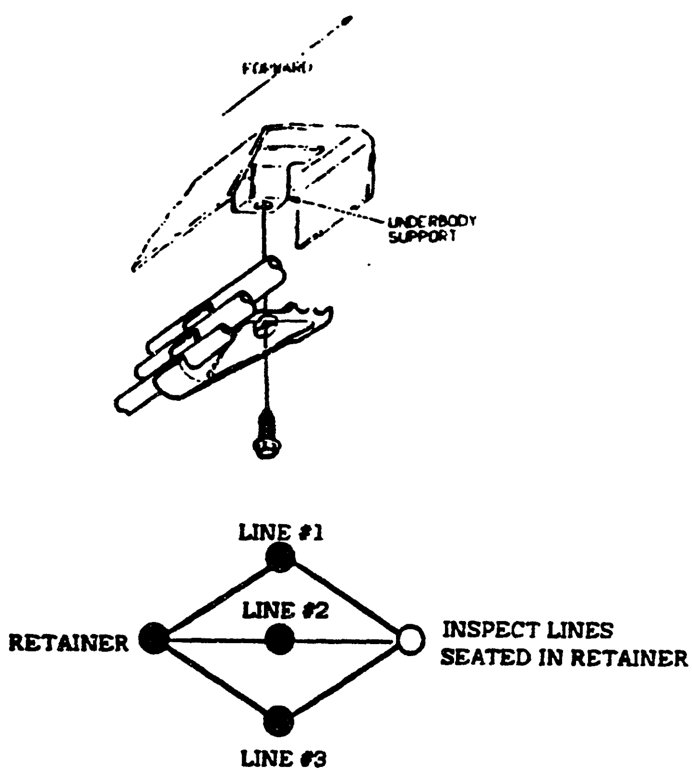
Thus, the liaison still represents operation or relationships between parts. The inclusion of these operations to part mating provides task level detail about the available sequence alternatives. Representation of the fastener operation as solely the two parts and the fastener is an oversimplification. It is as if the fastener must be finger started and secured consecutively. In practice, this is not necessarily the case, and therefore the simple graphical representation could be considered as restrictive in its ability to describe all possible assembly orders. This method of inclusion also permits operations to fit into the same algorithmic question and answer structure of the simplified sequence generation technique.

4.2.2 Non-assembly Operations

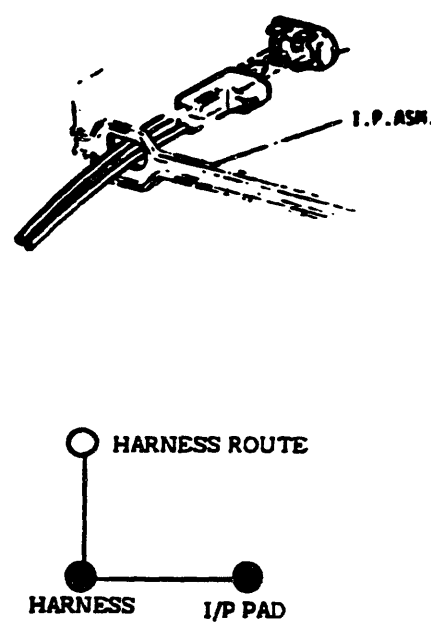
A similar method of representation as that introduced above is employed to include non-assembly operations or tasks into the liaison representational framework. Figure 4.7 shows three graphical representations for the inclusion of non-assembly tasks. Again, where tasks are not directly associated with part mating, a "phantom" node is placed in the liaison diagram and liaisons established



Example a: Headlamp Aim/Adjustment Operation



Example b: Inspection Operation



Example c: Flexible Part Routing Task

Figure 4.7: Graphical Representations of Non-assembly Operations

with parts requiring this operation. This permits the non-assembly activities to fit into the same question and answer structure as applied to part mating.

For example, in Figure 4.7a, a pair of phantom nodes are placed in the liaison diagram to represent the necessary adjustment operation for the vehicle headlamps. Liaisons are established with the adjuster (part) and the phantom node. The remaining two examples utilize phantom nodes in a similar manner to represent an inspection operation and a flexible part routing task.

The advantage of including non-assembly activities into the liaison representational scheme is that it can more thoroughly and accurately describe the assembly process required to complete the product. The interaction of these tasks with the physical part mating tasks is obvious. In the case of the headlamp and panel assembly, the adjustment or aim operation must be done after the headlamp, springs and adjuster components have been placed, however it must be done before the headlamp bezel (ornamentation) is mated to the panel. Another example of the interaction of non-assembly operations with part mating activities is discussed in the following section.

4.3 EXAMPLE APPLICATIONS

This section presents two examples in order to further illustrate the inclusion of operations into the liaison sequence analysis. The first example is merely an extension of an assembly used in Sections 2.2 and 3.2, the steering column subassembly. The second example highlights several complexities which arise from the analysis of the assembly of various engine accessories.

4.3.1 Steering Column Subassembly

The graphical representation shown in Figure 4.8 is identical to that used in Section 3.2 to describe the application of the liaison sequence technique. It consists of only simple part to part liaisons, and therefore does not contain all the operations necessary to complete the assembly of the product. It must be expanded to include the additional liaison detail and assembly requirements.

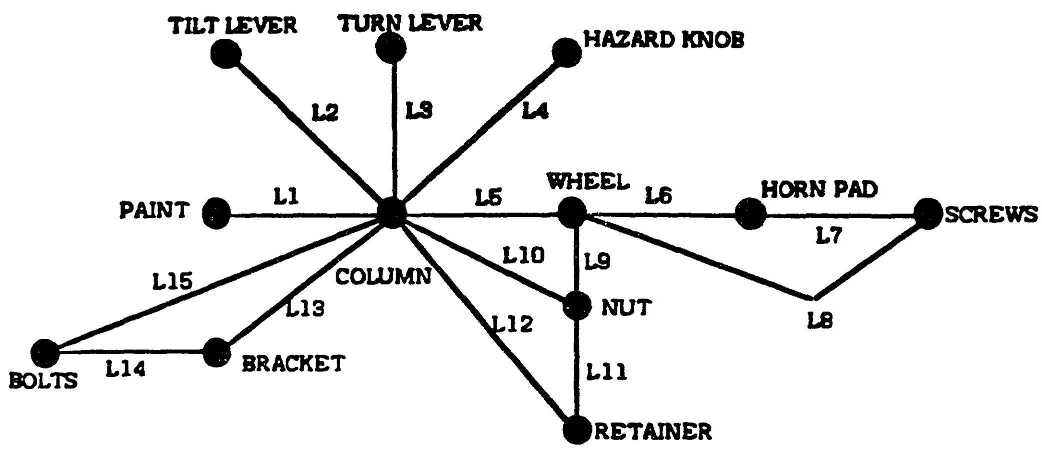


Figure 4.8: Steering Column Subassembly Liaison Diagram

The additional liaison detail is associated with the fastener operations used to assemble the bracket to column, steering wheel to column, and horn pad to steering wheel. Fastener operations, as described in Section 4.1.3, are multi-step part mating tasks, and therefore require the introduction of a phantom node to the liaison diagram for the secure operation. The additional non-assembly activities for this particular assembly are the result of the Motor Vehicle Safety Standard (MVSS) inspection and test requirements imposed by the Traffic and Safety Administration. The inclusion of these tasks as part of the assembly process must be documented in order to show "due care" in the assembly of the vehicle. These required operations are listed below:

Required Electrical Test of:	Horn Pad
	Turn/Cruise Lever
	Hazard Knob

Required Inspection of: Nut Secureness

Bracket Secureness

Retainer Presence

Horn Pad Secureness

Figure 4.9 shows the extended liaison diagram for the steering column subassembly. A slightly different symbol is used to denote the "phantom" nodes on the diagram. The determination of the liaison precedence constraints follows:

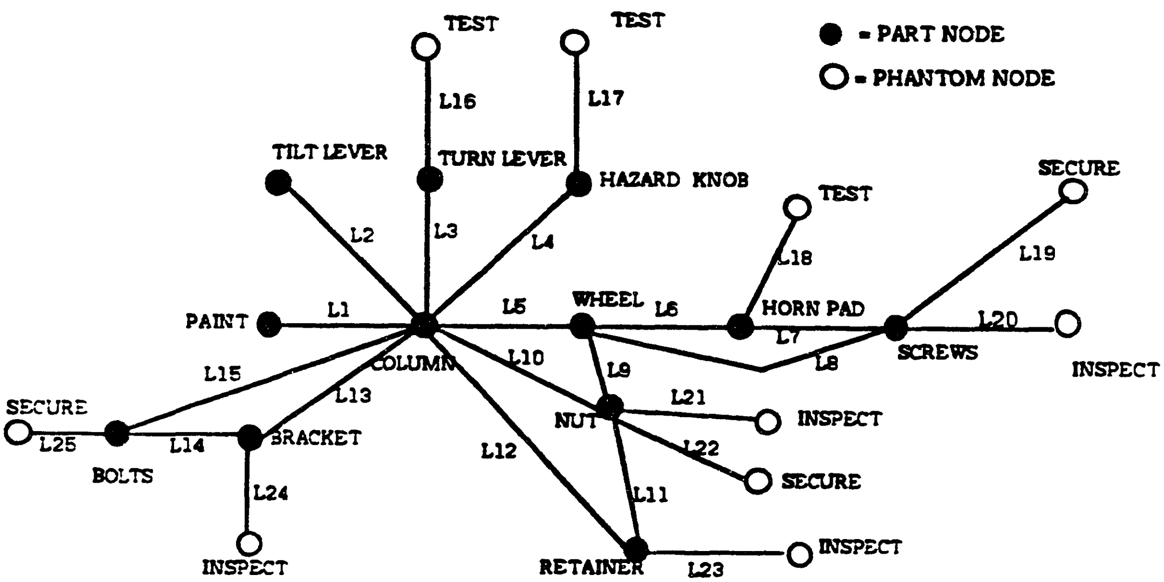


Figure 4.9: Extended Liaison Diagram for Steering Column Subassembly

Question 1: What liaison or liaisons must be established before liaison L(i) can be established?

i= 1 No liaison must be completed before liaison L1

i= 2 L1 > L2

i= 3 L1 > L3

i= 4 L1 > L4

i= 5	L1 > L5
i= 6	L9 > L6
	L11 > L6
	L21 > L6
	L22 > L6
	L23 > L6
i= 7	L6 > L7
i= 8	No liaison must be completed before liaison L8
i= 9	L5 > L9
i= 10	L5 > L10
i= 11	L22 > L11
i= 12	L22 > L12
i= 13	No liaison must be completed before liaison L13
i= 14	No liaison must be completed before liaison L14
i= 15	(L13 and L14) > L15
i=16	L3 > L16
i= 17	L4 > L17
i= 18	L6 > L18
i= 19	L7 > L19
i= 20	L19 > L20
i= 21	L22 > L21
i= 22	L10 > L22
i= 23	L12 > L23
i= 24	L25 > L24
i= 25	L15 > L25

Question 2: What liaison or liaisons must not be established so that liaison L(i) can be established?

i= 1 L1 > L2

L1 > L3

L1 > L4

L1 > L5

i= 2 No liaisons need be unestablished so that L2 can be done

i= 3 No liaisons need be unestablished so that L3 can be done

i= 4 No liaisons need be unestablished so that L4 can be done

i= 5 L5 > L10

i= 6 L6 > L7

i= 7 No liaisons need be unestablished so that L7 can be done

i= 8 L8 > L7

i= 9 L9 > L6

L9 > (L5 and L12)

i= 10 L10 > L12

L10 > (L5 and L6)

i= 11 L11 > (L9 and L6)

i= 12 L12 > L6

i= 13 L13 > L15

i= 14 L14 > L15

i= 15 No liaisons need be unestablished so that L15 can be done

i= 16 No liaisons need be unestablished so that L16 can be done

i= 17 No liaisons need be unestablished so that L17 can be done

i= 18 No liaisons need be unestablished so that L18 can be done

i= 19 No liaisons need be unestablished so that L19 can be done

i= 20 No liaisons need be unestablished so that L20 can be done

i= 21 L21 > L6

i= 22 L22 > L12

i= 23 L23 > L6

i= 24 No liaisons need be unestablished so that L24 can be done

i= 25 No liaisons need be unestablished so that L25 can be done

The interaction of the non-assembly tasks with the part to part liaisons is apparent. For example, electrical test liaisons L16, L17, and L18 cannot be completed until the components being tested have been mated to the column. Similarly, visual inspection of the retainer for presence must be preceded by its installation, but must occur before the installation of the horn pad to the steering wheel.

4.3.2 Engine Accessories

This section cites two additional examples of incorporating operations into the liaison representational scheme. These cases are drawn from the assembly of the engine accessories to the engine. The first example, shown in Figure 4.10, pertains to the removal and replacement of a engine coolant sensor. A temporary or slave coolant sensor is installed to the engine at the components assembly facility, so that the engine can be functionally tested prior to shipment, and remains in the engine At the final assembly facility, where the transaxle is married to the engine, an engine and transaxle specific coolant sensor is installed.

Prior to the permanent sensors installation, the temporary coolant sensor must be removed. Again, this is not a part mating task, but rather a material removal operation. The appropriate representation for these activities is shown in Figure 4.10. A "phantom" node is used to represent the removal task, while the installation of the engine/transaxle specific sensor consists of a part mating task which requires an additional secure operation.

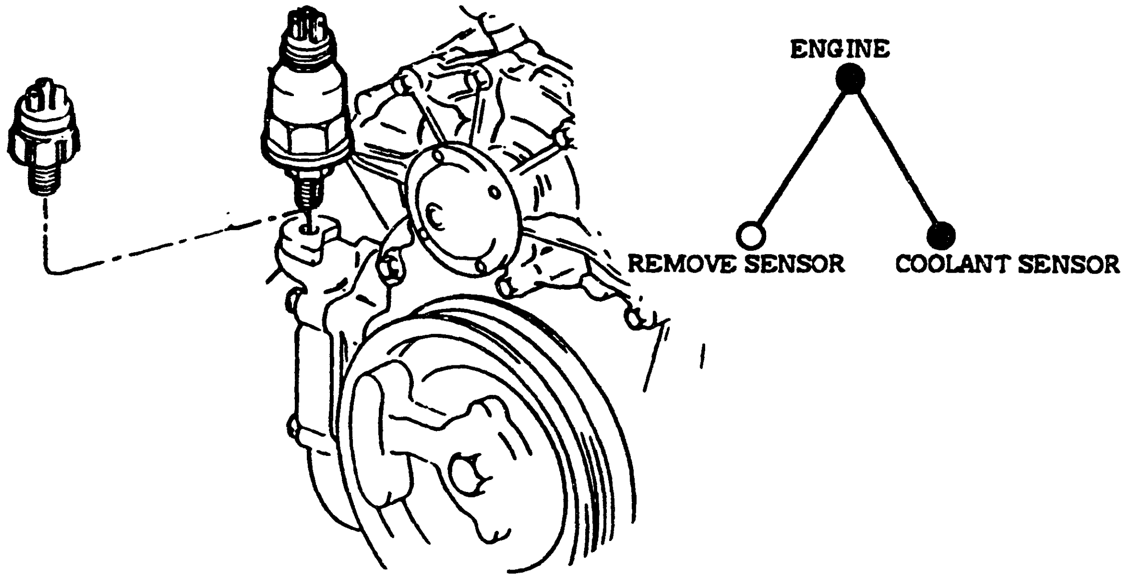


Figure 4.10: Graphical Representation of Coolant Sensor Installation/Removal

The second example deals with the connection of one engine electrical harness lead to the vehicle speed sensor, also found on the transaxle. These are shown in Figure 4.11, on the following page. Motor Vehicle Safety Standards require that the speed sensor be electrically tested, and so the connection of the harness to the speed sensor must be done prior to the installation of the entire engine and transaxle subassembly to the vehicle chassis, known as "engine stuff". However, during the "engine stuff" operation, the speed sensor connection interferes with a vehicle body member and is subject to in-process damage. As a result, the sensor must be disconnected from the harness after electrical test, but prior to engine stuff, and then finally reconnected.

The graphical representation, also shown in Figure 4.11, includes this connection, disconnection, and reconnection requirement. A "phantom" node is used to represent the sensor removal operation and two separate liaisons are placed between the sensor and connector nodes to represent the two single step part mating operations which occur between these two parts. It should be noted that a subsequent design change eliminated the interference at the time of engine merge, and thus the need for the two additional tasks of removal and reconnection.

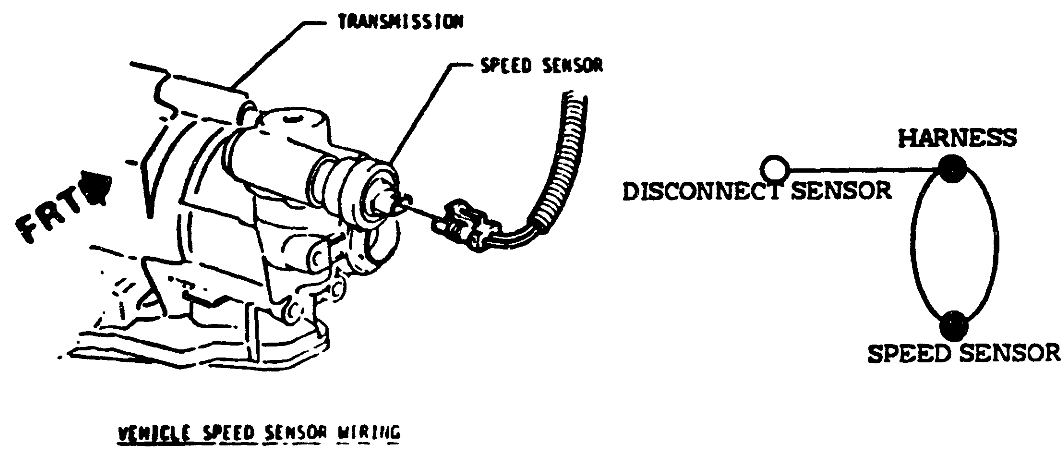


Figure 4.11: Graphical Representation for Speed Sensor Assembly Requirements

Summarizing briefly, assembly consists of a variety of tasks and activities other than simple part to part mating. A group listing or classification of these tasks is provided in the first part of this chapter. The inclusion of these additional kinds of operations into the liaison sequence analysis would be beneficial, however because many of these tasks are not part placement, they do not fit directly into the graphical representation scheme. The recommended approach is to provide a "phantom" node for these operations, and establish liaisons with the parts associated with these non-assembly activities. This allows the additional operations to function in the algorithmic question and answer structure of the liaison sequence analysis technique. Finally, examples drawn from industry are used to clarify how the additional assembly information and part mating detail can be included. The next chapter introduces other sequence constraints not associated with the geometry or assembly requirements of the product, as well as judgement criteria for sequence selection.

5.0 SEQUENCE CONSTRAINTS AND SELECTION CRITERIA

The previous chapters have discussed methods of determining, diagrammatically representing, and generating the valid assembly sequence alternatives for a given product. The precedence diagram, the most frequently applied representation, is incapable of representing all possible sequences for an assembly in one diagram, and is also unable to describe certain combinations of geometric constraints. Another technique, liaison sequence analysis, employs an algorithmic series of questions which, based on the product knowledge of the manufacturing engineer, determines the precedence constraints for a given assembly. Both the technique introduced by Bourjault and the simplified generation technique can represent all alternative assembly sequences in a single diagram. Chapter 4 discussed extensions to liaison sequence analysis, which permit the inclusion of tasks other than physical part mating into the liaison representational scheme.

The constraints on the valid assembly sequences discussed thus far have focussed, almost exclusively, on the geometric limitations imposed by the product itself, that is, the mechanically possible choices. There is, however, another level of sequence constraints that can further limit the available assembly sequence alternatives, namely facility constraints. Certain building characteristics, such as available floor space or height restraints, may dictate the location of specific tasks and thus reduce the realizable assembly sequence alternatives.

Beyond the question of constraint lies the question of selecting an assembly sequence from the available alternatives, which results in the lowest unit assembly cost. The impact of assembly sequence on the entire manufacturing system is enormous. It interacts with nearly every aspect of the facility and assembly methods (See Figure 5.1).

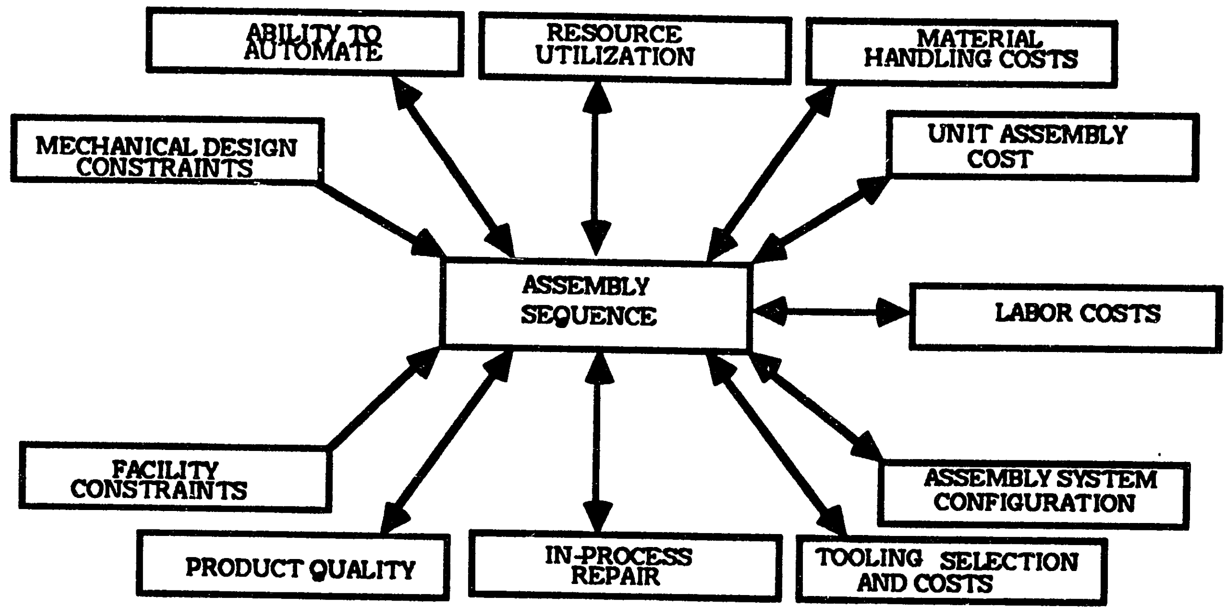


FIGURE 5.1: Interaction of Assembly Sequence

The selection of an assembly sequence can directly influence final product quality, assembly system configuration, material handling requirements, and unit assembly cost, among many other things. The determination and selection of assembly sequences, which satisfy criteria such as least cost, has long been dependent on the knowledge and expertise of the manufacturing engineer.

This chapter will address the topics of facility constraints and assembly sequence selection criteria, and is organized into two sections. The first section will discuss building or facility constraints, which often restrict the locations where a specific task may be completed. The second section will address the criteria or judgemental issues associated with the selection of assembly sequences from the available alternatives, and how they impact assembly costs.

5.1 FACILITY CONSTRAINTS

Facility restrictions are non-liaison type constraints which limit the location of certain tasks in the assembly sequence. The majority of these constraints can be grouped into the following three categories:

1. Work Height Limitations
2. Part Storage/Delivery Requirements
3. Special Operation Requirements

Examples are drawn from the assembly of the 1985/86 GM20 to clarify these points.

5.1.1 Work Height Limitations

The work height required to complete specific tasks is primarily determined by the physical accessibility necessary to complete the operation. Consideration must be given to the ergonomic work height for an assembly operator as well as the height requirements for assembly automation. The use of pits or elevated work platforms to accommodate height requirements is both expensive and usually results in severe parts stocking inefficiencies, caused by the limited accessibility to the area.

The most frequently encountered work height constraint is that of insufficient overhead. Several examples will assist in clarifying this point. The first deals with the installation of the vehicle gas tank to the car body. The operation consists of location of the tank to its underbody position, attachment of the fuel tank support straps, and finally the installation of the fasteners, which mate the straps to the car body. This is shown in Figure 5.2. The ergonomic work height for this task is 78 inches from the floor to the vehicle rocker panel, that is, 126 inches from the floor to the vehicle roof. Installation of the gas tank is limited geometrically by liaison precedence relations to other operations in vehicle assembly. Namely, it must precede the assembly of the rear axle and springs, shown in Figure 5.3, to the vehicle underbody. The installation of the GM20 vehicle fuel tank is done for two different car lines, each in a separate assembly facility. Because of the different overhead space availability in each assembly plant, the point in the sequence which the tank is installed is unique to each facility.

The "A" assembly plant is a two story facility constrained by an 11 foot ceiling on its second floor, the start of the assembly system. This leaves insufficient clearance for car carriers with overhead conveyor drives (See Figure 5.4). As a result, the vehicle is transported through the second floor assembly area on a body jack, which prohibits any work on the underside of the car. The car is transported by a car carrier on the first floor. No underbody operations, such as engine merge, brake lines, suspension, or fuel tank installation, may be completed in the first 57 assembly stations which reside on the second floor. In

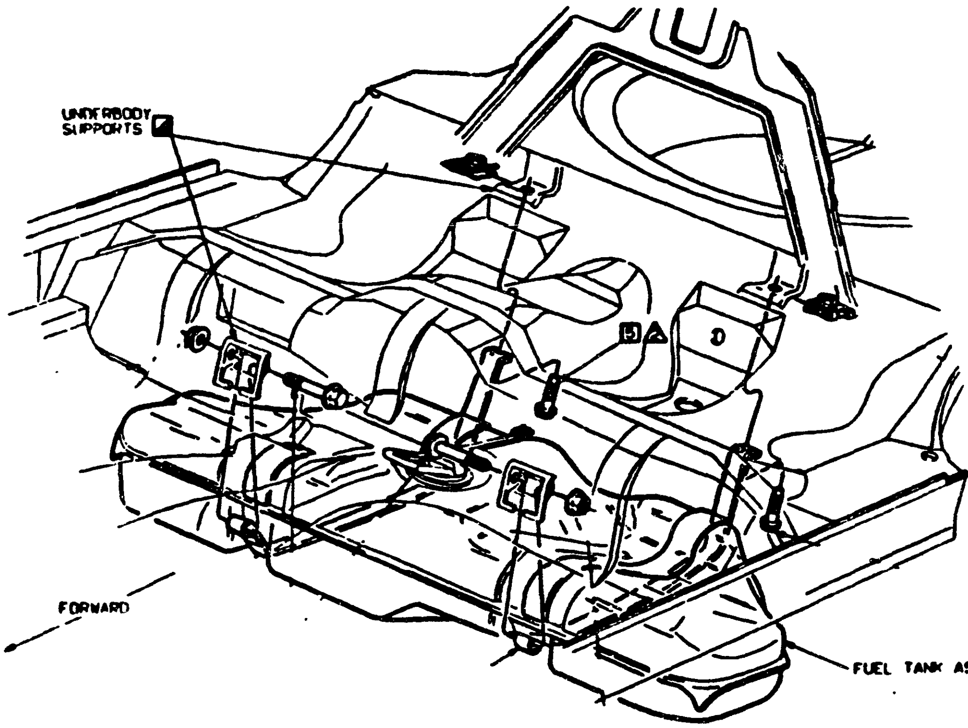


Figure 5.2: Gas Tank Installation Assembly Drawing

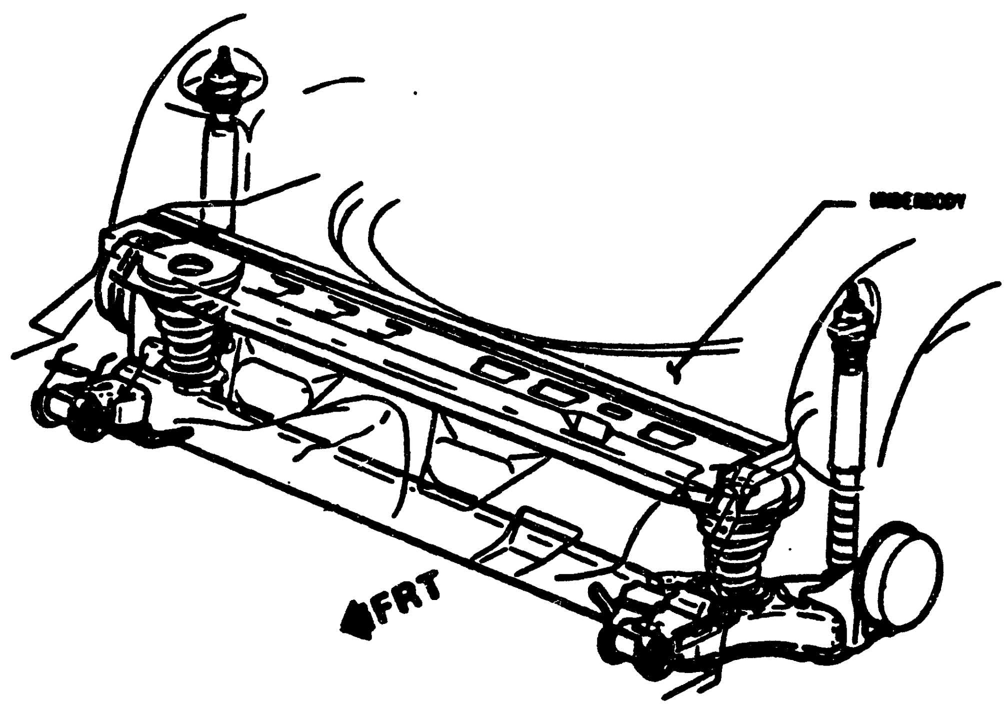


Figure 5.3: Rear Axle and Spring Assembly Drawing

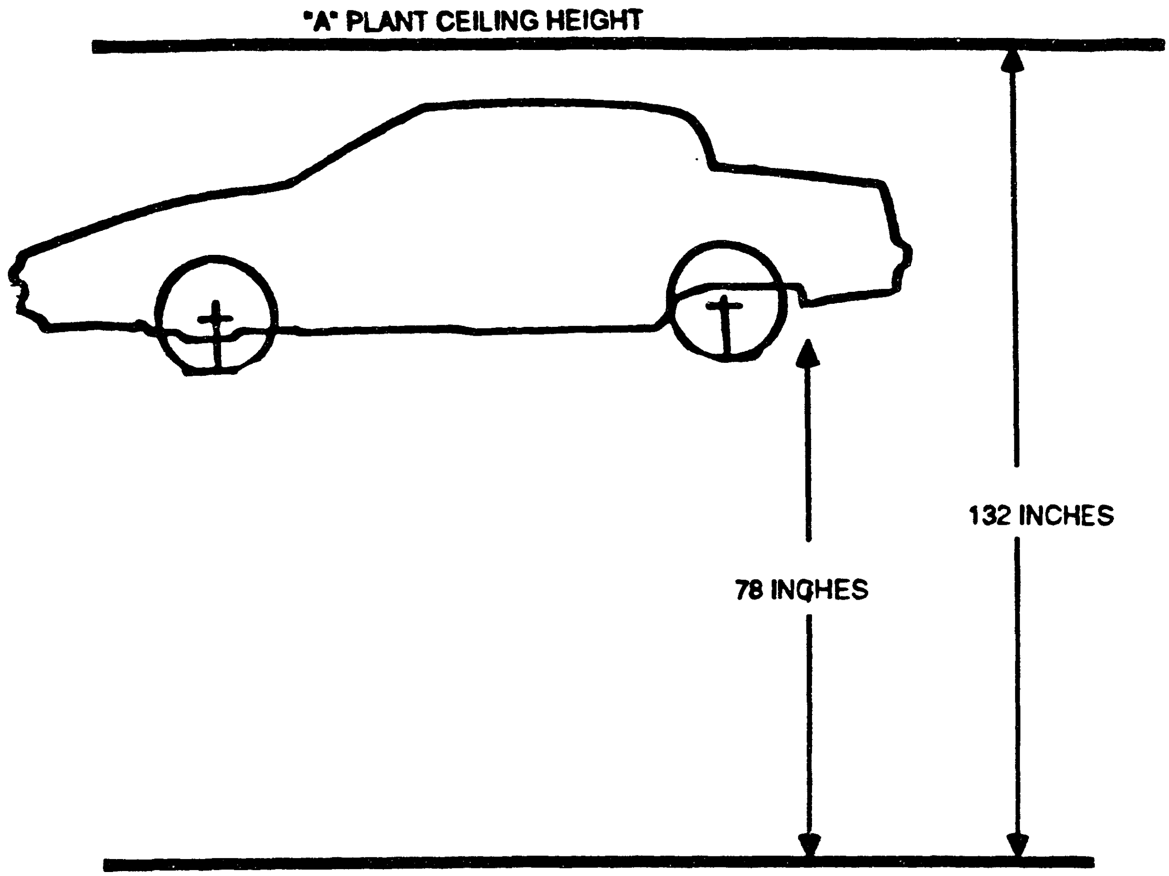


Figure 5.4: Building Overhead Clearance

the case of assembly plant "A", the vehicle fuel tank is installed on the first floor in the 82nd assembly station.

In contrast to this, the "B" assembly plant is also a two story assembly facility, however it has virtually unlimited ceiling height on both floors. The car is transported throughout the entire assembly plant on an overhead car carrier. The assembly sequence of underbody operations for the vehicle is not constrained by facility limitations. The gas tank installation is completed on the second floor in the tenth work station.

While vertical space availability can restrict location of specific tasks, such as the fuel tank, it can also significantly alter the methods of assembly for specific components. The same two facilities described above necessitate two different methods of installing the steering rack to the vehicle. The assembly drawing for this task is shown in Figure 5.5. Geometric or liaison constraints of the vehicle dictate that the steering rack must be installed relatively early in the vehicle assembly process. It must precede the installation of the steering column into the passenger compartment and the merge of the engine to the body. The most desirable approach to installation, from an ergonomic standpoint, is to load the steering rack from the underside of the car. The "B" assembly plant permits this method of installation early in the assembly process because of the available vertical space. The assembly operator can stand directly beneath the steering rack and support it during installation to the front of dash.

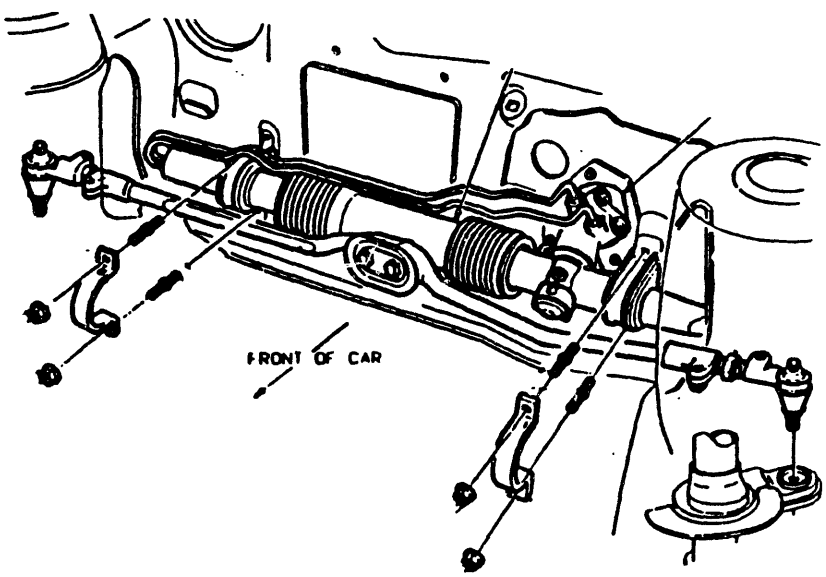


Figure 5.5: Steering Rack Assembly Drawing

In contrast, the "A" assembly plant does not allow access to the vehicle underbody in the first 57 stations, and precedence relations dictate that the steering rack be installed prior to station 40. As a result, the steering rack is loaded from above through the hood opening, and because of the physical dimensions of the component and operator position, two direct labor operators are required for installation. In this case, facility limitations drive changes in assembly methods and ultimately assembly cost.

Work height requirements of particular operations can also keep certain groups of tasks from being completed at the same work station. An operation requiring a high work height cannot be grouped with an operation requiring a low work height without a repositioning of the work piece between the operations, because of the limited work envelope of either an operator or piece of automation. Though not a restriction, it is not a desirable characteristic of an assembly sequence. This aspect will be discussed in section 5.2.

5.1.2 Part Storage/Delivery Requirements

The vertical work height restriction results from a conflict between operation accessibility and facility space, however availability of floor space can also constrain possible assembly sequences. These restrictions most often occur because of the part storage or delivery requirements of specific components.

Part storage limitations are most often associated with components which have one or more of the following attributes: large physical size, high usage rate, or high degree of parts proliferation, that is, optional colors or part numbers, for example. These attributes consume floor space that may be available only in specific plant locations. Thus, operations which introduce these parts to the assembly system must be given consideration as to their location in the assembly facility, and as a result, can reduce the assembly sequence alternatives. Several examples will assist in clarifying this point.

One example of floor space limitations is drawn from the assembly of the 1985/86 GM20 steering column assembly, discussed in several earlier sections.

Two of the components which make up the assembly, the column assembly and steering wheel, are relatively large in size and also have a high degree of parts proliferation in order to accommodate varying option requirements. Six different column assemblies are scheduled into the system, and because of varying color and spoke configuration options, nineteen different steering wheels are used. The container footprint for these parts is 4' by 4'. The available floor space dictates that these parts be stocked at assembly stations 1, 2, or 3 (See Figure 5.6). The assembly sequence alternatives are severely constrained because of the floor space restriction.

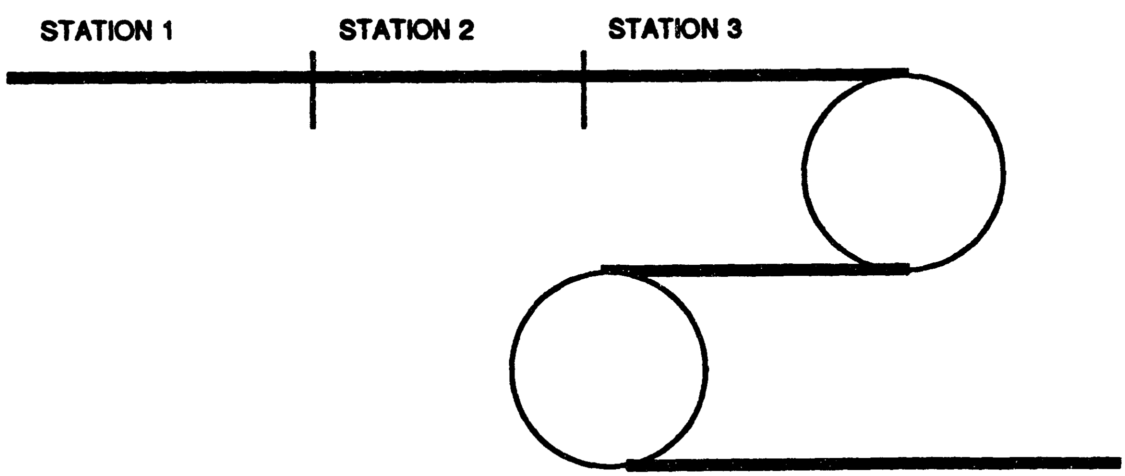


Figure 5.6: Simplified Floor Space Layout

The second example shows how the combination of floor space availability and part proliferation can force changes in the way assembly components are delivered to the assembly area. Front suspension struts, shown in Figure 5.7 on the following page, are one of the major front suspension components. Optional ride and handling packages have pushed the number of different struts to twenty-three (23). At this level, they cannot be efficiently stocked at the point of installation to the vehicle body. As a result, the front suspension struts are stored at a separate facility. The vehicle build order or sequence is provided to the strut facility, which places them in the correct order so as to match the appropriate vehicle. The struts are then transported to the assembly line in vehicle build sequence. This reduces the line stocking requirement to one hour's worth of production, or about four containers, in contrast to the twenty-three otherwise required. The penalty of this remote sequencing operation is the double handling required of the struts, however limited floor space availability makes this the only available alternative.

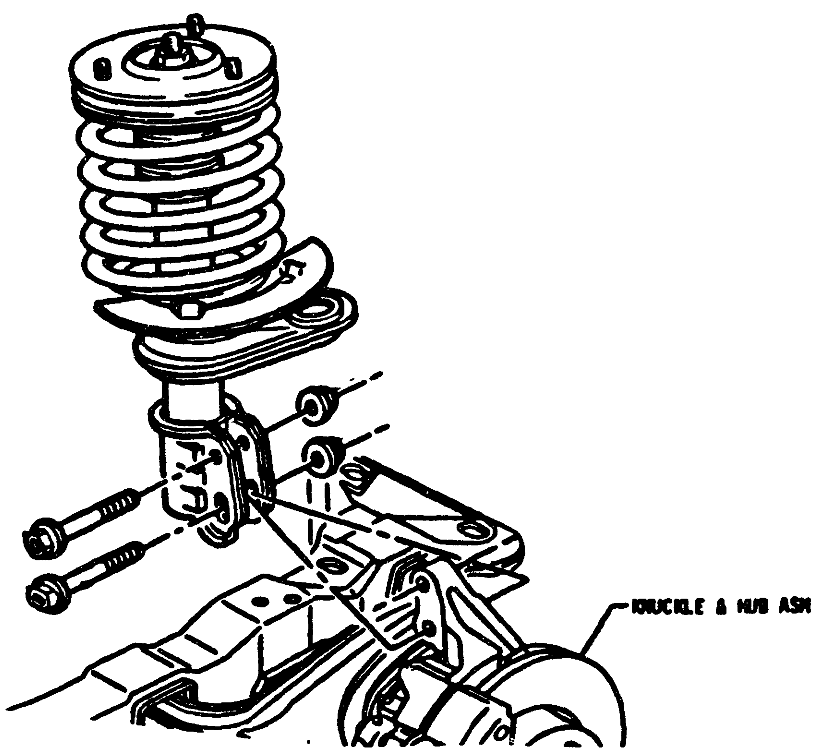


Figure 5.7: Front Suspension Strut Assembly Drawing

Another facility influence on assembly sequence selection is part delivery requirements. Large, frequently used components can occupy a significant amount of material handling labor. Location of these parts near delivery docks can reduce the delivery path to the line, and in turn, the indirect labor associated with these parts. This is best exemplified by a comparison of the delivery needs of two components. First, the engine assembly is delivered to the assembly line on a pallet which holds six (6) engines. At a production rate of 68 jobs per hour, this pallet will last less than five and one-half minutes. On the other hand, a pallet of fasteners will last up to ten (10) working days. It is obvious that location of the engine scheduling area, the point where the engine is introduced into the assembly system, near the delivery dock will significantly reduce the overall delivery path traveled to deliver engines throughout the year. By the same token, the location of the fastener operation will have little impact on indirect material handling labor.

5.1.3 Special Operation Requirements

The third type of facility constraint is that of special operation requirements. Though it sounds like a catch-all category, many assembly operations have particular facility needs. For example, tasks such as paint and solder have special ventilation requirements. Other tasks, such as liquid adhesives and silicon based fluids, require special handling equipment or waste disposal needs. Established facilities often have capability of handling such needs, but rearrangement can be expensive as well as detrimental to other manufacturing systems also utilizing this aspect of the facility. It is advantageous to place a high value on assembly sequences which favor a minimum of facility rearrangement. Application of this information will be shown on the examples presented in Chapter 6.

5.2 JUDGEMENTAL ISSUES AND SELECTION CRITERIA

Previous discussion has shown how all valid assembly sequences for a given product can be generated and represented. Constraints on the possible assembly sequences arise primarily from the geometric relationships that exist between the parts and the other necessary assembly tasks. The previous section described how the facility can further constrain the available alternatives because of limitations, such as floor space or vertical height restrictions.

The final issue, then, is selection of an assembly sequence from the remaining alternatives. As Figure 5.1 pointed out, selection of assembly sequence has a significant impact on many aspects of the total manufacturing system, ranging from final product quality and assembly system configuration to resource utilization and unit assembly cost. The criteria for selection are not clearly defined a priori, but are specific to the product under study. In some cases, certain selection criteria are in direct conflict with one another and a compromise must then be reached. The judgemental issues or selection criteria discussed in this chapter are separated into two major categories qualitative issues and quantitative issues.

5.2.1 Qualitative Selection Criteria

Qualitative selection criteria pertain to characteristics or attributes of particular states of assembly or state transitions. Particular states of assembly can be either desirable or undesirable from a manufacturing standpoint, and these can be usefully applied in sequence selection. The major qualitative characterizations of assembly states and state transitions can be placed in the following categories:

1. Functional Subassembly Candidates
2. Part Stability

3. Ease of Assembly/Accessibility

Examples are provided to assist in clarifying these points.

5.2.1.1 Functional Subassembly Candidates

One major qualitative issue is the identification of potential subassembly candidates. Subassemblies are groups of parts or components which are assembled separately from the base part. These parts exist as a separate entity prior to being married to the major assembly or base part. Liaison sequence analysis will blindly generate a large number of potential or candidate subassemblies, particularly with assemblies of significant parts count. Many of the generated subassembly candidates, however, are of little value or are undesirable.

Characteristics considered undesirable are a plurality of disconnected, non-functional subassemblies. For example, liaison sequence analysis may show that the liaison for the bolts and bracket, shown in Figure 5.8, is unprecedented. The bracket and bolt liaison could be established away from the base part and essentially exist as a subassembly. In this state, the bracket and bolt serve no useful purpose in the assembly of the product. Thus, disconnected, non-functional subassemblies can be eliminated as potential sequence alternatives.

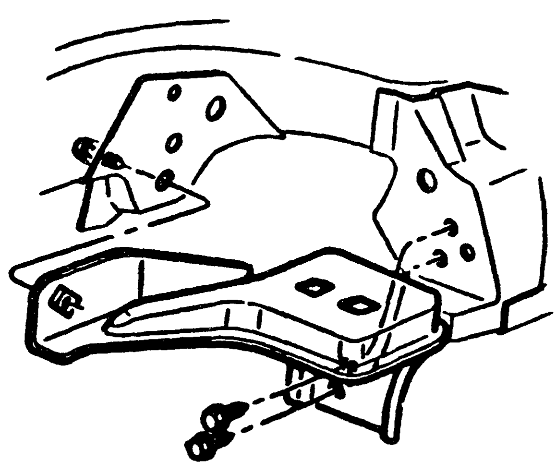


Figure 5.8: Bracket and Bolt Assembly Drawing

There are several qualities which make subassemblies desirable and cost-effective assembly sequence alternatives. A major reason for including a subassembly as a part of the assembly sequence is the ability to functionally test or inspect the subassembly prior to its attachment to other major components. From the design and manufacturing standpoint, this type of assembly is referred to as modular build. The ability to inspect or test, prior to installation to other components, can have a major impact on final repair costs. The advantage of employing subassemblies as part of the assembly sequence is shown in the following examples.

The first example is one which has been referred to throughout this thesis, the steering column subassembly. It has two attributes which make it an attractive choice as a subassembly in the assembly of the entire vehicle. First of all, it permits the MVSS required electrical test operations to be cost-effectively performed prior to the installation of the column to the dash and instrument panel. Failure of a component, such as the turn/cruise lever, can be repaired in much less time prior to installation to the vehicle than after the column has been installed. Since other parts do not obstruct the access to the lever and connector at the subassembly level, repair time is in the range of 1.5 to 2 minutes, compared to approximately 25 minutes required in final vehicle repair.

The other positive characteristic resulting from treating the steering column and its components as a subassembly is the simplified installation to the dash and instrument panel. Its underdash location is one of limited space availability (See Figure 5.9), requiring somewhat awkward operator positioning. Handling the steering column as an individual unit minimizes the time required to complete the installation operation when compared to handling each of the components individually.

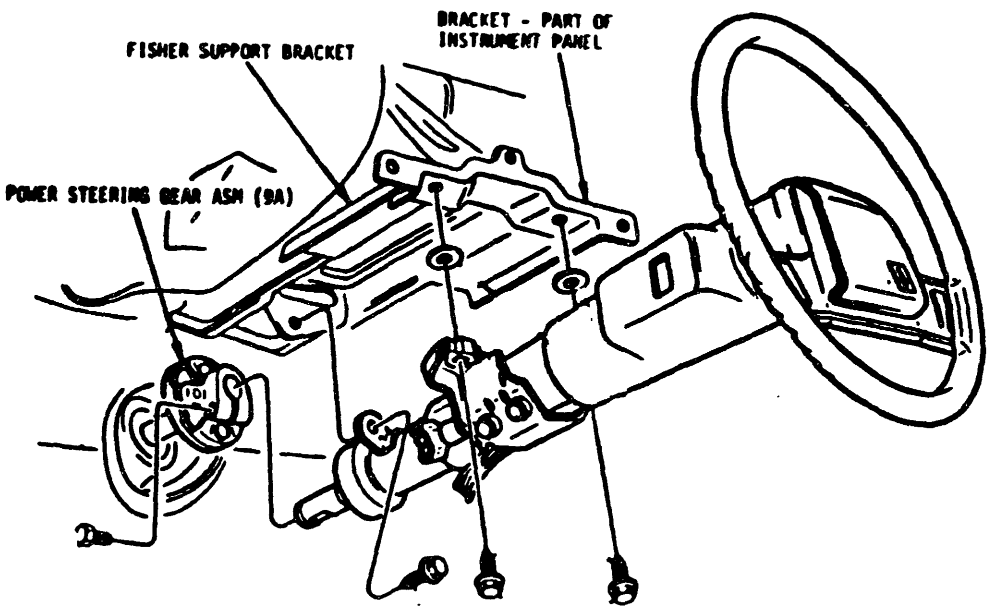


Figure 5.9: Steering Column Installation Drawing

The second example, the gas tank subassembly, was discussed earlier in this section. It shares the same qualitative characteristics, which makes it an attractive choice as a subassembly, as the steering column. It provides improved accessibility for the neck solder tasks and simplified installation to the vehicle underbody. It also provides the ability to test the fuel sender unit, shown in Figure 5.10 on the following page, prior to being fully installed to the vehicle. In this case, the repair savings are even more significant. Two types of electrical failures occur most frequently with the sender unit, a non-functional motor or a motor wire that is disconnected during the insertion of the sender unit into the fuel tank. A failure identified during the subassembly of the fuel tank requires approximately 45 seconds to replace the sender or correct the defect. On the other hand, the time required at final repair is approximately 3 hours as the rear suspension components must be disassembled and the fuel tank drained.

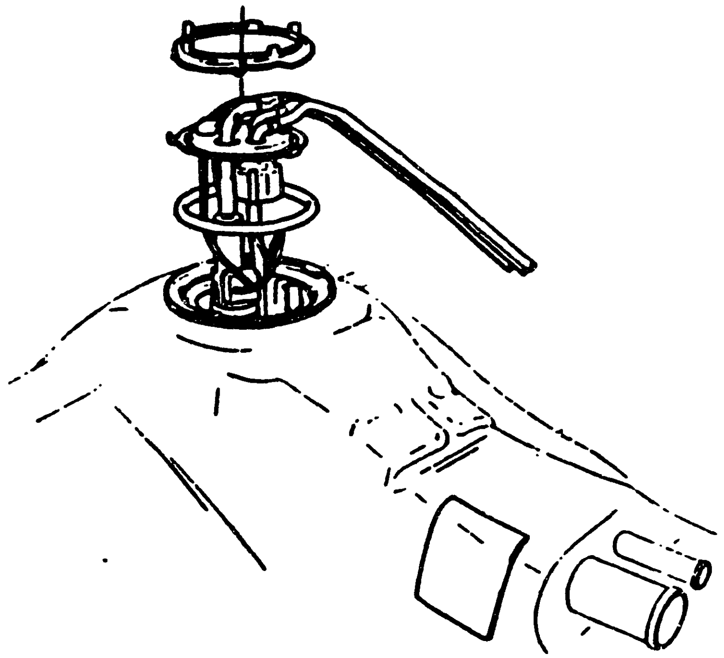


Figure 5.10: Fuel Sender Unit Installation

5.2.1.2 Part Stability

A second important qualitative attribute is part stability during particular states of assembly. For the most part, a stable assembly state is desirable, while an assembly state having unstable components is best avoided, if at all possible. However, part or assembly stability is more than a question of whether the part is mechanically fastened or held in some way to the rest of the assembly. It is also an issue of the orientation of the assembly, as to whether the part is actually unstable. For example, the switch, shown in Figure 5.11, is stable, despite being unfastened, as long as the base part is not reoriented. Sequences which require the base part to be oriented bottom side up prior to the switch being secured would require the use of a temporary jig or fixture to hold the switch in place.

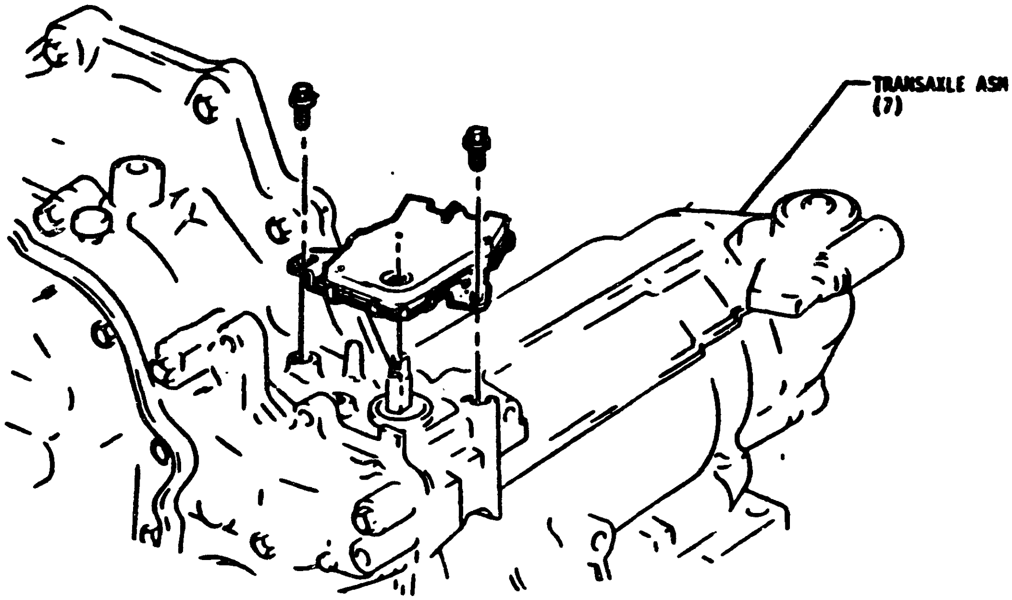


Figure 5.11: Stable Switch Position on Transaxle

The issue of part or assembly stability is important in that unstable components may require fixturing or jigging at some points of the assembly process to maintain their location. While in some cases there is no alternative to temporary fixturing, some assembly sequences can eliminate the need for special jigging. From a cost standpoint, temporary fixturing provides additional tooling expense to the cost of product assembly. Temporary support or stabilizing fixtures add no value to the product during the assembly process, and therefore consume labor or machine (resource) time better applied to other assembly tasks. The issue of non-value added work content is discussed in Section 5.2.2.1.

5.2.1.3 Ease of Assembly/Accessibility

The transition from one state to another can also be qualitatively characterized in terms of the ease of assembly or the physical accessibility to complete the task. Close physical proximity of a part to others can affect the time and tooling required to complete its installation. Certain orders of assembly can reduce the skill level or dexterity required of either operators or degrees of freedom required of automation to complete the task.

The installation of the starter to the engine and transmission assembly has an order of assembly which reduces the difficulty of the part mating tasks. The assembly drawing is shown in Figure 5.12. The assembly consists of the starter, two bolts, and shim, which are attached to the engine/transaxle combination. One possible assembly sequence is to place the shim onto the starter, move the starter into position, thread the bolts through the starter and shim, and finally secure the two bolts to the engine. This sequence is quite difficult. The shim is not fixed as it rests on the starter and therefore, it can be displaced during the installation of the bolts, or when the starter is moved into its final position on the engine. An easier sequence is to place the starter to the engine and loose assemble the longer of the two bolts through the starter to the engine. The starter is now held in place, and the shim can be slid into position, prior to securing the starter bolts. This assembly sequence reduces the complexity of the assembly operations by using the bolt as a temporary support for the starter. Again, different assembly sequences can significantly simplify the operations, and in turn, reduce assembly time required.

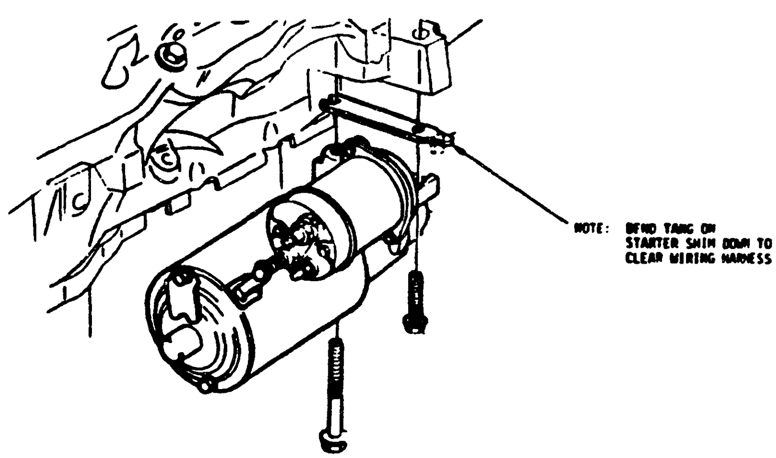


Figure 5.12: Starter Installation Assembly Drawing

Accessibility or ease of assembly can also influence the probability of part damage during the installation process. One example, discussed in the previous chapter, addressed the potential for in-process damage of the vehicle speed sensor during the merge of the engine to the car body. The difficulty of maneuvering the large engine assembly increased the potential for the sensor damage, thus resulting in a selection of an alternate assembly sequence.

5.2.2 Quantitative Selection Criteria

The second type of selection criteria, quantitative, employs more concrete characteristics about assembly states and state transitions. Quantitative attributes are most often associated with sequences or orders, which directly influence the unit assembly cost of the product. Major quantitative issues include: Non-value Added Operations, Resource/Labor Utilization, and Tooling Commonality.

5.2.2.1 Non-value Added Operations

Productive use of available assembly time is a key to efficient, cost-effective assembly. Non-value added operations comprise work content which does not increase the market value of the product during the manufacturing process. Non-value added work content can arise from many sources. While it is impossible to eliminate all non-value added operations in assembly, it is desirable to select assembly sequences which minimize the number of non-value added tasks, so to use this assembly time on productive operations. Sources of non-value added work content include tool changes, part or assembly reorientations, and in-station work height changes.

Tool changes are a necessary part of almost all manufacturing processes. Change of grippers or fastening and weld tooling are required to meet the needs of the next task in the sequence. Each transition or tool change consumes assembly time, which does not add value to the product. This time can vary between one and eight seconds, depending on tool size, resource type, system layout, etc.. Some assembly sequences minimize the number of unnecessary tool changes. For example in the case of the bracket and bolt assembly shown in Figure 5.13, the most efficient assembly order is to loose assembly bolts one through four, change tools, and secure them with the air wrench. The assembly time required to finger start each bolt is three seconds each, a tool change 2.5 seconds, and each secure operation requires 2.7 seconds. The total assembly time required to secure this bracket is 25.3 seconds with non-productive labor consuming less than ten percent of the assembly time.

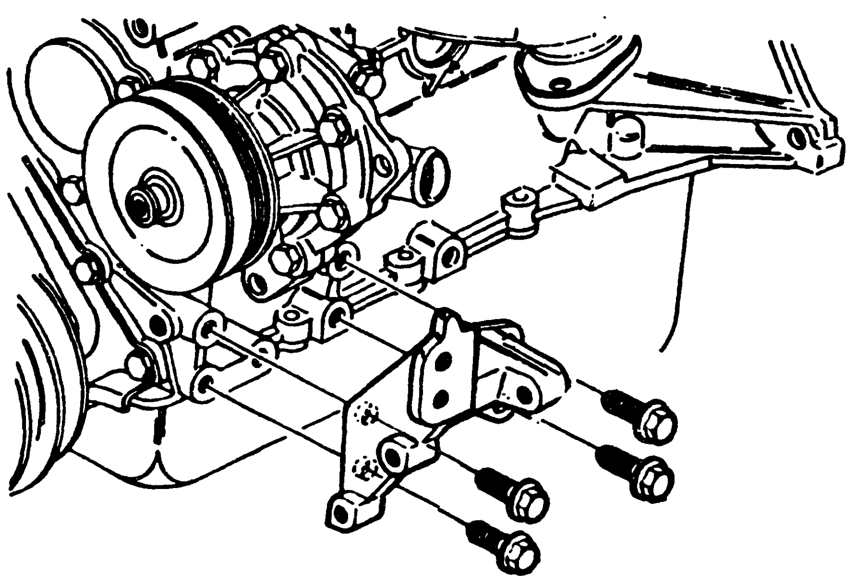


Figure 5.13: Bracket and Bolt Assembly

An alternative sequence is to successively finger start and secure each bolt. This would require a total of seven tool changes and a total assembly time of 40.3 seconds. The non-value added labor takes up 43.2 percent of the assembly time. While this is an extreme example, it does show the very real cost and time penalty associated with sequences which do not minimize non-value added work content.

Inefficiencies also arise from reorientations of the assembly. Again, not all assembly reorientations can be avoided, as some are required to provide necessary access to a part of the assembly. It is desirable, however, to utilize assembly sequences which minimize them, if at all possible. Assembly reorientations or flips which occur in a particular station also consume productive assembly time as, most often, no other operations can take place during the change of position.

In the automobile alternator example discussed in Chapter 2, Whitney uncovered an assembly sequence among the available alternatives which required no flips during the assembly process. Several other alternative assembly sequences for the automobile alternator required three reorientations of the assembly. The apparently efficient alternative sequence identified by Whitney not only reduced non-value added assembly tasks, but also reduced the number of directions of assembly required for automation to one. This, in turn, reduced the number of degrees of freedom required the specified piece of automation to assemble the product.

In-station work height changes penalize productive assembly time in much the same way as assembly reorientations. They are often required to provide access to a particular aspect of the component, such as the top of the engine versus the bottom. Again, it is advantageous to minimize the number of work height changes by selection of the assembly sequence. As in the cases of tool change time and assembly reorientations, the non-value added work content will result in either extended cycle time at a particular station, thus reducing production volume capability, or the need for additional resources to meet the necessary cycle time. Both alternatives result in increased unit assembly cost.

5.2.2.2 Resource/Labor Utilization

For any product assembly, a series of resources, such as programmable or fixed automation and manual operators, must be allocated to perform the required assembly tasks. Each must be outfitted with necessary task specific tooling. These resources can have a significant impact on the fixed and variable cost of the assembly system. Full utilization of the resources, therefore, influences the unit assembly cost for a product.

Best resource utilization in the case of an assembly line consisting of entirely manual resources is often referred to as line balancing. Work is assigned to each station or operator so as to best utilize the time available for a given cycle time. The intention of loading the available cycle time to the fullest is to reduce the number of operators required to assemble the product. The cost associated with a manual resource is almost entirely variable and therefore the unused cycle time adds to the unit assembly cost.

In the case of other resource types, such as fixed or programmable automation, a greater percentage of their cost is fixed. It is still advantageous to accomplish as many tasks as possible in the available cycle time so as to reduce the required number of resources and thus, the capital expenditures associated with the assembly of the product. The intention is to distribute the fixed costs, attributable to the purchase of the resource, over a number of tasks. and obtain the most productive work for the fixed cost.

Gustavson [1986] presents a simplified case, which employs a single resource type to assemble a specific product. Twelve tasks are required and it is assumed that each task requires the same assembly time. Figure 5.14, presented on the following page, shows the unit cost plotted against the production batch size. The most striking curve on the graph is that for the entirely programmable automation station. Its "saw-tooth" shape shows how unit cost can increase dramatically with the addition of another resource. Cost decreases as the resources are more fully utilized until a new resource is necessary. At that point the newly added resource is not fully utilized, however its fixed costs are still applied to the assembly of each unit. This is magnified in the case of the programmable automation because of the relatively high cost of adding another resource.

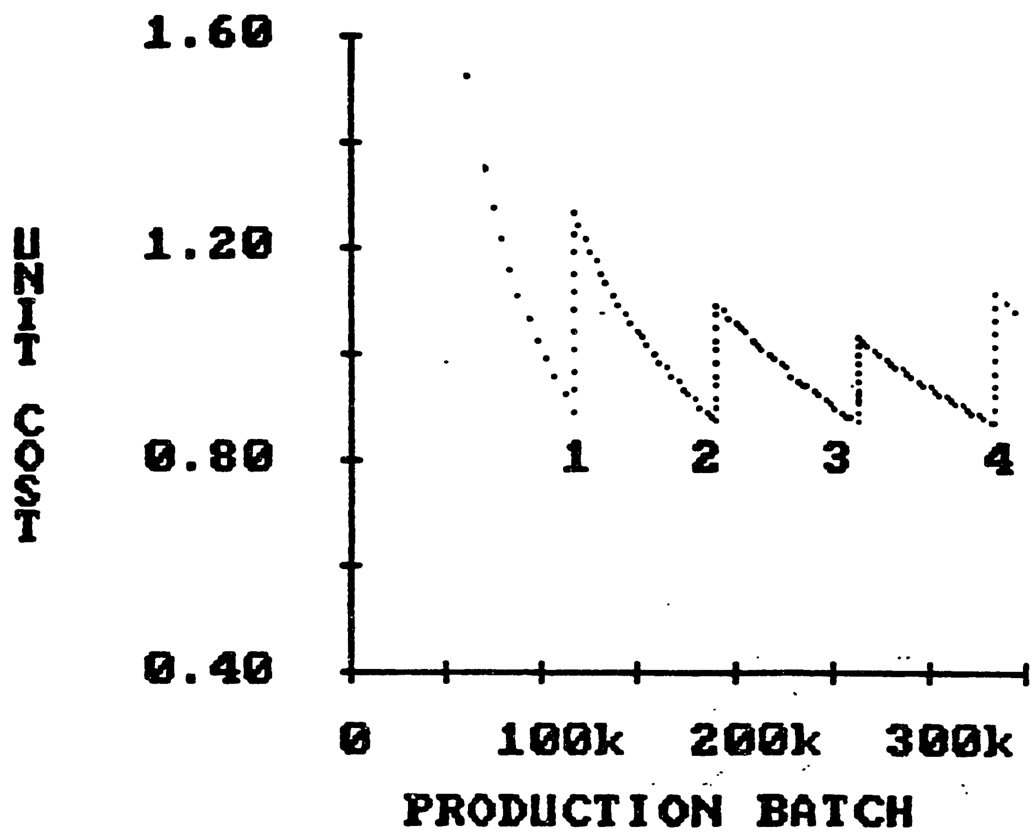


Figure 5.14: Unit Cost v.s. Production Batch Size/Resource Utilization

Source: Gustavson, 1986

In another case, reordering of the tasks, that is selection of another sequence, may better utilize the resources and allow for the elimination of an entire resource. Improved task distribution among the available resources can reduce the resource requirements for a given assembly. The example system, shown in Figure 5.15, underutilizes resource 1 (MAN-1). A reallocation of task 5 to the second manual resource (MAN-2), **given the sequence is valid,** would eliminate the need for resource 1 by better utilizing resource 2, and would not increase the total system cycle time or reduce system throughput. The result, in this case, is a reduction in cost associated with the assembly of this product.

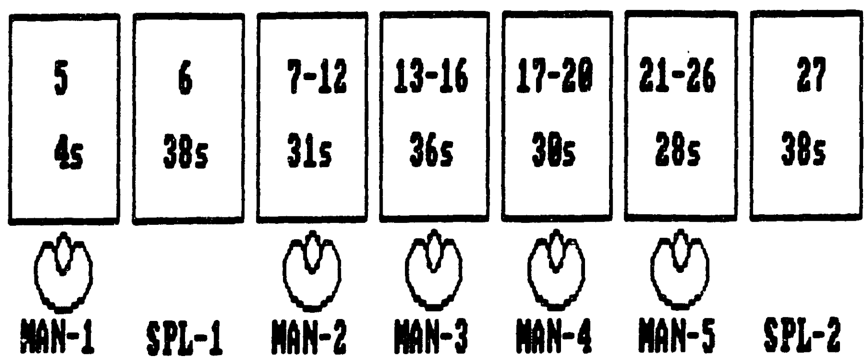


Figure 5.15: Underutilized Assembly Resource

5.2.2.3 Tooling Commonality

The time cost of frequent tool changes was discussed in Section 5.2.2.1, however frequent tool changes can also result in increased tooling costs. By combining operations which have similar tooling and hardware requirements, the total tool expenditures can be reduced. Product specific tooling can comprise a significant amount of the hardware costs for a particular assembly system. Therefore, the reduction in tool purchases for a particular product can have a significant impact on unit assembly cost.

Several of the valid assembly sequences for the door assembly, shown in Figure 5.16, allow the stud weld operations to be allocated among several different work stations, that is, the stud weld operations do not immediately follow one another. As a result, several weld heads and controllers must be purchased for these specific sequences, each at a substantial tooling cost. The more cost effective alternative is to combine the stud weld operations, so as to minimize the necessary tooling cost.

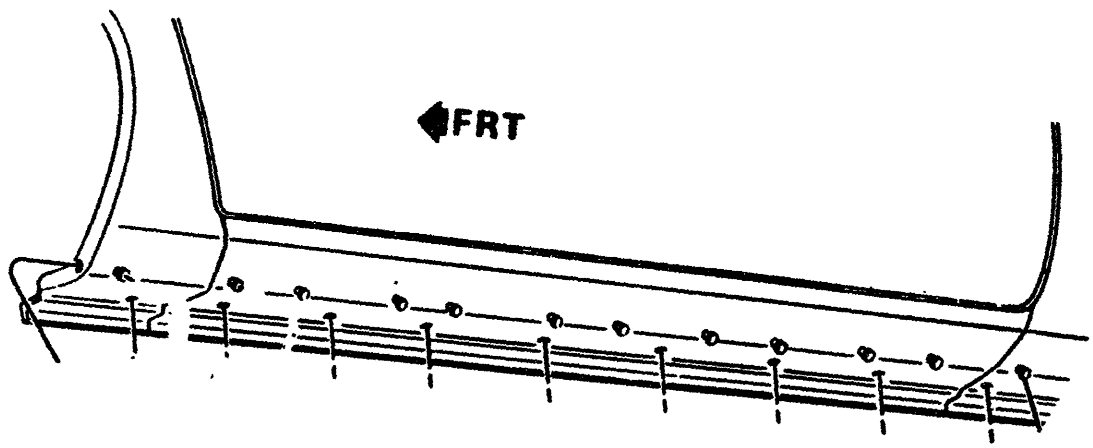


Figure 5.16: Door Stud Weld Locations

Combination of operations and minimization of tool purchases also reduce tool maintenance costs. A smaller number of tools reduce the number of items requiring periodic monitoring for process adjustment. For example, air tools must be periodically adjusted and inspection devices calibrated. The reduced tooling requirement cuts the preventative maintenance needs by reducing the number of tools which must be controlled to meet process requirements.

5.3 SUMMARY REMARKS

This chapter presented constraints other than the geometric constraints imposed by the product, which also limit the available assembly sequence choices. Facility constraints can strongly restrict the available assembly sequence alternatives. The second part of this chapter addressed the criteria for sequence selection. The qualitative attributes of assembly states and state transitions included identification of functional subassembly candidates, part stability, and ease of assembly or accessibility. The quantitative aspects of an assembly sequence include evaluation of the amount of non-value added work content, resource utilization, and tooling costs.

The selection criteria for assembly sequences are not always in agreement, but are many times at odds with one another. For example, to eliminate a potential tool change, an assembly reorientation may be required and vise versa. Compromises must be reached among the various criteria to obtain the most cost and quality conscious solution. The following chapter will present two cases, the steering column subassembly and the engine dress assembly, in order to exemplify the impact of sequence constraints and selection criteria on unit assembly cost

6.0 SEQUENCE CONSTRAINT AND SELECTION CRITERIA APPLICATION

This final chapter will present examples which will apply the sequence generation techniques and selection criteria, discussed in the previous chapters, to two products, each of which has distinct attributes. The first example, one which is discussed throughout this thesis, is the steering column subassembly. The second, more extensive example will apply assembly sequence constraints and selection criteria to major engine dress components, which include the generator, water pump, transaxle, sensors, engine electric harness, and engine mounts. Both will include tasks other than physical part mating, such as required test and inspection operations.

The impact of the alternative assembly sequences on unit assembly cost and assembly system configuration will be evaluated by ASDP (Assembly System Design Program)[Gustavson 1986]. Assembly system configurations consisting of manual operators only and of combinations of fixed and programmable automation along with manual operators are examined for each of the examples. Assembly task times supplied to ASDP are taken from standard time data available for these assemblies. Hardware data, such as resource and tooling cost, are based on best available estimated cost.

This chapter is organized into three major sections. The first section provides a brief introduction to ASDP, including the assembly data required and the program output. The second section presents the analysis of the assembly sequence alternatives pertaining to the steering column subassembly. The final section addresses the impact of the assembly sequence criteria as applied to the assembly of the engine dress components. A series of alternative sequences are evaluated for each of the candidate assemblies.

6.1 ASSEMBLY SYSTEM DESIGN PROGRAM (ASDP) DESCRIPTION

As mentioned previously, the Assembly System Design Program (ASDP) software is applied to the synthesis and steady-state analysis of assembly systems. It utilizes assembly task, resource capability, cost, and economic data in order to determine and evaluate the least cost assembly system configuration of manual operators, fixed automation, and programmable automation. The approach typically taken by manufacturing engineers can be referred to as "bottom-up". Given the necessary tasks and assembly sequence, the equipment and tooling is selected for each task. Subsequently, time and cost estimates are developed, upon which production volume capability and economic benefit is calculated.

While assembly systems designed by the "bottom-up" technique are always feasible or physically realizable, they may not reflect the most economical assembly system. The alternative method, that taken by ASDP, is called "top-down" and approaches the problem by creating assembly systems that meet production volume requirements and minimize overall unit production cost, which is comprised of fixed and variable production costs. ASDP uses a heuristic algorithm to determine candidate system solutions and their associated costs.

ASDP requires two individual data sets and additional economic and production volume information to create the assembly system solutions. The data input sheet for ASDP is shown in Figure 6.1 on the following page. The task data set defines all the task specific information for the given product. The information required in the task data set is listed below, along with a brief description:

Number of Tasks- Total number of tasks required to assemble the product.

Number of Resource Types- Total number of resource types (Manual, Fixed and Programmable Automation) that can be applied to the assembly of the product.

APPLICABLE TECHNOLOGY CHART

TITLE ______________________________ DATE __________

________ WORKING DAYS PER YEAR ________ ANNUALIZED COST FACTOR

________ SHIFTS AVAILABLE ________ AVERAGE LOADED LABOR RATE ($/h)

________ s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME ____________ TASK DATA SET NAME ____________

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- p INSTALLED COST/HARDWARE COST
- e UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK

OPERATION TIME (s)	TOOL NUMBER
HARDWARE COST ($)	

RESOURCE / TASK NUMBER	C p e v t_c m_s	C p e v t_c m_s	C p e v t_c m_s	C p e v t_c m_s
UNITS IN PRODUCTION BATCH	______	______	______	______
DESIRED PRODUCTION RATE (units/min)	______	______	______	______

Sheet ____ of ____

Figure 6.1: ASDP Data Sheet

Source: Charles Stark Draper Laboratory, Inc.

Resource Applicability to Each Task- In other words, can task 2 be done by Resource 1? For example, some tasks may only be performed by a manual operator.

Operation Time- Time required for the specific resource to complete the individual task.

Tool Number Required- Task specific tool

Tool/Material Handling Cost- Cost required for the purchase of the task specific tooling or material handling equipment.

Throughout the input and output stages of the the program, tasks are referred to by their task number only, with no accompanying description. Tasks are input in a known assembly sequence, as the program does not select from the available sequence alternatives. In order to evaluate a different product assembly sequence, an entirely different task data set must be created.

The second data set specifies the resource cost/performance data for each of the candidate resources for the given task listing. The listing of the resource data requirements follows, along with a brief description:

Symbolic Resource Name- Three character identifier for each resource.

Resource Hardware Price- Cost associated with the purchase of the basic resource hardware. Purchase of programmable automation, for example, not including installation cost.

(Total Cost)/(Hardware Cost)- Ratio which reflects additional costs associated with the installation of an assembly resource. Other cost include engineering, set-up, etc.

Percent Up-time Expected- Provides for any anticipated downtime for a specific resource, including resource failure or preventative maintenance.

Operating/Maintenance Rate- Direct operating cost for a resource. Includes maintenance or indirect labor cost as well as power or lubrication needs. Value specified in dollars per hour.

Tool Change Time- Time required for a resource to change tools when it is assigned two consecutive tasks which require different tooling.

Maximum Stations per Worker- Assigns any direct labor cost associated with monitoring the proper function of a resource. Includes manpower required for relief of manual operators.

Once task and resource data have been entered, two solution types are available, general and specific. Each requires supplemental data regarding batch size, station to station move time, and other economic data to generate their solutions. This information will be kept constant between each different assembly sequence for comparative purposes. These input variables will be discussed in the following section.

The general solution synthesizes several different assembly systems for various values of what is called an availability factor. The basic nature of the availability factor is to establish the cycle time available at any station. Once cycle time is established, as much work as possible is given to that resource. Unlike the currently available line balancing aids, such as CALB or Nulisp, ASDP considers not only operations and their associated task time, but also includes the time required for any tool changes required at a particular station. The general program synthesizes a least cost assembly system for various values of availability factor. The different availability factors are determined by the program. The output for the general solution is a resource listing of the resource types used in the least cost assembly system for each availability factor. The general solution also provides the unit assembly cost of the product for each availability factor, both in graphical and tabular form.

The specific solution provides extensive cost and assembly system detail regarding a synthesized system for a specific availability factor. The limiting availability factor of specific interest is chosen by the user in order to further explore the different system alternatives. For each task, the resource and tool assignment is provided, including annualized cost and task times. For each resource, the maximum time at any station, task number assigned, and number of workers charged to that resource is provided, as well as the unit assembly cost for the product.

6.1.1 Basic Sequence Evaluation Parameters

In order to provide a common ground for the comparison of the cost impact of differing assembly sequences, several of the economic, production, and time parameters employed by ASDP are given fixed values. These parameters are applied in both the specific and general solutions of ASDP. The name of the input variables along with a brief description is provided below, followed by the base value of the variable.

Annual Cost Factor- Referred to as Capital Recovery Factor. Pertains to depreciation of fixed costs. Base Value= .358

Average Loaded Labor Rate- Cost per hour of a nominal direct worker including burden. Base Value= $21.60/hour

Working Days per Batch- Available working days per year. Base Value= 235 days

Maximum Shifts Available- Available eight hour shifts per day Base Value= 2

Maximum Intervening Non-assigned Tasks for any Resource- permits non-consecutive task assignment when specified greater than zero. Allows non-sequential task grouping at a resource. Base Value= 0

Production Batch Size- Yearly required production volume. Base Value= 250,000 units

Percentage of Available Working Time to be Charged with Fixed Costs- Used to increase desired production rate, allowing the potential production of several different products during the year. Base Value= 100%

Station to station move time will also be kept constant between different assembly sequences for comparative purposes, however it will be specific to the product being analyzed.

6.2 STEERING COLUMN SUBASSEMBLY SEQUENCE ANALYSIS

The steering column subassembly has been the focus of several discussions throughout this thesis. It has been used to describe extensions to the liaison sequence analysis technique, as well as certain sequence constraints other than those directly related to part geometry. This section will include the application of sequence constraints and the cost impact of different selection criteria, like those discussed in Chapter 5. This section is organized into three major parts:

1. Facility/Assembly Background
2. Manual System Analysis
3. Manual/Automated System Analysis

On the surface, the assembly of the steering column appears to be a simple task, as the components are, for the most part, accessible and simple to install. However, as the next several sections will show, the assembly sequence selected for this simple product can greatly impact unit assembly cost.

6.2.1 Facility/Assembly Background

The major components which comprise the steering column subassembly are repeated from Chapter 2 and are shown in Figure 6.2 on the following page. The extended liaison diagram, which includes the required non-assembly tasks, is shown in Figure 6.3. The available sequence alternatives are strongly constrained by part storage limitations and special operation requirements. Significant part stocking area or floor space is required for both the column assembly and the steering wheel. Optional handling packages and available colors have resulted in six different column assemblies and nineteen steering wheels. Only work stations 1 and 3 are capable of stocking these parts near the assembly line. A simplified floor layout is shown in Figure 6.4.

The assembly of the steering column components also includes a paint operation, which introduces yet another facility constraint. Ventilation is available in station 2 of the assembly facility, and therefore it is advantageous to locate the paint operation in station 2, so as to minimize any major facility modifications. This aspect is also shown in Figure 6.4. To briefly summarize, these facility influences result in the following constraints:

1. The column schedule must be located in station 1, so as to precede paint.
2. Paint will be located in Station 2
3. The steering wheel will be in station 3, as it must follow the paint operation and station 3 is the last available storage area.

Before moving forward to the analysis section, where a comparison of alternate assembly sequences will be conducted, two comments regarding the liaison precedence diagram, shown in Figure 6.3, are worthy of note. First, it does not include a task for the mating or introduction of the column assembly to the assembly fixture which will support it throughout the assembly process.

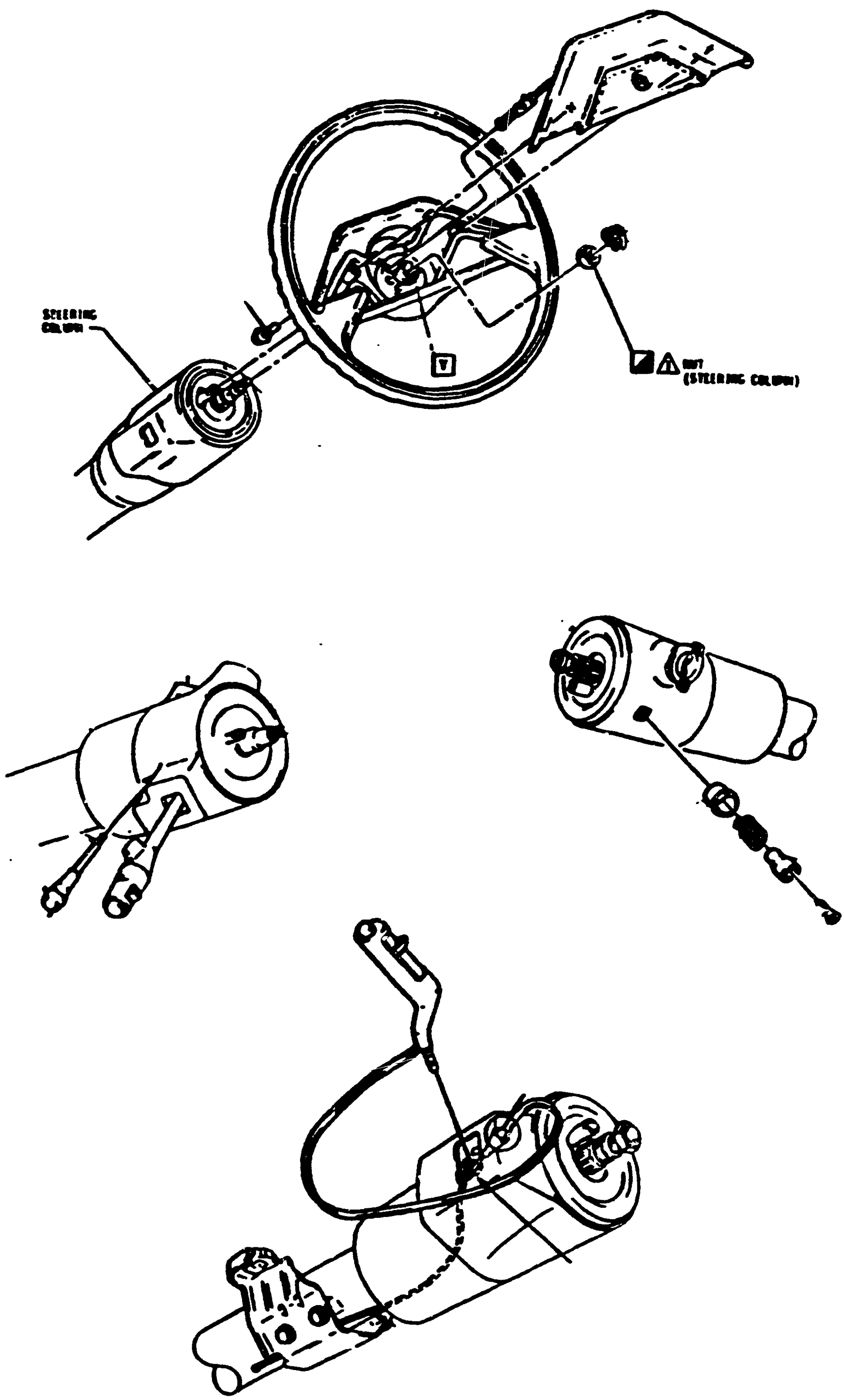


Figure 6.2: Steering Column Assembly Drawing

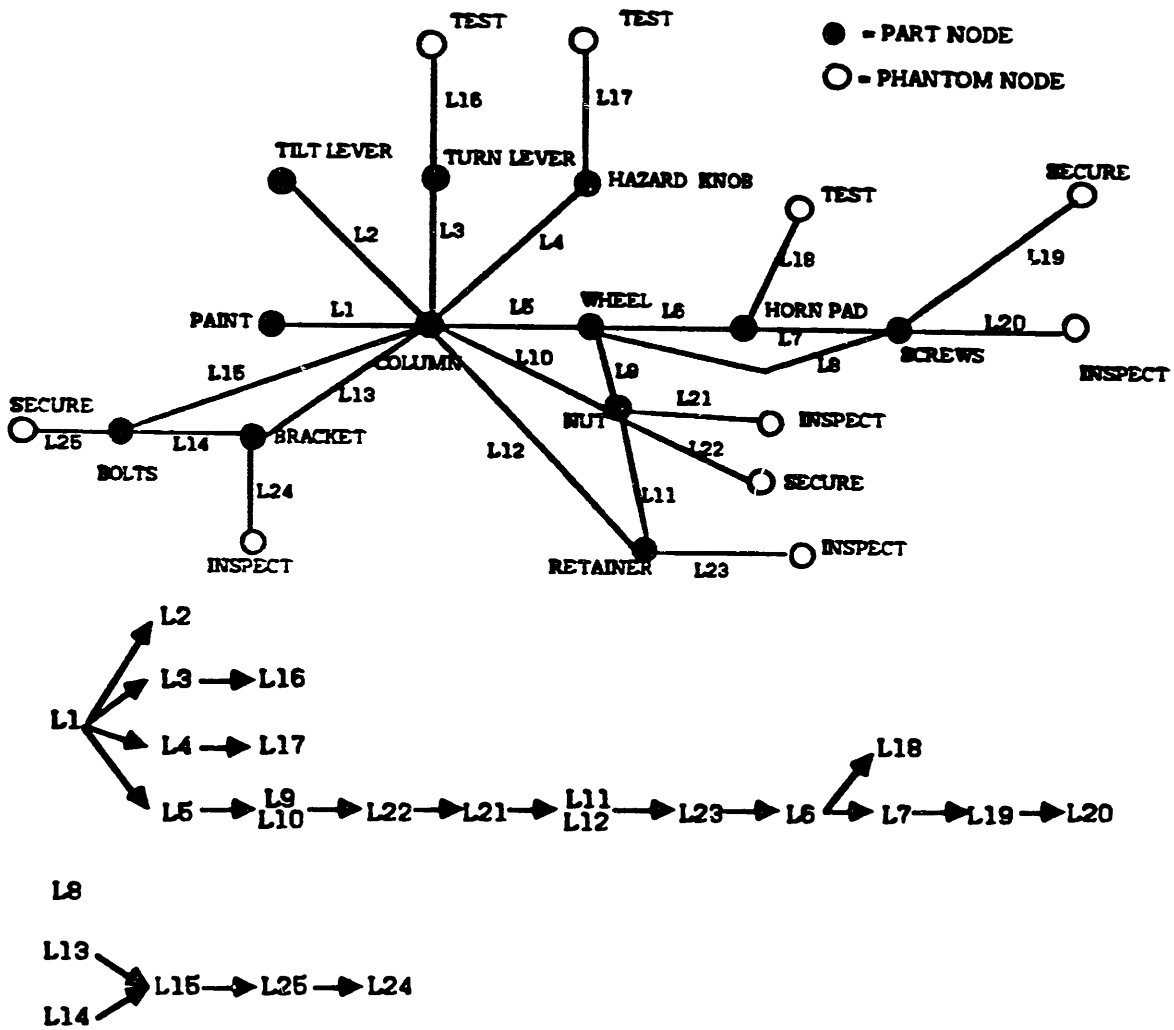


Figure 6.3: Steering Column Subassembly Liaison and Liaison Precedence Diagrams

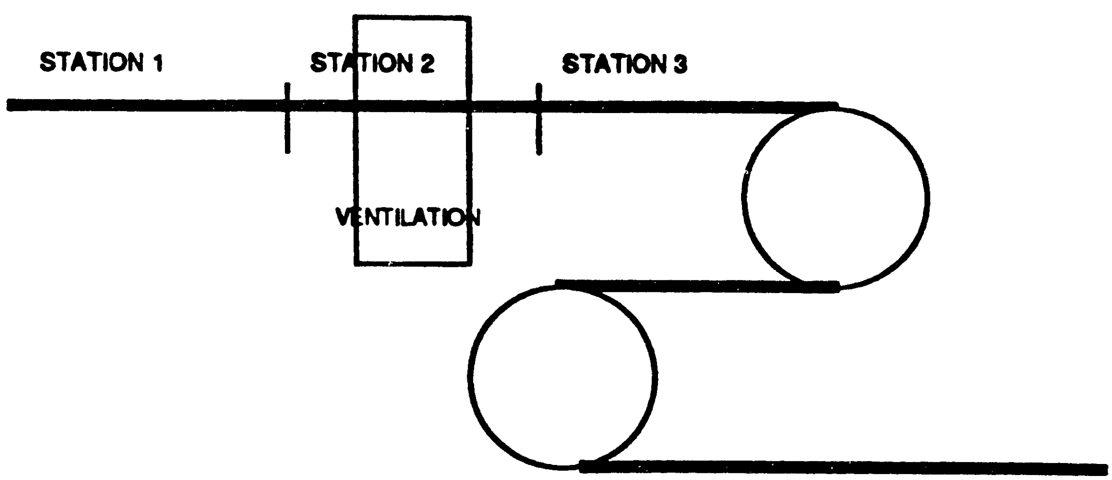


Figure 6.4: Simplified Floor Layout

Tasks, such as column schedule, which do not have an associated liaison will be added to the assembly sequences as required. Second, the diagram shows that two "subassemblies" may be created by establishing liaisons 8 and 14, wheel to screws and bolts to bracket, respectively. These will not be considered as valid sequence alternatives as they are unstable and serve no useful purpose in the assembly of the product.

6.2.2 Manual System Analysis

This section discusses the analysis of varying assembly sequences on assembly systems consisting of manual operators as the sole resource type, though a separate resource was specified for the paint operation in order to keep other tasks from being grouped with it. Nine different alternative assembly sequences were analyzed for their impact on assembly cost and system configurations, three for each of three unique assembly sequence "strategies". Sequences 1.0, 1.1, and 1.2 each embodied the first selection strategy, while sequences 2.0, 2.1, and 2.2 and sequences 3.0, 3.1, and 3.2 utilized the second and third selection strategies, respectively. Each of the alternative assembly sequences consists of twenty-eight total tasks, and abide by the facility constraints described in the previous section.

The selection of the first set of three assembly sequences focussed on two important cost aspects of assembly systems, resource utilization and grouping of similar assembly tasks. The assembly order for Sequence 1.0 can be found in Appendix A with the time, tooling, and tooling cost for each task. This strategy resulted in three key characteristics in the selection of this set of sequences. First, the MVSS electrical test operations of the horn pad, turn/cruise lever, and hazard knob would be done in succession in an attempt to reduce the purchases of the test equipment. Second, the column bracket bolts would all be finger started and the secure operation for each bolt would then be done consecutively.

This was also done in an effort to reduce tool cost associated with the secure operation. The additional benefit of this method of sequence selection is a reduction in the tool changes and associated tool change time required to assemble the product. Finally, given the minimum required production rate, the selection of the sequences would attempt to best utilize the available assembly labor. In particular, the first resource or operator, which precedes the paint operation, has a limited amount of work that can be performed. As many tasks as possible are assigned prior to the paint booth, namely those associated with the assembly of the column bracket, so as to better utilize this resource without violating the sequence constraints.

The second set of assembly sequences placed a priority on grouping similar operations with the probable result of reducing tool changes and tool purchases. No consideration was made as to resource utilization. The assembly order for Sequence 2.0 is shown with its associated task information in Appendix A. This sequence does not utilize the time available on resource or operator 1 to accomplish any other tasks prior to the paint operation. This alone could result in lengthened system cycle time or need for additional resources. The other differences in the second set of sequences are very minor in comparison to the first set of sequences. An attempt was made in both cases to reduce tool purchases and tool change time in both cases.

The third set of assembly sequences employed a significantly different strategy for assembly. Sequences 3.0, 3.1, and 3.2 used assembly orders which completed the installation and inspection of a component prior to any work on the next component. The task order for Sequence 3.0 can also be found in Appendix A. The primary benefit of this assembly philosophy is that a part can be tested or inspected as soon in the assembly process as possible, in order to identify parts for rework or repair. For example, the horn pad is electrically tested immediately after it has been snapped into place on the steering wheel, but before the two holding screws are installed. This simplifies the removal and replacement of the horn pad, in the event of an electrical test failure. The obvious result of this approach to sequence selection is that common operations are not grouped, increasing both the non-value added work content, and the possibility of additional tool purchases. The repair cost savings which result from this strategy are not included in the unit assembly cost of the product.

The nine different assembly sequences, each encompassing one of the three assembly strategies, were evaluated for their impact on unit assembly cost by ASDP. The resulting unit cost versus availability curve for three of the assembly sequences is shown in Figure 6.5 on the following page. The remaining six are not represented on the graph as they closely or identically mimic the other sequences in their set. In other words, the sequence changes made to Sequence 3.1 did not cause a significant difference in unit assembly cost curve of Sequence 3.0.

It is accurate to say that the unit assembly cost for Sequence 1.0 is equal to or below that of sequence alternative 2.0, and in all cases is below the unit assembly cost of sequence alternative 3.0 for the entire range of useful availability factors. No cost information is provided for availability factors less than .860 as it would require parallel work stations for the paint operation in order to accommodate production volume requirements.

The general system solution provided by ASDP shows that, from a cost perspective, sequence 1.0 is the best, while sequence 3.0 is the most costly. The question is to determine cause of the sometimes 20% cost advantage of sequence 1.0 over the other alternatives. The answer to this question comes from examination of the specific solution for each sequence.

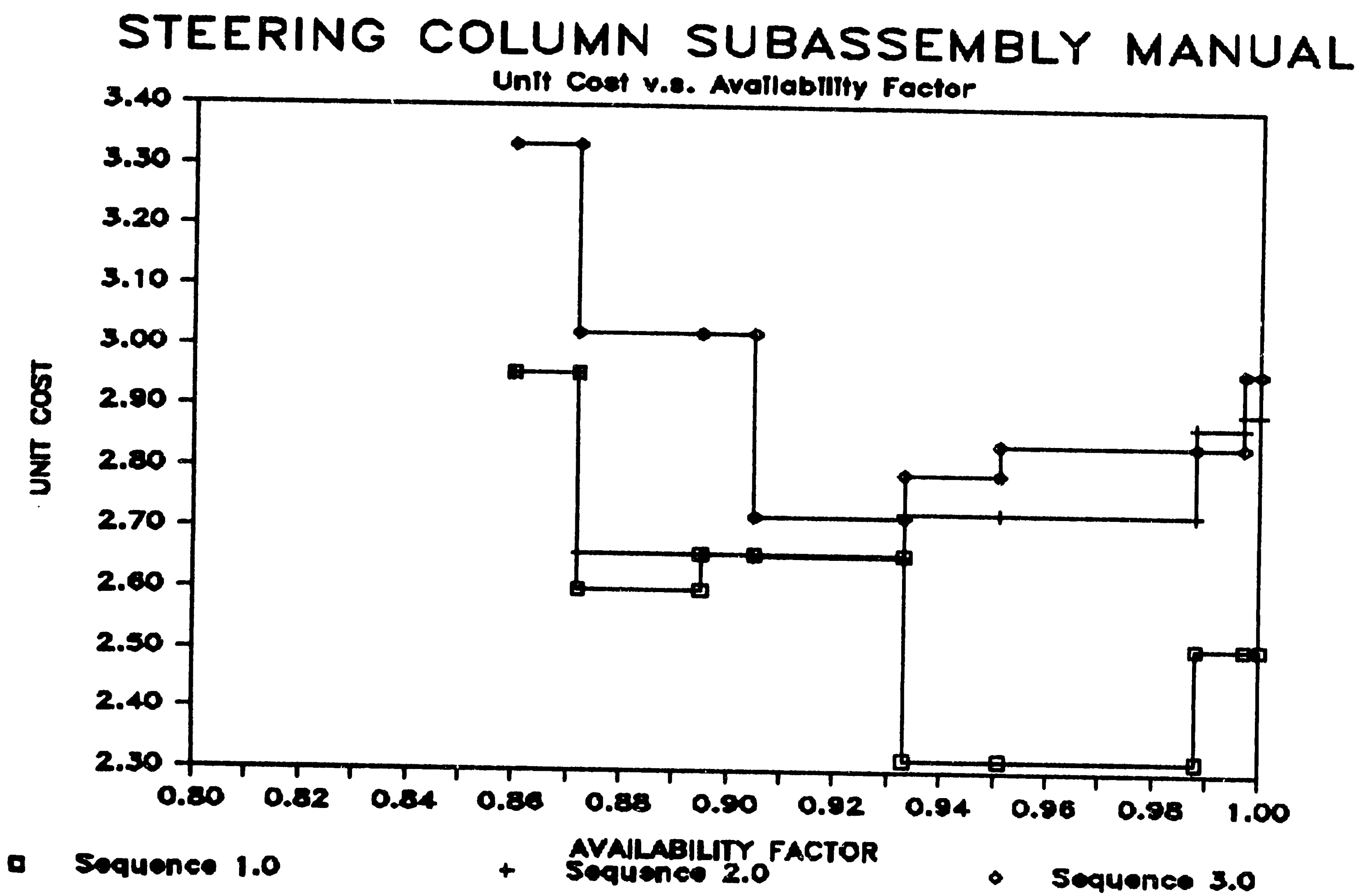


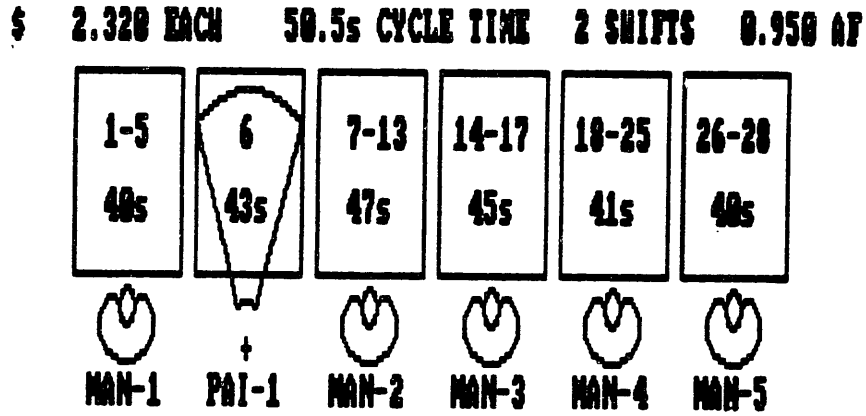
Figure 6.5: General Solution: Unit Cost v.s. Availability Factor

Figure 6.6 shows the assembly system schematic and resource task assignments for each of the alternative assembly sequences at an availability factor of .95. The most noticeable difference between the three schematics is that Sequences 2.0 and 3.0 each require an additional resource over that required by the system for Sequence 1.0. The likely cause of this is the underutilization of the first resource in the second and third sequences. The available cycle time on resource (MAN-1) is not fully taken advantage of. Further information about the cost difference between the three alternative sequences can be extracted from the fixed and variable cost information shown in Table 4.

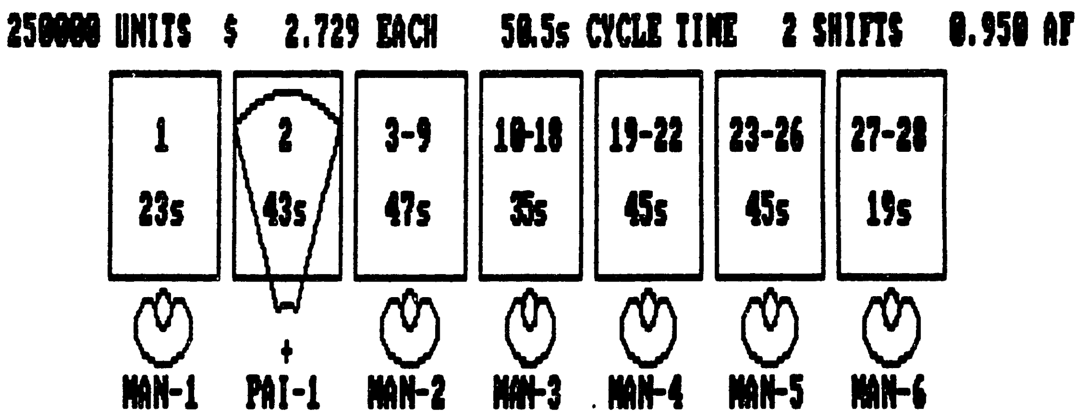
The majority of the cost differential between the alternative assembly sequences is due to the greater variable labor cost of Sequences 2.0 and 3.0. The $0.344 difference in variable cost comes from two sources: the additional resource used by Sequences 2.0 and 3.0, and the increased system operating maintenance rate associated with the additional resource. The fixed and variable assembly costs for the paint operation are the same for all three cases.

The remainder of the cost difference, $0.065 between Sequences 1.0 and 2.0 and $0.130 between Sequences 1.0 and 3.0 is attributable to fixed costs. A likely outcome of grouping tasks requiring similar tooling is the reduction in tooling purchases. As shown in Table 4, Sequence 1.0 requires the purchase of seven tools to assemble the product. Sequences 2.0 and 3.0 require the purchase of 8 and 9 tools, respectively. Specifically, the additional tools required for these sequences are electrical testers, which require a significant capital investment. This is the result of the the sequence selection strategy employed by sequences 2.0 and 3.0, that of not grouping tasks which require similar tooling.

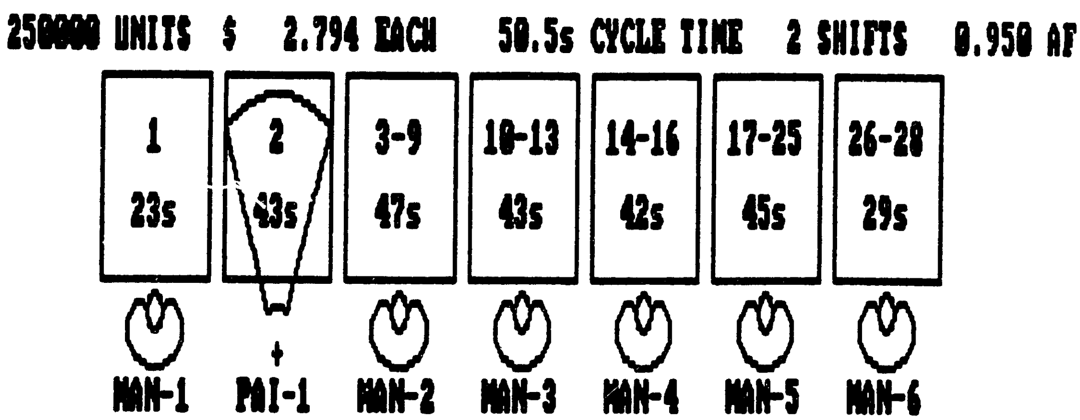
One final note is worthy of mention prior to proceeding into the next section. In the case of the general solution for Sequence 1.0 , the unit assembly cost for the availability factor of 1.00 was higher than that for availability factor .95



Sequence 1.0



Sequence 2.0



Sequence 3.0

Figure 6.6: Manual System Schematics and Task Assignments

Sequence 1.0

APPARENT SYSTEM COST = $ 539334

RESOURCE	TOTAL COST	NUMBER USED	TIME USED	UNIT COST FIXED	UNIT COST VARIABLE	NUMBER OF TASKS	NUMBER OF TOOLS	NUMBER OF WORKERS
MAN	468265	5	46.5	0.155	1.718	27	7	5.6
PAI	111784	1	43.0	0.086	0.361	1	1	1.1

1.19 UNITS PER MINUTE
46.5 seconds MAXIMUM TIME AT ANY STATION
268040 units PRODUCTION CAPACITY OF THIS SYSTEM
4.25 $/hr SYSTEM OPERATING/MAINTENANCE RATE

580049 COST ($) TO PRODUCE 250000 UNITS, WITH UNIT COST ($) 2.320
168000 ($) TOTAL CAPITAL INVESTMENT REQUIRED
122000 CAPITAL EXPENSE ($) FOR REQUIRED HARDWARE

Sequence 2.0

APPARENT SYSTEM COST = $ 565070

RESOURCE	TOTAL COST	NUMBER USED	TIME USED	UNIT COST FIXED	UNIT COST VARIABLE	NUMBER OF TASKS	NUMBER OF TOOLS	NUMBER OF WORKERS
MAN	570563	6	46.5	0.220	2.062	27	8	6.7
PAI	111784	1	43.0	0.086	0.361	1	1	1.1

1.19 UNITS PER MINUTE
46.5 seconds MAXIMUM TIME AT ANY STATION
268040 units PRODUCTION CAPACITY OF THIS SYSTEM
4.75 $/hr SYSTEM OPERATING/MAINTENANCE RATE

682347 COST ($) TO PRODUCE 250000 UNITS, WITH UNIT COST ($) 2.729
213750 ($) TOTAL CAPITAL INVESTMENT REQUIRED
152500 CAPITAL EXPENSE ($) FOR REQUIRED HARDWARE

Sequence 3.0

APPARENT SYSTEM COST = $ 606701

RESOURCE	TOTAL COST	NUMBER USED	TIME USED	UNIT COST FIXED	UNIT COST VARIABLE	NUMBER OF TASKS	NUMBER OF TOOLS	NUMBER OF WORKERS
MAN	586673	6	46.5	0.285	2.062	27	9	6.7
PAI	111784	1	43.0	0.086	0.361	1	1	1.1

1.19 UNITS PER MINUTE
46.5 seconds MAXIMUM TIME AT ANY STATION
268040 units PRODUCTION CAPACITY OF THIS SYSTEM
4.75 $/hr SYSTEM OPERATING/MAINTENANCE RATE

698457 COST ($) TO PRODUCE 250000 UNITS, WITH UNIT COST ($) 2.794
258750 ($) TOTAL CAPITAL INVESTMENT REQUIRED
182500 CAPITAL EXPENSE ($) FOR REQUIRED HARDWARE

Table 4: Fixed and Variable Unit Cost Breakdown

(See Figure 6.7 on following page). The variable labor cost for the assembly system of availability factor .95 is charged only for the time required to produce the required production batch of 250,000. Its cycle time is lower than that of the assembly system for availability factor 1.00, and therefore can produce the necessary batch in less time. It is assumed that the resources (labor) could be utilized elsewhere or charged out for the additional unused work time. Under many management philosophies (or labor agreements), it is undesirable, if not impossible, to assign resources to several different tasks for different parts of the work day. In the event that the manpower cannot be charged out for other work during the available time, the unit assembly cost for availability factors 1.0 and .95 are identical.

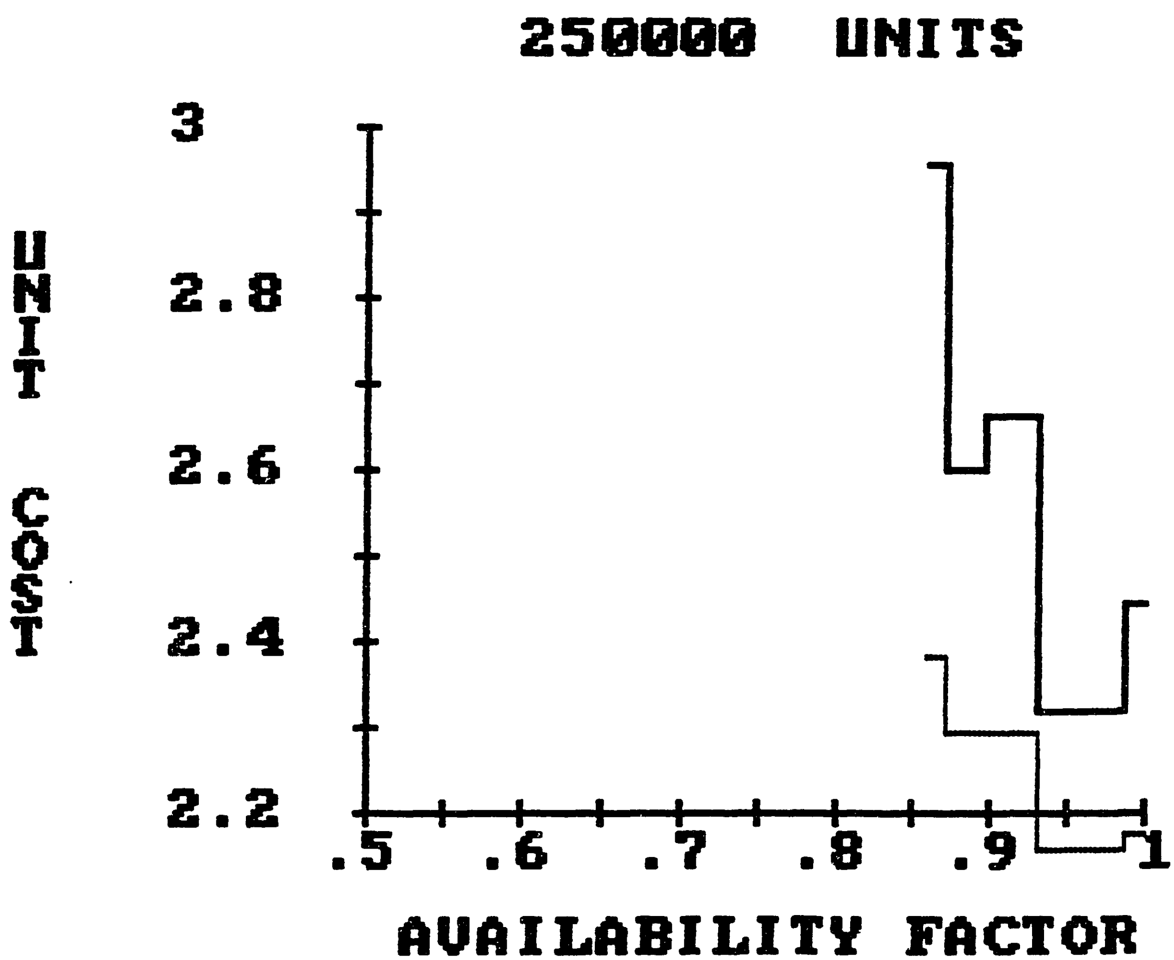


Figure 6.7: Unit Cost v.s. Availability Factor for Sequence 1.0

6.2.3 Manual/Automated System Analysis

This section presents the analysis of alternative assembly sequences on assembly systems consisting of manual operators, fixed automation, and programmable automation. Again, a separate resource was specified for the paint operation so as to keep other tasks from being grouped with it. In this case, seven different assembly sequences were evaluated for their impact on assembly system configuration and cost. The alternative assembly sequences consist of twenty eight tasks and four possible resources, and are constrained by the facility restrictions described in Section 6.2.1.

For the most part, the tasks required to assemble the steering column and its components are not conducive to automation. Operations such as major part scheduling or finger starting fasteners are best suited to manual assembly. Seven of the twenty eight tasks have resources other than manual operators applicable to them. The task completion and tool change times are specific to each resource. In particular, the task times for the fixed automation resource are less than the task times for the manual or programmable resources as it performs several of the operations simultaneously.

Of the seven sequences evaluated for cost and assembly system configuration, two most clearly point out the impact that sequence selection can have. The first assembly sequence, referred to as Sequence 1.0, placed all tasks that could be performed by the fixed or programmable resource in succession. This was done in an attempt to best utilize the time available on these two specific resources, if they were in fact the least cost resource. The task data for this sequence is found in Appendix B. An attempt was also made to order the remaining tasks so as to best utilize the manual operators and tooling for cycle times greater than 46 seconds (availability factor > .88). Unit assembly costs increase for availability factors less than .88 due to the duplication required of the paint operation because of cycle time constraints.

The second sequence, also found in Appendix B, does not group the fixed and programmable automation tasks as in the first case. If automation is still the most cost effective method of resource allocation, then two resources would be required for the seven tasks, where Sequence 1.0 would be able to apply only one resource. Sequence 2.0 also attempted to best utilize the remaining manual resources, as was done in the first case.

The general solution graph of unit cost v.s. availability factor, shown in Figure 6.8 on the following page, presents two of the seven assembly sequences evaluated by ASDP. The third sequence shown on the graph is of the least cost fully manual assembly system from the previous section, and is provided for comparative purposes. The unit assembly cost for Sequence 1.0 is below that of Sequence 2.0 for all availability factors greater than .92. For smaller values, the cost difference between the two sequences is increasing and in a very close range. The cost increase for availability factors below .90 is due primarily to labor unbalance and the cost of providing parallel work stations for the paint operation, because of its cycle time restrictions. The real cost and assembly configuration impact of assembly order can be seen for availability factor .95. Again, the specific solutions for both these cases are used to pinpoint the source of the costs.

The assembly system schematics for the two sequences and availability factor .95 are shown in Figure 6.9. The most obvious differences between the two alternatives are that Sequence 2.0 requires an additional fixed resource as well as an additional manual operator. This characteristic is a direct result of the assembly sequence chosen for Sequence 2.0. While the use of fixed automation is still the most cost effective method of completing several of the tasks as opposed to an entirely manual system, the sequence chosen does not permit them to be accomplished by a single fixed resource, as is the case with Sequence 1.0. It also makes ineffective use of the third manual operator as compared to the system solution for Sequence 1.0.

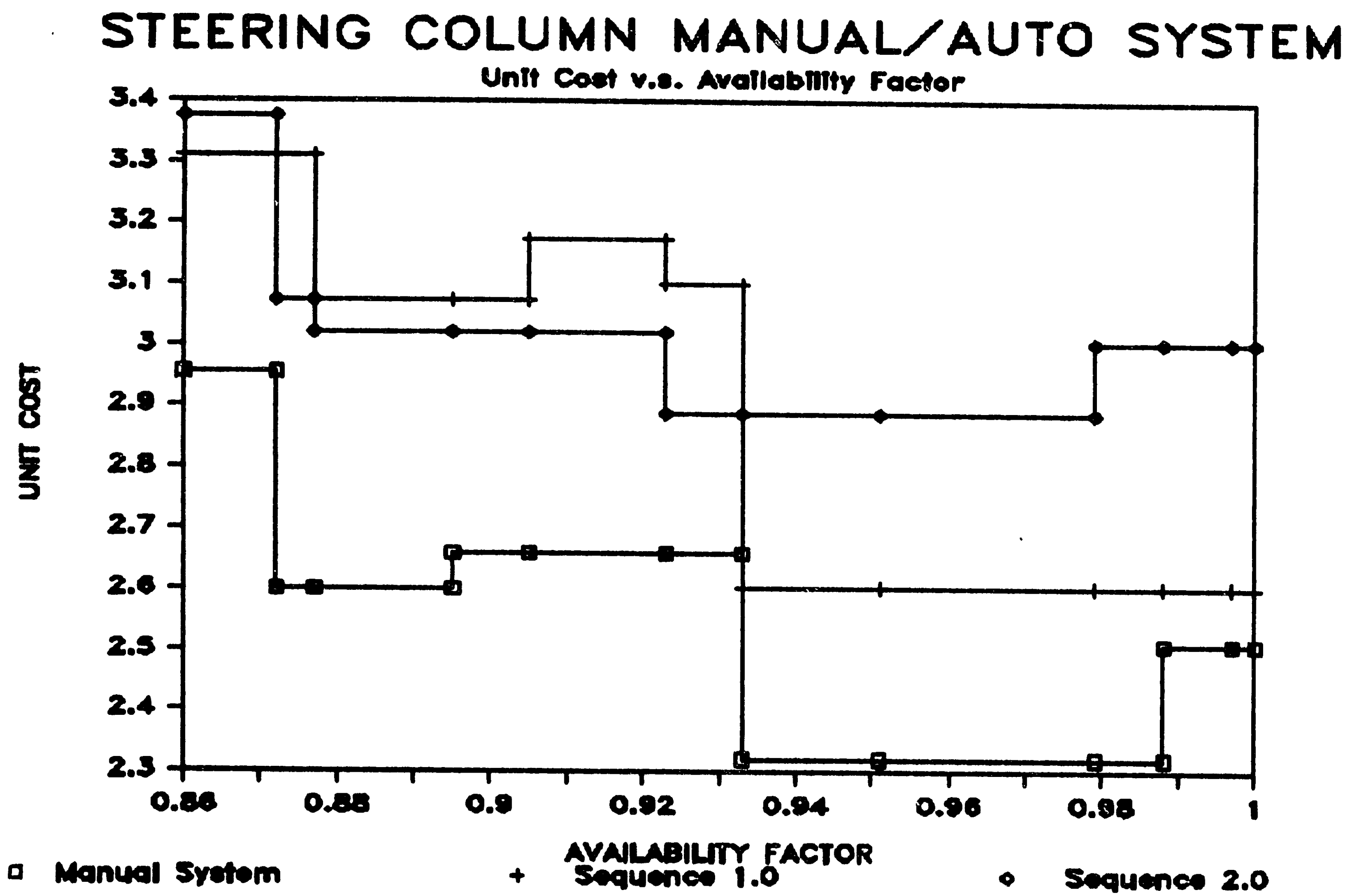
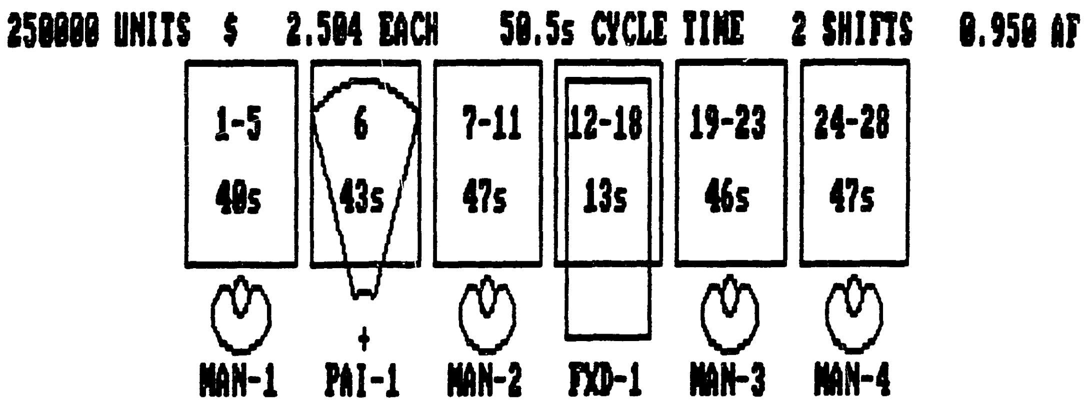
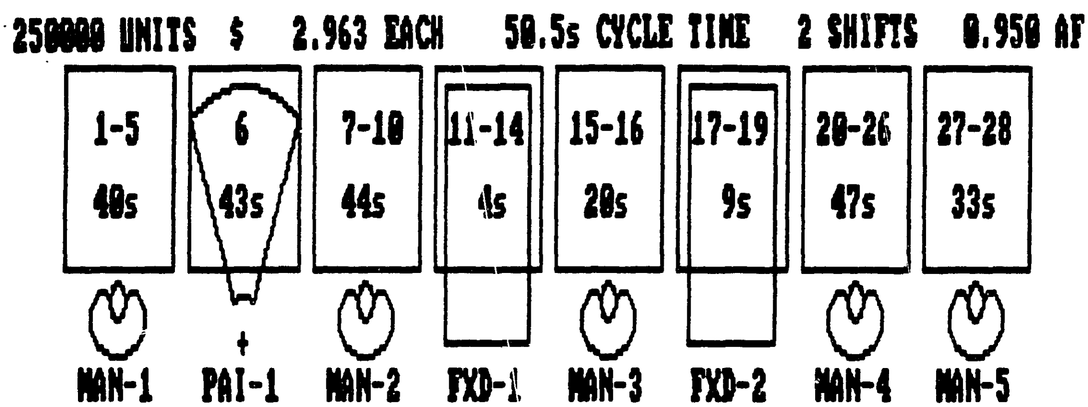


Figure 6.8: General Solution: Unit Cost v.s. Availability Factor



Sequence 1.0



Sequence 2.0

Figure 6.9: Assembly System Schematics

The breakdown of the unit fixed and variable costs attributable to each resource type is detailed in Table 5 on the following page. As in the analysis of the fully manual assembly system, the fixed and variable unit cost for the paint operation is the same for both sequences. Nearly ninety percent of the $.459 cost difference, as expected, is accounted for by the use of the manual resources. Sequence 2.0, as mentioned previously, requires an additional resource to assemble the product, this due primarily to the non-successive assignment of tasks that can be accomplished by the fixed resource type. This accounts for a $0.343 difference in variable cost associated with this resource. A small increase

Sequence 1.0

APPARENT SYSTEM COST = $ 504572

RESOURCE	TOTAL COST	NUMBER USED	TIME USED	UNIT COST FIXED	UNIT COST VARIABLE	NUMBER OF TASKS	NUMBER OF TOOLS	NUMBER OF WORKERS
MAN	363550	4	46.5	0.079	1.375	20	4	4.4
PAI	117154	1	43.0	0.107	0.361	1	1	1.1
FXD	145339	1	13.0	0.140	0.442	7	3	1.4

1.19 UNITS PER MINUTE
46.5 seconds MAXIMUM TIME AT ANY STATION
268040 units PRODUCTION CAPACITY OF THIS SYSTEM
5.00 $/hr SYSTEM OPERATING/MAINTENANCE RATE

626042 COST ($) TO PRODUCE 250000 UNITS, WITH UNIT COST ($) 2.504
228000 ($) TOTAL CAPITAL INVESTMENT REQUIRED
152000 CAPITAL EXPENSE ($) FOR REQUIRED HARDWARE

Sequence 2.0

APPARENT SYSTEM COST = $ 543345

RESOURCE	TOTAL COST	NUMBER USED	TIME USED	UNIT COST FIXED	UNIT COST VARIABLE	NUMBER OF TASKS	NUMBER OF TOOLS	NUMBER OF WORKERS
MAN	465848	5	46.5	0.145	1.718	20	5	5.6
PAI	117154	1	43.0	0.107	0.361	1	1	1.1
FXD	157777	2	9.0	0.172	0.459	7	3	1.4

1.19 UNITS PER MINUTE
46.5 seconds MAXIMUM TIME AT ANY STATION
268040 units PRODUCTION CAPACITY OF THIS SYSTEM
6.75 $/hr SYSTEM OPERATING/MAINTENANCE RATE

740779 COST ($) TO PRODUCE 250000 UNITS, WITH UNIT COST ($) 2.963
296250 ($) TOTAL CAPITAL INVESTMENT REQUIRED
197500 CAPITAL EXPENSE ($) FOR REQUIRED HARDWARE

Table 5: Fixed and Variable Unit Cost Breakdown

in the fixed cost associated with the manual resource is due to the tool purchase requirements of the assembly system. The remaining ten percent of the cost advantage afforded by Sequence 1.0 is traceable to the fixed automation resource. The unit assembly cost associated with the fixed resource type of Sequence 2.0 is $0.05 greater than that for Sequence 1.0, even though they both accomplish the same seven tasks and have identical tool requirements. The fixed costs rise due to the additional capital expense necessary to purchase another fixed resource. The remaining difference in variable costs between the two sequences results from the additional operating and maintenance expense for two resources as opposed to one for Sequence1.0.

6.2.4 Summary Comments

This section has shown how varying assembly sequences and selection criteria can have a major impact on unit assembly cost and assembly system configuration. In the case of an entirely manual assembly system for the steering column subassembly, differing assembly orders contributed to a 20 percent difference in unit assembly cost. The most significant sequence features from a cost standpoint were the grouping of similar tasks in an effort to reduce tooling purchase requirements and non-value added labor, and the full utilization of assigned resources.

A similar result was obtained when different assembly sequences were applied to resource types which included manual operators and fixed and programmable automation. The two differing sequences showed that grouping tasks by resource capability can also reduce unit assembly cost. In this case, grouping tasks, which permitted the use of one fixed automation station as opposed to two, reduced unit assembly cost by an additional 4 percent. The impact of grouping tasks to reduce tooling purchases and non-value added labor is the same for manual and automated systems as was shown for the completely manual system.

6.3 ENGINE DRESS COMPONENT ASSEMBLY SEQUENCE ANALYSIS

The assembly of the engine dress components to the base engine has been employed on several occasions in this thesis to address extensions to liaison sequence analysis, and was also used in Chapter 5 to describe the role of facility constraints and part storage considerations. This section uses the assembly of the major engine dress components to evaluate the impact of varying assembly sequences on unit cost and assembly system configuration. This product utilizes the same base economic and production parameters in ASDP as were used in the previous example, except where noted. This section is organized into three major parts:

1. Facility/Assembly Background
2. Manual System Analysis
3. Manual/Automated System Analysis

The assembly of the engine dress components involves a greater number of parts and non-assembly operations than in the case of the steering column subassembly. Several other complexities, such as trade-offs between tool changes and assembly reorientations, also arise.

6.3.1 Facility/Assembly Background

The major components or engine accessories which are assembled to the base engine can, for the most part, be effectively divided into the components which reside on the front and rear of the engine. The major exceptions are the transaxle and transaxle mounting bracket, which are shown in Figure 6.10 on the following page. The front of engine accessories used in this analysis are shown in Figure 6.11, and the rear of engine components in Figure 6.12.

The liaison and liaison precedence diagrams for the transaxle and transaxle bracket are presented in Figure 6.13. The diagram has been supplemented with MVSS required test and inspection tasks, as well as other non-assembly operations. The extended liaison and liaison precedence diagrams for the front and rear engine accessories are shown in Figures 6.14 and 6.15, respectively. The three components (nodes) shared by each of the diagrams are the engine harness, transaxle, and engine. Each have part to part interaction or relationships (liaisons) with several other engine dress components, and therefore are found in all three liaison diagrams.

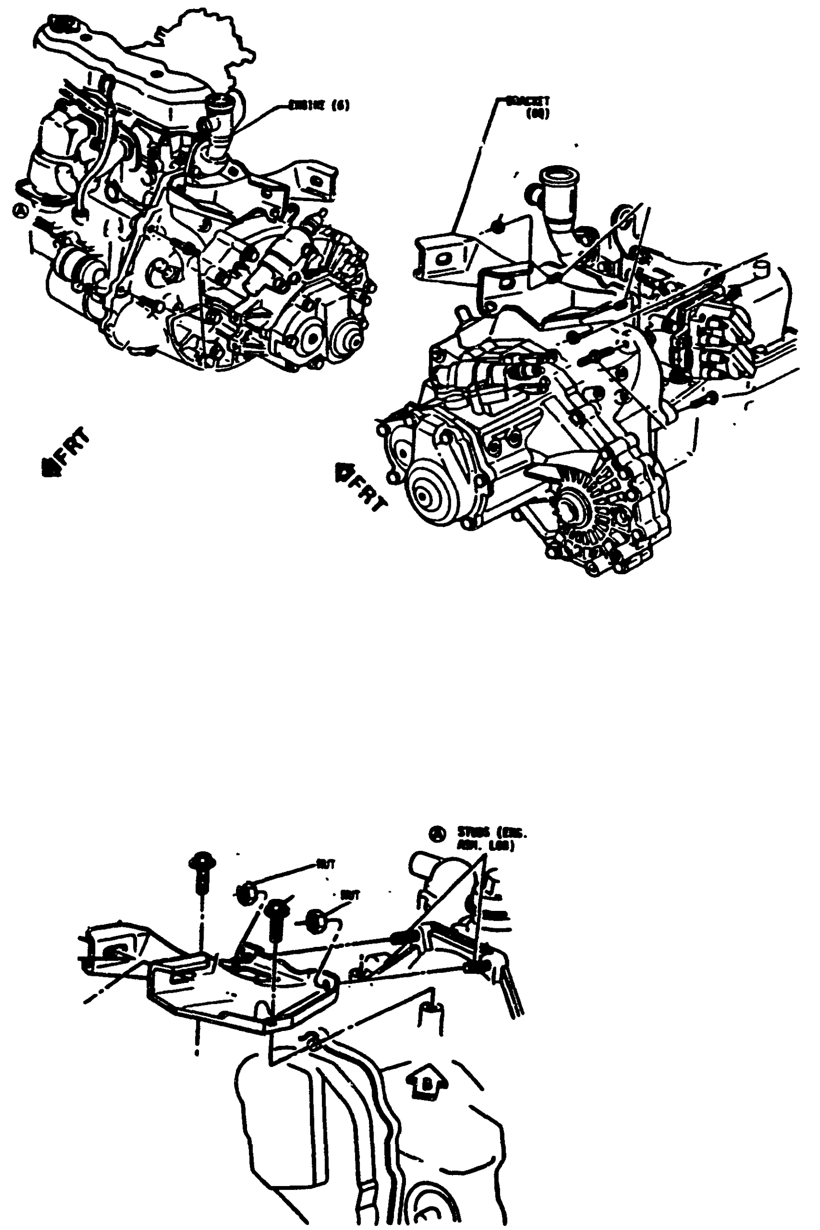


Figure 6.10: Transaxle and Transaxle Mount Bracket Assembly Drawing

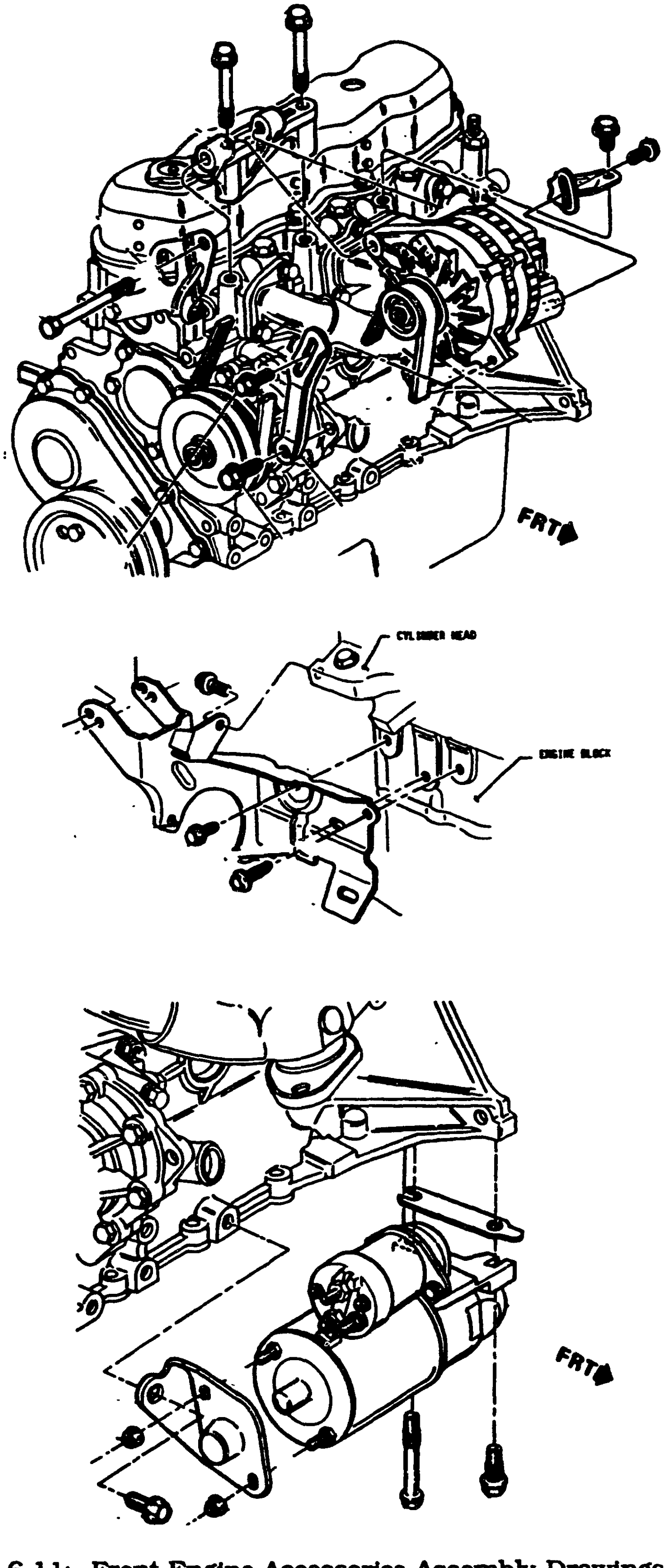


Figure 6.11: Front Engine Accessories Assembly Drawings

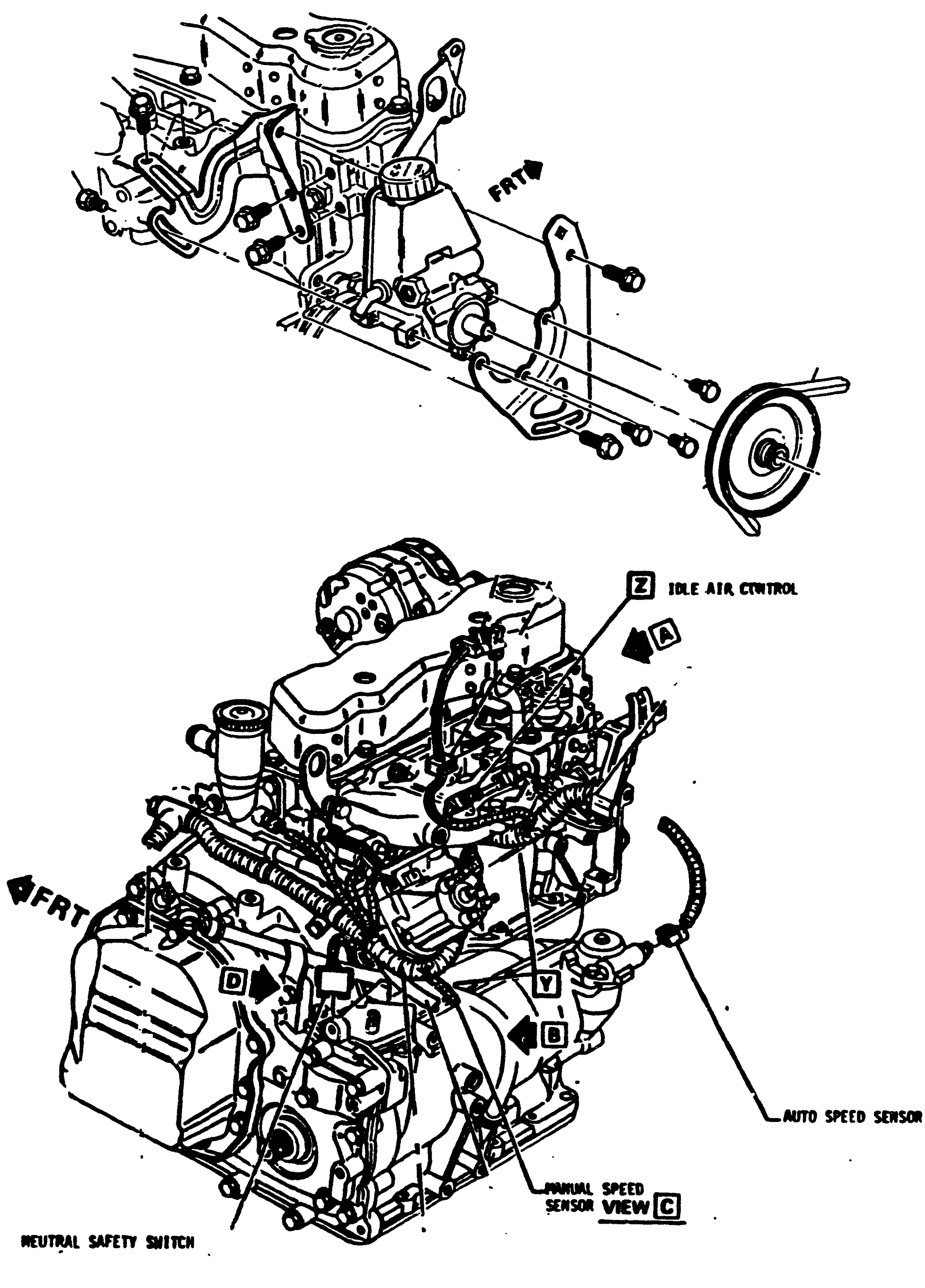


Figure 6.12: Rear Engine Accessories Assembly Drawings

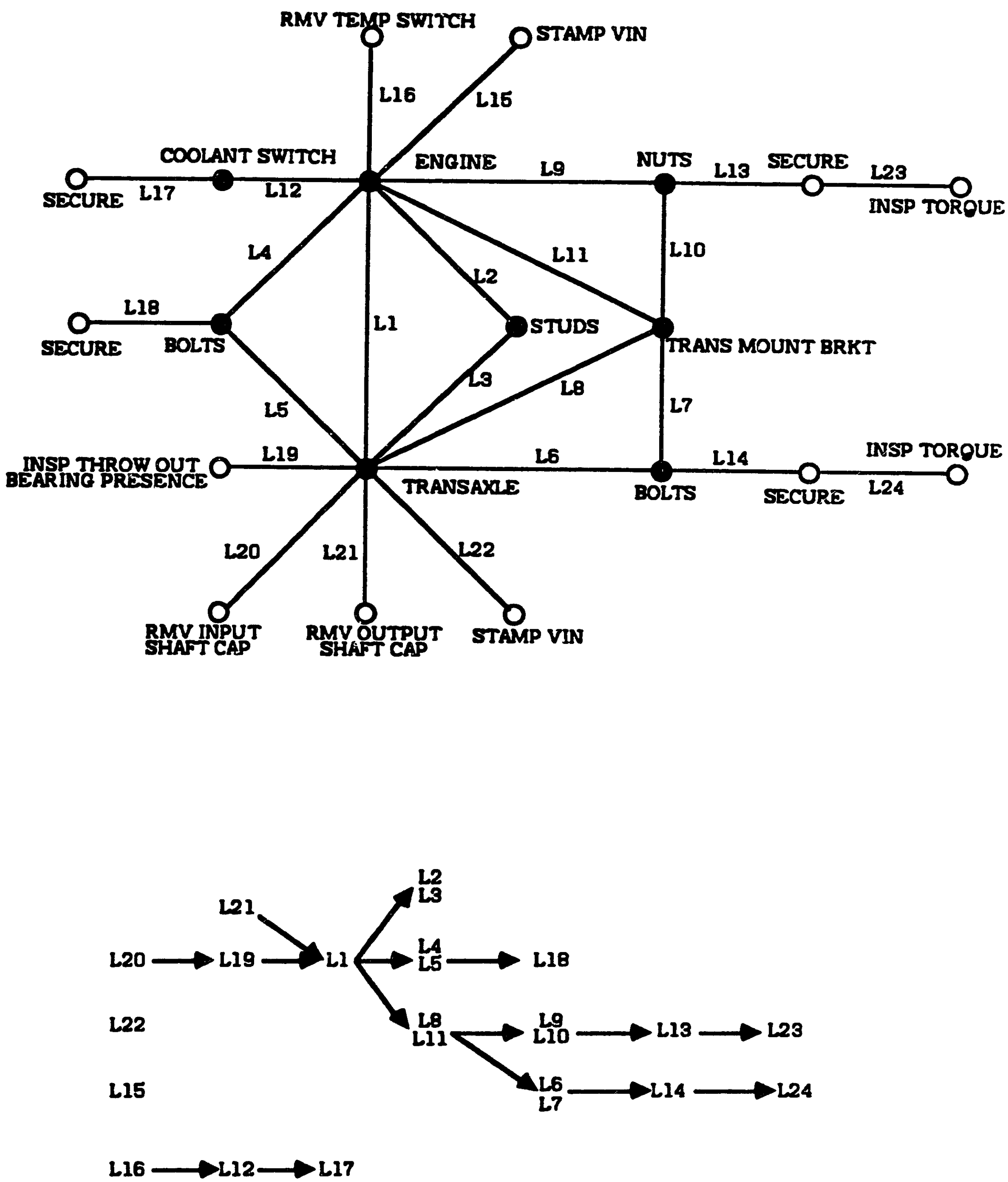


Figure 6.13: Transaxle and Transaxle Mount Liaison and Precedence Diagram

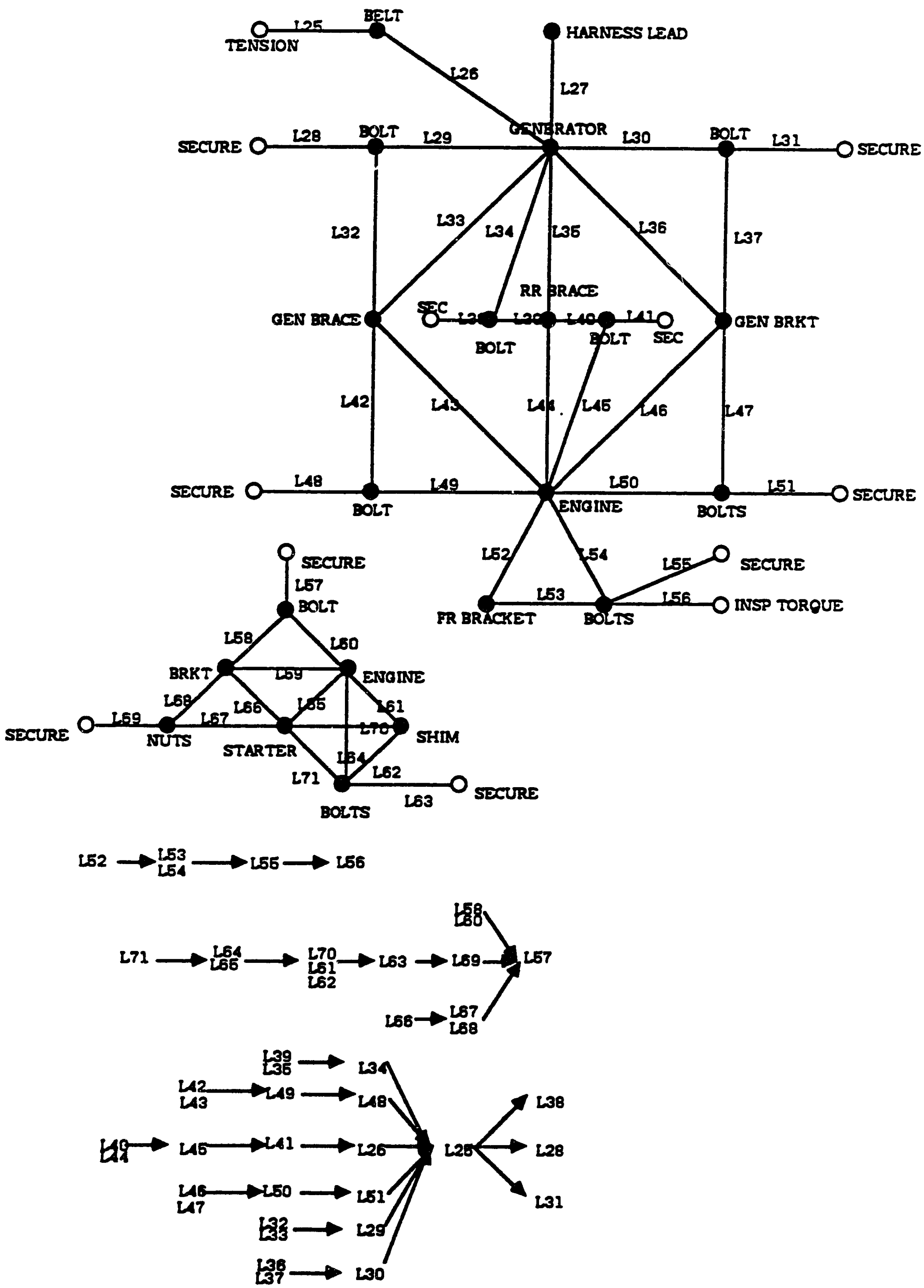


Figure 6.14: Front Engine Accessories Liaison and Precedence Diagram

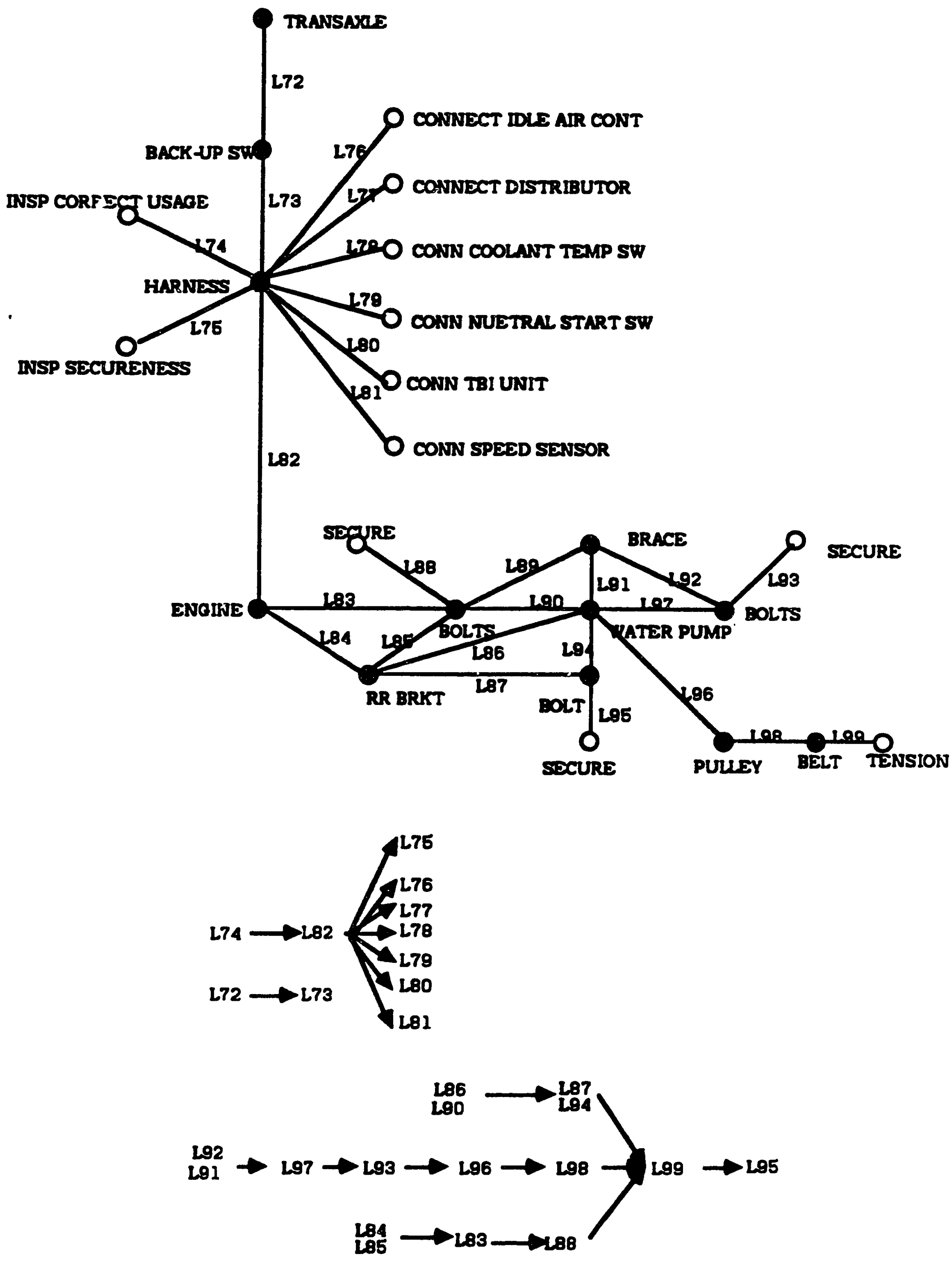


Figure 6.15: Rear Engine Accessories Liaison and Precedence Diagram

At first glance, the liaison count of 99 for the major engine dress components may seem a bit overwhelming, however several characteristics simplify its application. First, bacause of the physical location of the engine accessories on the base engine, the extended liaison precedence diagrams may be treated as entirely separate products, that is, the components on the front of the engine do not impose any mechanical precedence constraints on the rear of engine components. Second, the diagrams consist of many "closed loops" of nodes and liaisons for the mechanical components. As discussed in Chapter 3, for mechanical part assembly, the establishment of two liaisons in a triangular closed loop automatically establishes the third liaison. The actual number of tasks necessary to assemble the major engine dress components is therefore significantly less than the number of liaisons on the diagram.

The available assembly sequence alternatives for the engine dress components are constrained by several part storage limitations, primarily associated with the transaxle and base engine assembly. Various requirements for high altitude vehicles, specific state emission laws, and performance options has driven the number of base engines to four and the number of different transaxles to four as well. They are not only large in physical size, but also have a relatively high usage rate. The only available parts stocking space for these components is near the delivery dock, which is at the start of the assembly system. This location also reduces the material handling labor associated with these parts. The remainder of the engine accessories, such as the generator or water pump are relatively small and are not restricted by any part storage limitations.

Upon review of the liaison diagram and the assembly under study, several qualitative characteristics of the assembly sequence are worthy of note. First of all, no useful or functional subassemblies exist from the standpoint of the ability to test or inspect prior to further assembly. Many of the unprecedented liaisons represent marriage between parts, such as a bolt and bracket, that are unstable and serve no useful purpose as a subassembly. One other candidate subassembly is the marriage of the pulley to the water pump (See Figure 6.12). One alternative is to mate the water pump, front bracket, and pulley prior to attachment to the base engine. This approach would require a separate fixture for assembly. On the other hand, by assembling the components individually on the engine, the engine and its bracketry essentially serve as the fixture for stabilization during assembly. This approach eliminates the purchase of a redundant fixture and any double handling associated with treating the water pump as a subassembly. Second, the specific order in which components are assembled can significantly simplify their installation. In particular, the order in which the starter and its associated components are assembled can reduce the complexity of the attachment. This specific case was discussed in Chapter 5.

6.3.2 Manual System Analysis

This section presents the analysis of varying assembly sequences on assembly systems consisting of manual operators as the sole resource type. In this application on the assembly of engine dress components, three manual operators or resources types are specified. One is defined as a "front of engine" resource, the second as a "rear of engine" resource and the other is a combination or a "both front and rear" resource. This is done to accommodate some of the location requirements of the components on the engine assembly.

The resource defined as both front and rear can accomplish tasks on either side of the engine where the front resource and rear resource are restricted to tasks which reside on their respective sides of the engine (See Figure 6.16). In the case of the "front and rear" resource, there is a small time penalty associated with the transition or reorientation necessary to move from a task on the front of the engine to one on the rear and vise versa. All other cost information is the same for all three resource types. This permits economic evaluation of trade-offs between an assembly reorientation ("front and rear" resource moving to the other side of the product) and the addition of another resource or of an assembly reorientation and a required tool change.

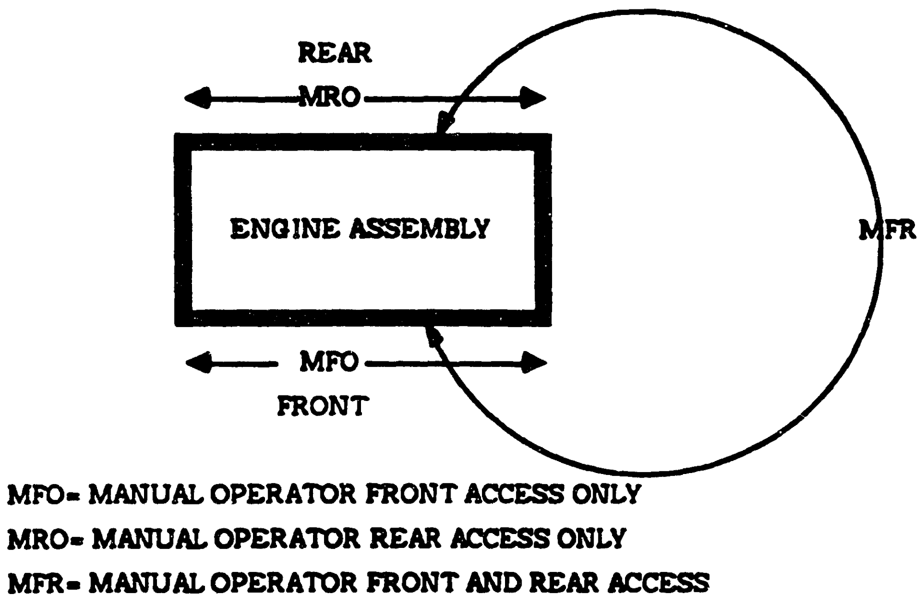


Figure 6.16: Front and Rear Resource Access

Six different assembly sequences were analyzed, using ASDP, for their impact on system cost and configuration, three for each of two assembly sequence selection approaches. Each of the six assembly sequences consists of 67 total tasks and abide by the facility constraints and influences addressed in the previous section.

The first set of assembly sequences, Sequences 1.0, 1.1, and 1.2, attempt to best utilize resources and assembly tooling by grouping similar operations, such as fastening tasks. The grouping of similar operations was done in an effort to reduce non-value added work content and tool purchase requirements. The task listing for Sequence 1.0 is found in Appendix C. Tasks were also grouped, as much as possible, by their location on the base engine, either front or rear. This was done in an attempt to reduce the number of assembly reorientations required (or walk time for the "front and rear" operator) and the resulting non-value added labor associated with reorientation. Work was assigned to resources with a target cycle time of approximately 45 to 53 seconds (.87 < Availability factor < 1.0), in order to best utilize their available cycle time.

The second set of assembly sequences used in this analysis, Sequences 2.0, 2.1, and 2.2, were very similar to the first pair of sequences in that they both grouped tasks with common tooling requirements in an effort to reduce necessary tooling purchases and non value added labor. In fact, the first twenty-two of the sixty-seven tasks were identical to those in Sequence 1.0 and 1.1. The assembly order for Sequence 2.0 can be found along with its associated task information in Appendix C. Unlike the first set of sequences, the second set of sequences did not group tasks of similar location on the engine, that is, not all front of engine tasks were done consecutively. This aspect of the sequences forced an economic evaluation of resource allocation at the transition points in the assembly sequence, when a front of engine task is followed by a rear of engine task or vise versa. The decision must be made as to whether it is more cost effective to incur the time penalty associated with reorienting the assembly (a non-value added task) to gain access to the other side of the engine or to add a new resource. This decision is dependent on the the time still available on the current resource and the assembly time requirement of the succeeding operation.

The resulting unit cost v.s. availability factor curve for two of the six sequences is shown in Figure 6.17 on the following page. Of the six sequences evaluated, these two best highlight the cost impact of assembly sequence criteria on cost and assembly system configuration.

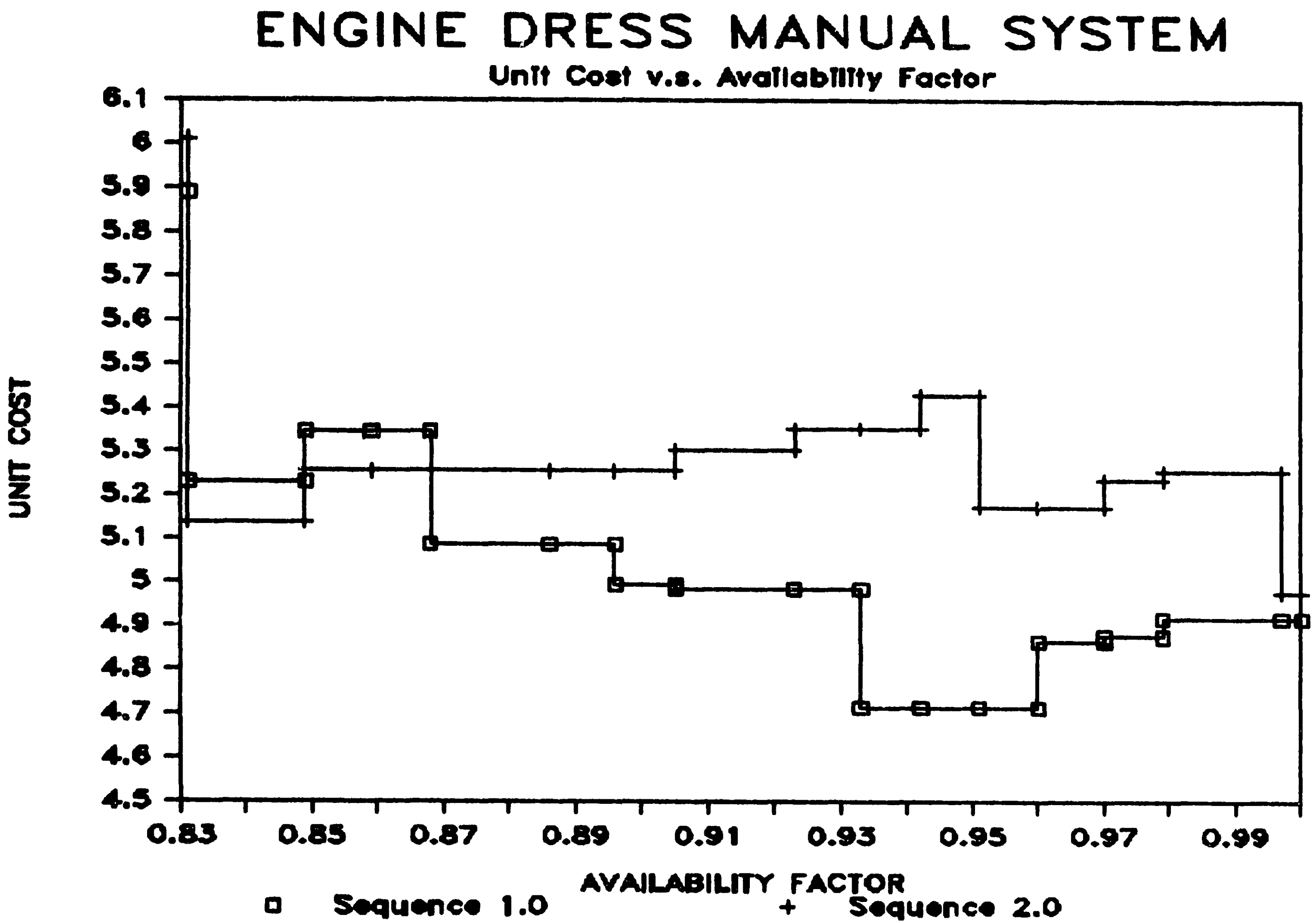
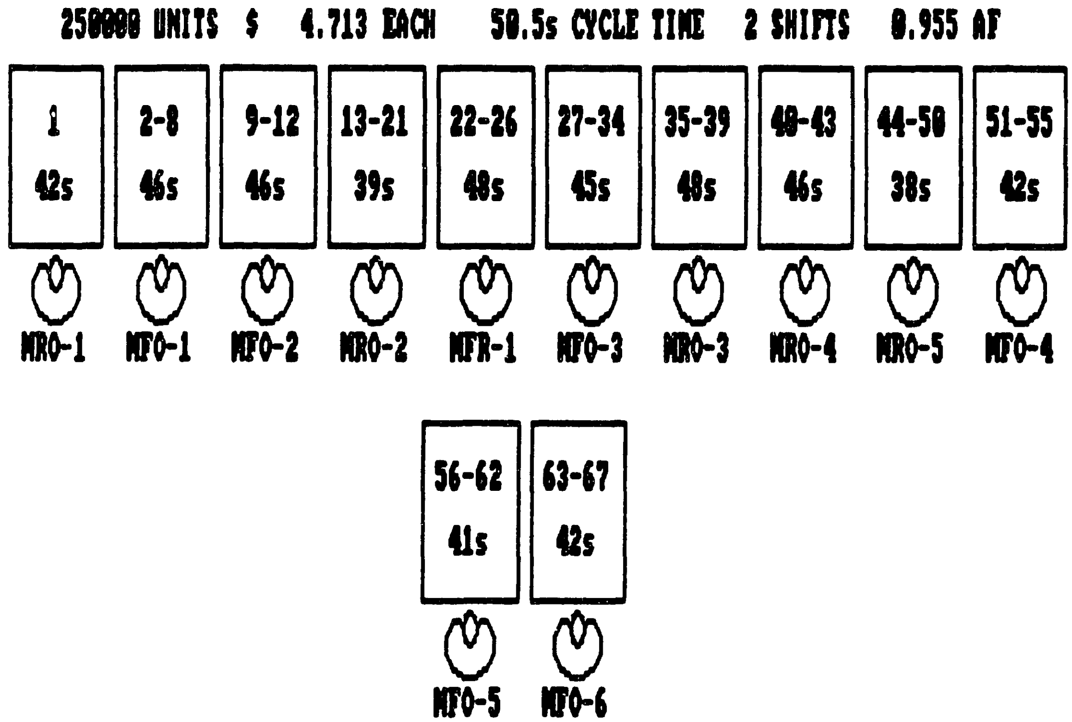


Figure 6.17: General Solution: Unit Cost v.s. Availability Factor

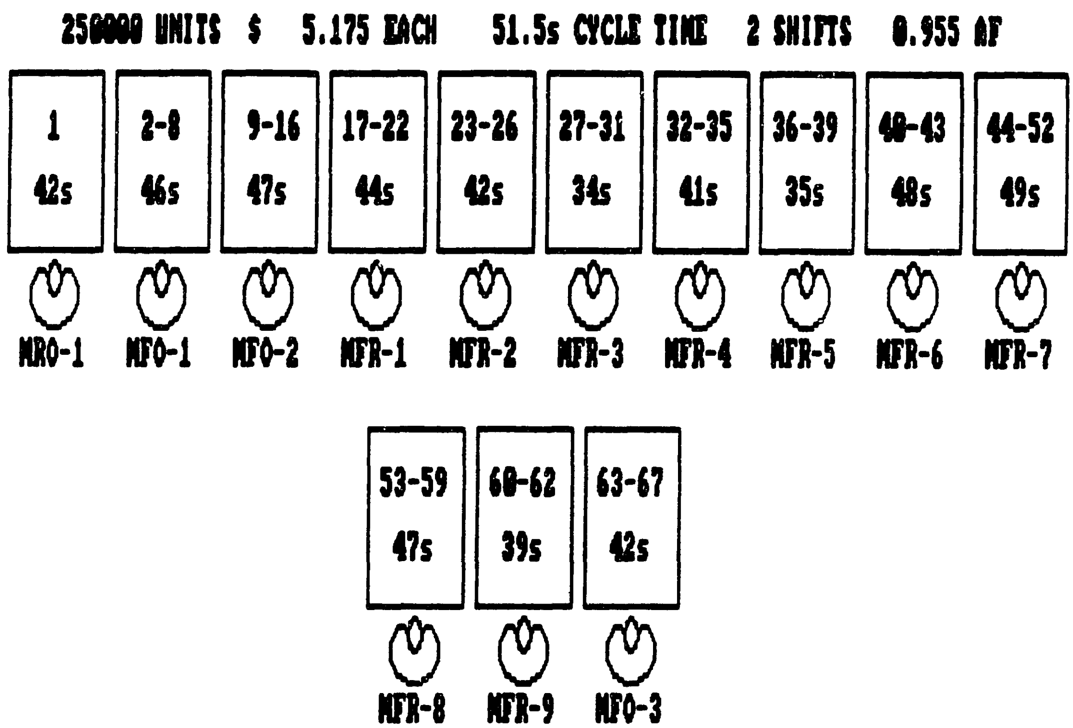
The general solution provided by ASDP shows that Sequence 1.0 is the lower cost alternative of the two sequences, when applied to a manual assembly system. This is true over the entire range of useful availability factors with the exception of values less than approximately .85. Costs in general begin to increase at this cycle time due to duplication requirements associated with major part scheduling operations, such as engine scheduling.

The cost advantage of Sequence 1.0 over Sequence 2.0 varies between 5 and 15 percent across the useful range of availability factors. Again, the specific solution for a given availability factor is used to uncover the sources of the difference in unit cost between the sequences. Figure 6.18, on the following page, shows the specific synthesized assembly system and task assignments for both Sequences 1.0 and 2.0 and availability factor .955. The most obvious difference between the two assembly systems is that the system for Sequence 2.0 requires an additional manual operator over that for Sequence 1.0. The need for this additional resource does not result from a drastically underutilized resource. Further examination of the schematics in Figure 6.18 shows that the configuration of the assembly systems differ significantly between the two sequences, that is, Sequence 1.0 employs almost exclusively manual resources which operate on one side of the engine only, while the majority of operators for Sequence 2.0 perform operations on both the front and rear of the engine.

The difference in the resource selection for the two assembly systems is due primarily to the character of each of the respective assembly sequences. The first assembly sequence grouped tasks which resided on the same side of the base engine. This permitted the allocation of resources which worked specifically one side of the engine. The second assembly sequence did not group operations in this manner and as a result used more resources capable of accomplishing tasks on both sides of the engine. While it was more cost effective for the second



Sequence 1.0



Sequence 2.0

Figure 6.18: Engine Dress Manual Assembly System Schematics

sequence to reorient the assembly (or move to the other side of the engine) rather than allocate a new resource at the transition from a front to a rear task, a time penalty is incurred for this reorientation. Because of the assembly reorientation required by the second assembly sequence, a total of 556 seconds of task time are required to assemble the product and its components as compared to 523 seconds for Sequence 1.0. The additional 33 seconds is comprised of six assembly reorientations of five seconds each and an additional tool change. This alone is equal to 73 percent of one resources cycle time.

A more detailed unit assembly cost breakdown for the two assembly systems is shown in Table 6 on the following page. The table also points out the difference in system configuration due to the characteristics of each assembly sequence. The assembly system for Sequence 1.0 employs only one front and rear resource type while the system for Sequence 2.0 uses nine. The dominant contributor to unit assembly cost is the variable cost associated with each resource. The difference of $0.433 is the result of the additional resource required by Sequence 2.0 and an increase in the operating maintenance associated with the additional resource.

The remaining unit assembly cost advantage of $0.029 of Sequence 1.0 over Sequence 2.0 comes from the additional tool purchase necessary for Sequence 2.0. As shown in Table 6, the assembly system for Sequence 2.0 necessitates the purchase of twenty tools while Sequence 1.0 requires only 19. In particular, Sequence 2.0 required the purchase of an additional tool to secure the generator bracket fasteners to the engine.

Sequence 1.0

APPARENT SYSTEM COST = $ 1093996

RESOURCE	TOTAL COST	NUMBER USED	TIME USED	UNIT COST FIXED	UNIT COST VARIABLE	NUMBER OF TASKS	NUMBER OF TOOLS	NUMBER OF WORKERS
MFR	89446	1	47.5	0.014	0.344	5	1	1.1
MFO	595534	6	46.0	0.320	2.062	36	10	6.7
MRO	493235	5	47.5	0.255	1.718	26	8	5.6

1.19 UNITS PER MINUTE
47.5 seconds MAXIMUM TIME AT ANY STATION
268040 units PRODUCTION CAPACITY OF THIS SYSTEM
6.01 $/hr SYSTEM OPERATING/MAINTENANCE RATE

1178215 COST ($) TO PRODUCE 250000 UNITS, WITH UNIT COST ($) 4.713
411000 ($) TOTAL CAPITAL INVESTMENT REQUIRED
274000 CAPITAL EXPENSE ($) FOR REQUIRED HARDWARE

Sequence 2.0

APPARENT SYSTEM COST = $ 1164443

RESOURCE	TOTAL COST	NUMBER USED	TIME USED	UNIT COST FIXED	UNIT COST VARIABLE	NUMBER OF TASKS	NUMBER OF TOOLS	NUMBER OF WORKERS
MFR	886381	9	48.5	0.390	3.156	46	13	10.0
MFO	308778	3	47.0	0.184	1.051	20	6	3.3
MRO	98630	1	42.0	0.044	0.350	1	1	1.1

1.17 UNITS PER MINUTE
48.5 seconds MAXIMUM TIME AT ANY STATION
262835 units PRODUCTION CAPACITY OF THIS SYSTEM
6.59 $/hr SYSTEM OPERATING/MAINTENANCE RATE

1293789 COST ($) TO PRODUCE 250000 UNITS, WITH UNIT COST ($) 5.175
431250 ($) TOTAL CAPITAL INVESTMENT REQUIRED
287500 CAPITAL EXPENSE ($) FOR REQUIRED HARDWARE

Table 6: Engine Dress Manual System Unit Cost Breakdown

6.3.3 Manual/Automated System Analysis

This section presents the analysis of alternative assembly sequences on assembly systems which are composed of manual operators, fixed, and programmable automation. Each of the alternative assembly sequences consist of sixty-seven tasks and abide by the facilty and parts storage restrictions described in Section 6.3.1.

As was the case with the steering column subassembly, the majority of the tasks and assembly line activities required for the assembly of the engine dress components are not conducive to automation. Assembly line activities such as the fixturing of the engine, handling of flexible parts, or finger starting fasteners are best accomplished by manual operators, however tasks such as fastener secure operations, Vehicle Identification Number (VIN) stamping, or accessory belt tensioning are candidates for automation. Approximately forty percent of the sixty-seven total tasks were deemed suitable for automation.

Four different resource types were determined to be applicable to the assembly tasks for the engine dress components. They consisted of a manual operator, fixed automation and two different types of programmable automation. Two separate programmable resource types were specified in order to meet tool weight and work envelope requirements of specific tasks. In particular, the VIN stamp operation requires a tool of significant size and weight. As in the case of the steering column subassembly, task completion times, tool change time and tool costs are specific to each resource type. Tasks time for the fixed automation resource are typically less than those for the other resource types as it accomplishes several operations simultaneously. This requires additional tools and the increased cost is reflected in the tooling cost associated with the fixed automation resource.

The need for assembly reorientation during the assembly process also plays a role in the operation time for these task orders. As was shown the previous section, reorientation time adds to the total assembly task time for a specific operation. This additional time is also applied to tasks requiring reorientation in this analysis as required by the selected assembly sequence. Section 6.3.2 showed that, while it is most desirable to group tasks which have similar locations on the base engine, it is generally more cost effective to reorient an assembly to better utilize a resources available cycle time than to add a new resource. This was exhibited on resources (manual) which consist primarily of variable cost.

As in analysis of the manual assembly systems, six different assembly sequences were analyzed for their impact on unit assembly cost and assembly system configuration, three for each of two individual sequence selection characteristics. The first set of assembly orders, Sequences 1.0, 1.1, and 1.2, placed all tasks that could be performed by the fixed or programmable resources in succession. This was done in an attempt to best utilize the available cycle time on these resource types, if they were determined to be the least cost resource for a given series of operations. A direct result of this approach was that the assembly line tasks that could be accomplished by manual resource types only were also in successive order.. The task data for assembly sequence alternative 1.0 is found in Appendix D. Tooling commonality and the location of the tasks on the base engine was also a major consideration in the selection of this set of sequences so as to reduce tooling purchases and required assembly reorientations.

The second set of assembly sequences does not group the fixed and programmable automation tasks as in the first case. The assembly sequence for Sequence 2.0 can be found in Appendix D. Since the tasks are not in succession, several additional fixed or programmable automation types would be required, if they are determined to be the most cost effective alternative, as opposed to the ability to group these tasks for Sequence 1.0. An effort was made to reduce the tooling purchaes and assembly reorientations necessary for this sequence as well.

The general solution graph of unit cost versus availability factor, shown in Figure 6.19 on the following page, presents a pair of sequences selected from the six used in this analysis. The unit assembly cost for Sequence 1.0 is below that of Sequence 2.0 for the majority of the range of availability factors or cycle times. The cost advantage of Sequence 1.0 over Sequence 2.0 varies between 4 and 20 percent for availability factors greater than .46. Costs in general are increasing at this point as several of the manual tasks which require significant operation times, such as engine, transaxle, and harness scheduling, must use parallel work stations. The available cycle time for the operators at these work stations is not well utilized.

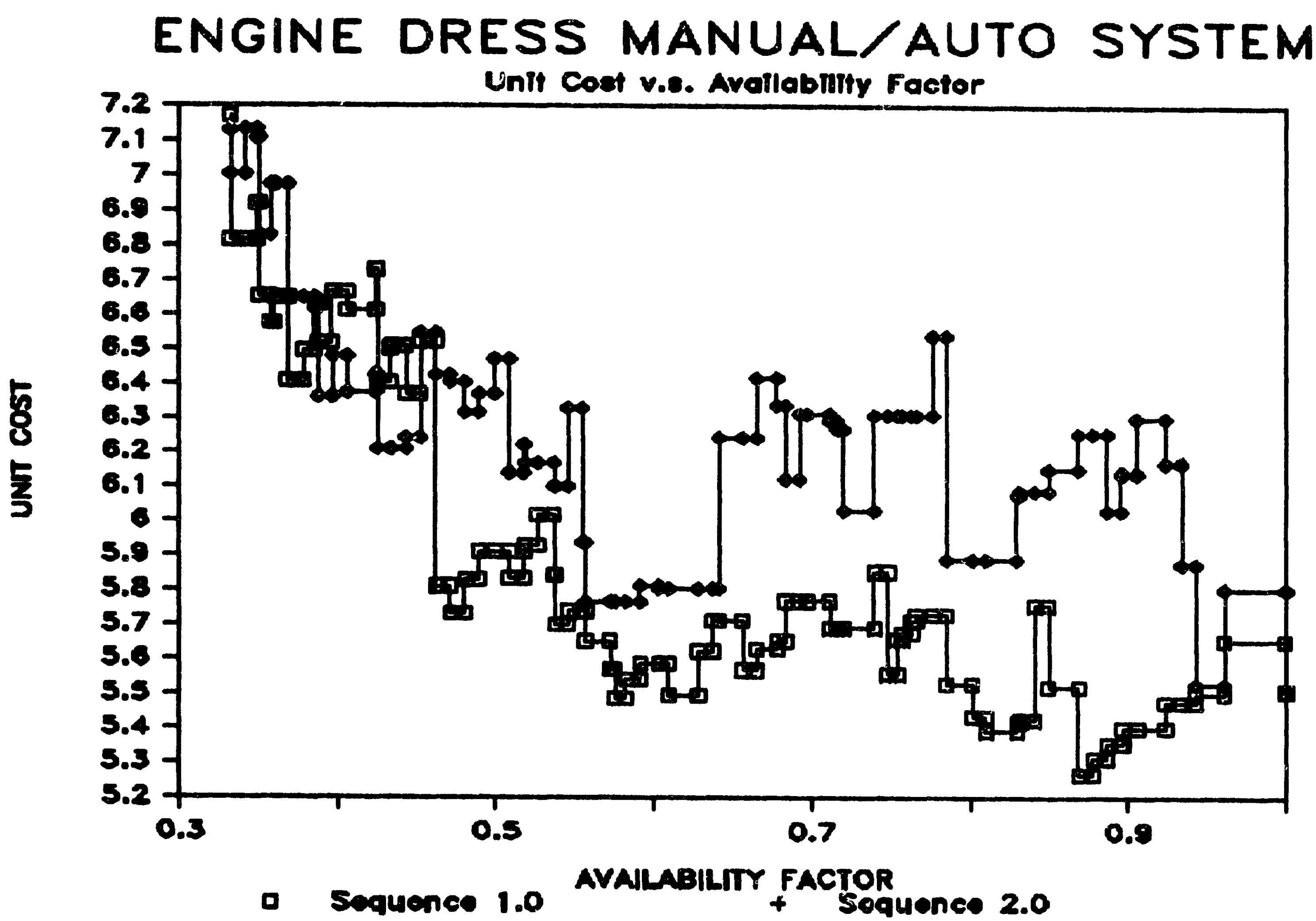
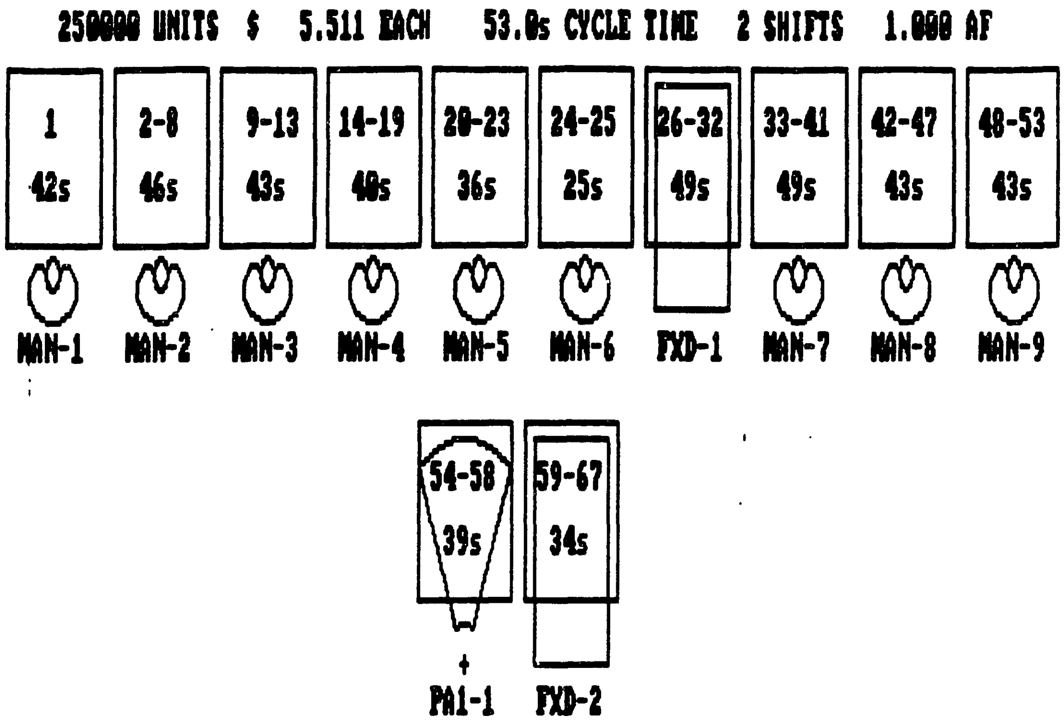


Figure 6.19: General Solution: Unit Cost v.s. Availability Factor

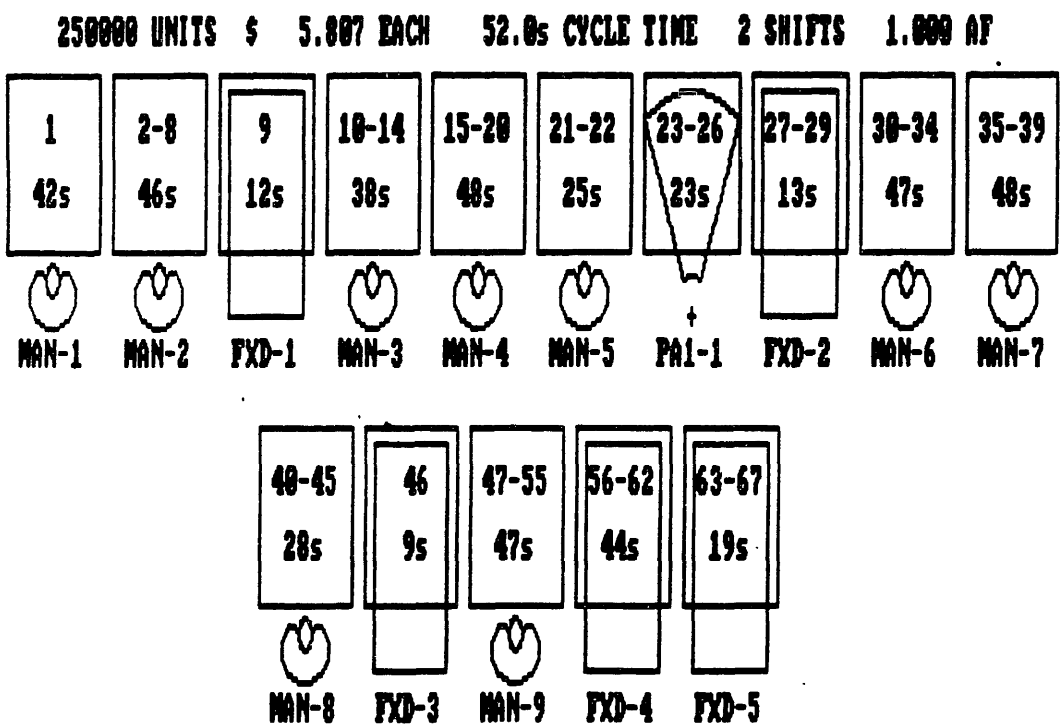
The specific solution provided by ASDP is used to identify the difference in unit cost and assembly system configuration in the two sequences for two different availability factors or cycle times. The first comparison made between the two assembly sequences is made for availability factor of 1.0. Since the engine dress assembly system is directly associated with a car assembly line, it is desirable to operate the supply line at or near the production rate of the main production line. This prevents a large accumulation of inventory between the engine dress line and the main assembly line. The assembly system schematics for the two assembly sequences and useful availability factor 1.0 are shown in Figure 6.20 on the following page.

On the surface, the most notable difference in the two schematics is that Sequence 2.0 uses five fixed resource types, while the assembly system for Sequence 1.0 employs only two. The manual and programmable resources allocated are the same for both systems. The requirement for three additional resources in the assembly system for Sequence 2.0 is a direct result of the inability to group tasks under a afforded by this sequence. On the other hand, Sequence 1.0 permits the tasks which may be accomplished by fixed automation to be combined at a single station until the total operation time exceeds available cycle time.

Further detail regarding the unit fixed and variable costs associated with the respective assembly systems for Sequences 1.0 and 2.0 can be extracted from Table 7. The majority of the difference in unit assembl;y cost between the two systems is attributable to the fixed automation resource. The need for the additional three fixed resources for Sequence 2.0 is directly accountable for the \$0.49 cost advantage of Sequence 1.0 over Sequence 2.0. An additional cost penalty of \$0.086 is assigned to the assembly system for Sequence 2.0 because of increased variable operating and maintenance rate associated with the fixed



Sequence 1.0



Sequence 2.0

Figure 6.20: Engine Dress Manual/Automated System Schematics

Sequence 1.0

APPARENT SYSTEM COST = $ 995821

RESOURCE	TOTAL COST	NUMBER USED	TIME USED	UNIT COST FIXED	UNIT COST VARIABLE	NUMBER OF TASKS	NUMBER OF TOOLS	NUMBER OF WORKERS
MAN	880483	9	48.5	0.209	3.313	46	7	10.0
PA1	95425	1	39.0	0.287	0.095	5	3	0.2
FXD	401887	2	49.0	0.524	1.083	16	6	3.2

1.11 UNITS PER MINUTE
49.0 seconds MAXIMUM TIME AT ANY STATION
250288 units PRODUCTION CAPACITY OF THIS SYSTEM
9.50 $/hr SYSTEM OPERATING/MAINTENANCE RATE

1377795 COST ($) TO PRODUCE 250000 UNITS, WITH UNIT COST ($) 5.511
712500 ($) TOTAL CAPITAL INVESTMENT REQUIRED
430500 CAPITAL EXPENSE ($) FOR REQUIRED HARDWARE

Sequence 2.0

APPARENT SYSTEM COST = $ 1088396

RESOURCE	TOTAL COST	NUMBER USED	TIME USED	UNIT COST FIXED	UNIT COST VARIABLE	NUMBER OF TASKS	NUMBER OF TOOLS	NUMBER OF WORKERS
MAN	848608	9	48.0	0.209	3.185	46	7	10.0
PA1	57459	1	23.0	0.139	0.091	4	1	0.2
FXD	545747	5	43.5	1.014	1.169	17	10	3.4

1.15 UNITS PER MINUTE
48.0 seconds MAXIMUM TIME AT ANY STATION
260308 units PRODUCTION CAPACITY OF THIS SYSTEM
14.00 $/hr SYSTEM OPERATING/MAINTENANCE RATE

1451814 COST ($) TO PRODUCE 250000 UNITS, WITH UNIT COST ($) 5.807
951000 ($) TOTAL CAPITAL INVESTMENT REQUIRED
612500 CAPITAL EXPENSE ($) FOR REQUIRED HARDWARE

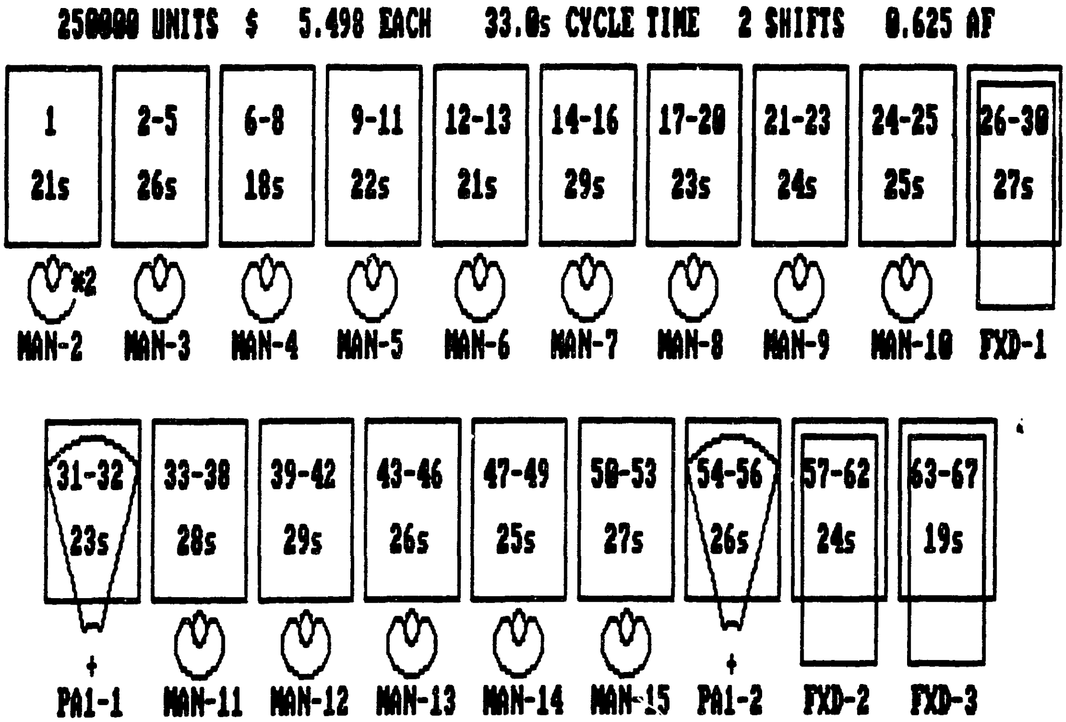
Table 7: Engine Dress Manual/Automated System Unit Cost Breakdown

resource types. The costs attributable to the fixed resources alone contributes a better than ten percent difference in unit assembly cost between the two sequences. It is worthy to note that the cost breakdown in Table 7 shows that Sequence 2.0 actually has a $0.128 unit cost advantage over Sequence 1.0 in the area of variable cost associated with the manual resource type despite having the same number of operators. As discussed at the end of Section 6.2.2, variable costs are charged only for the assembly time required to produce the specified batch. It is assumed that the remaining time may be applied or charged out to another product. In this case, the total system cycle time for Sequence 2.0 is one second less than that for Sequence 1.0, and therefore requires less time to assemble the 250,000 units. As mentioned in the previous section, it is not always desirable to temporarily charge personnel out. In the event that they cannot be reassigned for the unused portion of their time, the variable costs associated with Sequences 1.0 and 2.0 would be equal, and the cost difference between the two systems would be even more substantial.

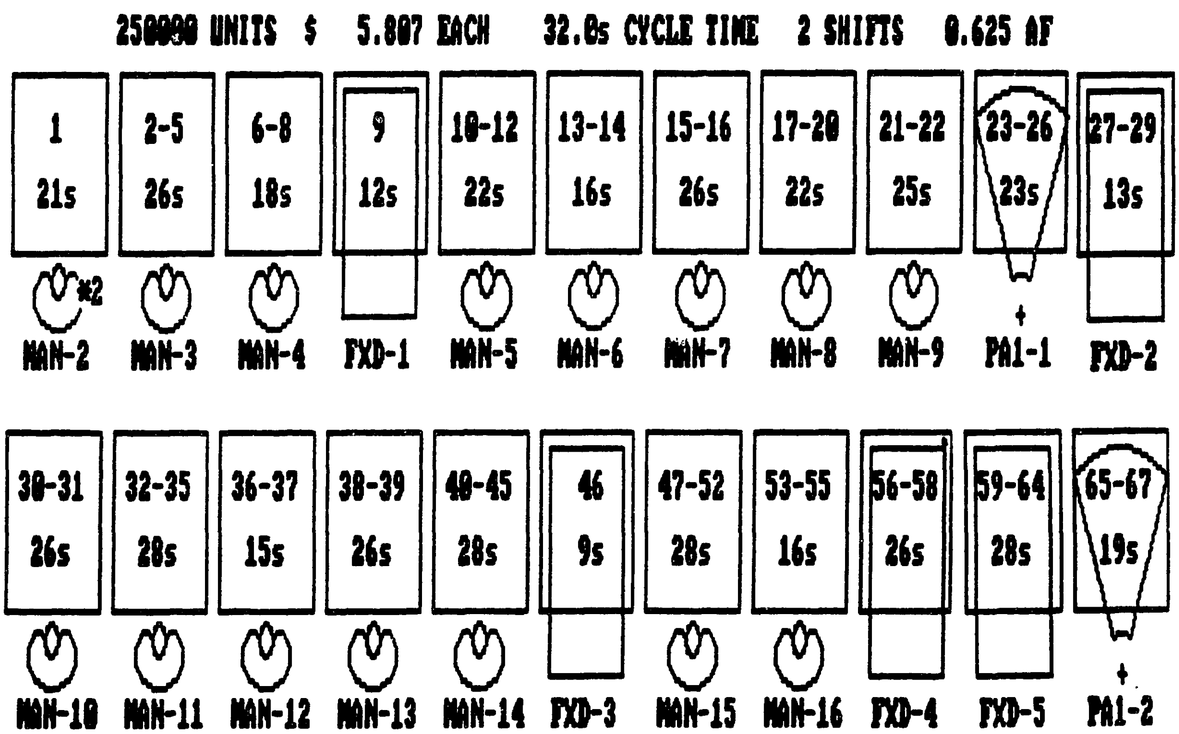
The second comparison is made for the same two assembly sequences, but for a significantly smaller availability factor. Most often, the assembly of a product is not directly tied to the assembly of another product as has been the case in the previous two examples. For entirely manual systems, the most economical assembly system typically occurs at or near the availability factor of one, that of maximum cycle time, however for systems consisting of fixed, programmable, and manual resources, the most economical system seldom occurs near availability factor of one. At a smaller availability factor, an assembly system can produce the specified batch in part of the year rather than the full year, and the resources may be reprogrammed, reworked, and reassigned to another product.

The assembly system schematics for the two assembly sequences at availability factor .625 are shown in Figure 6.21 on the following page. Again, the apparent difference between the two schematics is that the system for Sequence for Sequence 2.0 has two additional fixed resources and an additional manual resource type. Both systems employ two programmable resources. The requirement of an additional manual operator is due to an imbalance of operations or an underutilization of the available cycle time on several operators. The need for two additional fixed automation stations by Sequence 2.0 is due to the assembly sequence which does not permit best utilization of the fixed resource.

As expected, the unit assembly cost for Sequence 1.0 is less than that for Sequence 2.0 because of the additional resource requirements. In fact, sixty-three percent of the additional unit assembly cost of the second assembly system is attributable to the increased fixed and variable costs associated with the two



Sequence 1.0



Sequence 2.0

Figure 6.21: Engine Dress Manual/Automated System Schematics

additional fixed resources. The remaining thirty-seven percent of the cost difference is comprised primarily of the variable associated with the additional manual operator.

6.3.4 Summary Comments

This section has shown how differing assembly sequence characteristics can have a major impact on unit assembly cost and assembly system configuration. Differing assembly sequences were shown to contribute to an 5 to 20 percent difference in unit assembly cost. The analysis of varying assembly sequences for the engine dress components on an assembly system comprised of solely manual resources highlighted two major points. First of all, the comparison of two different assembly sequences showed that it is most cost effective to group tasks with similar locations on the major base part so as to minimize the number of required assembly reorientations and associated non-value added labor. The additional task time of one sequence alternative sequence over another amounted to seventy-three percent of one resources available cycle time. This additional task time contributed to the need for an additional resource and an increased unit assembly cost for the product. Second, it was shown that when assembly time is still available on the current manual resource, it is cost effective to reorient the assembly to gain access to the next task rather than assign a new manual resource.

The analysis of differing assembly sequences on assembly systems consisting of manual, fixed, and programmable resource types showed that grouping tasks by resource capability can also reduce unit assembly cost. In the case of the major engine dress components, it was shown that by grouping operation which could be accomplished by the same resource type contributed to a ten percent cost advantage over other sequences which did not group tasks in this manner. The impact of this selection criteria on unit assembly cost was shown over a wide range of availability factors or cycle times. While the selection of the fixed resource types even for a limited number of tasks was the most cost effective alternative, the requirement of several additional fixed resource types by the second sequence resulted in an increase in the fixed costs associated with the assembly system. The variable cost of operating and maintaining these aditional fixed resources was also a contributor to the increased unit assembly cost of the product. The impact of grouping tasks so as to reduce necessary tooling purchases and non-value added labor was the same as in previous examples.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The subsections that follow give a review of the conclusions and recommendations that are a result of the study and research done in this thesis. The page numbers identify where the related discussion can be found in the text of this thesis.

7.1 CONCLUSIONS

1. The prior diagrammatic representations, namely the connection matrix, the parts tree, and precedence diagram, are incapable of representing all possible mechanical assembly sequence constraints. (Page 33)
2. The method presented by Bourjault and the simplified method by De Fazio and Whitney of determining and generating assembly sequences is capable of representing all possible mechanical constraints for a given product. (Page 33)
3. The assembly sequence generation method of Bourjault or that by De Fazio and Whitney can be usefully extended to include tasks or assembly line activities other than mechanical part to part mating operations. These non-assembly tasks, such as test, inspection, and secure operations, also interact with the mechanical constraints of the product. (Page 50)
4. The available alternative assembly sequences can be strongly constrained by physical limitations imposed by the chosen assembly facility. Major facility influences on the available assembly sequence alternatives include Work Height Limitations, Part Storage/Delivery Requirements, and Special Operation Requirements. (Page 72)

5. It is advantageous to minimize the number of assembly reorientations in an effort to reduce the amount of non-value added work content associated with the assembly of the product. (Page 130)

6. The assembly sequence selection criteria significantly influences the unit assembly cost and assembly system configuration for assembly systems comprised of only manual resources and of systems comprised of fixed, programmable, and manual resource types. Differences in unit assembly cost were shown to be as much as twenty percent for differing assembly sequences. Sequence characteristics which directly influence unit assembly costs are as follows:

<u>Manual Systems</u>

* Group tasks with similar tooling requirements so as to reduce the necessary tooling purchases and the associated non-value added labor. (Page 108)
* Group tasks which have similar location on the base or main part so as to reduce the number of required assembly reorientations and the associated non-value added work content. (Page 130)
* Select assembly sequences which best utilize the full cycle available on each manual resource in an effort to reduce the number of manual operators and associated variable cost for a given system and production rate. (Page 108)

<u>Manual/Automated Systems</u>

* Group tasks with similar tooling requirements so as to reduce the necessary tooling purchase and the associated non-value added work content. (Page 115)
* Group tasks which have similar location on the base or main part so as to reduce the number of required assembly reorientations. (Page 137)
* Group tasks which have similar resources or technology applicable to them in an attempt to reduce the number of resources required in a given system and to better utilize the available cycle time for an allocated resource. (Page 137)

7.2 RECOMMENDATIONS

1. The liaison sequence analysis technique should be used as an alternative to the use of the precedence diagram in the planning of efficient assembly systems. It has the advantage of being able to generate all possible assembly sequence alternatives for a product. The method of generating the possible assembly sequences is algorithmic and therefore does not presuppose any of the engineers bias in the generation of the possible alternatives.
2. Computer based aids should be developed to assist in the useful application of the liaison sequence analysis technique. These aids could assist in the creation of the state-space network which represents all possible assembly sequences, as well as the selection of desirable paths (sequences) from the network.

APPENDIX A: Steering Column Manual Assembly Data

APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Subassembly (Manual) 1.0 DATE ____

235 WORKING DAYS PER YEAR

.358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE

21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MAN1.0

TASK DATA SET NAME COL1.0

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ϵ: 100 v: 1.5 t_c: 2.5 m_s: 0.9	PAI C: 35,000 ρ: 1.2 ϵ: 99.5 v: 1.75 t_c: 2.5 m_s: 0.9	C: ρ: ϵ: v: t_c: m_s:	C: ρ: ϵ: v: t_c: m_s:
1. Schedule and Fixture Column	23 | 100	X		
2. (L13) (L14) Column Bracket to Column (one bolt)	7 | 100	X		
3. (L15) Finger Start 2nd Bolt	3 | 100	X		
4. (L15) Finger Start 3rd Bolt	3 | 100	X		
5. (L15) Finger Start 4th Bolt	3 | 100	X		
6. (L1) Paint Column	X	43 | 200 15,000		
7. Schedule Steering Wheel	17 | 100	X		
8. (L5) Place Wheel to Column	7 | 100	X		
9. (L9) (L10) Finger Start Wheel Nut	3 | 100	X		
10. (L22) Secure Steering Wheel Nut	4 | 110 19,000	X		
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 1 of ____

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Subassembly (Manual) 1.0 DATE ______

235 WORKING DAYS PER YEAR

.358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE

21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MAN1.0

TASK DATA SET NAME COL1.0

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ε: 100 v: 1.5 t_c: 2.5 m_s: 0.9	PAI C: 35,000 ρ: 1.2 ε: 99.5 v: 1.75 t_c: 2.5 m_s: 0.9	C: ρ: ε: v: t_c: m_s:	C: ρ: ε: v: t_c: m_s:
11.(L21) Inspect for Nut Secureness	1 | 110 13,000	X		
12.(L11) Install Retainer Clip	5 | 120 2,500	X		
13.(L23) Inspect Retainer for Presence	2 | 100	X		
14.(L3) Install Turn/Cruise Lever	14 | 130 1,000	X		
15. Schedule Horn Pad	9 | 100	X		
16.(L7) Horn Pad to Wheel	8 | 100	X		
17.(L7) Secure (2) Horn Pad Screws	9 | 140 2,000	X		
18.(L19) Feel for Horn Pad Secureness	2 | 100	X		
19.(L2) Install Tilt Lever	8 | 100	X		
20.(L4) Install Hazard Switch	9 | 150 2,000	X		
UNITS IN PRODUCTION BATCH				
DESIRED PRODUCTION RATE (units/min)				

Sheet 2 of ____

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Subassembly (Manual) 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME: MAN1.0 TASK DATA SET NAME COL1.0

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK:

OPERATION TIME (s) | TOOL NUMBER

HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ε: 100 v: 1.5 t_c: 2.5 m_s: 0.9	PAI C: 35,000 ρ: 1.2 ε: 99.5 v: 1.75 t_c: 2.5 m_s: 0.9	C: ρ: ε: v: t_c: m_s:	C: ρ: ε: v: t_c: m_s:
21. (L25) Secure 1st Column Bolt	3 | 160 13,000	X		
22. (L25) Secure 2nd Column Bolt	3 | 160 13,000	X		
23. (125) Secure 3rd Column Bolt	3 | 160 13,000	X		
24. (L25) Secure 4th Column Bolt	3 | 160 13,000	X		
25. (L24) Feel for Bracket Secureness	2 | 100	X		
26. (L17) E-Test Hazard Switch	7 | 170 30,000	X		
27. (L16) E-Test Turn/Cruise Lever	21 | 170 30,000	X		
28. (L18) E-Test Horn Pad	12 | 170 30,000	X		
UNITS IN PRODUCTION BATCH				
DESIRED PRODUCTION RATE (units/min)				

Sheet 3 of ____

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Subassembly (Manual) 2.0 DATE

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MAN2.0 TASK DATA SET NAME COL2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK.

OPERATION TIME (s) | TOOL NUMBER
HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PAT C: 35,000 ρ: 1.2 ϵ: 99.5 v: 1.75 t_c: 2.5 m_s: 0.9	C: ρ: ϵ: v: t_c: m_s:	C: ρ: ϵ: v: t_c: m_s:
1. Schedule Column to Fixture	23 | 100	X		
2. (L1) Paint Column	X	43 | 200 15,000		
3. Schedule Steering Wheel	17 | 100	X		
4. (L5) Place Steering Wheel to Column	7 | 100	X		
5. (L9) (L10) Finger Start Wheel Nut	3 | 100	X		
6. (L22) Secure Steering Wheel Nut	3 | 110 19,000	X		
7. (L21) Inspect for Nut Secureness	1 | 110 19,000	X		
8. (L11) Install Retainer Clip	5 | 120 2,500	X		
9. (L23) Inspect Retainer for Presence	2 | 100	X		
10. (L13) (L14) Column Bracket to Column	7 | 100	X		
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet: 1 of

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Subassembly (Manual) 2.0 DATE ____

235 WORKING DAYS PER YEAR — .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE — 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME. MAN2.0 — TASK DATA SET NAME. COL2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PAT C. 35,000 ρ: 1.2 ϵ: 99.5 v: 1.75 t_c: 2.5 m_s: 0.9	C. ρ: ϵ: v: t_c: m_s:	C. ρ: ϵ: v: t_c: m_s:
11. (L15) Finger Start 2nd Bolt	3 | 100			
12. (L15) Finger Start 3rd Bolt	3 | 100			
13. (L15) Finger Start 4th Bolt	3 | 100			
14. (L25) Secure 1st Bolt	3 | 130 13,000			
15. (L25) Secure 2nd Bolt	3 | 130 13,000			
16. (L25) Secure 3rd Bolt	3 | 130 13,000			
17. (L25) S-cure 4th Bolt	3 | 130 13,000			
18. (L24) Feel for Bracket Secureness	2 | 100			
19. (L3) Install Turn/Cruise Lever	14 | 140 1,000			
20. Schedule Horn Pad	9 | 100			
UNITS IN PRODUCTION BATCH				
DESIRED PRODUCTION RATE (units/min)				

Sheet 2 of ____

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Subassembly (Manual) 2.0 DATE ____

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE (\$/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MAN2.0 TASK DATA SET NAME COL2.0

FOR EACH RESOURCE:

- C HARDWARE COST (\$)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE (\$/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST (\$)

TASK NUMBER \ RESOURCE	MAN C: 500, ρ: 1.5, ε: 100, v: 0.5, t_c: 2.5, m_s: 0.9	PAT C: 35,000, ρ: 1.2, ε: 99.5, v: 1.75, t_c: 2.5, m_s: 0.9	C: ρ: ε: v: t_c: m_s:	C: ρ: ε: v: t_c: m_s:
21.(L7) Horn Pad to Wheel	8 | 100	X		
22.(L7) Secure (2) Horn (L8) Screws	9 | 150 / 2,000	X		
23.(L19) Feel For Horn Pad Secureness	2 | 100	X		
24.(L2) Install Tilt Lever	8 | 100	X		
25.(L4) Install Hazard Switch	9 | 160 / 2,000	X		
26.(L17) E-Test Hazard Switch	7 | 170 / 30,000	X		
27.(L16) E-Test Turn/Cruise Lever	21 | 170 / 30,000	X		
28.(L18) E-Test Horn Pad	12 | 170 / 30,000	X		

UNITS IN PRODUCTION BATCH ____ ____ ____ ____

DESIRED PRODUCTION RATE (units/min) ____ ____ ____ ____

Sheet 3 of ____

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APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Subassembly (Manual) 3.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MAN3.0 TASK DATA SET NAME COL3.0

FOR EACH RESOURCE

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN	PAT		
	C: 500; ρ: 1.5; ε: 100; v: 0.5; t_c 2.5; m_s 0.9	C: 35,000; ρ: 1.2; ε: 99.5; v: 1.75; t_c 2.5; m_s 0.9	C: ρ: ε: v: t_c: m_s:	C: ρ: ε: v: t_c: m_s:
1. Schedule Column to Fixture	23 | 100			
2. (L1) Paint Column		43 | 100 / 15,000		
3. Schedule Steering Wheel	17 | 100			
4. (L5) Place Wheel to Column	7 | 100			
5. (L9) Finger Start Wheel Nut (L10)	3 | 100			
6. (L22) Secure Wheel Nut	4 | 110 / 19,000			
7. (L21) Inspect for Nut Secureness	1 | 110 / 19,000			
8. (L11) Install Retainer Clip	5 | 120 / 2,500			
9. (L23) Inspect for Retainer Presence	2 | 100			
10. Schedule Horn Pad	9 | 100			
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 1 of ____

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Subassembly (Manual) 3.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MAN3.0 TASK DATA SET NAME COL3.0

FOR EACH RESOURCE

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER; HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PAT C: 35,000 ρ: 1.2 ε: 99.5 v: 1.75 t_c: 2.5 m_s: 0.9	C: ρ: ε: v: t_c: m_s:	C: ρ: ε: v: t_c: m_s:
11. (L7) Horn Pad to Wheel	8 | 100			
12. (L18) E-Test Horn Pad	12 | 130 30,000			
13. (L7) Secure (2) Horn Pad (L8) Screws	9 | 140 2,000			
14. (L19) Feel for Pad Secureness (L20)	2 | 100			
15. (L3) Install Turn/Cruise Lever	14 | 150 1,000			
16. (L16) E-Test Turn/Cruise Lever	21 | 130 30,000			
17. (L13) Column Bracket to (L14) Column (one bolt)	7 | 100			
18. (L15) Finger Start 2nd Bolt	5 | 100			
19. (L25) Secure First Bolt	3 | 160 13,000			
20. (L25) Secure 2nd Bolt	3 | 160 13,000			
UNITS IN PRODUCTION BATCH				
DESIRED PRODUCTION RATE (units/min)				

Sheet 2 of ____

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APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Subassembly (Manual) 3.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MAN3.0 TASK DATA SET NAME COL3.0

FOR EACH RESOURCE

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER; HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c 2.5 m_s 0.9	PAT C: 35,000 ρ: 1.2 ε: 99.5 v: 1.75 t_c 2.5 m_s 0.9	C: ρ: ε: v: t_c m_s	C: ρ: ε: v: t_c m_s
21. (L14) Finger Start 3rd Bolt (L15)	3 | 100	X		
22. (L25) Secure 3rd Bolt	3 | 160 13,000	X		
23. (L14) Finger Start 4th Bolt (L15)	3 | 100	X		
24. (L25) Secure 4th Bolt	3 | 160 13,000	X		
25. (L24) Feel for Bracket Secureness	2 | 100	X		
26. (L2) Install Tilt Lever	8 | 100	X		
27. (L4) Install Hazard Switch	9 | 170 2,000	X		
28. (L17) E-Test Hazard Switch	7 | 130 30,000	X		
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 3 of ____

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APPENDIX B: Steering Column Manual/Automated Task Data

APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Manual/Auto 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME: MAUT2.0 TASK DATA SET NAME: COLAUT4.0

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER; HARDWARE COST ($)

TASK NUMBER / RESOURCE	MAN C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PAI C: 35,000 ρ: 1.5 ϵ: 99.5 v: 1.5 t_c: 2.0 m_s: 0.9	FXD C: 15,000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.0 m_s: 5.0	PA2 C: 20,000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 5.0 m_s: 5.0
1. Schedule Steering Column	23 | 100			
2. (L13) (L14) Column Bracket to Column (1 bolt)	8 | 100			
3. (L14) (L15) Finger Start 2nd Bolt	3 | 100			
4. (L14) (L15) Finger Start 3rd Bolt	3 | 100			
5. (L14) (L15) Finger.Start 4th Bolt	3 | 100			
6. (L1) Paint Column		43 | 200 15,000		
7. Schedule Steering Wheel	17 | 100			
8. (L5) Wheel to Column	7 | 100			
9. (L9) (L10) Finger Start Wheel Nut	3 | 100			
10. (L2) Install Tilt Lever	8 | 100			
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 1 of ____

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APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Manual/Auto 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME: MAUT2.0 TASK DATA SET NAME COLAUT4.0

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PAI C: 35,000 ρ: 1.5 ϵ: 99.5 v: 1.5 t_c: 2.0 m_s: 0.9	FXD C: 15,000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.0 m_s: 5.0	PA2 C: 20,000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 5.0 m_s: 5.0
11. (L4) Install Hazard Switch	9 | 150 2,000			
12. (L25) Secure 1st Column Bolt	3 | 120 13,000		1 | 300 27,000	4 | 400 15,000
13. (L25) Secure 2nd Column Bolt	3 | 120 13,000		1 | 300 27,000	4 | 400 15,000
14. (L25) Secure 3rd Column Bolt	3 | 120 13,000		1 | 300 27,000	4 | 400 15,000
15. (L25) Secure 4th Column Bolt	3 | 120 13,000		1 | 300 27,000	4 | 400 15,000
16. (L22) Secure Steering Wheel Nut	3 | 130 19,000		1 | 310 15,000	3 | 410 17,000
17. (L21) Inspect for Nut Secureness	1 | 130 19,000		1 | 310 15,000	1 | 410 17,000
18. (L11) (L12) Install Retainer Clip	5 | 140 2,500		3 | 320 8,000	5 | 420 10,000
19. (L3) Install Turn/Cruise Lever	14 | 110 1,000			
20. (L23) Inspect for Retainer Presence	2 | 100			
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

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APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Manual/Auto 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME: MAUT2.0 TASK DATA SET NAME: COLAUT4.0

FOR EACH RESOURCE.

C HARDWARE COST ($)
ρ INSTALLED COST/HARDWARE COST
ϵ UP-TIME EXPECTED (%)
v OPERATING/MAINTENANCE RATE ($/h)
t_c SECONDS TOOL CHANGE TIME
m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PAI C: 35,000 ρ: 1.5 ϵ: 99.5 v: 1.5 t_c: 2.0 m_s: 0.9	FXD C: 15,000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.0 m_s: 5.0	PA2 C: 20,000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 5.0 m_s: 5.0
21. Schedule Horn Pad	9 | 100 —	X	X	X
22. (L6) Horn Pad to Wheel	8 | 100 —	X	X	X
23 (L8) (L19) Secure (2) Horn Pad Screws	9 | 160 2,000	X	X	X
24. (L20) Inspect Horn Pad for Secureness	2 | 100 —	X	X	X
25. (L24) Feel for Column Bracket Secureness	2 | 100 —	X	X	X
26. (L16) E-test Turn/Cruise Lever	21 | 170 30,000	X	X	X
27. (L17) E-test Hazard Switch	7 | 170 30,000	X	X	X
28. (L18) E-test Horn Pad	12 | 170 30,000	X	X	X
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

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APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Manual/Auto 2.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME. MAUT2.0 TASK DATA SET NAME: COLAUT2.0

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C:500 ρ:1.5 ϵ:100 v:0.5 t_c:2.5 m_s:0.9	PAI C:35,000 ρ: 1.5 ϵ: 99.5 v: 1.75 t_c: 2.0 m_s:0.9	FXD C15,000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.0 m_s:5.0	PA2 C20,000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 5.0 m_s:5.0
1. Schedule Steering Column	23 | 100	X	X	X
2. (L13) (L14) Column Bracket to Column (one bolt)	8 | 100	X	X	X
3. (L14) (L15) Finger Start 2nd Bolt	3 | 100	X	X	X
4. (L14) (L15) Finger Start 3rd Bolt	3 | 100	X	X	X
5. (L14) (L15) Finger Start 4th Bolt	3 | 100	X	X	X
6. (L1) Paint Column	X	43 | 200 15000	X	X
7. Schedule Steering Wheel	17 | 100	X	X	X
8. (L5) Wheel to Column	7 | 100	X	X	X
9. (L9) Finger Start Wheel Nut	3 | 100	X	X	X
10. (L3) Install Turn/Cruise Lever	14 | 110 1,000	X	X	X
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 1 of ___

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APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Manual/Auto 2.0 DATE ____

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MAUT2.0 TASK DATA SET NAME COLAUT2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK.

OPERATION TIME (s) | TOOL NUMBER
HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C:500 ρ:1.5 ϵ:100 v:0.5 t_c:2.5 m_s:0.9	PA1 C:35,000 ρ: 1.5 ϵ: 99.5 v: 1.75 t_c: 2.0 m_s:0.9	FXD C:15,000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.0 m_s:5.0	PA2 C:20,000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 5.0 m_s:5.0
11. (L25) Secure 1st Column Bolt	3 | 120 13,000		1 | 300 27,000	4 | 400 15,000
12. (L25) Secure 2nd Column Bolt	3 | 120 13,000		1 | 300 27,000	4 | 400 15,000
13. (L25) Secure 3rd Column Bolt	3 | 120 13,000		1 | 300 27,000	4 | 400 15,000
14. (L25) Secure 4th Column Bolt	3 | 120 13,000		1 | 300 27,000	4 | 400 15,000
15. (L2) Install Tilt Lever	8 | 100			
16. (L4) Install Hazard Switch	9 | 100			
17. (L22) Secure Steering Wheel Nut	3 | 130 19,000		3 | 310 15,000	3 | 410 17,000
18. (L21) Inspect for Nut Secureness	1 | 130 19,000		1 | 310 15,000	1 | 410 17,000
19. (L11) Install Retainer Clip (L12)	5 | 140 2,500		3 | 320 8,000	5 | 420 10,000
20. (L23) Inspect for Retainer Presence	2 | 100			
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 2 of ____

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APPLICABLE TECHNOLOGY CHART

TITLE Steering Column Manual/Auto 2.0 DATE ______

235 WORKING DAYS PER YEAR — .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE — 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME. MAUT2.0 — TASK DATA SET NAME COLAUT2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C:500 ρ:1.5 ε:100 v:0.5 t_c:2.5 m_s:0.9	PAI C:35,000 ρ: 1.5 ε: 99.5 v: 1.75 t_c: 2.0 m_s: 0.9	FXD C:15,000 ρ: 1.5 ε: 98 v: 1.5 t_c: 2.0 m_s: 5.0	PA2 C:20,000 ρ: 2.25 ε: 98 v: 2.0 t_c: 5.0 m_s: 5.0
21. Schedule Horn Pad	9 | 100	X	X	X
22. (L6) Horn Pad to Wheel	8 | 100	X	X	X
23. (L8) Secure (2) Horn Pad (L19) Screws	9 | 160 / 2,000	X	X	X
24. (L20) Inspect Horn Pad for Secureness	2 | 100	X	X	X
25. (L24) Feel for Column Bracket Secureness	2 | 100	X	X	X
26. (L16) E-test Turn/Cruise Lever	21 | 170 / 30,000	X	X	X
27. (L17) E-test Hazard Switch	7 | 170 / 30,000	X	X	X
28. (L18) E-test Horn Pad	12 | 170 / 30,000	X	X	X
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 3 of ____

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APPENDIX C: Engine Dress Component Manual Assembly Task Data

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE (\$/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL1.0

FOR EACH RESOURCE:

- C HARDWARE COST (\$)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE (\$/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST (\$)

TASK NUMBER	RESOURCE	MFR C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MFO C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MRO C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C: ρ: ε: v: t_c: m_s:
1.	Schedule Engine and Fixture	42 | 101 20000	42 | 201 20000	42 | 301 20000	
2.	Schedule Transaxle	15 | 102 20000	15 | 102 20000	15 | 102 20000	
3.	(L20) Remove Input Shaft Cap	3 | 103 4000	3 | 203 4000	3 | 303 4000	
4.	(L21) Remove Output Shaft Cap	3 | 103 4000	3 | 203 4000	3 | 303 4000	
5.	(L19) Inspect Throw Bearing	2 | 103 4000	2 | 203 4000	2 | 303 4000	
6.	(L1) Mate Transaxle to Engine	12 | 102 20000	12 | 202 20000	12 | 302 20000	
7.	(L4) (L5) Finger Start Bolts	3 | 102 20000	3 | 202 20000	3 | 302 20000	
8.	(L2) (L3) Finger Start Studs	3 | 102 20000	3 | 202 20000	3 | 302 20000	
9.	(L18) Secure Bolts and Studs	11 | 104 17000	11 | 204 17000	11 | 304 17000	
10.	(L15) Stamp Engine VIN	17 | 105 12000	12 | 205 12000		

UNITS IN PRODUCTION BATCH 250,000

DESIRED PRODUCTION RATE (units/min) ______

Sheet 1 of 7

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APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 1.0 DATE ________

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL1.0

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

	TASK NUMBER / RESOURCE	MFR C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MFO C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MRO C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C: ρ: ε: v: t_c: m_s:
11.	(L22) Stamp Transaxle VIN	13 | 105 / 12000	13 | 205 / 12000	X	
12.	(L8) (L11) Trans Mount to Engine	10 | 100	5 | 200	5 | 300	
13.	(L6) (L7) Finger Start Bolts	6 | 100	6 | 200	6 | 300	
14.	(L9) (L10) Finger Start Nuts	6 | 100	6 | 200	6 | 300	
15.	(L14) Secure Bolts	6 | 106 / 18000	6 | 206 / 18000	6 | 306 / 18000	
16.	(L24) Inspect Bolt Torque	1 | 106 / 18000	1 | 206 / 18000	6 | 306 / 18000	
17.	(L13) Secure Nuts	6 | 106 / 18000	6 | 206 / 18000	6 | 306 / 18000	
18.	(L23) Inspect Nut Torque	1 | 106 / 18000	1 | 206 / 18000	1 | 306 / 18000	
19.	(L16) Remove Temporary Switch	3 | 107 / 6000	3 | 207 / 6000	3 | 307 / 6000	
20.	(L12) Install Coolant Switch	3 | 107 / 6000	3 | 207 / 6000	3 | 307 / 6000	
	UNITS IN PRODUCTION BATCH	250,000			
	DESIRED PRODUCTION RATE (units/min)				

Sheet: 2 of 7

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APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL1.0

FOR EACH RESOURCE

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER; HARDWARE COST ($)

TASK NUMBER	RESOURCE	MFR (C 500, ρ 1.5, ϵ 100, v 0.5, t_c 2.5, m_s 0.9)	MFO (C 500, ρ 1.5, ϵ 100, v 0.5, t_c 2.5, m_s 0.9)	MRO (C 500, ρ 1.5, ϵ 100, v 0.5, t_c 2.5, m_s 0.9)	(C, ρ, ϵ, v, t_c, m_s)
21	(L17) Secure Coolant Switch	2 | 107 / 6000	2 | 207 / 6000	2 | 307 / 6000	
22.	Get Electrical Harness	14 | 100	14 | 200	14 | 300	
23.	(L74) Inspect for Harness Usage	2 | 100	2 | 200	2 | 300	
24.	(L75) (L82) Harness to Engine	17 | 100	17 | 200	17 | 300	
25.	(L72) Back up Switch to Transaxle	10 | 108 / 6000	10 | 208 / 6000	10 | 308 / 6000	
26	(L73) Back up Switch to Harness	2 | 100	2 | 200	2 | 300	
27.	(L71) Get Starter and Bolts	12 | 100	12 | 200	12 | 300	
28.	(L64) (L65) Bolts to Engine	8 | 100	8 | 200	8 | 300	
29.	(L61) (L62 (L70) Shim PLacement	3 | 100	3 | 200	3 | 300	
30.	(L66) (L67) (L68) Rear Bracket to Starter and Nuts	8 | 100	8 | 200	8 | 300	
UNITS IN PRODUCTION BATCH		250,000			
DESIRED PRODUCTION RATE (units/min)					

Sheet: 3 of 7

84C:G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL1.0

FOR EACH RESOURCE

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER / RESOURCE	MFR C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MFO C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MRO C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C ρ ϵ v t_c m_s
31. (L58) (L59) (L60) Finger Start Bolt to Engine	3 | 100	3 | 200	X	
32. (L63) Secure Bolts	5 | 109 11000	5 | 209 11000	X	
33. (L69) Secure Nuts	4 | 110 7000	4 | 210 7000	X	
34. (L57) Secure Bolt	2 | 110 7000	2 | 210 7000	X	
35. (L83) (L84) (L85) Rear Pump Bracket to Engine	17 | 100	X	12 | 300	
36. (L86) (190) Water Pump to Rear	9 | 100	X	9 | 300	
37. (L87) (L94) Water Pump Bclts	6 | 100	X	6 | 300	
38. (L91) (L92) (L97) Front Brace to Pump	9 | 100	X	9 | 300	
39. (188) Secure Rear Bolts	9 | 111 11000	X	9 | 311 11000	
40. (L93) Secure Front Brace Bolts	15 | 111 11000	X	15 | 311 11000	
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet: 4 of 7

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 1.0 DATE

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL1.0

FOR EACH RESOURCE

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MFR C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MFO C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MRO C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C: ρ ε v t_c m_s
41. (L96) Force Fit Pulley to Pump	8 | 112 25000	X	8 | 312 25000	
42. (L98) Place Belt to Pulley	3 | 100 —	X	3 | 300 —	
43. (L99) Tension Belt	12 | 117 13000	X	12 | 117 13000	
44. (L95) Secure Bolt	14 | 118 12000	X	14 | 318 12000	
45. (L76) Connect Idle Air Control	3 | 100 —	X	3 | 300 —	
46. (L77) Connect Distributor	3 | 100 —	X	3 | 300 —	
47. (L78) Connect Coolant Temperature Switch	4 | 100 —	X	4 | 300 —	
48. (L79) Connect Nuetral Start Switch	4 | 100 —	X	4 | 300 —	
49. (L80) Connect TBI Unit	4 | 100 —	X	4 | 300 —	
50. (L81) Connect Speed Sensor	3 | 100 —	X	3 | 300 —	
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet: 5 of 7

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL1.0

FOR EACH RESOURCE

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER; HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MFR C 500 ρ 1.5 ε 100 v 0.5 t_c 2.5 m_s 0.9	MFO C 500 ρ 1.5 ε 100 v 0.5 t_c 2.5 m_s 0.9	MRO C 500 ρ 1.5 ε 100 v 0.5 t_c 2.5 m_s 0.9	C. ρ ε v. t_c m_s
51. (L52) (L53) (L54) Front Bracket and Bolt to Engine	17 | 100	12 | 200	X	
52. (L55) Secure Bracket Bolts	5 | 113 37000	5 | 213 37000	X	
53. (L56) Inspect Bolt Torque	2 | 113 37000	2 | 213 37000	X	
54. (L46) (L47) (L50) Generator Bracket to Engine	9 | 100	9 | 200	X	
55. (L30) (L36) (L37) Generator to Bracket and Bolt	9 | 100	9 | 200	X	
56. (L42) (L43) (L49) Brace to Engine and Bolt	7 | 100	7 | 200	X	
57. (L29) (L32) (L33) Brace to Generator and Bolt	5 | 100	5 | 200	X	
58. (L40) (L44) (L45) Rear Brace to Engine	7 | 100	7 | 200	X	
59. (L34) (L35) (L39) Rear Brace to Generator	5 | 100	5 | 200	X	
60. (L51) Secure Generator to Engine	8 | 114 13000	8 | 214 13000	X	
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet: 6 of 7

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 1.0 DATE ________

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL1.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK.

OPERATION TIME (s) | TOOL NUMBER

HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MFR C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MFO C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MRO C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C: ρ: ε: v: t_c m_s
61. (L48) Secure Brace to Engine	3 | 114 13000	3 | 214 13000	X	
62. (L41) Secure Rear Brace to Engine	3 | 114 13000	3 | 214 13000	X	
63. (L26) (L27) Place Belt to Generator and Harness Lead	10 | 100 —	10 | 200 —	X	
64. (L25) Tension Generator Belt	11 | 115 13000	11 | 215 13000	X	
65. (L28) Secure Pivot Bolt	4 | 116 12000	4 | 216 12000	X	
66. (L31) Secure Front Brace Bolt	8 | 116 12000	8 | 216 12000	X	
67. (L38) Secure Rear Brace Bolt	4 | 116 12000	4 | 216 12000	X	
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 7 of 7

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 2.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL2.0

FOR EACH RESOURCE.

C HARDWARE COST ($)
ρ INSTALLED COST/HARDWARE COST
ϵ UP-TIME EXPECTED (%)
v OPERATING/MAINTENANCE RATE ($/h)
t_c SECONDS TOOL CHANGE TIME
m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK.

OPERATION TIME (s) | TOOL NUMBER
HARDWARE COST ($)

	TASK NUMBER / RESOURCE	MFR C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MFO C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	MRO C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C: ρ: ϵ: v: t_c: m_s:
1.	Schedule Engine and Fixture	42 | 101 20000	42 | 201 20000	42 | 301 20000	
2.	Schedule Transaxle	15 | 102 20000	15 | 102 20000	15 | 102 20000	
3.	(L20) Remove Input Shaft Cap	3 | 103 4000	3 | 203 4000	3 | 303 4000	
4.	(L21) Remove Output Shaft Cap	3 | 103 4000	3 | 203 4000	3 | 303 4000	
5.	(L19) Inspect Throw Bearing	2 | 103 4000	2 | 203 4000	2 | 303 4000	
6.	(L1) Mate Transaxle to Engine	12 | 102 20000	12 | 202 20000	12 | 302 20000	
7.	(L4) (L5) Finger Start Bolts	3 | 102 20000	3 | 202 20000	3 | 302 20000	
8.	(L2) (L3) Finger Start Studs	3 | 102 20000	3 | 202 20000	3 | 302 20000	
9.	(L18) Secure Bolts and Studs	11 | 104 17000	11 | 204 17000	11 | 304 17000	
10.	(L8) (L11) Trans Mount to Engine	10 | 100	10 | 200	10 | 300	
	UNITS IN PRODUCTION BATCH	250,000			
	DESIRED PRODUCTION RATE (units/min)				

Sheet 1 of 7

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APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 2.0 DATE ____

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME. MNL1.0 TASK DATA SET NAME ENGMNL2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER / RESOURCE	MFR C:500 ρ:1.5 ε:100 v:0.5 t_c:2.5 m_s:0.9	MFO C500 ρ:1.5 ε:100 v:0.5 t_c:2.5 m_s:0.9	MRO C:500 ρ:1.5 ε:100 v:0.5 t_c:2.5 m_s:0.9	C: ρ: ε: v: t_c: m_s:
11. (L6) Finger Start Bolts (L7)	6 | 100	6 | 200	6 | 300	|
12. (L9) Finger Start Nuts (L10)	6 | 100	6 | 200	6 | 300	|
13. (L14) Secure Bolts	6 | 106 37000	6 | 206 37000	6 | 306 37000	|
14. (L24) Inspect Bolt Torque	1 | 106 37000	1 | 206 37000	1 | 306 37000	|
15. (L13) Secure Nuts	6 | 106 37000	6 | 206 37000	6 | 306 37000	|
16. (L23) Inspect Nut Torque	1 | 106 37000	1 | 206 37000	1 | 306 37000	|
17. (L16) Remove Temporary Switch	3 | 107 6000	3 | 207 6000	3 | 307 6000	|
18. (L12) Install Coolant Switch	3 | 107 6000	3 | 207 6000	3 | 307 6000	|
19. (L17) Secure Temperature Switch	2 | 107 6000	2 | 207 6000	2 | 307 6000	|
20. Get Electrical Harness	14 | 100	14 | 200	14 | 300	|
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 2 of 7

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 2.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER; HARDWARE COST ($)

	TASK NUMBER \ RESOURCE	MFP C:500 ρ:1.5 ϵ:100 v:0.5 t_c:2.5 m_s:0.9	MFO C500 ρ1.5 ϵ100 v0.5 t_c2.5 m_s0.9	MRO C:500 ρ:1.5 ϵ 100 v 0.5 t_c 2.5 m_s0.9	C. ρ ϵ v. t_c m_s
21.	(L72) Inspect Harness Usage	2 | 100	2 | 200	2 | 300	
22.	(L74) Harness to Engine	17 | 100	17 | 200	17 | 300	
23.	(L15) Stamp Engine VIN	12 | 105 12000	12 | 205 12000		
24.	(L22) Stamp Transaxle VIN	13 | 105 12000	13 | 205 12000		
25.	(L72) Back up Switch to Transaxle	10 | 108 6000		5 | 308 6000	
26.	(L73) Back up Switch to Harness	2 | 100		2 | 300	
27.	(L71) Get Starter and Bolts	12 | 100	7 | 200		
28.	(L64) (L65) Bolts to Engine	8 | 100	8 | 200		
29.	(L61) (L62) (L70) Shim Placement	3 | 100	3 | 200		
30.	(L66) (L67) (L68) Rear Bracket to Starter and Nuts	8 | 100	8 | 100		

UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet: 3 of 7

84C1G232

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 2.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL2.0

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER; HARDWARE COST ($)

TASK NUMBER	RESOURCE	MFR (C 500, ρ 1.5, ϵ 100, v 0.5, t_c 2.5, m_s 0.9) Operation time (s)	Tool number	Hardware cost ($)	MFO (C 500, ρ 1.5, ϵ 100, v 0.5, t_c 2.5, m_s 0.9) Operation time (s)	Tool number	Hardware cost ($)	MRO (C 500, ρ 1.5, ϵ 100, v 0.5, t_c 2.5, m_s 0.9) Operation time (s)	Tool number	Hardware cost ($)	C. ρ ϵ. v. t_c m_s
31. (L58) (L59) (L60)	Finger Start Bolt to Engine	3	100		3	200					
32. (L83) (L84) (L85)	Rear Pump Bracket to Engine	17	100					12	300		
33. (L86) (L90)	Water pump to Rear Bracket	9	100					9	300		
34. (L87) (L94)	Water Pump Bolts	6	100					6	300		
35. (L91) (L92) (L97)	Front Brace to Pump	9	100					9	300		
36. (L63)	Secure Starter Bolts	10	109	11000	5	209	11000				
37. (L69)	Secure Starter Nuts	4	110	7000	4	210	7000				
38. (L57)	Secure Engine Bolt	2	110	7000	2	210	7000				
39. (L88)	Secure Rear Pump Brace Bolts	14	111	11000				9	311	11000	
40. (L93)	Secure Front Brace Bolts	15	111	11000				15	311	11000	
	UNITS IN PRODUCTION BATCH	250,000									
	DESIRED PRODUCTION RATE (units/min)										

Sheet: 4 of 7

84C1G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 2.0 DATE ________

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL2.0

FOR EACH RESOURCE

- c HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

	TASK NUMBER / RESOURCE	MFR c:500 ρ:1.5 ϵ:100 v:0.5 t_c:2.5 m_s:0.9	MFO c:500 ρ:1.5 ϵ:100 v:0.5 t_c:2.5 m_s:0.9	MRO c:500 ρ:1.5 ϵ:100 v:0.5 t_c:2.5 m_s:0.9	c ρ ϵ v t_c m_s
41.	(196) Force Fit Pulley to Pump	8 ¦ 112 25000	X	8 ¦ 312 25000	
42.	(L98) Place Belt to Pulley	3 ¦ 100	X	3 ¦ 300	
43.	(L52) (L53) (L54) Front Bracket and Bolt to Engine	17 ¦ 100	12 ¦ 200	X	
44.	(L55) Secure Bolts	5 ¦ 113 37000	5 ¦ 213 37000	X	
45.	(L56) Inspect Bolt Torque	2 ¦ 113 37000	2 ¦ 213 37000	X	
46.	(L76) Connect Idle Air Control	3 ¦ 100	X	3 ¦ 300	
47.	(L77) Connect Distributor	3 ¦ 100	X	3 ¦ 300	
48.	(L78) Connect Coolant Temperature Switch	4 ¦ 100	X	4 ¦ 300	
49.	(L79) Connect Nuetral Start Switch	4 ¦ 100	X	4 ¦ 300	
50.	(L80) Connect TBI Unit	4 ¦ 100	X	4 ¦ 300	
	UNITS IN PRODUCTION BATCH	250,000			
	DESIRED PRODUCTION RATE (units/min)				

Sheet: 5 of 7

84C1C333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 2.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

? SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL2.0

FOR EACH RESOURCE

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

	TASK NUMBER \ RESOURCE	MER C 500, ρ 1.5, ε 100, v 0.5, t_c 2.5, m_s 0.9	MEO C 500, ρ 1.5, ε 100, v 0.5, t_c 2.5, m_s 0.9	MRO C 500, ρ 1.5, ε 100, v 0.5, t_c 2.5, m_s 0.9	C, ρ, ε, v, t_c, m_s
51.	(L81) Connect Speed Sensor	3 | 100	X	3 | 300	
52.	(L46) (L47) (L50) Generator Bracket to Engine	14 | 100	9 | 200	X	
53.	(L30) (L36) (L37) Generator to Bracket and Bolt	9 | 100	9 | 200	X	
54.	(L42) (L43) (L49) Brace to Engine and and Bolt	7 | 100	7 | 200	X	
55.	(L29) (L32) (L33) Brace to Generator and Bolt	5 | 100	5 | 200	X	
56.	(L40) (L44) (L45) Rear Brace to Engine	7 | 100	7 | 200	X	
57.	(L34) (L35) (L39) Rear Brace to Generator	5 | 100	5 | 200	X	
58.	(L51) Secure Generator Bracket to Engine	8 | 114 / 13000	8 | 214 / 13000	X	
59.	(L48) Secure Brace to Engine	3 | 114 / 13000	3 | 214 / 13000	X	
60.	(L41) Secure Rear Brace to Engine	3 | 114 / 13000	3 | 214 / 13000	X	
	UNITS IN PRODUCTION BATCH	250,000			
	DESIRED PRODUCTION RATE (units/min)				

Sheet 6 of 7

84C1G332

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual 2.0 DATE ________

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME MNL1.0 TASK DATA SET NAME ENGMNL2.0

FOR EACH RESOURCE

C	HARDWARE COST ($)
ρ	INSTALLED COST/HARDWARE COST
ϵ	UP-TIME EXPECTED (%)
v	OPERATING/MAINTENANCE RATE ($/h)
t_c	SECONDS TOOL CHANGE TIME
m_s	MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK

OPERATION TIME (s) / TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MFR C 500 ρ 1.5 ϵ 100 v 0.5 t_c 2.5 m_s 0.9	MFO C 500 ρ 1.5 ϵ 100 v 0.5 t_c 2.5 m_s 0.9	MRO C 500 ρ 1.5 ϵ 100 v 0.5 t_c 2.5 m_s 0.9	C ρ ϵ v t_c m_s
61. (L99) Tension Water Pump Belt	17 | 117 13000		12 | 317 13000	
62. (L95) Secure Pump Bolts	14 | 118 12000		14 | 318 12000	
63. (L26) Place Belt to Generator (L27) and Harness Lead	13 | 100	10 | 200		
64. (L25) Tension Generator Belt	11 | 117 13000	11 | 217 13000		
65. (L28) Secure Pivot Bolt	4 | 118 12000	4 | 218 12000		
66. (L31) Secure Front Brace	8 | 118 12000	8 | 218 12000		
67. (L38) Secure Rear Brace Bolt	4 | 118 12000	4 | 218 12000		
UNITS IN PRODUCTION BATCH	250,000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 7 of 7

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APPENDIX D: Engine Dress Component Manual/Automated Task Data

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 1.0 DATE ______

235 WORKING DAYS PER YEAR

.358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE

21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME. AUT1.0

TASK DATA SET NAME ENGAUT1.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK:

OPERATION TIME (s) | TOOL NUMBER

HARDWARE COST ($)

TASK NUMBER	RESOURCE	MAN	PA1	FXD	PA2
		C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C: 22000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5	C: 40000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.5 m_s: 5	C: 40000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5
1.	Schedule Engine and Fixture	42 | 101 20000			
2.	Schedule Transaxle	15 | 102 20000			
3. (L20)	Remove Input Shaft Cap	3 | 103 4000			
4. (L21)	Remove Output Shaft Cap	3 | 103 4000			
5. (L19)	Inspect Throw Bearing	2 | 103 4000			
6. (L1)	Mate Transaxle to Engine	12 | 102 20000			
7. (L4) (L5)	Finger Start Bolts	3 | 102 20000			
8. (L2) (L3)	Finger Start Studs	3 | 102 20000			
9. (L8) (L11)	Trans Mount to Engine	10 | 100 —			
10. (L6) (L7)	Finger Start Bolts	6 | 100 —			
	UNITS IN PRODUCTION BATCH	250000			
	DESIRED PRODUCTION RATE (units/min)				

Sheet 1 of 7

840:G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 1.0 DATE ____

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME. AUT1.0 TASK DATA SET NAME ENGAUT1.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PA1 C: 22000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5	FXD C: 40000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.5 m_s: 5	PA2 C: 40000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5
11. (L9) (L10) Finger Start Nuts	6 | 100			
12. Get Electrical Harness	14 | 100			
13. (L74) Inspect Harness Usage	2 | 100			
14. (L82) Harness to Engine	17 | 100			
15. (L72) Back-up Switch to Transaxle	5 | 108 6000			
16. (L73) Back-up Switch to Harness	2 | 100			
17. (L16) Remove. Coolant Temperature Switch	3 | 107 6000			
18. (L12) Install Coolant Temperature Switch	3 | 107 6000			
19. (L17) Secure Temperature Switch	2 | 107 6000			
20 (L83) (L84) (L85) Rear Pump Bracket to	12 | 100			
UNITS IN PRODUCTION BATCH	250000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 2 of 7

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 1.0 DATE ____

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME AUT1.0 TASK DATA SET NAME ENGAUT1.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PA1 C. 22000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5	FXD C: 40000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.5 m_s: 5	PA2 C: 40000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5
21. (L86) (L90) Water Pump to Rear Bracket	9 | 100	X	X	X
22. (L87) (L94) Water Pump Bolts	6 | 100	X	X	X
23. (L91) (L92) (L97) Front Brace to Pump	9 | 100	X	X	X
24. (L15) Stamp/Etch VIN to Engine	12 | 105 12000	X	X	14 | 405 45000
25. (L22) Stamp/Etch VIN to Transaxle	13 | 105 12000	X	X	18 | 405 45000
26. (L18) Secure Bolts and Studs	11 | 104 18000	16 | 204 25000	12 | 304 25000	16 | 404 25000
27. (L14) Secure Transaxle Bolts	6 | 106 18000	9 | 206 21000	4 | 306 25000	9 | 406 21000
28. (L24) Inspect Bolt Torque	1 | 106 18000	2 | 206 21000	2 | 306 25000	2 | 406 21000
29. (L13) Secure Transaxle Nuts	6 | 106 18000	9 | 206 21000	4 | 306 25000	9 | 406 21000
30. (L23) Inspect Nut Torque	1 | 106 18000	2 | 206 21000	2 | 306 25000	2 | 406 21000
UNITS IN PRODUCTION BATCH	250000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 3 of 7

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual7 Auto 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME AUT1.0 TASK DATA SET NAME ENGAUT1.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER; HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN	PA1	FXD	PA2
	C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C: 22000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5	C: 40000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.5 m_s: 5	C: 40000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5
31. (L88) Secure Rear Pump Brace Bolts	14 | 111 11000	16 | 211 15000	11 | 311 22000	16 | 411 15000
32. (L93) Secure Front Pump Brace Bolts	10 | 111 11000	6 | 211 15000	9 | 311 22000	5 | 411 15000
33. (L96) Force Fit Pulley to Pump	8 | 112 25000	X	X	X
34. (L98) Place Belt to Pulley	3 | 100	X	X	X
35. (L76) Connect Idle Air Control	3 | 100	X	X	X
36. (L77) Connect Distributor	3 | 100	X	X	X
37. (L78) Connect Coolant Temperature Switch	4 | 100	X	X	X
38. (L79) Connect Nuetral Start Switch	4 | 100	X	X	X
39. (L80) Connect TBI Unit	4 | 100	X	X	X
40. (L81) Connect Speed Sensor	3 | 100	X	X	X
UNITS IN PRODUCTION BATCH	250000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 4 of 7

84C1G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME AUT1.0 TASK DATA SET NAME ENGAUT1.0

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ϕ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C:500 ϕ:1.5 ϵ:100 v:0.5 t_c:2.5 m_s:0.9	PA1 C: 22000 ϕ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5	FXD C.40000 ϕ:1.5 ϵ:98 v:1.5 t_c:2.5 m_s:5	PA2 C40000 ϕ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5
41. (L71) Get Starter and Bolts	14 | 100	X	X	X
42. (L64) (L65) Bolts to Engine	8 | 100	X	X	X
43. (L61) (L62) (L70) Shim Placement	3 | 100	X	X	X
44. (L66) (L67) (L68) Rear Bracket to Starter and Nuts	8 | 100	X	X	X
45. (L58) (L59) (L60) Finger Start Bolt to Engine	3 | 100	X	X	X
46. (L52) (L53) (L54) Front Bracket and Bolts to Engine	12 | 100	X	X	X
47. (L46) (L47) (L50) Generator Bracket to Engine	9 | 100	X	X	X
48. (L30) (L36) (L37) Genertaor to Bracket and Bolt	9 | 100	X	X	X
49. (L42) (L43) (L49) Brace to Engine and Bolt	7 | 100	X	X	X
50. (L29) (L32) (L33) Brace to Generator and Bolt	5 | 100	X	X	X
UNITS IN PRODUCTION BATCH	250000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 5 of 7

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 1.0 DATE ______

235 WORKING DAYS PER YEAR — .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE — 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME AUT1.0 — TASK DATA SET NAME ENGAUT1.0

FOR EACH RESOURCE:

- C — HARDWARE COST ($)
- ρ — INSTALLED COST/HARDWARE COST
- ε — UP-TIME EXPECTED (%)
- v — OPERATING/MAINTENANCE RATE ($/h)
- t_c — SECONDS TOOL CHANGE TIME
- m_s — MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN	PA1	FXD	PA2
	C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C: 22000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5	C: 40000 ρ: 1.5 ε: 98 v: 1.5 t_c: 2.5 m_s: 5	C: 40000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5
51. (L40) (L44) (L45) Rear Brace to Engine	7 | 100 —	X	X	X
52. (L34) (L35) (L39) Rear Brace to Generator	5 | 100 —	X	X	X
53. (L26) (L27) Belt to Generator and Harness Lead	10 | 100 —	X	X	X
54. (L55) Secure Front Bracket Bolts	12 | 113 37000	10 | 213 42000	10 | 313 42000	10 | 413 42000
55. (L56) Inspect Bolt Torque	2 | 113 37000	2 | 213 42000	2 | 313 42000	2 | 413 42000
56. (L63) Secure Starter Bolts	10 | 109 11000	8 | 209 14000	4 | 309 26000	8 | 409 14000
57. (L69) Secure Starer Nuts	4 | 110 7000	5 | 210 11000	4 | 310 18000	5 | 410 11000
58. (L57) Secure Engine Bolt	2 | 110 7000	3 | 210 11000	2 | 310 18000	3 | 410 11000
59. (L51) Secure Generator Bracket to Engine	8 | 114 13000	8 | 214 15000	2 | 314 26000	8 | 414 15000
60. (L18) Secure Brace to Engine	3 | 114 13000	3 | 214 15000	2 | 314 26000	3 | 414 15000
UNITS IN PRODUCTION BATCH	250000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 6 of 7

640:G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual7 Auto 1.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME AUT1.0 TASK DATA SET NAME ENGAUT 1.0

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PA1 C: 22000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5	FXD C: 40000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.5 m_s: 5	PA2 C: 40000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5
61. (L41) Secure Rear Brace to Engine.	3 | 114 1 000	3 | 214 15000	2 | 314 26000	3 | 414 15000
62. (L99) Tension Water Pump Belt	12 | 117 13000	12 | 217 17000	7 | 317 30000	12 | 417 17000
63. (L25) Tension Generator Belt	12 | 117 13000	12 | 217 17000	8 | 317 30000	12 | 417 17000
64. (L95) Secure Water Pump Bolts	14 | 118 12000	10 | 218 18000	2 | 318 36000	10 | 418 18000
65. (L28) Secure Pivot Bolt	8 | 118 12000	7 | 218 18000	2 | 318 36000	7 | 418 18000
66. (L31) Secure Front Brace	7 | 118 12000	7 | 218 18000	2 | 318 36000	7 | 418 18000
67. (L38) Secure Rear Brace Bolt	4 | 118 12000	4 | 218 18000	2 | 318 36000	4 | 418 18000

UNITS IN PRODUCTION BATCH 250000

DESIRED PRODUCTION RATE (units/min) ______

Sheet 7 of 7

84C10333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/ Auto 2.0 DATE ______

235 WORKING DAYS PER YEAR

.358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE

21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME: AUT1.0

TASK DATA SET NAME ENGAUT2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK:

OPERATION TIME (s) | TOOL NUMBER
HARDWARE COST ($)

	TASK NUMBER / RESOURCE	MAN	PA1	FXD	PA2
		C. 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C: 22000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5	C. 40000 ρ: 1.5 ϵ. 98 v: 1.5 t_c: 2.5 m_s: 5	C. 40000 ρ: 2.25 ϵ: 98 v: 2.0 t_c: 4.0 m_s: 5
1.	Schedule Engine and Fixture	42 | 101 20000			
2.	Schedule Transaxle	15 | 102 20000			
3.	(L20) Remove Input Shaft Cap	3 | 103 4000			
4.	(L21) Remove Output Shaft Cap	3 | 103 4000			
5.	(L19) Inspect Throw Bearing	2 | 103 4000			
6.	(L1) Mate Transaxle to Engine	12 | 102 20000			
7.	(L4) Finger Start Bolts (L5)	3 | 102 20000			
8.	(L2) Finger Start Studs (L3)	3 | 102 20000			
9.	(18) Secure Bolts and Studs	11 | 104 17000	11 | 204 25000	12 | 304 25000	
10.	(L8) Trans Mount to Engine (L11)	10 | 100			
	UNITS IN PRODUCTION BATCH	250000			
	DESIRED PRODUCTION RATE (units/min)				

Sheet 1 of 7

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 2.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME AUT1.0 TASK DATA SET NAME ENGAUT2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER; HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PA1 C: 22000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5	FXD C: 40000 ρ: 1.5 ε: 98 v: 1.5 t_c: 2.5 m_s: 5	PA2 C: 40000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5
11. (L6) (L7) Finger Start Bolts	6 | 100	X	X	X
12. (L9) (L10) Finger Start Nuts	6 | 100	X	X	X
13. Get Electrical Harness	14 | 100	X	X	X
14. (L74) Inspect Harness Usage	2 | 100	X	X	X
15. (L82) Place Harness to Engine	17 | 100	X	X	X
16. (L71) Get Starter and Bolts	9 | 100	X	X	X
17 (L64) (L65) Bolts to Engine	8 | 100	X	X	X
18. (L61) (L62) (L70) Shim Placement	3 | 100	X	X	X
19. (L66) (L67) (L68) Rear Bracket to Starter	8 | 100	X	X	X
20. (L58) (L59) (L60) Finger Start Bolt to	3 | 100	X	X	X
UNITS IN PRODUCTION BATCH	250000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 2 of 7

8401G333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 2.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME. AUT1.0 TASK DATA SET NAME ENGAUT2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PA1 C: 22000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5	FXD C: 40000 ρ: 1.5 ε: 98 v: 1.5 t_c: 2.5 m_s: 5	PA2 C: 40000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5
21. (L15) Stamp/Etch VIN to Engine	12 | 105 12000	X	X	14 | 405 45000
22. (L22) Stamp/Etch VIN to Transaxle	13 | 105 12000	X	X	18 | 405 45000
23. (L14) Secure Transaxle Bolts	6 | 106 18000	9 | 206 21000	4 | 306 25000	9 | 406 21000
24. (L24) Inspect Bolt Torque	1 | 106 18000	2 | 206 21000	2 | 306 25000	2 | 406 21000
25. (L13) Secure Transaxle Nuts	6 | 106 18000	9 | 206 21000	4 | 306 25000	9 | 406 21000
26. (L23) Inspect Nut Torque	1 | 106 18000	2 | 206 21000	2 | 306 25000	2 | 406 21000
27. (L63) Secure Starter Bolts	10 | 109 11000	12 | 209 14000	4 | 309 26000	12 | 409 14000
28. (L69) Secure Starter Nuts	4 | 110 7000	5 | 210 11000	4 | 310 18000	5 | 409 11000
29. (L57) Secure Engine Bolt	2 | 110 7000	3 | 210 11000	2 | 310 18000	3 | 410 11000
30. (L52) (L53) (L54) Front Bracket and Bolts to Engine	17 | 100 —	X	X	X
UNITS IN PRODUCTION BATCH	250000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 3 of 7

84C1C233

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 2.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME. AUT1.0 TASK DATA SET NAME ENGAUT2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

	TASK NUMBER / RESOURCE	MAN C:500 ρ:1.5 ε:100 v:0.5 t_c:2.5 m_s:0.9	PA1 C: 22000 ρ: 2.25 ε: 96 v: 2.0 t_c: 4.0 m_s: 5	FXD C:40000 ρ:1.5 ε:98 v:1.5 t_c:2.5 m_s: 5	PA2 C:40000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5
31.	(L46)(L47)(L50) Generator Bracket to Engine	9 | 100	X	X	X
32.	(L30)(L36)(L37) Generator to Bracket and Bolt	9 | 100	X	X	X
33.	(L42)(L43)(L49) Brace to Engine and Bolt	7 | 100	X	X	X
34.	(L29)(L32)(L33) Brace to Generator and Bolt	5 | 100	X	X	X
35.	(L40)(L41)(L45) Rear Brace to Engine	7 | 100	X	X	X
36.	(L34)(L35)(L39) Rear Brace to Generator	5 | 100	X	X	X
37.	(L26)(L27) Belt to Generator and Harness Lead	10 | 100	X	X	X
38	(L83)(L84)(L85) Rear Pump Bracket to Engine	17 | 100	X	X	X
39	(L86)(L90) Water Pump to Rear Bracket	9 | 100	X	X	X
40.	(L87)(L94) Water Pump Bolts	6 | 100	X	X	X

UNITS IN PRODUCTION BATCH 250000

DESIRED PRODUCTION RATE (units/min)

Sheet 4 of 7

84010333

APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 2.0 DATE ____

235 WORKING DAYS PER YEAR

.358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE

21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME AUT1.0

TASK DATA SET NAME ENGAUT2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK:

OPERATION TIME (s) | TOOL NUMBER

HARDWARE COST ($)

TASK NUMBER	RESOURCE	MAN	PA1	FXD	PA2
		C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	C: 22000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5	C: 40000 ρ: 1.5 ε: 98 v: 1.5 t_c: 2.5 m_s: 5	C: 40000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5
41.	(L91) (L92) (L97) Front Brace to Pump	9 | 100			
42.	(L76) Connect Idle Air Control	3 | 100			
43.	(L77) Connect Distributor	3 | 100			
44.	(L78) Connect Speed Sensor	3 | 100			
45.	(L79) Connect Nuetral Start Switch	4 | 100			
46.	(L93) Secure Front Pump Brace Bolts	15 | 111 11000	6 | 211 16000	9 | 311 17000	6 | 411 16000
47.	(L96) Force Fit Pulley to Pump	8 | 112 25000			
48.	(L98) Place Belt to Pump Pulley	3 | 100			
49.	(L80) Connect TBI Unit	4 | 100			
50.	(L16) Remove Coolant Temperature Switch	3 | 107 6000			
	UNITS IN PRODUCTION BATCH	250000			
	DESIRED PRODUCTION RATE (units/min)				

Sheet 5 of 7

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APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 2.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME. AUT1.0 TASK DATA SET NAME ENGAUT2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ε UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK.

OPERATION TIME (s) ¦ TOOL NUMBER
HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ε: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PA1 C: 22000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5	FXD C: 40000 ρ: 1.5 ε: 98 v: 1.5 t_c: 2.5 m_s: 5	PA2 C: 40000 ρ: 2.25 ε: 98 v: 2.0 t_c: 4.0 m_s: 5
51. (L12) Install Temperature Switch	3 ¦ 107 5000			
52. (L17) Secure Temper-ure Switch	2 ¦ 107 5000			
53. (L78) Connect Temerature Switch to Harness	4 ¦ 100 —			
54. (L72) Back-up Switch to Transaxle	5 ¦ 108 6000			
55. (L73) Back-up Switch to Harness	3 ¦ 100 —			
56. (L88) Secure Rear Pump Brace Bolts	14 ¦ 111 11000	16 ¦ 211 15000	11 ¦ 311 22000	16 ¦ 411 15000
57. (L55) Secure Front Bracket Bolts	17 ¦ 113 37000	10 ¦ 213 42000	10 ¦ 313 42000	10 ¦ 413 42000
58. (L56) Inspect Bolt Torque	2 ¦ 113 37000	2 ¦ 213 42000	2 ¦ 313 42000	2 ¦ 413 42000
59. (L51) Secure Generator Bracket to Engine	8 ¦ 114 13000	8 ¦ 214 15000	2 ¦ 314 26000	8 ¦ 414 15000
60. (L18) Secure Brace to Engine	3 ¦ 114 13000	3 ¦ 214 15000	2 ¦ 314 26000	3 ¦ 414 15000
UNITS IN PRODUCTION BATCH	250000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 6 of 7

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APPLICABLE TECHNOLOGY CHART

TITLE Engine Dress Manual/Auto 2.0 DATE ______

235 WORKING DAYS PER YEAR .358 ANNUALIZED COST FACTOR

2 SHIFTS AVAILABLE 21.60 AVERAGE LOADED LABOR RATE ($/h)

4 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME. AUT1.0 TASK DATA SET NAME ENGAUT2.0

FOR EACH RESOURCE.

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER / HARDWARE COST ($)

TASK NUMBER \ RESOURCE	MAN C: 500 ρ: 1.5 ϵ: 100 v: 0.5 t_c: 2.5 m_s: 0.9	PA1 C. 22000 ρ: 2.25 ϵ: 98 v. 2.0 t_c: 4.0 m_s: 5	FXD C. 40000 ρ: 1.5 ϵ: 98 v: 1.5 t_c: 2.5 m_s: 5	PA2 C 40000 ρ: 2.25 ϵ: 98 v: 2.0 t_c 4.0 m_s: 5
61. (L12) Secure Rear Brace to Engine	3 | 114 13000	3 | 214 15000	2 | 314 26000	3 | 414 15000
62. (L99) Tension Water Pump Belt	12 | 117 13000	12 | 217 17000	7 | 317 30000	12 | 417 17000
63. (L25) Tension Generator Belt	12 | 117 13000	12 | 217 17000	8 | 317 30000	12 | 417 17000
64. (L95) Secure Water Pump Bolts	14 | 118 12000	10 | 218 18000	2 | 318 36000	10 | 418 18000
65. (L28) Secure Pivot Bolt	8 | 118 12000	7 | 218 18000	2 | 318 36000	7 | 418 18000
66. (L31) Secure Front Brace	7 | 118 12000	7 | 218 18000	2 | 318 36000	7 | 418 18000
67. (L38) Secure Rear Brace Bolt	4 | 118 12000	4 | 218 18000	2 | 318 36000	4 | 418 18000
UNITS IN PRODUCTION BATCH	250000			
DESIRED PRODUCTION RATE (units/min)				

Sheet 7 of 7

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