COST MODELING OF ALTERNATIVE AUTOMOBILE ASSEMBLY TECHNOLOGIES

: A COMPARATIVE ANALYSIS

by

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ABSTRACT

Today, the world automobile industry is preparing to face its next challenge. The advent of low-priced computers has led to the introduction of a vast array of alternative manufacturing technologies. At the same time, new materials whose capabilities surpass those of conventional sheet metal are being developed. These current major developments offer automakers a wide range of technological alternatives. Current manufacturers are now faced with deciding which of these technologies will enable them to stay competitive, while new entrants are faced with choosing which technologies to employ.

This study focuses on assessing the performance of alternative manufacturing technologies by building a consistent frame work, an assembly cost model, of an automobile assembly process. The assembly cost model provides a formalism to determine how new technologies, concepts, and materials affect the cost of assembly. The model provides a complete picture of the assembly process in terms of capital equipment, labor, production rate, plant capacity, down time, and other process and cost variables. This allows new technologies to be considered in the context of the global assembly operation. The model also allows us to perform sensitivity analysis to identify important variables and their impacts on the final assembly cost. The model is built up from interchangeable modules, representing different subassemblies, and different levels of automation. Meaningful comparisons between groups of modules and whole systems are made. In a case study, four alternative assembly technologies and their performance in terms of unit cost are discussed. Afterwards, Payback period and Return on Investment(ROI) analysis are performed to investigate the profitability of the alternatives.

1. Assembly with manual body welding.
2. Assembly with automated body welding.
3. Assembly with automated body welding and plastic skin.
4. Assembly with hybrid between manual and automated body welding.

Alternative 3 is the lowest cost method followed by 2, 4, and 1. The unit cost difference between alternatives 3 and 1 is $27. The results of the Payback period and ROI of the additional investments show that

alternatives 2 and 3, i.e., automation, are not profitable. The ROI for alternative 2 is only 4.85% and for alternative 3 it is 8.1%, while the ROI for alternative 4 (hybrid) is 18.5%. This surpasses the assumed accepted capital recovery rate of 12% in the model.

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Introduction

The automobile companies are venturing in many directions in order to improve their product. The two most visible trends are the moves toward plastic, or composite materials, and the growing application of computers in both manufacturing and vehicle control and instrumentation (Groover, 1984), (Orr, 1985), (Kirkland, 1986), and (Wrigley, 1986).

No single set of materials or manufacturing technology is in the forefront. Automobile companies seize upon potential new technologies, rather than purposefully pursuing a particular technology for specific reasons. A consistent framework to analyze how companies select a technology by synthesizing available information could prove useful.

It is difficult to assess the performance of new technologies, since many plants introduce several at a time, and incremental changes in production occur continually. Production managers have some idea how well the technology performs, but a thorough and dispassioned assessment of the new technology is difficult to accomplish.

General industry practice bases cost comparisons on part weight and part material, and assumes that the technology used to produce and assemble them is the same. Cost estimation is difficult to perform in advance of actually manufacturing the component, and is rarely done at an early stage in component design.

A decision-making formalism should link production and assembly with throughput and product performance data. It would enable component and vehicle designers to compare the costs of alternative manufacturing technologies in the context of the global assembly process. As well, a computerized application of the formalism could assess the sensitivity of the results to the assumptions employed, and analyze alternative scenarios.

Adoption of new technology in the automobile industry has not been without problems. In hindsight, management expected too much of a technology that was not fully understood, and that people were not trained adequately to support. For example, robots were a source of frustration, because their limits were not recognized. They are acceptable in traditional assignments such as painting and spot welding, but they cannot detect and adjust to the everyday variables in a process that a human operator can. As an auto engineer said about his experience with robots and the machine vision system; "We've installed sealer robots that cannot detect seams that have moved, holes in panels, or sealer flow changes. The vision system can detect shifts in the mounting plate, but not much else. The sealer robots were supposed to eliminate ten employees, but have actually eliminated only four jobs." (Winter, 1986).

Before discussing an assembly model in more depth, the benefits and the limitations of modeling must be placed in perspective. While a cost model can illustrate sensitivity to downtime and increased maintenance costs, it does not prevent them. A cost model may compare different shop configurations but it can explain only to a limited extent how some companies use their employees more efficiently than others. There are some intangibles which may not be compared quantitatively. It is therefore important to use a cost model as a tool rather than a solution.

Methodology

A consistent framework to analyze material flows, factor prices, assembly line organization, and manufacturing operations is required to understand the economics of vehicle manufacturing. The Materials Systems Lab determined that a computer-based, technical cost model of the vehicle manufacturing process could be developed and applied to the problems of analyzing alternative manufacturing technologies.

The cost model is based upon the flow employed in the manufacture of a unimated (front-wheel-drive) automobile body. The model is based upon an assembly plant employing conventional technology; i.e., most of the manufacturing operations are performed manually, except the underbody and side frame subassembly operations. The assembly flow with conventional technology differs little from advanced technology. Even in cars with plastic body panels, the present level of plastic application is minimal. However, this one manual assembly model cannot assess different technologies unless the model is modified.

The model has a set of unit operation modules which represent the assembly flow. The function of a module representing a certain station is interchangeable among different manufacturing technologies because the assembly flow is same. The differences of the same functional modules are the number of laborers and the equipments employed. The modification involves building a set of interchangeable modules with the same function.

While, at first glance, it may seem unrealistic to analyze advanced manufacturing technologies by modeling conventional assembly operations, the differences between advanced and conventional manufacturing facilities today are smaller than one might imagine. Arguably, each automobile manufacturing plant is unique unto itself. Some plants are quite old (for example, the Chrysler Jefferson Ave.Plant); others are very new (e.g., Pontiac Fiero or Chrysler Sterling Heights or GM Linden Plant). Some plants have longer lines of in- process inventory than others; some use toy tab method for temporarily maintaining integrity between the underbody and the side frames; and some just look different.

However, a closer examination of the various assembly plants currently operating in the US reveals that, in a very real sense, most of the differences between these plants are trivial. For example, there are several plants which have highly automated welding lines, with a vast array of welding machines and robots. Yet, all that has really happened is that machinery has been employed to replace manpower. In fact, in many automated facilities, the line flow is exactly the same as it would be if no automation were used; machines are quite literally occupying the same place as men would otherwise.

Even a look at the Pontiac Fiero facility reveals that there are far more similarities than differences between it and more conventional plants. While on the one hand the flow of manufacturing is different there, it is confined to the metal finishing operations after the welding and to the painting of the vehicle. Even the space frame is basically built the same way as a conventional steel body, except there is no need for deck lids, hood, and fenders.

The basic concept of automobile assembly has not changed much in the last forty years or so (Abernathy, 1978). The space frame concept and plastic usage has changed the flow of assembly only a little (Automotive Engineering, 1986). More plastics applications with part consolidation could simplify the assembly process further. However, it is believed this change will be incremental. The Chrysler Sterling Heights plant is supposed to be one of the most modernized in the world. Indeed, its welding line is completely automated. Nonetheless, the basic structure of assembly flow remains intact. Furthermore, though Ford has some very modernized plants, it is rather reluctant to invest further to automate the rest of the plants. Therefore, it can be concluded that automobile manufacturing technology in terms of assembly will not change much until the assembly lines become very simplified through parts consolidation with plastic technology.

Currently, the plastic bodied cars make use of unique Mill and Drill machine to ensure dimensional accuracy between space frame and plastic body panel. However, from the example of GM's Mini Van project, a plant with conventional technology, producing a unimated body car can be converted to a plastic oriented Mini Van plant while the basic structure of the former plant remains intact. Nevertheless, a broader range of plastic applications through parts consolidation and modular concept could alter the whole philosophy of automobile assembly.

This model can be used as the basic structure for any kind of automobile assembly process. The model has sets of interchangeable modules, representing different substations, and stations for different levels of technology and different methods of manufacturing. For example, by building a consistent frame work to explore the differences in each technology, planners can examine many different types of plant lay- out easily by arranging the set of modules and making a best choice within the budgetary limits.

In the model, the unit cost represents the contribution of the labor, capital related and some indirect labor cost over the annual production volume. Some indirect labor cost such as material handling and repair workers, are included because they are sensitive to the technology adopted in a plant. However, just a comparison of unit costs of different technologies may not be sufficient to justify the profit maximization of a company, because each manufacturing technology requires different level of initial investment. This required initial investment is crucial in appraising different technologies.

In many cases of investment justification, the cost of equipment is overlooked (Poli, 1986). For example, if the cost of a welding robot is $100,000, and the annual cost of one laborer is $50,000, then the payback period may be calculated to be two years. There are two possible mistakes. One is to overlook the costs of equipment other than the robot itself, such as the computerized control system, different conveyor system, automated fixtures, robogate body framing system, etc. The cost of the whole system must be considered as an initial investment, not just the cost of a single robot. The second mistake is to ignore the system cost of manual operation. In the result given, the payback period is unreasonably short. Furthermore, the cost of educating and training workers for the automated system must be considered as an initial investment, in addition to the equipment costs.

Payback period and return on investment (RCI) are the most widely adopted justification methods. The equation for the payback period calculation is I/(S-E), where I is the initial investment, S is a future annual saving, and E is future annual expenses. If the payback period is shorter than 3 years, the value of ROI is very close to the inverse of the payback. However, if the payback period is longer than 3 years, a discounted cash flow method must be used to give a more realistic value of ROI. The equation for ROI is:

$$\text{Payback period} = \sum_{1}^{n} \frac{1}{(1 + ROI)^{n}}$$

The value of ROI can be calculated by trial and error with the help of a programmable calculator. The ROI, if positive, can then be compared with the cost of finance as an annual interest rate. The greater the margin by which the ROI exceeds the cost of finance, the greater the expected profitability of the investment (Boothroyd, 1982), (Coller,et al, 1982), (Engelberger, 1980), (Ionnou, et al 1984), and (Tanner, 1978).

Background

The process of the assembly of an automobile consists of five distinct stages:

- o underbody subassembly,
- o main body assembly,
- o paint,
- o trim, and
- o chassis.

In traditional automobile manufacture (and in many trucks today), body and chassis were manufactured separately, and then joined together. More recently, the industry has seen the development of the unimated body (also known as the uni-body) vehicle, whose body and frame are no longer independent structures. With the call for down sized and light-weight automobiles, the unimated body has been modified to accomodate these needs, including large scale production of front-wheel-drive automobiles.

Nowadays, most automobiles are designed around the unimated body concept, except heavy full sized cars and trucks. Surprisingly, the move to the unimated body did not cause major changes in the manufacturing process. For both the unimated body and the older rail frame and body designs, the manufacturing process has remained the same. The major exception is the material/manufacturing flow of the unimated body, which is closer to a single line operation because the build up of the chassis for a unimated body is very simple compared to that of the framed body.

Using plastic in the body panels of cars is another current trend in manufacturing automobiles. At this point in its development, plastic/composite panels are attached to the so called space frame to form a skin by either bolting or glueing. The space frame is a complete body-in-white, without a deck lids, fenders, and a hood.

This raises the question of just how much a plant like the Fiero plant differs from other steel based automobile assembly plants. The space frame still has to go through all the standard welding processes. However, some metal finishing work such as mig welding, grinding, and washing is no longer required. Instead, extra work will be added on in the painting shop. Fascia has to go through separate painting booths, because it is made out of a softer material than body panels. Consequently, there are three separate paths for space frame, rigid body panels, and fascia. However, it is not unusual to see plants with plastic panel cars purchase painted fascia from the outside to simplify the painting process.

Present automobile assembly technology is heading down two paths. One is the substitution of robots and computers for human labor to increase productivity while maintaining the structure of the traditional assembly method. Another is a slow diversion from the main stream assembly flow structure along with the adoption of plastic for automotive materials. The present model is based on the uni-body assembly flow with conventional technology, where much of the welding is done manually. Since the flows are the same, any counterpart of any substation or station in the model was readilly found in other automobile plants with advanced technology. The model is designed to assess the relative economic consequences of these different approaches to manufacturing stations.

Cost model and automobile assembly process description

The process of automobile assembly was divided into five unit operations. This division can be applied to any kind of automobile manufacturing technology. Even a manufacturing technology that uses the space frame and plastic panels uses a similar operational structure and processes within each unit of operation. The operations are:

1. Underbody subassembly.
2. Body assembly.
3. Painting.
4. Trimming.
5. Chassis and Final.

Each of these operations is briefly characterized below.

Underbody subassembly and body assembly are welding processes that requires a heavy investment in single purpose welding machinery, special tooling, robots, and hand welding guns. Underbody subassembly and body assembly lines are designed for a single body type.

Painting combines sealing, coating, and drying, and requires the highest level of capital investment, owing to the sheer size of the facility required, and to the EPA standards which regulate the emissions of these facilities. However, a paint shop, once constructed, has a long service life.

The trim and chassis lines are bolting and drilling operations that do not require a substantial investment in single purpose tooling. This is especially true for trim lines where the emphasis is on general purpose tooling. Alternatively, the chassis and final lines do require substantial equipment investments; however, a large amount of this tooling can be reused in the event of a change-over. The trim line, chassis and final assemly lines all require considerable manpower (table 1 and 2).

The assembly model focuses upon the underbody subassembly and the body assembly stations where advanced automated welding operation takes place. The greatest detail in the model can currently be found in its modeling of the underbody subassembly and body assembly lines.

Model Elements

The assembly model can calculate the unit cost of two different methods of automobile manufacturing. The first is conventional sheet metal body and the other is space frame with plastic skin. Each method can be subdivided at least twice depending on the degree of automation in the body assembly.

The underbody subassembly station divides into four major lines: the motor compartment subassembly line, the rear compartment subassembly line, the floor pan assembly line, and the press welding line. Because each line independently manufactures subassemblies for the automobile, they need not be in the same building. The underbody subassembly station's welding process is almost 100% automated and the flow of process is very similar regardless of the methods of manufacturing. In

Table 1
Distribution of direct labor
(Assembly with manual welding)

	Number of laborers		Investment per labor
Underbody subass	17	1.1%	$1,582,620
Body assembly	246	16.9%	$208,259
Painting	269	18.5%	$434,201
Trimming	495	34.0%	$16,044
Chassis & Final	330	22.7%	$117,740
Inspection	99	6.8%	$0
Total # of direc	1456	100.0%	

Table 2
Distribution of direct labor
(Assembly with automated welding)

	Number of laborers		Investment per labor
Underbody subass	17	1.3%	$1,582,620
Body assembly	108	8.3%	$861,153
Painting	269	20.7%	$434,201
Trimming	495	38.0%	$16,044
Chassis & Final	330	25.4%	$117,740
Inspection	83	6.3%	
Total # of direc	1302	100.0%	

other words, the underbody subassembly station in the model can be used commonly for sheet metal body or space frame with plastic panel car assembly.

The manual body assembly can be divided into six major stations: the robot side frame station, off line subassemblies station, underbody pick up welding station, body framing station, respot station, and metal finishing station. The automated body assembly process has an identical material flow as the manual body assembly, restructured to accomodate the concept of robotized manufacturing. The model has a whole set of unit operations for the automated (robotized) body assembly. For the space frame, the whole body-in-white process is identical to the conventional sheet metal body, but there is no metal finishing station.

The model segmentation mirrors the automaker's efforts to modularize the manufacture of the automobile. Modular vehicle construction accomodates an easier interchange between different manufacturing and material technologies, and changes complete welding operations into metal fastening operations.

In the model, the painting, trimming, and chassis & final are not divided into substations, since the sequence is fairly simple compared to that of welding. Again, this lack of detail on these assembly line operations is a consequence of the current technological emphasis by automakers on welding technology. The painting process for the sheet metal body and plastic panel car is very similar; however, the plastic skin needs additional steps. Trimming, chassis and final operations in the model can be commonly used for any kind of automobile manufacturing technology.

Cost Factors

Typical direct cost factors for automobile assembly include capital equipment, taxes, utilities, insurance, maintenance, consumables, materials, and labor (table 3). Indirect costs of automobile assembly include the cost of building, engineering R&D, support equipment and facilities, and support and administrative labor. Nevertheless, the model assumes that the level of capital investment and expenses for the indirect cost facters are independent of the manufacturing technology. Therefore, even though it is likely that these indirect costs contribute significantly to the cost of assembly, they are not included in the assessment of the impact of technology. However, overhead variable burden is included in the model as some part of cost factors. In industry practice, overhead variable burden is a sum of all uncategorized costs other than direct labor cost. Occasionally overhead variable burden is expressed as a percentage of direct labor rate (without fringe benefit), and it is then called burden rate (Jellen, et al,1983) and (Glautier, 1980). In a typical conventional plant burden rate is 180%. In an automated plant, burden rate goes up because of two factors. One is from the extra capital investment for the automation, and the other is from the reduced number of direct laborers. The burden rate in a typical automated plant is around 210%-230%. Therefore, if the number of direct laborers per shift and the burden rate of a plant is known, then the total expense can be estimated.

Table 3. Factor prices

LABOR		UNIT	$/UNIT
Hourly rate + fringe		man-hour	$24.00
ENERGY		**UNIT**	**$/UNIT**
Electricity price		kwh	$0.0525
CAPITAL RELATED			
Cost of capital			12.00%
Tax	% of	equip. cost	1.20%
Insurance	% of	equip. cost	1.20%
Maintenance	% of	equip. cost	5.00%
Years of capital recovery			
Nonreusable equipment in Body shop			5
Robot and reusable equipment in body shop			10
Painting			15
Trim			15
Chassis & Final			15
Conveyor System			10
Installation Cost	% of	equip. cost	30.00%

However, in the model some of the variable burden is already built in, such as maintenance, tax, insurance, capital charge, repair man, and material handling personnel. Therefore, the burden rates for the rest of the overhead must be less than the original rates. Furthermore, the rest of the overhead not counted in the model is not dependent on the technology being used. Therefore, it is assumed that variable burdens in the model (rest of the overhead) are the same regardless of the method of manufacturing. This assumption enables validating the results of the model.

For example, the reduced burden rate for a conventional plant can be easily calculated.

$$180\% - \frac{\text{Built in overhead cost}}{\text{Total direct labor cost without fringe benefits}}$$

The reduced burden rate gives the amount of the rest of the overhead. The burden rate for the automated plant in the model is given below:

$$\frac{\text{Built in overhead + Rest of the overhead (common value)}}{\text{Total direct labor cost without fringe benefits}}$$

Total direct labor cost is reduced due to automation.

Built in overhead is increased due to extra capital related cost.

If the burden rate is calculated to be within 210% to 230%, then it indirectly shows that the model properly reflects the real situation.

The model does not account for direct cost factors like utilities and the cost of paints in a unit operation. Utilities cost too little, and the cost of painting varies with the type equipment used. A utility cost of $3 is added to the final assembly cost.

Within the model, each unit operation or substation is characterized by a list of required equipment and its total cost, the number of laborers required, and the cost of direct labor. Tax, insurance, and maintenance costs are assumed to be a fixed percentage of total equipment cost. The capital charge is amortized to estimate an effective annual payment for the capital equipment. The sum of capital charge, tax, insurance, and maintenance is called the capital related cost.

Equipment costs are based on the industry averages and input exogenously (table 4). The prices can be varied. The amount of equipment required in a unit operation is fixed by the production rate (54cars/hr) of the plant the model is based on. The production rate and amount of equipment required are linearly related. For example.

$$y = 50 + (x-54)/54 * 50$$

Suppose 50 is the number of robots required at the production rate of 54/hr. 54 is a production rate. X is a new production rate. Y is a new number of robots required at the production rate x. Sometimes, y can be the length of the conveyor system. 30 % of installation cost is the assumed cost for all of the equipment and the conveyor system. The cost for the painting shop has already been accounted for in the installation cost.

Table 4.

Unit prices of typical equipments in the automobile industry

Equipment	Unit price
Auto welder	$350,000
Press welder	$1,000,000
Welding robot	$100,000
Material handling robot	$60,000
Spray painting robot	$80,000
Assembly robot	$100,000
Hand welding gun	$20,000
Mig welding gun	$3,500
Stud welding gun	$10,000
Spray booth	$26,000/ft
Body oven	$9,000/ft
Overhead power and free conveyor with carriers & safety net	$1,500/ft
Inverted power and free conveyor with carriers & safety net	$1,600/ft
Floor conveyor	$400/ft
Monorail conveyor	$240/ft
Body carrying truck	$10,000

The total investment in a typical robot system will be from two to four times the actual robot cost, depending on the application. In major body assembly systems (spot welding), the cost of fixturing, controlling, welding equipment and its ancillary, and material handling will often be at least three to four times the cost of the robot itself. That is, a system incorporating $1M worth of robot may cost in total $3M to $4M. In other robot applications, which tend towards one or two robots per installation, as typified by off-line small part fabrication, machine tool loading/unloading and material handling, the total investment is generally in the range of twice the robot cost (Robot Application for Industry, 1982).

Labor costs are computed based on a wage rate and fringe benefits per hour. These values are industry averages among skilled, semiskilled, and unskilled laborers. However, the model does not account for indirect labor such as white collar workers. The number of laborers in a substation is fixed on a production rate (54/hr). The equation to calculate the number of laborers at a different production rate is almost identical with that of equipment. For example.

$$y = 85 + (x-54)/54 * 85 * 0.9$$

Y and 85 are number of laborers. The only difference is 0.9. The reason is that though the work load of the individual laborer is balanced throughout the station, each of them is not working up to his or her maximum capacity. Therefore, there are some slack moments in the worker's activity. Since human beings are a lot more flexible than machines, those slack spots can be pushed closer to maximum individual work load. Hence, if 10 new laborers are required then only 9 workers are going to be added after the rescheduling of the work schedule.

Financial considerations include capital costs, taxes, insurance, and maintenance. These are derived from standard financial calculations. Capital costs are based on a rental of equipments to be paid back over the life of projects, at a 12% interest rate, which are then amortized over the production volume per year. Capital costs are depreciated at an assumed interest rate over a specified time period. It is assumed that the capital recovery year for the nonreusable equipments in the body shop is 5 years and the reusable equipments in the body is 10 years. The capital recovery year for the painting, trim, and chassis is assumed 15 years (Brealey and Meyers, 1981).

$$\text{Capital cost} = \text{Investment} * \frac{\text{Interest rate}}{1-(1-\text{Interest rate})^{-n}}$$

Where n is the number of years to recover investment. Taxes, insurance, and maintenance are computed as a percentage of the capital investment and amortized over production volumes. For example, maintenance calculation is as follows:

$$\text{Tax} = \frac{\text{Equipment Cost} * 5\% \text{ (maintenance rate)}}{\text{Production volume /year}}$$

Process parameters such as production volume and down time could affect the unit cost of assembly (table 5). Production up to maximum capacity would decrease the assembly cost whether the plant is automated or not. Down time is one of the most significant cost factors among process parameters. The plant upon which the model is based has 46 minutes of relieving time per shift by contract between union and management. During that time, the whole plant is shut down, and preventive maintenance work is done. However, break-downs still occur. Then, in process inventory starts to be used. Mostly, break-downs are minor, and are repaired before the in process inventory is used up.

Using this information, the cost of operating each substation is estimated. The cost contribution of the capital, taxes, insurance, and maintenance per assembly is calculated by dividing each by yearly production volume. Labor content per assembly is calculated by multiplying the number of laborers in a shift, by the number of shifts, and by total working hours per year, and by hourly wage, plus fringe benefits, then divide the quantity by annual production volume. Equation for the labor cost is given below.

$$\frac{\text{\# of labor/shift}*2*8*250*(\text{Hourly wage+fringe benefits})}{\text{Production volume /year}}$$

Thus, for each substation identified, the model calculates the portion of total assembly cost per assembly (subassembly,part) and the distribution of the portion of assembly cost per part between labor and capital related costs (capital,tax,insurance,maintenance) contributed by each station or substation.

Table 5

Process Parameters

Number of shift	2	
Working Days/year	250	
Hours/shift	8.00	
Downtime/shift	0.80	
Working Hours/shift	7.20	
Annual production volume	194400	
Production rate /hr	54	(Plant capacity)
Real Production rate /hr	48.6	

Each of these individual unit operational costs is summed to yield a total cost of assembly per car, and the contribution of capital and labor to total cost. The model gives the total investment for equipment and number of laborers. The total investment of equipment, and the total number of laborers change as production parameters, as the number of jobs per hour (production rate) changes.

Structure of the model

Underbody subassembly

Each automobile manufacturer fabricates a number of different underbody structures, or vehicle platforms. The number of platforms a company manufactures will vary from company to company, usually depending upon the size and economic well-being of the firm.

In conventional unimated body assembly, the underbody is manufactured on its own subassembly line, and the completed underbody subassembly is automatically inspected, and then transfered by the overhead power and free conveyor system to the next station where it is joined with side frames. The capacity of most underbody subassembly stations is about 70 jobs per hour.

In the model, the underbody system consists of 21 automatic welders, 12 robots, and 3 press welders which make around 900 spot welds automatically. Total number of laborers in the underbody subassembly is 15. In the underbody system, single automatic welder performs, in average, 25 spot welds. A press welder represents about 3 automatic welders. A robot does 11 to 14 spot welds.

Underbody subassembly is subdivided into four unit operations; namely, motor compartment, floor pan, rear compartment, and a press welding station for joining these three subassemblies. These unit operations are all highly automated processes. The geometry of these subassemblies requires automated handling and manufacturing to cope with the production volume.

The physical layouts of the motor compartment, rear compartment, and floor pan subassembly stations are similar. The primary differences between them (and between similar stations in other facilities) are the kind and cost of capital equipment, and the number of laborers.

These three lines operate in parallel in most facilities. Each subassembly (motor compartment, floor pan, and rear compartment) is transferred separately through three different roller conveyor systems (also called accumulators), and joined at the press welding station to form an underbody.

Each underbody subassembly station is equipped with an auto welder and its ancillaries, and a material transfer conveyor system. The press welding staton uses a press welder and table top welder, supported by an automatic material transfer system and a computerized dimensional inspection system. The basic equipment for the floor pan subassembly station is a number of robots and presswelder, with a transfer system.

For the underbody subassembly lines, the differences between high technology assembly plants and conventional assembly plants take two forms. A high tech plant uses automated systems to load, unload, and transfer parts between stations, and press welders are used wherever possible. In a conventional plant, more labor intensive methods for subassembly loading and transfer are used.

From the viewpoint of the model, these differences can be readily incorporated, since the differences in technology can be translated into a pure trade-off of capital for labor. The introduction of high tech-methods does not introduce a structural change in the way that cars are made; rather, it introduces new combinations of capital and labor for producing the same component or subassembly. Nevertheless, the differences between underbody welding systems conventional and high-tech plants are minimal. Both systems require a similar level of capital investment. The difference in the number of laborers between two systems are at most 10 to 15. In the model, it is assumed that the underbody system for a conventional plant can be used as a common ground for any kind of manufacturing technology.

While the model assumes that the underbody subassembly stations are in the assembly plant, this may not be the case. Because the same platform may be used for several vehicles, economies of scale lead to the consolidation of the subassembly stations for several vehicles into a single, central facility. These central underbody subassembly fabrication plants are ordinarily located at the stamping plants, from which underbody subassemblies are shipped to each assembly plant on a daily basis.

However, this model contains all of the four underbody subassembly stations. Motor compartment and press welding station are modeled based on the configuration of the GM Framingham Assembly Plant. The rear compartment and floor pan are modeled based on the GM Fiero Plant. Comparisons were made with GM Fisher body's highly automated subassembly stations and Chrysler Sterling Heights Plant. Though each plant has a slightly different configuration for underbody subassembly stations, overall similarities are overwhelming in terms of the level of capital investment and the material flows.

Among the subassembly stations, the press welding station is the most automated. In fact, there usually is no direct labor involved. A press welder rapidly welds parts which are large and heavy while maintaining dimensional stability. There are 40 to 50 welding tips in a press welder, while there are only 10 to 12 tips in an auto welder in the underbody subassembly. The functions and features of a table top welder are similar to those of auto welder, except it is bigger than an auto welder. The uniqueness of the press welding station lies in the existence of the computerized dimensional inspection system. After the motor compartment, floor pan, and rear compartment are welded together by press welders and table top welders, the entire underbody structure moves to the inspection machine set, which checks dimensional accuracy to ensure mating with side frames and other body parts. After the inspection, the underbody is transferred to the underbody pick up welding station by overhead power and free conveyor. Usually this overhead conveyor system has a function of job bank or process inventory for 2 hours.

Manual body assembly

1. Robot side frame assembly.
2. Off line subassembly stations.
3. Underbody pick up welding station.
4. Body framing station.
5. Manual body respot.
6. Metal finishing station.

In many cases, the body side frame subassembly line is automated with robots, even if it is a low technology plant. The off line subassemblies and underbody pick welding stations are manually operated. The body framing and respct line are also manually operated in the model. In a high technology plant, the body framing station is called a robogate station, and most of the direct labor has been replaced by robots (figure 1, 2, and 3).

Robot side frame assembly

This station has two parallel lines, for the left and right sides of the side frame. There are 6 robots on each line. Robots are used to increase reliability and weld quality by assuring the dimensional accuracy of the side frame. Dimensional accuracy is critical for door openings. Side frame parts are placed on a large and complicated welding fixture (tool tray) to provide dimensional stability. There are usually three tool trays, to accomodate two-door, four-door, and wagons. A complete body side assembly consists of the quarter panel, roof rail, center pillar, rocker panel, front body hinge pillar and wheel housing.

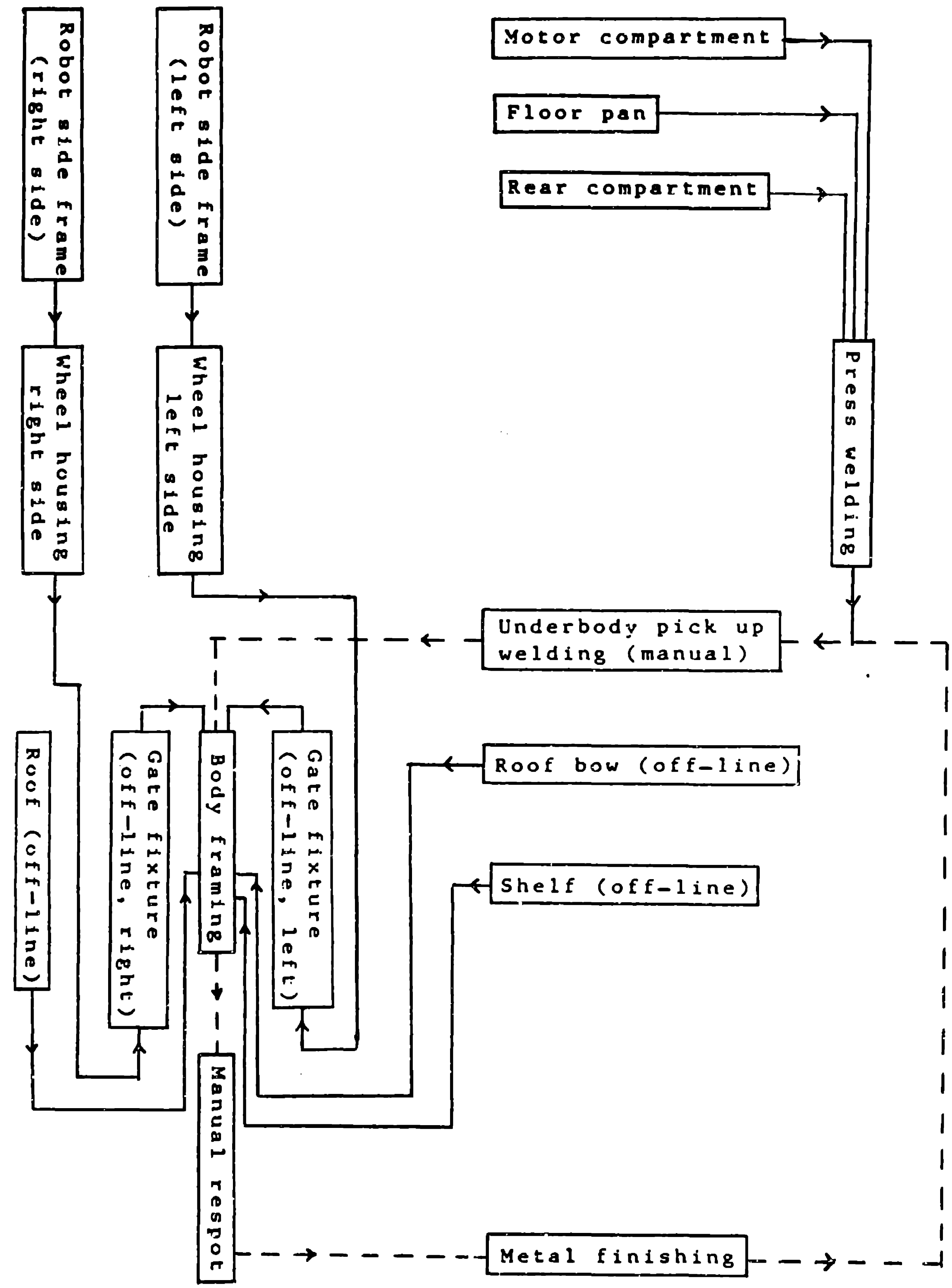


Figure 1. Flow of Manual body assembly

------ Floor Conveyor

——— Overhead Conveyor

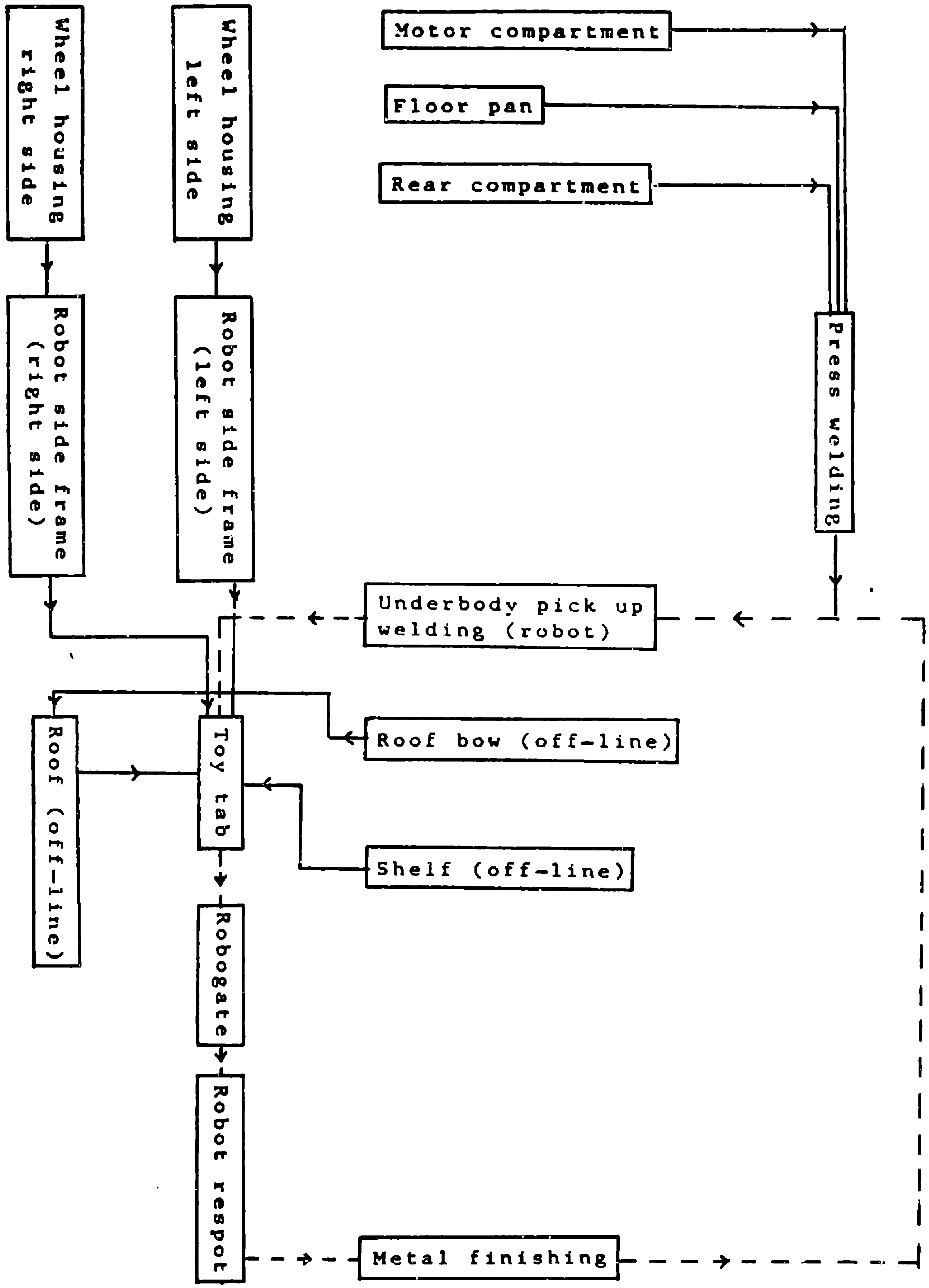


Figure 2. Flow of Automated body assembly

---- Floor Conveyor

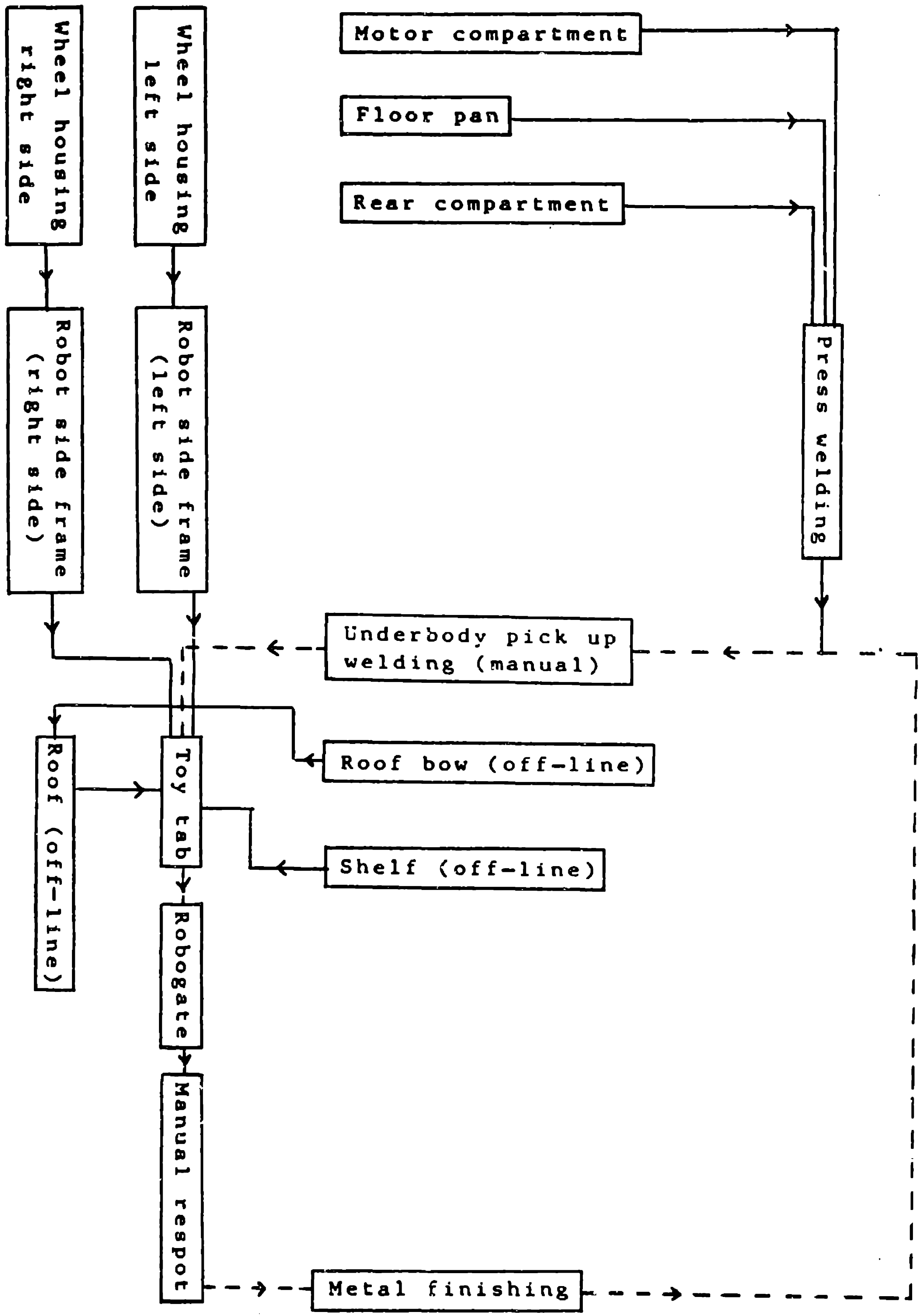


Figure 3. Flow of Hybrid body assembly

However, if the body framing station is operated manually, then wheel housing is welded to the side frame to form a complete side frame assembly in the body framing station where 70 gate fixtures are located. In this case, the welding of the wheel housing to side frame is omitted in the body side frame assembly station. Other equipment includes an auto welder, material transfer conveyor between robots and auto welders, unloading system, and overhead power and free conveyor to next station. There are 5 on each line to a total of 10 workers.

After the welding, a fully automated soft touch unloading mechanism transfers the body side frame to an overhead power and free conveyor. The side frame is transferred to the off line wheel housing station to pick up the wheel housing subassembly. Then these two subassemblies are transferred together to the gate fixtures in the body framing station, where they are welded to complete the body side frame assembly.

Off-line minor subassembly stations

Wheel housing, roof, roof bow, and shelf subassemblies are assembled in these stations. Roof, roof bow, and shelf are transferred seperately to the body framing station. These stations are labor intensive and the hand welding gun system and fixtures are primary equipment. Eighteen workers are involved in these stations.

Underbody pick up welding.

After the underbody subassembly station, underbody subassemblies are transferred to be mounted on carrying trucks. The first on line body assembly station is underbody pick up welding station. Some reinforcement parts are attached and some welding is performed then underbody mounted on carrying truck is transfered to the body framing station. This station is labor intensive and the hand welding gun systems are primary equipments. 10 workers are involved.

Manual body framing station.

The two different stations in the body framing station are an on-line and an off-line gate fixture station. Here the major body structures, side frames and roof, are welded to the underbody subassembly. Complete body side frame assembly, clamped on a gate fixture, is transferred by monorail from the off-line body framing stations, where gate fixtures are located, to the on-line body framing station. Two off-line body framing stations, on each side of the on-line body framing station, run parallel to the on-line body framing station. On each of the off-line body framing stations, there are 35 gate fixtures where side frame and wheel housing are clamped and welded. Some reinforcement parts are also welded to the side frame to form a complete body side frame assembly.

In the on-line body framing station, the completed underbody, which is clamped to the body carrying truck, is mated with the side frame gate fixtures on the left and right sides. First, the side frame gate fixture is locked to the body truck and manually clamped to the underbody assembly, and then the underbody and the side frame are welded. The roof bows and shelf are installed and welded, and then the roof is placed and welded to establish the dimensional inter-relationship between the major body subassemblies. Complete structural welding is not peformed in this station. The numbers and places of welding are such that it is just enough to maintain the integrity of the whole structure. This kind of welding is called tack welding.

The pitfall of the manually operated body framing station is the dimensional variation caused by the multiple trucks and side frame gates. Dimensional stability is critical for the later installation of deck lids, hood, and fenders.

The body framing station is very labor intensive, using a total of 40 workers, 9 on each side of the off-line gate fixture station and 22 on the on-line station. The primary equipment consists of hand welding guns, gate fixtures, body carrying trucks, and monorail conveyors.

Manual body respot station.

The model is based on a plant with the production capacity of 54 cars per hours, which dictates the required number of equipment and laborers required in the manual welding line. At this production rate, 130 hand welding guns, 1120 ft. of floor conveyor, 32 body carrying trucks, and 65 laborers are required. These items are sensitive to changes in line speed. These numbers are based on standard time data, derived from the industry's study of time and motion. If the line speed varies, the model automatically changes the required number of laborers and equipment according to the standard data.

Just after the body framing station, the gate fixtures are unlocked from the truck and unclamped from the side frames to be transferred back to the off-line body framing station. In the respot station, complete structural strength among major subassemblies is gained. 700 to 750 spots are welded in the respot station. At a line speed of 54 jobs/hr, one laborer performs 11 to 12 spot welds per car.

Metal finishing station.

Basic equipment includes stud welding guns, MIG welding guns, drill fixtures for fender, door, hood, and deck lid, floor conveyor, and overhead power and free conveyors. MIG welding is done from roof rail to quarter panel for sealing purposes, then grinding is done. After the doors, fenders, hood, and deck lid are attached, the body goes through a washing booth before it is transferred to the painting shop. 85 workers are assigned to this station. [This station is not required for space frame with plastic panelled cars.]

Automated body assembly

The underbody subassembly station is used as a common ground regardless of the type of manufacturing technology.

The basic structure of the assembly flow is identical to that of the manual body assembly. The major differences are the relocation of some jobs and the substitution of robots for human laborers (DiPietro, 1983).

1. Side frame assembly.
2. Off line assembly.
3. Underbody pick up welding.
4. Toy tab station.
5. Robogate body framing station.

6. Robot respot station.

7. Metal finishing station.

Side frame assembly

All of the work in the off-line body framing station, where wheel housing and reinforcement parts are tack welded to the side frame, is transferred to the robot side frame station. The number of robots is increased from 12 to 24 to handle the extra work. Side frame assembly is completed at this station to simplify subsequent operations. There is no need for side frame gate fixtures, which enables major body subassemblies to be toy tabbed. The complete body side frame assembly is inspected by an on-line automatic laser vision before it is transferred to the toy tab station.

Off line subassembly

The functions of the off-line subassembly stations are the same as those of the manually operated body assembly. However, the number of laborers is reduced, and robot and automatic welders are used instead of hand welding guns. For off-line robot welding applications, the turn table fixture is utilized to save space. One significant difference is that roof bows are transferred to the roof subassembly station. These roof bows are welded to the roof panel to form a complete roof module. This further simplifies later operations in the body framing station.

Underbody pick up welding

The function of underbody pick up welding is identical to the manual operation. 14 robots are engaged in the process, a number that is duplicated for back-up purposes. To accommodate precision robot welding, a cartrac conveyor and cartrac pallet are used. The cartrac conveyor system is unique. The bodies are accurately positioned within plus or minus 1mm fore-aft and plus or minus 1/2 mm up-down. The body is located on a precision tooling tray before each of the robots, and is mounted on the cartrac pallet. The pallet is moved by varying the degree of angulation of five wheels that are driven by a rotating circular tube. The system provides for stop and go, continuous movement, and accumulation, and provides flexibility for both automated and manual assembly operations. No human laborers are involved in the robotized underbody pick up welding.

Toy tab station

The major elements of the body are joined to the underbody with metal tabs, which temporarily support body structure prior to precision gaging in the robogate body framing station.

First, the body side frame is robotically loaded to the underbody, and then toy tabbed by human laborers. Secondly, the shelf and roof module are loaded by robots and toy tabbed manualy before the robogate body framing operation. This step eliminates a costly separate roof loading and indexing operation, which is not only expensive, it requires precision and is prone to malfunction. There are 4 material handling robots and 2 human laborers.

Robogate body framing station

The robogate body framing station is equipped with a shuttle system that has three specific tooling gates. The system includes a stop/go, and over/under shuttle with precision pallets. The body is automatically clamped to ensure precision location for the framing operations. The single tool concept includes a specific tooling for each body style, and gates that are automatically indexed for each body style. Panels are precisely located and automatically clamped to ensure that each part is in its correct location every time. The robogate body framing system allows production line flexibility because gates can be changed within 6-8 seconds. No human labor is involved. The primary equipment consists of robots (8), tooling gate shuttle system, and the cartrac transfer and control system.

Robot respot station

Subsquently, the body enters the robot respot station, which differs from the manual respot station in minor ways. When it has been welded, the body-in-white goes through the robotic piercing line. Robots pierce net holes in the motor compart rails, and in the front body hinge pillar and the rear end panel, for precision installation of doors, deck lids, and fenders. Then the cartrac pallet carries the body into the on-line vision inspection system where a full body laser inspection takes place. The inspection automatically covers about 100 prescribed points, and generates statistical quality control data to check that the body is being built within the limit of specified tolerances. Then the body-in-white is carried to the metal finishing station. In the robot respot station, 50 robots perform approximately 700-750 additional spot welds, and 4 overhead gantry style piercing robots do net hole piercing, and there is 1 on-line laser vision inspection system. No human labor is involved.

Metal finishing station

The station is identical to the manual body assembly station, except for the manually operated fixture for the piercing of net holes for door, fenders, food, and deck lids installation. The number of laborers is reduced from 85 to 80.

Painting shop

The basic equipment for painting is: ELPO tank, prime booth, blackout booth, color booths, ovens, paint sprays, and a overhead power and free conveyor. Again, the basic flow structure of a painting shop is standardized regardless of the level of technology. The additional steps required for plastic skinned car are described separately in the model.

When the body building is finished, the body-in-white is transfered from either a truck on a floor conveyor or from a pallet on a cartrac conveyor, to the overhead power and free conveyor system, which leads the body to the Oleum deck for cleaning and the body goes through the following sequence.

1. Oleum deck.
2. High pressure washer.

3. Phosphate.
4. ELPO Tank.
5. ELPO wet sand.
6. ELPO oven.
7. Cooling tunnel.
8. Sealer deck.
9. Prime booth.
10. Prime oven.
11. Blackout booth.
12. Electric oven.
13. Wet sand deck.
14. Wet sand oven.
15. Door header marking.
16. First color booth.
17. First color oven.
18. Second color booth.
19. Second color oven.
20. Repair and two tone color booth.
21. Repair and two tone oven.

Painting is a rather labor intensive operation at this stage. Automation is mostly confined to the painting booth. Most plants are equipped with automated or robot sprayers, while manual hand sprayers are used as well on small portions of the body. Manual labor is concentrated on the sealer line, wet sand deck, and door header marking station. The whole painting shop requires 245 workers per shift.

The body-in-white or space frame goes through the Oleum deck, high pressure washer, and phosphate to clean off the greasy surfaces. Then it goes through an ELPO tank, and the subsequent steps of the ELPO system. The main purpose of ELPO coating is anti-corrosion. However, the quality of the ELPO coating also eventually affects the paint surface quality. For sheet metal body cars, body-in-white goes through the ELPO tank slower than the space frame. A slower speed means better surface quality. But, since the space frame is hidden under the plastic panels, the space frame goes through faster. The length of the ELPO tank for the space frame could be shorter, but auto makers usually build ELPO for dual purposes.

The body-in-white or space frame next goes through the sealer deck to seal the entire body. The space frame then goes to the mill and drill machine station and through subsequent additional processes. It is then returned to the prime booth or is transferred to the chassis and final station. In the latter case, the painting operations on the space frame are completed. There are currently two different methods to apply plastic panels to the space frame of plastic skinned cars. Panels that do not have any load bearing capacity, like the Pontiac Fiero, are painted after the sealer deck, and the mill and drill operations are done before the painting. The plastic panels are attached to a fixture mounted on a truck to be painted and are then returned to the prime booth for subsequent processes. The operation is done separately because the material for the plastic skin is such that the high temperature of the color oven causes large thermal expansion (Automotive Engineering, 1986). The thermal expansion produces high strain in the space frame, which destabilizes the whole structure. After painting is completed, the panels are transferred to the trim shop to be mated with the space frame. The separate painting operations for the space frame and panels cause a slight variation in the entire sequence of the assembly process. That is, after the painting, the chassis and final is followed by trim, while ordinarily trim is followed by chassis and final.

Panels that do have some load bearing capacity follow a different sequence. After the mill and drill operation, plastic panels are attached to the space frame, which goes through some additional processes, mostly washing and drying operations, they then go back to the prime booth, and from there follow the painting processes used for the sheet metal body-in-white. In this case, parts consolidation helps to accommodate the load bearing capacity, and is also possible because the material for the panels has a thermal expansion comparable to that of the space frame. In the model, it is assumed that the concept of parts consolidation does not affect the structure of the body shop. Nevertheless, the model can handle any variation or omission of certain unit operations in the body-in-white assembly.

The body-in-white or space frame with the plastic panel, or the plastic panel on a fixture goes through the primer booth and oven. The prime coat is a surface treatment before the base (color) coat. Blackout is a black coat applied on the door header (hinge pillar), which enhances the style of the car. The body-in-white then goes through the color booths and ovens. After the completion of painting, it is transferred to the trim shop.

Trimming

Trimming is the most labor intensive operation. It requires 450 workers per shift, and the station is not equipped with any noticeable machinery. Hard trimming work (electric wiring) is followed by soft trim (interior). Only three different conveyor systems are needed: a floor conveyor, a truck for carrying bodies, and a monorail conveyor for suppplying seats. The length of the floor conveyor is about 5000 ft, and 250 trucks are required for 54 cars per hour. An extension of the floor conveyor is necessary to produce beyond its maximum capacity. After the completion of the trim, car bodies are transfered to the chassis by tri-rail or power and free conveyor.

Automation of the trim operation is limited to window glass installation where the toxic chemical urethane has to be applied. On some occasions, wheel opening moldings are installed by robots. Usually, the robotized trimming operation has a separate loop from the main trim shop conveyor system. Each body is removed from the main line, processed through the loop, and then reinserted into the main line (King, 1984).

The automobile body is automatically unloaded from the trim shop main floor conveyor, and loaded to an automated guided vehicle or a cartrac pallet for processing of the automatic trim operations. The first operation performed in the loop is the preparation of the quarter window module for installation to the body. The quarter window module is inspected for damage and then loaded to the accumulating preloader. One robot on each side of the line picks up the quarter window module from the preloader and places it to the automated urethane dispensing machine. After the proper amount of urethane is applied to the glass, the robot loads the quarter window module to the body.

The body is then delivered to the next station for installation of the windshield and back window glass. The preparation and installation of the windshield is similar to that of window glass. The glass is inspected and loaded to a delivery conveyor which positions the glass for a robot to pick it up and position it for an automatic silane application to clear it before the urethane application. The robot rotates the glass 360 degrees for the application and wipe operation of the silane.

After cleaning of glass, the robot turns the glass to the urethane dispensing equipment, and rotates it 360 degrees in a convoluting plane for proper application. The robot then deposits the glass to a holding fixture for the next operation. Next, the robot picks up the glass, and positions it into a checking fixture to verify that the proper amount of urethane has been applied. The same robot then rotates and loads the glass to the body in station. For the above operation, 8 electric robots are involved.

The next robotic operation in the trim loop installs the wheel opening moldings. Four robots pick up wheel opening moldings from racks, and position the moldings to the wheel openings. Each robot is equipped with a special end effector to position the wheel opening molding to the body. Four self drilling screws are then installed with a special drill and drive attachment on the end of the robot arm.

The body is then delivered to the unloading station where an automatic unloader places the body back onto the carrying truck on the main line. This robot application in the trim shop is not modeled since it represents a very small portion of the entire trim shop and its impact is negligible.

Chassis and Final

The equipment for chassis and final includes: tri-rail conveyors, overhead power and free conveyors, monorails, towveyor conveyors, power hand tools, parallel floor conveyors, camber fixtures, body bolting machine, equipment set for tire building, ALDL test head (computerized emission testing device), toe-in check system, and roll on check system. Most of the operation is done manually. There are 300 workers per shift.

The chassis line travels parallel to the car body line where the exhaust system and fuel tank and minor related parts are attached to the body. On the chassis line the complete power train, front axle, and rear axle are built and mounted on a cradle. Then a car body and a cradle join together. This marriage happens at towveyor. After the towveyor, suspension is adjusted, and then tires are attached. Afterwards, the oil, gas, and other fluids are added. After the ALDL emission check, toe in check, and roll on check, the whole assembly process is completed.

Discussion of results and analysis

Four cases of different manufacturing technologies will be discussed.

1. Assembly with manual body welding.
2. Assembly with automated body welding.
3. Assembly with automated body welding and plastic panel.
4. Assembly with hybrid between manual and automated body welding.

Before discussing each case, the sensitivity of the important variables in the assembly model and their implications will be discussed.

Variables that affect the calculations are labor rate, the number of shifts per day, the working days per year, number of hours per shift, downtime per shift, annual production volume, capital recovery rate, and years of capital recovery. Among these, the important ones are the labor rate, downtime, production volume (size of the plant), capital recovery rate, and years of capital recovery.

Labor rate varies between companies and countries. The variances between companies in a country may not be significant; however, those between countries are notable. From figure 4, it can be seen that automation becomes economical if the labor rate is above $20 at the production rate of 60 cars per hour. The current average U.S. auto industry labor cost is about $24/hr including fringe benefits. This suggests automation might be economical. However, in a country like Korea, where the average labor cost is around $3.5 per hour, automation may not be efficient at the production rate of 60 cars /hr.

The next question is at what production rate/hr automation becomes

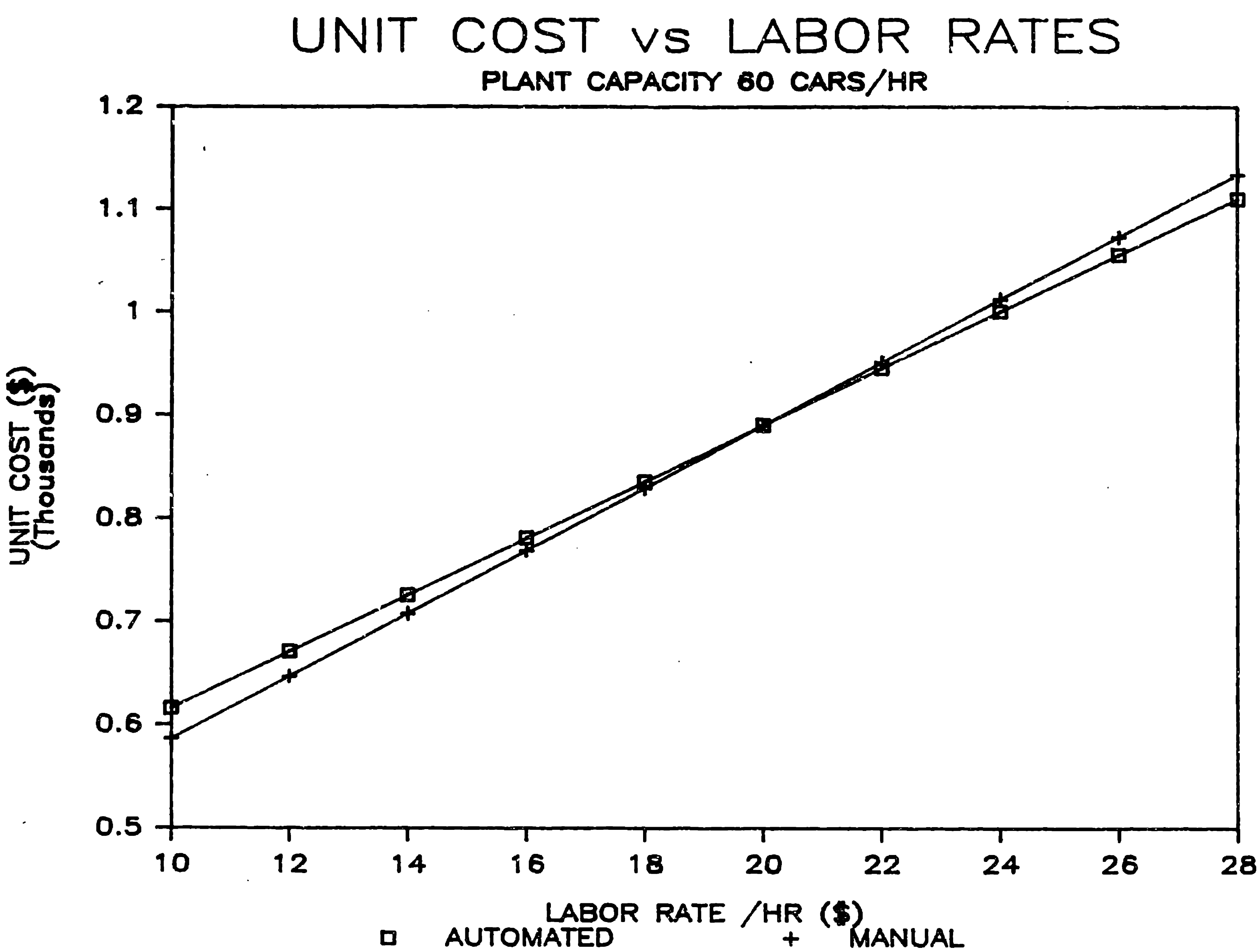
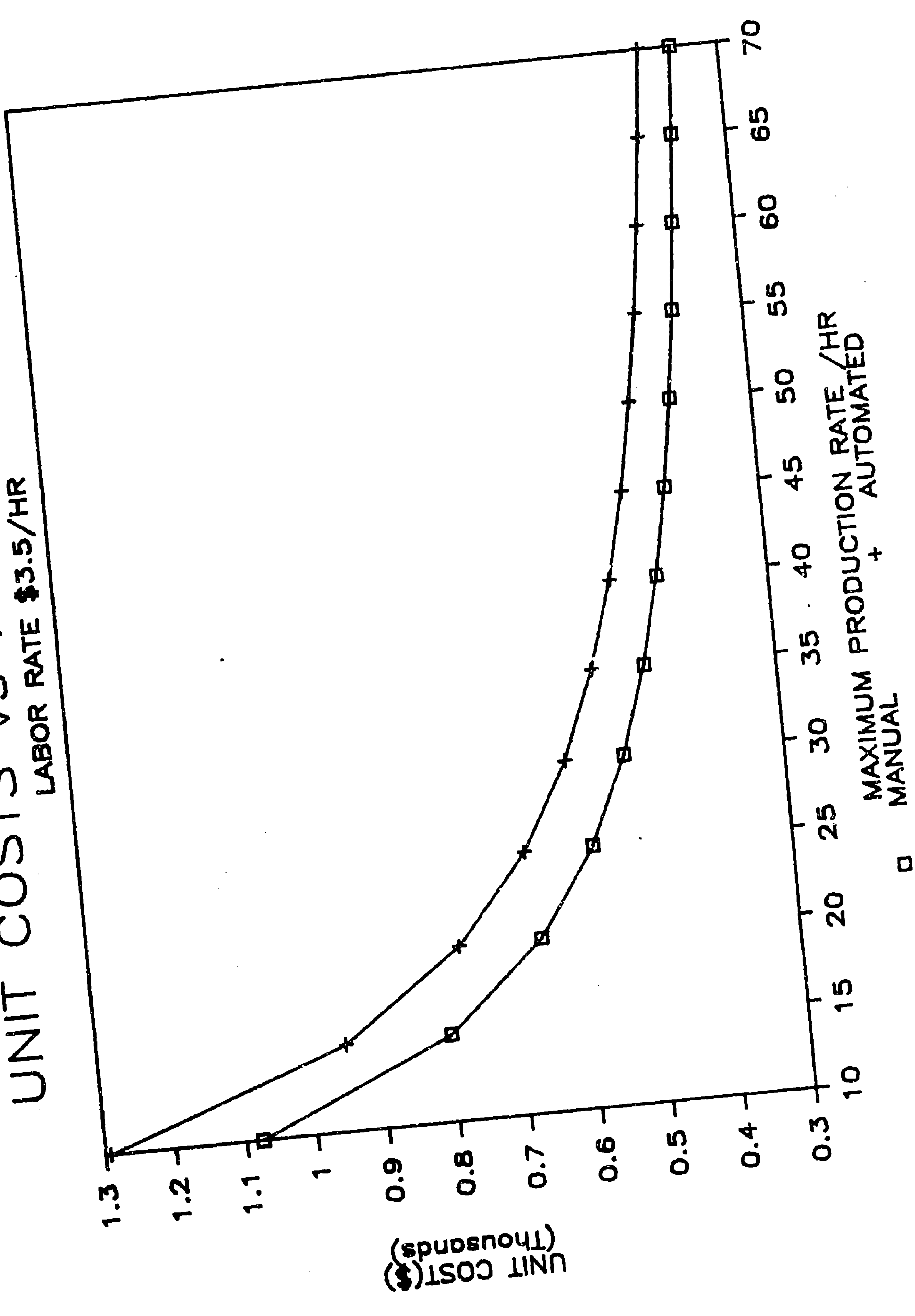

UNIT COST vs LABOR RATES
PLANT CAPACITY 60 CARS/HR
UNIT COST ($)
(Thousands)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
10
12
14
16
18
20
22
24
26
28
LABOR RATE /HR ($)
AUTOMATED
MANUAL

Figure 4

profitable in Korea? From figure 5, it can be seen that automation is not economical throughout every capacity of a plant. From figure 6 it can be seen that in the U.S., automation becomes feasible over manual operation from the production rate of 45 per hour and upwards. This conclusion is expected from figure 4. Figures 5 and 6 show that as production increases, the fixed costs for equipment also increase, while in figure 4, the fixed cost is fixed at the production rate of 60. In other words, in figures 5 and 6, unit costs for different assembly methods, as a function of plant capacity are shown, and the unit costs decrease as the plant capacity increases. The production rate of 60 per hour is considered a standard capacity for U.S. plants newly automated with robots. Figure 6 explains why the production rate of 60/hour is chosen in plants newly automated with robots.

Another important variable is downtime. Suppose a plant with the capacity for a production rate of 60 cars per hour (figure 7); it can be seen that the two significant cost factors are capital related cost and labor cost. The unit cost is higher if the plant is not operating at peak efficiency. For example, 48 minutes of downtime per shift of 8 hours causes a reduction of the production rate from 60 to 54, while the production input is for 60. The capital related cost factor is more sensitive to downtime compared to the labor cost. Especially, if a plant is operating at below 40 % efficiency (below 28 cars/hr in figure 7) the cost of capital related expenses increases exponentially. In figure 8, unit cost is expressed as a function of downtime. As the downtime increases, unit cost increases exponentially. GM has recently invested heavily in automation in a rather overnight fashion, causing



UNIT COSTS VS PLANT CAPACITY
LABOR RATE $3.5/HR
UNIT COST($)
(Thousands)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
10
15
20
25
30
35
40
45
50
55
60
65
70
MAXIMUM PRODUCTION RATE /HR
MANUAL
AUTOMATED

Figure 5

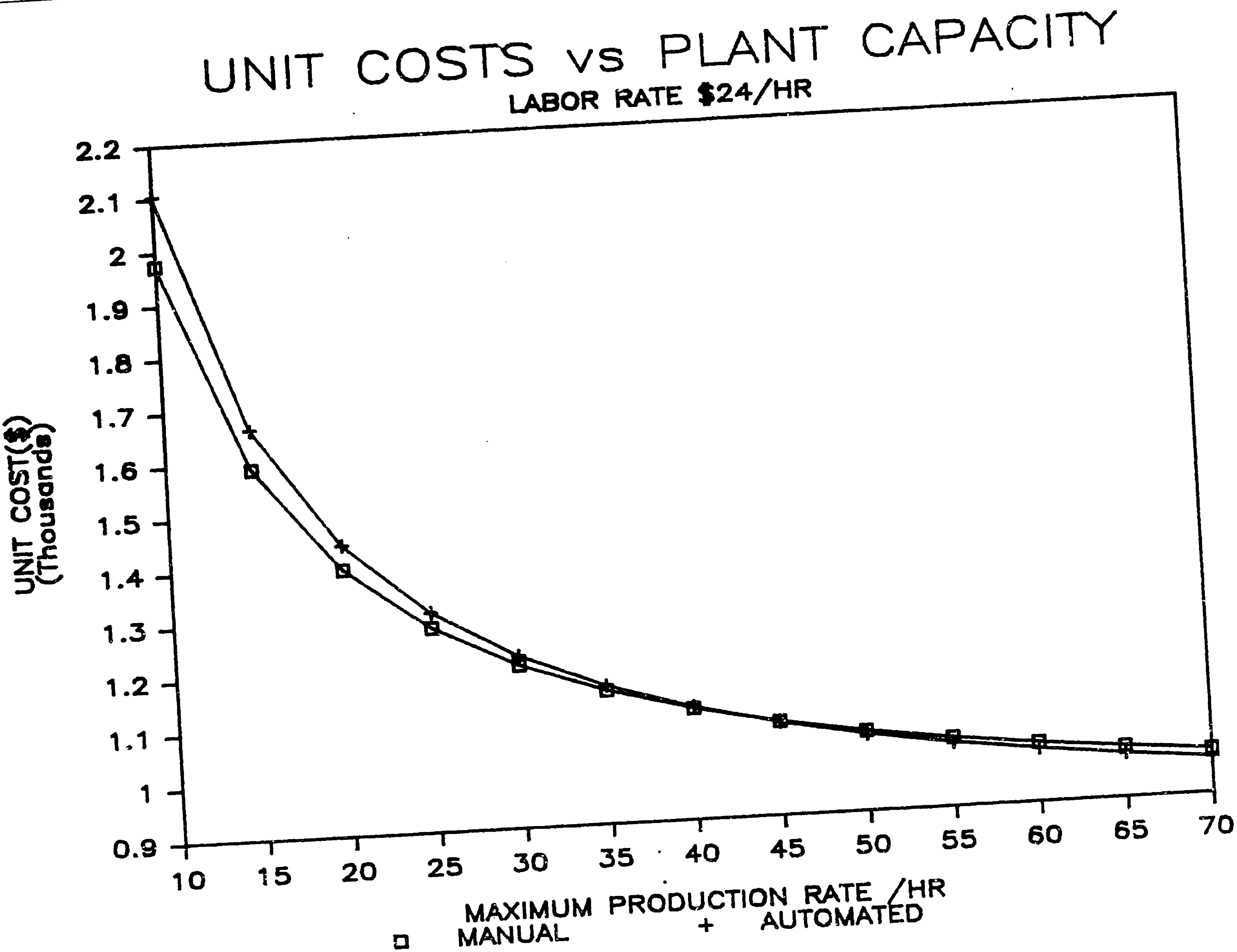

UNIT COSTS vs PLANT CAPACITY
LABOR RATE $24/HR
UNIT COST($)
(Thousands)
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
10
15
20
25
30
35
40
45
50
55
60
65
70
MAXIMUM PRODUCTION RATE /HR
MANUAL
AUTOMATED

Figure 6

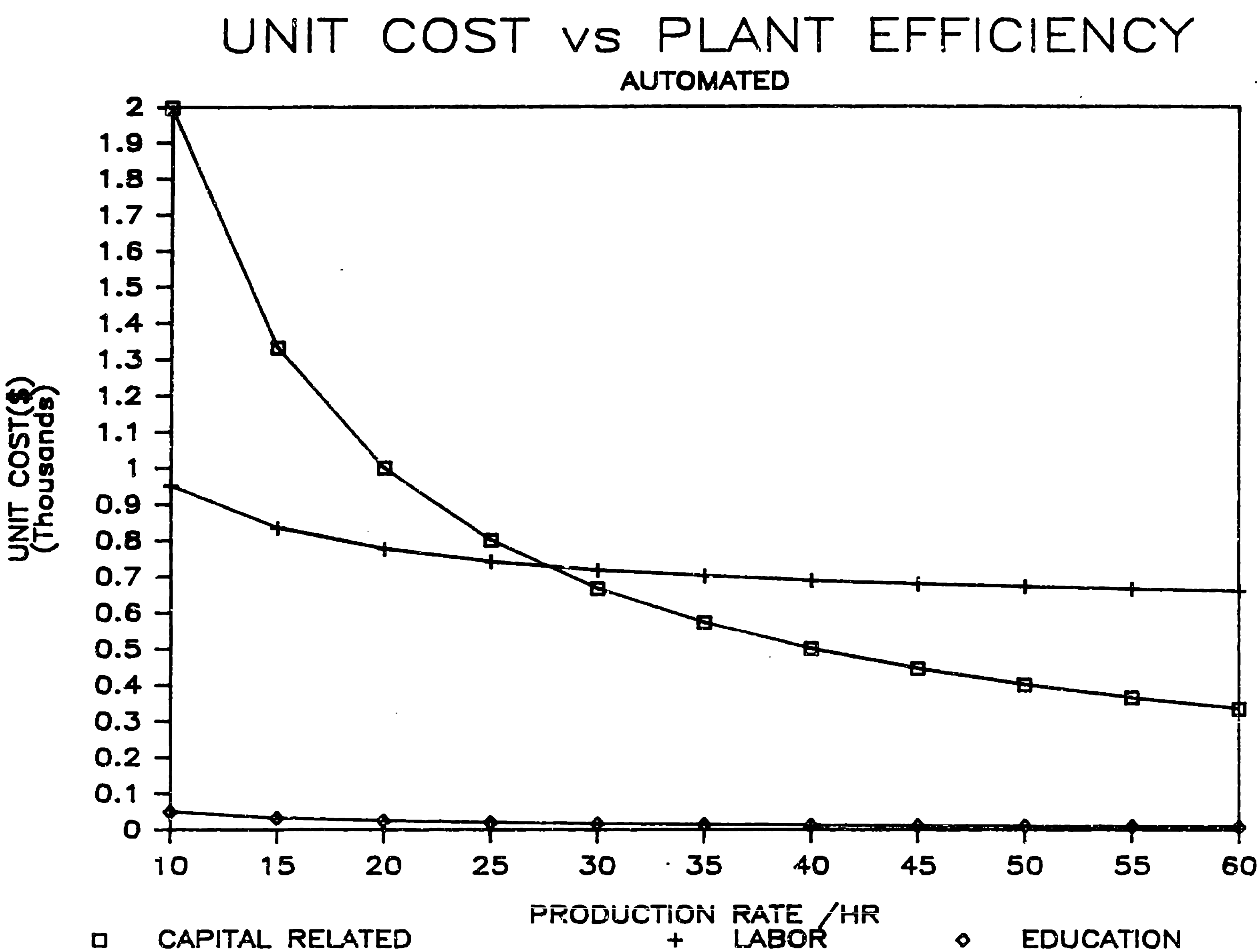

UNIT COST vs PLANT EFFICIENCY
AUTOMATED
UNIT COST($)
(Thousands)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
15
20
25
30
35
40
45
50
55
60
PRODUCTION RATE /HR
CAPITAL RELATED
LABOR
EDUCATION

Figure 7

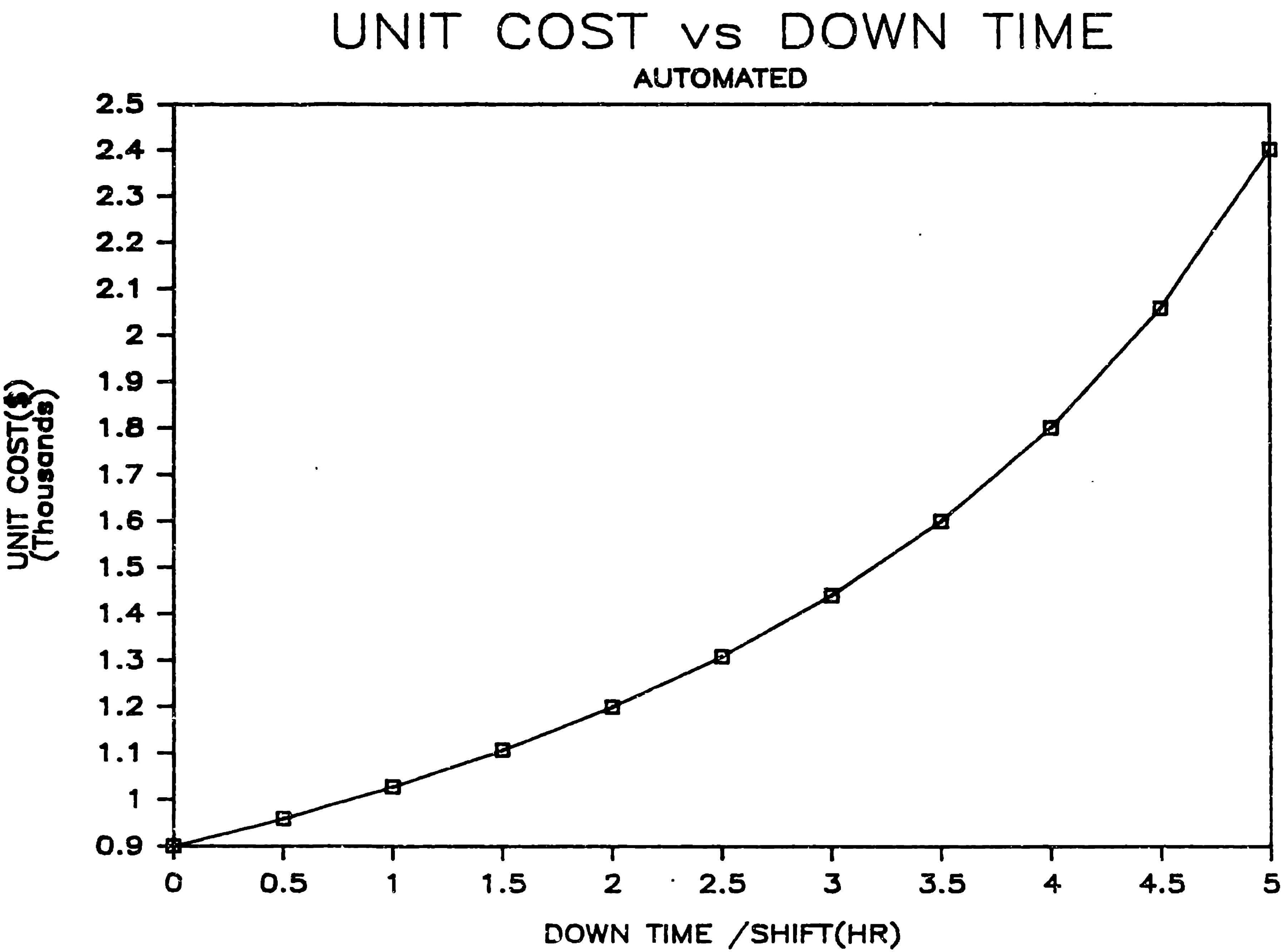

UNIT COST vs DOWN TIME
AUTOMATED
UNIT COST($)
(Thousands)
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
DOWN TIME /SHIFT(HR)

Figure 8

numerous bugs in the system, and subsequent diminished operation (Winter, 1986). It is said that GM is losing its cost competitiveness even against other U.S. auto makers. Figure 5 shows how costly it can be if an automated plant is operating with low efficiency.

In the model it is assumed that a 12% interest rate is the accepted recovery rate. At a higher interest rate, over 18%, manual operation becomes more economical than automation (figure 9). This means that the interest rate must be lower than 18% for automation to be economical at a labor rate of 24$ /hr. Nonetheless, if the wage is lowered enough, even at a very low interest rate automation may not be justified (figure 10). This implies that automation is favorable where the wage is high and the interest rate is low.

In figure 11, as the years of capital recovery increase, unit cost decreases. This means a longer model life for a car costs less. However, the average model life has generally been reduced. This suggests that the auto manufacturers' strategy has shifted from lower costs to a higher market share to satisfy diversified customer taste.

Case study

The costs of assembling a car by four different methods are estimated, and these estimates provide summaries of the model out-put (figures 12,13,14,15). Each summary describes the required investment, the number of laborers for each assembly operation, and the breakdown of unit costs for the case. After a discussion of the unit costs of

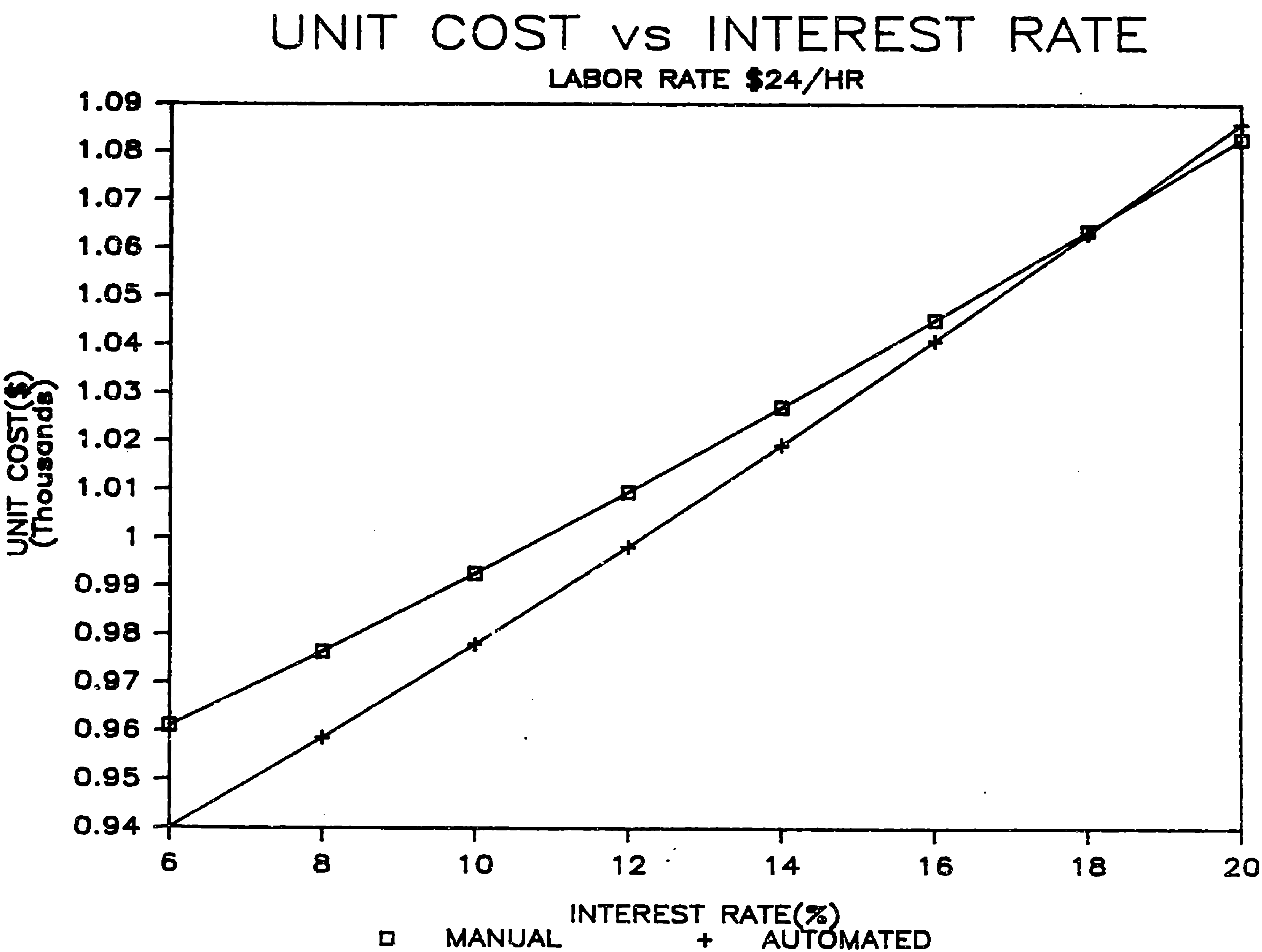

UNIT COST vs INTEREST RATE
LABOR RATE $24/HR
UNIT COST($) (Thousands)
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
6
8
10
12
14
16
18
20
INTEREST RATE(%)
MANUAL
AUTOMATED

Figure 9

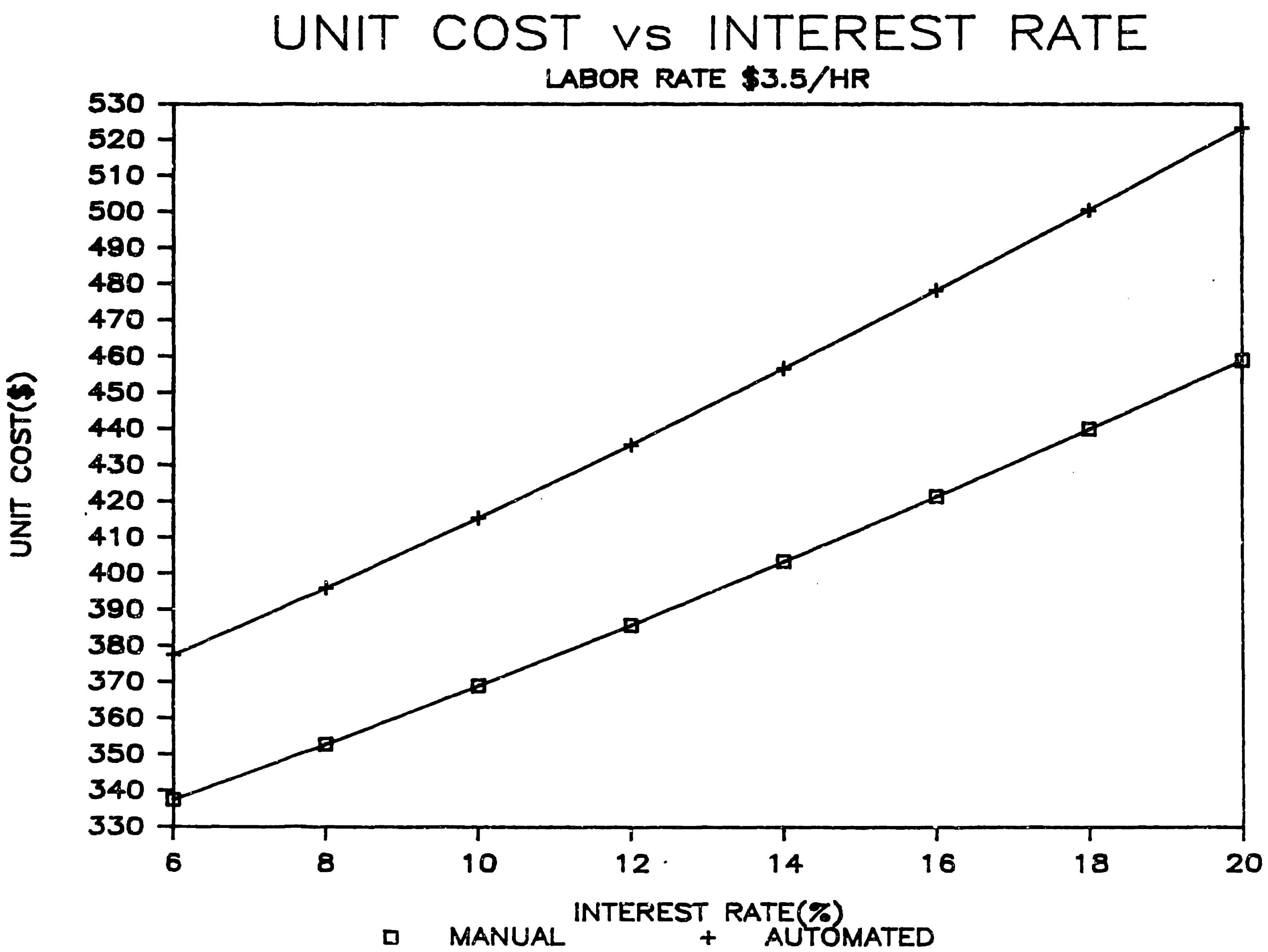

UNIT COST vs INTEREST RATE
LABOR RATE $3.5/HR
UNIT COST($)
530
520
510
500
490
480
470
460
450
440
430
420
410
400
390
380
370
360
350
340
330
6
8
10
12
14
16
18
20
INTEREST RATE(%)
MANUAL
AUTOMATED

Figure 10

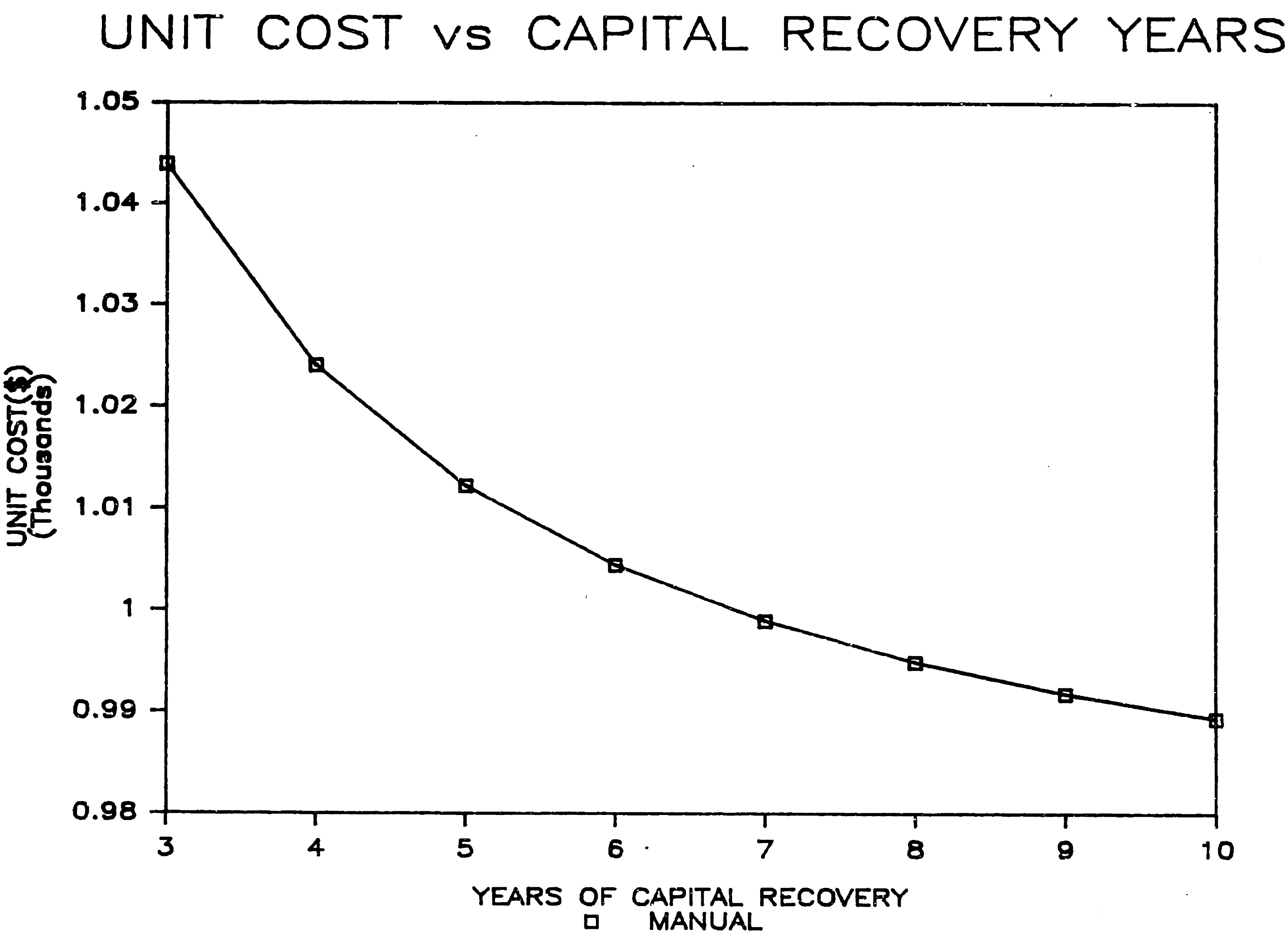

UNIT COST vs CAPITAL RECOVERY YEARS
UNIT COST($)
(Thousands)
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
3
4
5
6
7
8
9
10
YEARS OF CAPITAL RECOVERY
MANUAL

Figure 11

alternative assembly methods, the payback period and return on investment for additional investment will be discussed, while keeping the manual case as a base.

According to the results, assembly with automated body welding and plastic panel (space frame with plastic skin) is the least costly method of manufacturing, followed by automated body welding, hybrid, and manual body welding. The reason is that though this assembly method requires the highest investment outlay, the labor savings is the greatest among the alternatives. The cost differences among the alternatives basically derive from the trade-off between labor cost and capital related cost. The cost of energy is assumed to be the same, regardless of the differences in technologies. This assumption is safe, since most of the variations among the alternatives are confined to the body assembly operation. Furthermore, even if a robotized body shop consumes more energy than a manual one, the difference remains insignificant.

The variable burdens (overhead) in the summaries amount to about $311/car. This figure represents all the plant expenses other than capital related, direct labor, and some indirect labor costs, such as material handling and repair men. In the case of assembly with manual body welding, the model accounts for the unit cost of the overhead to be $368.22. This is the sum of unit costs contributed by capital related expenses, material handling, and repair workers. That represents a 97.6% burden rate (figure 16). Therefore, the typical manual assembly plant burden rate 180% minus 97%, ie, 83% represents the burden rate for the rest of the overhead and its amount is $311/car. The overhead

	Capital investment	Number of laborers
Underbody subassy	$26,377,000	17
Body assembly	$51,162,406	246
Painting	$116,800,050	269
Trimming	$7,941,760	495
Chassis & Final	$38,854,222	330
Inspection		99
Total Capital Investment	$241,135,438	
Total # of direct labor	1456	
Material handling labor	98	
Repair men	89	

Distribution of cost

		$/car
Capital related	27.79%	$282.11
Material handling	4.29%	$43.51
Repair men	3.90%	$39.60
Energy	0.30%	$3.00
Direct labor	63.73%	$647.04
	100.00%	$1,015.26

Overhead	$311.17
Burden rate	180.0%
Direct labor cost Without fringe benefits	$377.44

Figure 12

ASSEMBLY WITH MANUAL BODY WELDING

	Capital investment	Number of laborers
Underbody subassy	$26,377,000	17
Body assembly	$92,947,106	108
Painting	$116,800,050	269
Trimming	$7,941,760	495
Chassis & Final	$38,854,222	330
Worker Education	$10,000,000	
Inspection		83
Total Capital Investment	$292,920,138	
Total # of direct labor	1302	
Material handling labor	98	
Repair men	77	

Distribution of cost

		$/car
Capital related	33.26%	$333.84
Material handling	4.34%	$43.51
Repair men	3.41%	$34.22
Education	0.82%	$8.19
Energy	0.30%	$3.00
Labor	57.88%	$580.93
	100.00%	$1,003.70

Overhead	$311.17
Burden rate	217.5%
Direct labor cost without fringe benefits	$337.45

Figure 13

ASSEMLY WITH AUTOMATED BODY WELDING

	Capital investment	Number of laborers
Underbody subassy	$26,377,000	17
Body assembly	$84,381,580	20
Painting	$136,963,100	308
Trimming	$7,941,760	495
Chassis & Final	$38,854,222	330
Worker Education	$10,000,000	
Inspection		83

Total Capital Investment	$304,517,662
Total # of direct labor	1252
Material handling labor	98
Repair man	77

Distribution of cost

		$/car
Capital related	34.72%	$343.31
Material handling	4.40%	$43.51
Repair men	3.46%	$34.22
Education	0.83%	$8.19
Energy	0.30%	$3.00
Labor	56.28%	$556.49
	100.00%	$988.73

Overhead	$311.17
Burden rate	229.0%
Direct labor cost without fringe benefits	$324.62

Figure 14

ASSEMBLY WITH AUTOMATED BODY WELDING AND PLASTIC PANEL

	Capital investment	Number of laborers
Underbody subassy	$26,377,000	17
Body assembly	$61,112,606	205
Painting	$116,800,050	269
Trimming	$7,941,760	495
Chassis & Final	$38,854,222	330
Inspection		99
Total Capital Investment	$251,085,638	
Total # of direct labor	1415	
Material handling labor	98	
Repair man	89	

Distribution of cost

		$/car
Capital related	29.14%	$294.01
Material handling	4.31%	$43.51
Repair men	3.92%	$39.60
Energy	0.30%	$3.00
Labor	62.33%	$628.93
	100.00%	$1,009.05

Overhead	$311.17
Burden rate	183.2%
Direct labor cost without fringe benefits	$377.44

Figure 15

ASSEMBLY WITH HYBRID BETWEEN MANUAL AND AUTOMATED BODY WELDING

Distribution of cost

		$/car
Capital related	27.79%	$282.11
Material handling	4.29%	$43.51
Repair men	3.90%	$39.60
Energy	0.30%	$3.00
		$368.22
Direct labor	63.73%	$647.04
	100.00%	$1,015.26

Overhead (portion counted by the model)	$368.22	--- (1)
Overhead (portion not counted by the model)	$311.17	--- (2)
Direct labor cost Without fringe benefits	$377.44	--- (3)
Burden rate for (1) :	(1) / (3) =	97.6%
Burden rate for (2) :	(2) / (3) =	82.4%
Total burden rate :		180.0%

Figure 16

Example of burden rate calculation. (Assembly with manual body welding) contribution to the unit cost for the automated body assembly is $422.7. Since all the alternatives have the same assumed plant capacity of 60 cars/hr, it is reasonable to assume that the overhead not accounted for in the model is the same. The summation of $422.7, accounted for by the model and $311 not accounted for by the model but assumed, is $734/car. That represents a burden rate of 217.5% for the assembly with automated body operation (figure 17). It was once mentioned that the burden rate for the automated plant is around 210%-230%. The variable burden in the model indirectly supports the reliability of the model.

Another way to check the reliability of the model is to see how the investments are distributed among the operations. The required investment for the paint shop can be a yard stick. The paint shop requires 40% to 45% of the total investment of the whole plant, in the case of assembly with automated body welding. In the model, the paint shop represents 45% of the total investment where the body shop is automated and the space frame concept is utilized (Table 6).

Among the alternatives, the automated (robotized) plant requires spending for worker education, which includes two factors. One is the education itself and the other is the labor cost of displaced workers due to automation.

The total one year salary of displaced workers amounts to about $17 million. This figure comes from the difference between the number of laborers used on assembly with manual welding. and assembly with robotized welding. The yearly labor cost of one worker is $48,000. The multiplication of these two numbers gives $17 million

Distribution of cost

		$/car
Capital related	33.26%	$333.84
Material handling	4.34%	$43.51
Repair men	3.41%	$34.22
Education	0.82%	$8.19
Energy	0.30%	$3.00
		$422.77
Labor	57.88%	$580.93
	100.00%	$1,003.70

Overhead (portion counted by the model)	$422.77	--- (1)
Overhead (portion not counted by the model)	$311.17	--- (2)
Direct labor cost Without fringe benefits	$337.45	--- (3)
Burden rate for (1) :	(1) / (3) =	125.3%
Burden rate for (2) :	(2) / (3) =	92.2%
Total burden rate :		217.5%

Figure 17

Example of burden rate calculation. (Assembly with automated body welding)

Table 6
Distribution of investment
(Assembly with automated body welding and plastic skin)

	Capital investment	
Underbody subassy	$26,377,000	8.7%
Body assembly	$84,381,580	27.7%
Painting	$136,963,100	45.0%
Trimming	$7,941,760	2.6%
Chassis & Final	$38,854,222	12.9%
Worker Education Inspection	$10,000,000	3.3%
Total Capital Investment	$304,517,662	100.0%

($48,000*164*2shift). The average spending for worker education and training in a newly automated plant, among GM CPC plants, is about $27 million (DiPietro, 1986). Therefore, the spending for the education itself is estimated at $10 million. However, the model does not account for the cost of displaced workers. It assumes that the plant is newly built instead of being converted from an old manually operated plant.

Union contracts mandate that workers displaced due to automation cannot be laid off. Instead, they are retrained for different types of jobs for one year. Then they are offered new jobs mostly in new locations. They can be laid off if they refuse the offer.

Assembly with manual body welding requires the largest number of laborers and repair men. The number of material handling laborers is assumed to be same among all the alternatives. In automated plants, the number of repair men is assumed to be smaller. By using robots and the robogate system for body framing, the quality of body-in-white is improved by reducing variations among products, and less repair work is needed. However, automated plants may not need a smaller repair work area. The repair work system is embedded into the assembly process, and it might be risky to reduce the function of the rework area to save some capital outlay. However, reducing the number of repair workers does not jeopardize the situation. If extra repair work is necessary, hiring additional repair workers is easier than expanding the repair work area.

Using a just-in-time delivery system can reduce the number of material handling laborers. In most of the plants, parts are handled 2 or 3 times before they actually get to the stations whether a system is robotized or not. Rather, just-in-time delivery is related to pure management skill.

The hybrid between the manual and automated body operation shows the abilities of the modularized assembly model (figure 15). The unit cost calculation for different assembly configurations can be readily performed by rearranging the modularized unit operations. However, the type of rearrangement requires a thorough knowledge of the welding process.

The body framing operation is critical to achieve uniform dimensional accuracy of the body-in-white. The robogate station in the automated body assembly improves the quality of the body-in-white compared to manual body assembly. Respotting may not contribute significantly to improve quality, once the basic structure of the body is already formed. There is no difference in the quality of the welding itself, whether it is done by robots or by manual labor. The hybrid method reduces dimensional variations by obtaining critical dimensional stability with minimal capital outlay by installing the robogate station, while most of the remaining manual assembly stations are unchanged.

Even though assembly with the space frame and plastic skin is the least expensive, the difference at most is about $27. The unit cost method can be very useful in assessing the performance of alternative technologies, but if the variances of the unit costs are small, it is unlikely that the method is useful in decision-making. In any case, it is safer to have alternative methods of assessment. Therefore, the payback period and return on investment (ROI) methods are included.

Payback period and ROI analysis

Assembly with manual body operation will serve as a base case because it requires the least amount of initial capital investment. Payback period and ROI will also be used to calculate any additional investments to the base case such as assembly with manual body welding. In calculating ROI, the discounted cash flow method accommodates the time value of money (figure 18). The investment horizon for this analysis is assumed to be 10 years since the useful life of a robot is 10 years. It is assumed that the hourly wage of $24 will increase a dollar per year for the next ten years. The equivalent annual hourly wage is calculated to be $28 for the next ten years. After 5 years, major model change will necessitate retooling. It is assumed that after 10 years the salvage value is zero for all of the equipment in the body shop. The assembly with a space frame and plastic skin requires an additional investment in the painting shop. The useful life of the painting shop is assumed to be 15 years in the model, for the purpose of unit cost calculation. However, it is assumed to be 10 years when used in the ROI calculation, in order to have the same investment horizon. This method of calculation is unfavorable to the space frame case, thus it is considered conservative.

The results of the payback period and ROI for the three alternative additional investments to the manual assembly case are summarized in table 7 and 8. The results show that ROIs for the automated body assembly and the space frame with plastic skin are 4.85% and 8.1%, respectively. These are lower than the assumed capital recovery rate of

Additional Investment	\$292920138-\$241135438 + \$28995786-\$22892206 =	\$57,888,280
Annual labor saving	(1643-1477)*\$28*2*250 =	\$18,592,000
Extra maintenance	\$16095796-\$13201382 =	\$2,894,414
Extra tax	\$7725982-\$6336663 =	\$1,389,319
Net annual saving after tax (52%)	(\$1859200-\$2894414 + \$1389319)*52% =	\$7,440,299

$$\text{Payback period} = \frac{\text{Additional Investment}}{\text{Net annual saving}}$$

$$= \frac{\$57,888,280}{\$7,440,299} = 7.78 \text{ years}$$

$$\text{Payback period} = \quad 7.78 = \sum_{1}^{10} \frac{1}{(1 + \text{ROI})^{10}}$$

$$\text{ROI} \quad = \quad 4.85\%$$

Figure 18 Example calculation for Payback period and Return on investment (Alternative 2) (Refer to table 7 for data)

Table 7 Cost data for Payback period and Return on investment

Alternatives	1	2	3	4
Investment	$241,135,438	$292,920,138	$304,517,662	$251,085,638
Retooling	$22,892,206	$28,995,786	$28,739,760	$22,882,406
Equivalent wage	$28	$28	$28	$28
Maintenance	$13,201,382	$16,095,796	$16,662,871	$13,698,402
Tax and Insurance	$6,336,663	$7,725,982	$7,998,178	$6,575,233
Number of laborers	1643	1477	1427	1602

Table 8 Summary of Payback period and ROI

Alternative	2	3	4
Payback period	7.78	6.69	4.38
ROI	4.85%	8.1%	18.5%

12%. However, the hybrid shows a ROI of 18.5%. The payback periods are 7.78 years for the manual, 6.69 years for the automated body assembly, and 4.39 years for the hybrid. The results, when considered from an economic standpoint, are not favorable to automation. The hybrid might be a viable option.

Conclusions and Future Work

The total cost of assembling an automobile can be estimated by systematically evaluating the input factors that contribute to the cost. The model assumes the labor and capital related costs are significant and sensitive to the final cost. An estimation of overhead cost can be useful to validate the reliability of the model. The cost of equipment is a capital related cost that requires an extensive industry survey and a huge data base to assess, because of the complexity of the automobile assembly plant. Regression analysis, which would correlate cost and part size or weight, is not attempted. The spread sheet methodology best manages an extensive data base and a systematic approach to unit cost calculation.

There are several ways to assemble an automobile. Most of the difference is in the degree of automation of the body welding process. Even if a plant is automated with robots, and the underbody combines hard automation and robotization, the rest of the assembly process is still labor intensive. The trim operation is the most labor intensive, followed by the chassis, and painting. Painting requires the largest capital investment at 40-50% of the total investment, depending on the degree of automation in the body shop.

Using a digital computer for the cost estimation, a sensitivity analysis on the parameters affecting costs can be readily performed. The effectiveness of automation is related to the size of a plant. A plant must produce at least 45 cars per hour for automation to be cost competitive with manual operation. Final unit cost is very sensitive to direct labor cost. The hourly wage, plus fringe benefits must be over $20 for automation to be economical. The interest rate is an important determinant of capital recovery, since a huge amount of capital is invested. The interest rate must be lower than 18% for automation to be economical, at the present U.S. labor cost of $24/hour. The final cost is also sensitive to the down time of a plant. Capital related cost is much more sensitive to the down time than labor cost if a plant is operating with low up time, below 50%.

Among the four alternatives in the case study, assembly using an automated body operation with plastic panel is the least costly method, followed by assembly with automated body operation, the hybrid between the manual and automated, and the manual. The difference between the least and most expensive method is $27. Payback period and ROI analysis is performed to enhance the performance testing for the alternative technologies, and to support the decision-making process.

Even though the unit costs for the two automated cases are higher than for the manual case, the perspective of ROI shows the two automated cases are not economically favorable. However, there are other unquantifiable benefits of automation. Nontheless, it is not clear whether those unquantifiable benefits overwhelm the disadvantages of the financial perspective. Recent trends show that U.S. auto manufacturers are cutting down on future investment projects in automation.

However, the assembly with automated body welding and plastic panel shows some promise. Its ROI is an encouraging 8.1%, and there is a great possibility of using a simplified welding process through parts consolidation as the quality of the engineering plastic materials improves. The hybrid method may be a useful alternative to improve product quality, especially in countries where the labor cost is low.

Future Work

Future work should be directed three ways. First, the metal fabrication plant which links the assembly plant with the stamping plant, must be modeled for a more complete and accurate estimation of the assembly cost. Secondly, an estimation of the effects of parts consolidation with composite materials or sheet metal on the final assembly cost must be performed. Thirdly, a study to compare the cost of in-house manufacturing vs purchasing from the outside vendor is recommended.

At present, most the metal fabrication work is done at the stamping plant through hard automation, and the fabricated parts are then supplied to several assembly plants. Those parts are standardized, and can be used for several different types of models. This means that an economy of scale is realized for sheet metal oriented cars. However, in the case of a plastic panel and space frame oriented car like the Pontiac Fiero, most of the fabrication work is done at the assembly plant. The fabrication work in the assembly plant is characteristically manually oriented, as it reflects the low production volume. Therefore, the two different natures of the fabrication work must be studied.

This model is specially useful in analysis of the effect of materials substitution or parts consolidation on costs. For example, if the floor pan in the underbody structure is made out of composite materials, then one ignores the modularized floor pan subassembly station in the model. However, for a more complete analysis, a comparison of the total cost of molding vs stamping and metal fabrication must be performed. A study of the interface between plastic and sheet metal for attachment is further recommended.

Appendix A - Example Cost Model Frame Work

1. Underbody Subas] BODY IN
2. Main Assembly] WHITE
3. Painting
4. Trimming
5. Chassis & Final

INPUT FACTORS and FACTOR PRICES

Number of shift	2	
Working Days/year	250	
Hours/shift	8.00	
Down Time/shift	0.80	
Working Hours/shift	7.20	
Annual production volume	216000	
Production rate /hr	60	(Plant cacity)
Real Production rate /hr	54	

=====> LABOR

	UNIT	$/UNIT
	man-hour	$24.00

=====> ENERGY	UNIT	$/UNIT
Electricity price	kwh	$0.0525

=====> CAPITAL RELATED

Cost of capital		12.00%
Tax	% of equip. c	1.20%
Insurance	% of equip. c	1.20%
Maintenance	% of equip. c	5.00%

Years of capital recovery		
Nonreusable equipments in Body shop		5
Robot and reusable equipments in bod		10
Painting		15
Trim		15
Chassis & Final		15
Conveyor System		10
Installation Cost	% of equip. c	30.00%

Underbody Subassembly (hard automation)

1. Motor Compartment.
2. Floor Pan
3. Rear compartment
4. Press welding station

1.Motor Compartment

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Auto welder (+trans)	15	$350,000	$5,250,000
Weld controller	80	$7,000	$560,000
Over head pick up & place conveyor	1	$225,000	$225,000
Roller conveyor	1	$75,000	$75,000
Automatic part feeder	1	$50,000	$50,000
Welding gun & fixture set	5	$30,000	$150,000
		Total	$8,203,000

=====> OTHERS

			$/subassembly
Cost of capital		12.00%	$10.54
Tax	% of equip. c	1.20%	$0.46
Insurance	% of equip. c	1.20%	$0.46
Maintenance	% of equip. c	5.00%	$1.90
Total			$13.35

=====> LABOR

	UNIT	$/UNIT	$/Subassembly
	man-hour	$24.00	$4.94
Number of Laborers	11		
Number of shift	2		
Working Days/year	250		
Hours/shift	8		
Annual production volume	216000		

=====> ENERGY

	UNIT	$/UNIT	$/Subassembly
	kwh	$0.0525	

=====> Current number of jobs per hour 60

TOTAL COST OF MOTOR COMPARTMENT WELDING			$/Subassembly
			$18.28
Distribution of cost	Capital	72.99%	
	Labor	27.01%	

2.Floor Pan

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Welding robot, Programmable controller, Fixture, and transfer system	13	$100,000	$5,200,000
Press welder	1	$1,000,000	$1,000,000
		Total	$8,060,000

=====> OTHERS

			$/subassembly
Cost of capital		12.00%	$10.35
Tax	% of equip. c	1.20%	$0.45
Insurance	% of equip. c	1.20%	$0.45
Maintenance	% of equip. c	5.00%	$1.87
	Total		$13.11

=====> LABOR

	UNIT	$/UNIT	$/Subassembly
	man-hour	$24.00	$0.49
Number of Laborers :	1		

TOTAL COST OF FLOOR PAN WELDING			$/Subassembly
			$13.61
Distribution of cost	Capital	96.37%	
	Labor	3.63%	
		100.00%	

3.Rear Compartment

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Auto welder	4	$350,000	$1,400,000
Weld controller	30	$7,000	$210,000
Roller conveyor	1	$75,000	$75,000
Overhead pick-up & place hoist	2	$225,000	$450,000
		TOTAL	$2,775,500

=====> OTHERS

				$/subassembly
Cost of capital			12.00%	$3.56
Tax	% of	equip. c	1.20%	$0.15
Insurance	% of	equip. c	1.20%	$0.15
Maintenance	% of	equip. c	5.00%	$0.64
		Total		$4.52

=====> LABOR

UNIT	$/UNIT	$/Subassembly
man-hour	$24.00	$1.98

Number of Laborers : 4

TOTAL COST OF REAR COMPARTMENT WELDING — $/Subassembly: $6.49

Distribution of cost		
	Capital	69.57%
	Labor	30.43%
		100.00%

4.PRESS WELDING (R/C + F/P + M/P)

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Press Welder	2	$1,250,000	$2,500,000
Table top Welder	2	$500,000	$1,000,000
Inspection Machine	1	$500,000	$500,000
Conveyor system	1	$1,000,000	$1,000,000
Overhead hoist	2	$300,000	$600,000
Load,unload,holding fixture	9	$5,000	$45,000
		TOTAL	$7,338,500

=====> OTHERS

			$/subassembly
Cost of capital		12.00%	$9.42
Tax	% of equip. c	1.20%	$0.41
Insurance	% of equip. c	1.20%	$0.41
Maintenance	% of equip. c	5.00%	$1.70
	TOTAL		$11.94

=====> LABOR

Number of laborers 0

TOTAL COST OF PRESS WELDING — $/subassembly: $11.94

Distribution of cost		
	Capital	100.00%
	Labor	0.00%
		100.00%

TOTAL COST OF UNDERBODY WELDING

TOTAL COST OF UNDERBODY WELDING — $/subassembly: $50.32

Distribution of cost			
	Capital	85.28%	$42.91
	Labor	14.72%	$7.41
		100.00%	$50.32

Capital investment $26,377,000
# of Laborer 17

Body Assembly (conventional plant)

1. Robot side frame Station
2. Off line subassemblies
3. Underbody pick up station
4. Body framing Station
5. Manual Body respot
6. Metal finishing Station

1.Robot Side Frame Assembly

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Welding Robot	13	$160,000	$2,080,000
Auto welder with part feeder	4	$300,000	$1,200,000
Fixture for load,hold,unload	6	$25,000	$150,000
Robot welding fixture	4	$100,000	$400,000
Side frame main conveyor	2	$750,000	$1,500,000
	TOTAL		$3,289,000
		Reusable	$3,640,000

=====> OTHERS

			$/subassembly
Cost of capital for reusable		12.00%	$2.98
Cost of capital		12.00%	$4.22
Tax	% of equip.	1.20%	$0.38
Insurance	% of equip.	1.20%	$0.38
Maintenance	% of equip.	6.00%	$1.92
Total			$9.90

=====> LABOR

	UNIT	$/UNIT	$/Subassembly
	man-hr	$24.00	$2.47
Number of Laborers :	6		

TOTAL COST OF ROBOTIZED SIDE FRAME SUBASSEMBLY	$/Subassembly
	$12.37

Distribution of cost		
	Capital	80.04%
	Labor	19.96%
		100.00%

2. Off line subassemblies

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Wheelhousing			
Hand welding gun (trans & controller included)	11	$20,000	$220,000
Auto welder	2	$350,000	$700,000
Weld controllers	6	$7,000	$42,000
Welding fixture	8	$20,000	$160,000
Steering column supt			
Auto Welder	1	$350,000	$350,000
Weld Controller	2	$7,000	$14,000
Automated Stud welding system	2	$60,000	$120,000
Mig Welding system	1	$5,000	$5,000
Shelf			
Hand welding gun	9	$20,000	$180,000
Simple welding fixture	4	$5,000	$20,000
Welding fixture	4	$20,000	$80.000
Roof bow			
Welding robot	1	$160,000	$160,000
Welding fixture	3	$20,000	$60,000
Hand welding gun	3	$20,000	$60,000
	Total		$2,614,300
		Reusable	$160,000

=====> OTHERS

			$/subassembly
Cost of capital for reusable		12.00%	$0.13
Cost of capital		12.00%	$3.36
Tax	% of equip.	1.20%	$0.15
Insurance	% of equip.	1.20%	$0.15
Maintenance	% of equip.	5.00%	$0.64
	Total		$4.44

=====> LABOR

UNIT	$/UNIT	$/Subassembly
man-hr	$24.00	$8.89

Number of Laborers : 20

Total cost of off line subassemblies

$/Subassembly
$13.33

Distribution of cost

Distribution of cost	Capital	33.31%
	Labor	66.69%
		100.00%

3. Underbody pick up welding station

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Hand welding gun	29	$20,000	$580,000
Body carrying truck	13	$10,000	$130,000
Welding fixture	5	$5,000	$25,000
	Total		$955,500

=====> OTHERS

			$/subassembly
Cost of capital		12.00%	$1.23
Tax	% of equip.	1.20%	$0.05
Insurance	% of equip.	1.20%	$0.05
Maintenance	% of equip.	5.00%	$0.22
	Total		$1.55

=====> LABOR

	UNIT	$/UNIT	$/Subassembly
	man-hr	$24.00	$4.94
Number of Laborers :	11		

Total cost of underbody pick up

	$/Subassembly
	$6.49

Distribution of cost		
	Capital	23.94%
	Labor	76.06%
		100.00%

4. Body framing Station

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Hand welding gun	129	$20,000	$2,580,000
Body carrying truck	18	$10,000	$180,000
Gate fixture	78	$42,000	$3,276,000
Welding jigs	10	$20,000	$200,000
		Total	$8,106,800

=====> OTHERS

			$/subassembly
Cost of capital		12.00%	$10.41
Tax	% of equip.	1.20%	$0.45
Insurance	% of equip.	1.20%	$0.45
Maintenance	% of equip.	5.00%	$1.88
	Total		$13.19

=====> LABOR

UNIT	$/UNIT	$/Subassembly
man-hr	$24.00	$19.56

Number of Laborers : 44

TOTAL COST OF BODY FRAMING STATION

$/Subassembly
$32.74

Distribution of cost

Capital	40.28%
Labor	59.72%
	100.00%

5. Manual Body respot

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Hand Welding Gun system	144	$20,000	$2,880,000
Body carrying Truck	36	$10,000	$360,000
12 Gun Gantry Welder	1	$400,000	$400,000
Welding Jigs	3	$15,000	$45,000
Mig welding gun	8	$3,500	$28,000
Off line fixture for steering column support welding	2	$20,000	$40,000
Floor conveyor(unit=ft)	1,244	$400	$497,600
Production Line (lights,tool rail,etc)	1,244	$2,000	$2,488,000
	Total		$4,878,900
		Reusable	$3,134,880

=====> OTHERS

			$/subassembly
Cost of capital for reusable		12.00%	$2.57
Cost of capital		12.00%	$6.27
Tax	% of equip.	1.20%	$0.45
Insurance	% of equip.	1.20%	$0.45
Maintenance	% of equip.	5.00%	$1.86
	Total		$11.58

=====> LABOR

	UNIT	$/UNIT	$/subassembly
	man-hr	$24.00	$31.78
Number of Laborers :	72		

Total Cost of Manual Body respot & Roof welding	$/assembly
	$43.36

Distribution of cost		
	Capital	26.71%
	Labor	73.29%
		100.00%

6. Metal Finishing

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Trunk drill fixture	3	$15,000	$45,000
Door inspection fixture	7	$20,000	$140,000
Fender drill fixture	2	$75,000	$150,000
Hood drill fixture	1	$40,000	$40,000
Overhead jigs	14	$5,000	$70,000
Stud welding gun	49	$10,000	$488,889
Stud welding fixture	5	$20,000	$100,000
Mig welding gun	23	$3,500	$80,500
Spot welding gun	4	$20,000	$80,000
Body carrying Truck	115	$10,000	$1,150,000
Jervis B.Webb lift system	1	$250,000	$250,000
Over and under conveyor	28	$3,000	$84,000
Silicon bronze booth	1	$150,000	$150,000
Washing booth	1	$150,000	$150,000
Floor conveyor(unit=ft)	2,056	$400	$822,400
Production Line	2,056	$2,000	$4,112,000
	Total		$3,047,706
		Reusable	$6,005,320

=====> OTHERS

			$/subassembly
Cost of capital for reusable		12.00%	$4.92
Cost of capital		12.00%	$3.91
Tax	% of equip.	1.20%	$0.50
Insurance	% of equip.	1.20%	$0.50
Maintenance	% of equip.	5.00%	$2.10
	Total		$11.94

=====> LABOR

	UNIT	$/UNIT	$/Subassembly
	man-hr	$24.00	$41.56
Number of Laborers :	94		

Total Cost of Metal Finishing			$/assembly
			$53.49
Distribution of cost	Capital	22.31%	
	Labor	77.69%	
		100.00%	

Overhead Conveyor system for body welding

Overhead P/F conveyor(unit=ft)	9,500	$1,500	$14,250,000
Inverted P/F conveyor(unit=ft)	0	$1,600	$0
Mono Rail(unit=ft)	4,500	$240	$1,080,000
	Total		$15,330,000

			$/subassembly
Cost of capital		12.00%	$12.56
Tax	% of equip.	1.20%	$0.85
Insurance	% of equip.	1.20%	$0.85
Maintenance	% of equip.	5.00%	$3.55
	Total		$17.81

TOTAL COST OF MANUAL BODY ASSY

			$/assembly
Distribution of cost	Capital	39.21%	$70.41
	Labor	60.79%	$109.19
		100.00%	$179.60

Nonreusable equipment cost	$22,892,206
Reusable equipment cost	$28,270,200
Number of laborers in body assy	246

TOTAL COST OF BODY IN WHITE ASSEMBLY

			$/assembly
Distribution of cost	Capital	49.29%	$113.33
	Labor	50.71%	$116.59
		100.00%	$229.92

Automated body shop

1. Side Frame Assembly
2. Off Line assembly
3. Underbody pick up welding
4. Toy tab station
5. Robogate body framing station
6. Robot respot station
7. Metal finishing station

Underbody Assembly

TOTAL COST OF UNDERBODY WELDING			$/subassembly
			$50.32
Distribution of cost	Capital	85.28%	$42.91
	Labor	14.72%	$7.41
		100.00%	$50.32

1. Side Frame Assembly

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Electric Welding Robot	27	$160,000	$4,320,000
Side frame main conveyor	4	$1,000,000	$4,000,000
Auto welder with part feeder	4	$300,000	$1,200,000
Fixture for load,hold,unload	12	$30,000	$360,000
Tool tray	4	$150,000	$600,000
Laser Vision Inspection System	1	$500,000	$500,000
	TOTAL		$5,564,000
		Reusable	$8,710,000

=====> OTHERS

			$/subassembly
Cost of capital for reusable		12.00%	$7.14
Cost of capital		12.00%	$7.15
Tax	% of equip.	1.20%	$0.79
Insurance	% of equip.	1.20%	$0.79
Maintenance	% of equip.	6.00%	$3.97
Total			$19.83

=====> LABOR

	UNIT	$/UNIT	$/Subassembly
	man-hr	$24.00	$2.93
Number of Laborers :	7		

TOTAL COST OF ROBOTIZED SIDE FRAME SUBASSEMBLY			$/Subassembly
			$22.77
Distribution of cost	Capital	87.12%	
	Labor	12.88%	
		100.00%	

2. Off line subassy Assembly

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Wheelhousing			
Welding robot	4	$160,000	$640,000
Indexing turn table and Welding Fixture	2	$90,000	$180,000
Steering column supt			
Auto Welder	1	$350,000	$350,000
Weld Controller	2	$7,000	$14,000
Automated Stud welding system	2	$60,000	$120,000
Mig Welding system	1	$5,000	$5,000
Shelf			
Welding robot	2	$160,000	$320,000
Indexing turn table and Welding fixture	2	$90,000	$180,000
Roof bow			
Welding Robot	1	$160,000	$160,000
Auto welder	1	$250,000	$250,000
Roof			
Bonding system	1	$300,000	$300,000
Auto welder	1	$350,000	$350,000
Material handling robot with conveyor system	1	$200,000	$200,000
Mono rail conveyor(unit=ft)	478	$200	$95,600
	Total		$2,397,980
		Reusable	$1,716,000

=====> OTHERS

			$/subassembly
Cost of capital for reusable		12.00%	$1.41
Cost of capital		12.00%	$3.08
Tax	% of equip.	1.20%	$0.23
Insurance	% of equip.	1.20%	$0.23
Maintenance	% of equip.	5.00%	$0.95
	Total		$5.90

=====> LABOR

UNIT	$/UNIT	$/Subassembly
man-hou	$24.00	$4.94

Number of Laborers : 11

Total cost of Off line subassy assembly

$/Subassembly
$10.83

Distribution of cost	Capital	54.42%
	Labor	45.58%
		100.00%

3. underbody pick up welding

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Welding robot,	16	$100,000	
Welding fixture,			
Programmable controller, and transfer			$6,400,000
Back up robot	16	$160,000	$2,560,000
	Total		$7,488,000
		Reusable	$4,160,000

=====> OTHERS

			$/subassembly
Cost of capital for reusable		12.00%	$3.41
Cost of capital		12.00%	$9.62
Tax	% of equip.	1.20%	$0.65
Insurance	% of equip.	1.20%	$0.65
Maintenance	% of equip.	5.00%	$2.70
	Total		$17.02

=====> LABOR

UNIT	$/UNIT	$/Subassembly
man-hr	$24.00	$0.00

Number of Laborers : 0

Total cost of underbody pick up welding

$/Subassembly
$17.02

Distribution of cost

Capital	100.00%
Labor	0.00%
	100.00%

4. Toy tab station

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Material handling robot	4	$100,000	
Programmable controller, and transfer			$800,000
	Total		$440,000
		Reusable	$600,000

=====> OTHERS

				$/subassembly
Cost of capital for reusable			12.00%	$0.49
Cost of capital			12.00%	$0.57
Tax	% of	equip.	1.20%	$0.06
Insurance	% of	equip.	1.20%	$0.06
Maintenance	% of	equip.	5.00%	$0.24
		Total		$1.41

=====> LABOR

	UNIT	$/UNIT	$/Subassembly
	man-hou	$24.00	$0.99
Number of Laborers :	2		

Total cost of Toytab station

$/Subassembly
$2.40

Distribution of cost		
	Capital	58.86%
	Labor	41.14%
		100.00%

5. Robogate Station

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Gate fixture shuttle system	1	$6,000,000	$6,000,000
Electric welding robot	9	$160,000	$1,440,000
	Total		$5,382,000
		Reusable	$4,290,000

=====> OTHERS

				$/subassembly
Cost of capital for reusable			12.00%	$3.52
Cost of capital			12.00%	$6.91
Tax	% of	equip.	1.20%	$0.54
Insurance	% of	equip.	1.20%	$0.54
Maintenance	% of	equip.	5.00%	$2.24
		Total		$13.74

=====> LABOR

UNIT	$/UNIT	$/Subassembly
man-hr	$24.00	$0.00

Number of Laborers : 0

Total cost of Robogate system

$/Subassembly
$13.74

Distribution of cost

Capital	100.00%
Labor	0.00%
	100.00%

6. Robot respot line

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Electric welding robot, Programmable controller, Transfer system,and fixtures	56	$100,000	$16,800,000
Piercing gantry robot Programmable controller, Transfer system,and fixtures	4	$120,000	$1,680,000
Back up robot	11	$160,000	$1,792,000
Digital Video Inspection system	1	$1,500,000	$1,500,000
	Total		$5,163,600
		Reusable	$23,140,000

=====> OTHERS

			$/subassembly
Cost of capital for reusable		12.00%	$18.96
Cost of capital		12.00%	$6.63
Tax	% of equip.	1.20%	$1.57
Insurance	% of equip.	1.20%	$1.57
Maintenance	% of equip.	5.00%	$6.55
	Total		$35.29

=====> LABOR

UNIT	$/UNIT	$/Subassembly
man-hour	$24.00	$0.00

Number of Laborers : 0

Total cost of Robot Respot line

$/Subassembly
$35.29

Distribution of cost

Capital	100.00%
Labor	0.00%
	100.00%

7. Metal Finishing

Same as conventional Metal finishing,
Except some manual drill fixtures

	Total		$2,560,206
		Reusable	$6,005,320

=====> OTHERS

			$/subassembly
Cost of capital for reusable		12.00%	$4.92
Cost of capital		12.00%	$3.29
Tax	% of equip.	1.20%	$0.48
Insurance	% of equip.	1.20%	$0.48
Maintenance	% of equip.	5.00%	$1.98
	Total		$11.14

=====> LABOR

UNIT	$/UNIT	$/Subassembly
man-hou	$24.00	$41.56

Number of Laborers : 88

Total Cost of Metal Finishing

$/assembly
$59.37

Distribution of cost	Capital	33.30%
	Labor	77.69%
		100.00%

Overhead Conveyor system for the body welding

Overhead P/F conveyor(unit=ft)	9,500	$1,500	$14,250,000
Inverted P/F conveyor(unit=ft)	0	$1,600	$0
Mono Rail(unit=ft)	4,500	$240	$1,080,000
	Total		$15,330,000

=====> OTHERS

			$/subassembly
Cost of capital		12.00%	$12.56
Tax	% of equip.	1.20%	$0.85
Insurance	% of equip.	1.20%	$0.85
Maintenance	% of equip.	5.00%	$3.55
	Total		$17.81

TOTAL COST OF AUTOMATED BODY ASSY

			$/assembly
Distribution of cost	Capital	70.78%	$122.14
	Labor	29.22%	$50.41
		100.00%	$172.56

Nonreusable equipment cost $28,995,786
Reusable equipment cost $62,871,320

Number of laborers in body assy 108

Hybrid system

Nonreusable equipment cost $22,882,406
Reusable equipment cost $38,230,200

TOTAL COST OF BODY IN WHITE ASSEMBLY(automated bodyshop)

			$/assembly
Distribution of cost	Capital	74.06%	$165.06
	Labor	25.94%	$57.82
		100.00%	$222.88

PAINTING(sheet metal body)

1. Oleum deck
2. High pressure washer
3. Phosphate
4. ELPO Tank
5. ELPO wet sand
6. ELPO Oven
7. Cooling tunnel
8. Sealer deck
9. Prime Booth
10. Prime Oven
11. Blackout Booth
12. Electric Oven
13. Wet sand deck
14. Wet sand Oven
15. First color booth
16. First color oven
17. Second color booth
18. Second color oven
19. Repair & tutone booth
20. Repair & tutone color oven

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Oleum deck(unit=ft)	78	$5,000	$390,000
High pressure washer	1	$400,000	$400,000
Phosphate System(unit=ft)	389	$10,000	$3,890,000
ELPO tank system	1	$12,000,000	$12,000,000
ELPO wet sand deck(unit=ft)	222	$3,000	$666,000
ELPO Oven (unit=ft)	433	$7,500	$3,247,500
Cooling tunnel (unit=ft)	67	$6,500	$435,500
Body cooling Enclosure (dual line)	422	$9,000	$3,798,000
Sealer deck(unit=ft)	522	$350	$182,700
Prime Booth (unit=ft)	120	$32,000	$3,840,000
Automated roof spray	2	$300,000	$600,000
Stationary Air-Electrostatic station	2	$200,000	$400,000
Manual spray	6	$10,000	$60,000
Sealer Oven (unit=ft) (dual line)	501	$9,000	$4,509,000
Door head Blackout Booth (unit = ft)	50	$12,000	$600,000
Manual spray	2	$10,000	$20,000
Electric Oven (unit=ft)	244	$7,500	$1,830,000
Wet sand deck(unit=ft)	222	$3,000	$666,000
Wet sand Oven(unit=ft) (dual line)	301	$9,000	$2,709,000
First Color Booth (unit=ft)	215	$33,000	$7,095,000
Tack Off line(unit=ft)	25	$8,000	$200,000
Flash tunnel(unit=ft)	45	$1,000	$45,000

Turbo bell station	3	$1,300,000	$3,900,000
Reciprocating spray station	1	$300,000	$300,000
Manual spray	8	$10,000	$80,000
First color oven (unit=ft)	158	$12,000	$1,896,000
Second Color Booth (unit=ft)	215	$33,000	$7,095,000
Tack Off line(unit=ft)	25	$8,000	$200,000
Flash tunnel(unit=ft)	45	$1,000	$45,000
Turbo bell station	3	$1,300,000	$3,900,000
Reciprocating spray station	1	$300,000	$300,000
Manual spray	8	$10,000	$80,000
Second color oven (unit=ft) (dual line)	158	$12,000	$1,896,000
Repair & Tutone Booth(unit=ft	205	$33,000	$6,765,000
Tack Off line(unit=ft)	25	$8,000	$200,000
Flash tunnel(unit=ft)	55	$1,000	$55,000
Turbo bell station	3	$1,300,000	$3,900,000
Reciprocating spray station	1	$300,000	$300,000
Manual spray	8	$10,000	$80,000
Unmask station(unit=ft)	50	$8,000	$400,000
Repair Tutone Oven(unit=ft)	511	$7,200	$3,679,200
Color Finesse(unit=ft)	167	$8,000	$1,336,000
Tutone Finesse(unit=ft)	167	$6,500	$1,085,500
Sand & Mask(unit=ft)	44	$8,000	$352,000
Sand off line(unit=ft)	28	$8,000	$224,000
Support System			
Body truck washer	1	$450,000	$450,000
High pressure Grate cleaner system	1	$250,000	$250,000
Thermal cleaning unit	1	$800,000	$800,000
Centural Sludge system (unit = ft)	180	$5,000	$900,000
Stainless steel paint mix room equipment(20 systems)	1	$1,500,000	$1,500,000
Stainless steel paint circulating lines(20lines)	1	$3,500,000	$3,500,000
Paint temp. control system	1	$750,000	$750,000
Main color clean room	1	$2,300,000	$2,300,000
Automatic Vehicle Identification with computerized rescheduling	1	$3,000,000	$3,000,000
Three job indexing conveyor	1	$120,000	$120,000
Lift and Roll table	10	$27,000	$270,000
Turn table	10	$97,000	$970,000
Hold table	10	$23,000	$230,000
Stop for skid conveyor	20	$5,000	$100,000
ELPO Paint carriers	25	$4,400	$110,000
Body Carrying skids	1,333	$850	$1,133,050
Overhead P/F conveyor (unit = ft)	27,778	$700	$19,444,600
	TOTAL		$116,800,050

=====> OTHERS

			$/subassembly
Cost of capital		12.00%	$79.39
Tax	% of equip.	1.20%	$6.49
Insurance	% of equip.	1.20%	$6.49

Maintenance	% of	equip.	5.00%	$27.04
Total				$119.41

=====> LABOR

UNIT	$/UNIT	$/Car
man-hr	$24.00	$119.78

Number of Laborers : 270

==

TOTAL COST/CAR TO PAINT

$/Car
$239.19

Distribution of cost

Capital	49.92%
Labor	50.08%
	100.00%

Painting process with Plastic body panel

The process is almost identical with that of sheet metal body car. However, some extra processes have to be added.

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Sheet metal bodied car painting process			$116,800,050
Mill and Drill machine	1	$6,000,000	$6,000,000
Adhesive Apply station	2	$750,000	$1,500,000
Plastic panel washing system (unit=ft)	322	$8,000	$2,576,000
Body washer system(unit=ft)	211	$9,000	$1,899,000
Dry-Off oven(unit=ft)	300	$7,200	$2,160,000
Production Lines(unit=ft)	1667	$350	$583,450
Over head P/F conveyor (unit = ft)	7,778	$700	$5,444,600
	TOTAL		$136,963,100

			$/subassembly
Cost of capital		12.00%	$93.10
Tax	% of equip.	1.20%	$7.61
Insurance	% of equip.	1.20%	$7.61
Maintenance	% of equip.	5.00%	$31.70
Total			$140.02

=====> LABOR

UNIT	$/UNIT	$/Car
man-hou	$24.00	$136.89

Number of Laborers : 308

TOTAL COST/CAR TO PAINT	$/Car
	$276.91

Distribution of cost		
	Capital	50.57%
	Labor	49.43%
		100.00%

TRIMMING

1. Hard trim(electric wiring,...)
2. Soft trim(interior)

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Floor conveyor(unit=ft)	5,556	$460	$2,555,760
Body Carrying Truck	269	$3,500	$941,500
Production line(unit=ft)	8,889	$500	$4,444,500
	TOTAL		$7,941,760

=====> OTHERS

			$/car
Cost of capital		12.00%	$5.40
Tax	% of equip. cost	1.20%	$0.44
Insurance	% of equip. cost	1.20%	$0.44
Maintenance	% of equip. cost	5.00%	$1.84
Total			$8.12

=====> LABOR

UNIT	$/UNIT	$/car
man-hour	$24.00	$220.00

Number of Laborers : 495

Total cost of Trimming

$/car
$228.12

Distribution of cost

Capital	3.56%
Labor	96.44%
	100.00%

CHASSIS & FINAL

1.Pre towbeyor (condenser,gas tank,exhaust system...)
2.Engine forming
3.Engine and front axle mounting on a cradle
4.Car body marries with cradle and rear axle on a towbeyor
5.Suspension adjustment
6.Tire building station(off line)
7.Bumper subassy & underbody deadner (second floor)
8.Oil,gas,..etc,fluid is filled
9.ALDL check (emission)
10.Toe in check(camber check)
11.Roll on check

/

=====> EQUIPMENT

	UNIT	$/UNIT	$/STATION
Towveyor Conveyor(unit=ft)	556	$600	$333,600
Towveyor Truck	24	$3,000	$72,000
Mono rail conveyor(unit=ft)	11,111	$240	$2,666,640
Overhead P/F conveyor(unit=ft	11,111	$900	$9,999,900
Engine & rear axle mounting fixture	44	$20,000	$880,000
Computerized engine inspection system	2	$150,000	$300,000
Floor conveyor for Cradle (unit = ft)	133	$460	$61,180
Cradle body mount	4	$20,000	$80,000
Strut front suspension fixture	4	$50,000	$200,000
Body bolting machine	2	$220,000	$440,000
Camber set fixture	2	$250,000	$500,000
Parallel Floor conveyor (unit = ft)	2,222	$460	$1,022,120
Tire wheel bore cleaner	2	$50,000	$100,000
Wheel loader	1	$100,000	$100,000
Soaper	1	$150,000	$150,000
Mounter	2	$100,000	$200,000
Tire Rim match mark	1	$250,000	$250,000
Inflator	3	$250,000	$750,000
Balancing machine	2	$100,000	$200,000
Audit machine	1	$250,000	$250,000
Weight adjusting machine	1	$200,000	$200,000
Roller conveyor system (unit = ft)	250	$600	$150,000
Tire feeder (unit=ft)	400	$600	$240,000
Underbody deadner spray booth(unit=ft)	30	$15,000	$450,000
Production Line(unit=ft)	1,111	$500	$555,500
ALDL Intelligent Test Head	6	$150,000	$900,000
Toe in check system	1	$1,000,000	$1,000,000

Roll on check system	1	$1,000,000	$1,000,000
Production Line(unit=ft)	4,444	$2,000	$8,888,000
	TOTAL		$38,854,222

=====> OTHERS

			$/car
Cost of capital		12.00%	$26.41
Tax	% of equip. c	1.20%	$2.16
Insurance	% of equip. c	1.20%	$2.16
Maintenance	% of equip. c	5.00%	$8.99
Total			$39.72

=====> LABOR

UNIT	$/UNIT	$/car
man-hour	$24.00	$146.67

Number of Laborers : 330

Total cost of Chassis

Distribution of cost		
	Capital	21.31%
	Labor	78.69%
		100.00%

Appendix B - References

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Plant lay-outs.