WORKING PAPER

THE ROLE OF TECHNOLOGY IN AUTOMOBILE DESIGN AND PRODUCTION

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FOREWORD

The Technology, Economy and Society Program focuses its research on technological evolution, competition and appropriate management strategies, on an understanding and identification of those economic and social conditions and circumstances under which new technologies can evolve and on an assessment of the social aspects of these developments,

This report, which was originally published in Swedish as a contribution to the MIT Future of the Automobile Program, attempts to show how some of these issues are approached in the automobile industry as succesive generations of passenger cars are brought through the various stages from conceptualization to series production.

Thomas H. Lee
Director

ABSTRACT

This mini-essay is based on work done by the Swedish team in the technology part of the Future of the Automobile Program. This program was initiated by MIT and carried out under the leadership of professors Alan Altshuler and Daniel Roos during the period 1980-84. The automobile is viewed as a product of an industrial system. The evolutionary changes of this system and its major functions of designing and producing an automobile are described. Examples of experimental car design and its role are given. The interplay between increased use of modularization and integration in designs and the change from dedicated mechanization to flexible automation in production is discussed. The concluding chapter briefly treats some Swedish experiments with alternative production systems, which explicitly deal with the social and technical dimensions of the system.

PREFACE

One of the four parts – Part C – of the MIT Future of the Automobile Program examined technological opportunities and uncertainties, and resulted both in a final chapter in the international core book (Altshuler *et al*, 1984), which stresses technological opportunities for adaptation, and a separate volume on the product and production technology of future automobiles (Appel and Hilber, 1984). A separate Swedish project treated production systems in the future (Berggren, 1983). This paper is a translated and revised version of my contribution to a report which summarizes the Swedish effort within the Future of the Automobile Program (Sjöstedt, Tenryd, et al., 1984) It uses material from the three sources mentioned above, and several forum papers, among these Bianchi and Calderale (1984) and Blödorn (1983). Saab-Scania, SKF and Volvo also generously provided material. A certain Swedish flavor has been retained in this translation, partly because the original report was aimed at a Swedish audience, and partly because the report was intended as a complement to the international core volume, and as such, highlights some Swedish research findings which could not be included in the limited space of the core volume.

This report examines the automobile as a technical product and describes the complicated and changing processes that precede the creation of a new automobile. The report should be seen as a complement to other publications rather than as a complete summary. For this reason, only limited attempts have been made to describe possible changes in the technical design of future automobiles. However, an extensive international inquiry has been carried out on this subject. The results were reported in Appel and Hilber (1984) and in the Euroforum '84 Proceedings (1984). No findings have been included from other separate Swedish projects. Among other subjects, these projects included a thorough examination of the possibilities for alternative fuels (Bengström, Sjöstedt, Valdsoo and Wedel, 1984 and Valdsoo, 1984) and electric automobiles (Liljemark and Pettersson, 1984). Some other project reports are also included in the list of references, such as Grant and Gadde (1984), Steen (1984), Svidén (1984) and Sölvell and Vahlne (1984).

It is unfortunately impossible to name all those who have made this report possible. Professor Hermann Appel from the Technische Universität Berlin meritoriously coordinated the international work within the technical sector. Professor Mazakasu Iguchi from Tokyo University and Professor Ulf Karlsson from Chalmers Institute of Technology inspired large segments of the outline of the report and made valuable contributions. The French team leader, Professor Michel Frybourg also very actively supported the work. Erik Elgeskog, Christer Karlsson and Stephan Wallman contributed valuable information on product development, and Tomas Engström critically revised the chapters on production technology. Staffan Nilsson provided the diagrams. The first translation was made by Johan Wernstedt at Chalmers Institute of Technology. Linda Cechura at IIASA has made the final transcription and edited the paper.

I owe my sincere thanks to all those both mentioned and unmentioned, as well as to the Institute of Management of Innovation and Technology in Gothenburg, which holds the copyright of my original report, and to IIASA for its permission to publish this paper.

Laxenburg, March 1987
Lars Sjöstedt

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A SHORT SUMMARY – THE ROLE OF TECHNOLOGY IN AUTOMOBILE DESIGN AND PRODUCTION

Based on the results of various research projects of the Swedish part of the Future of the Automobile Program, this paper attempts to describe the organization of the system in which automobiles are conceived, designed and built. The perspective is predominantly technical and the format has the character of a mini-essay.

The first chapter approaches the automobile as a consumer product and discusses not only how the automobile has matured during its 100 years of existence, but also how its technical complexity has increased in recent years under the influence of changing conditions.

The next chapter presents the automobile in the context of an industrial system and examines some characteristics of such a system. Some criteria for the innovation capacity and competitiveness of an industrial system are discussed and the long times involved in developing and using a car are emphasized.

Experimental cars have long been used for image building purposes and to test early market reactions as well as the performance and reliability of new technical solutions. Lately, they have become an important tool for testing new manufacturing techniques and for shaping new business relations to potential materials and component suppliers. Following the energy crisis, a horde of experimental cars were built. Some of these are briefly presented with exphasis put on the choice of materials.

Chapter Four discusses how the procedure of designing a car is changing under the influence of computer-aided techniques and how this can potentially speed up the process by allowing many specialist functions to work with a joint data base. This possibility permits some jobs to be done simultaneously which were once done only in sequence. Computer-Aided Design is also the connecting link between product integration and process design. The chapter also presents modularization and integration as means of simplifying the packaging of a car and of achieving maximum economies of scale while simultaneously producing a range of models.

The next chapter gives some examples of design solutions for car and automotive components, which were chosen to highlight the design trends discussed in the previous chapter. One rather extensive and detailed example is one supplier's long and dedicated effort to develop integrated hub units. This example illustrates a stable trend for major component suppliers to assume a greater responsibility for component development. At the other end, are minor suppliers, who tend to lose their freedom and become totally dependent on single car manufacturers.

Chapter Six describes the evolution of the mechanically paced driven line, so successfully introduced by Ford around 1910, to the flexible robotized production systems now being introduced. Starting with a brief description of the main operations in the step-by-step manufacturing of an automobile, the potential for robotization is discussed using results from an international questionnaire.

A section of Chapter Six discusses the great potential for change being created by the use of flexible automation as opposed to type or model-bound dominated mechanization. Furthermore, when a functional approach to various tasks is stressed, the clear borderline that previously existed between blue and white collar labor tends to become blurred while the difference between direct and indirect work also disappears.

The final chapter treats the human being in manufacturing – and as an element in a socio-technical system. The chapter included some observations on Japanese production systems, stressing that in spite of such widely publicized organizational principles as just-in-time production and minimization of times for machine setting and adjustments, they are still adherring to the mechanically driven line.

Most of the material in the chapter is derived from extended research on alternative production systems carried out at Chalmers Institute of Technology first, indepently and later, under the auspices of the Future of the Automobile Program. Theories for lines are briefly summarized and some main characteristics of the Swedish development are presented. An example of the basic contents of an agreement between unions and management for an alternative system is given, and some systems which have actually been implemented are briefly described.

THE ROLE OF TECHNOLOGY IN AUTOMOBILE DESIGN AND PRODUCTION

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1. THE AUTOMOBILE AS A TECHNICAL SYSTEM – A MATURE PRODUCT WITH AN EVOLUTIONARY DESIGN

1.1. A Hundred-Year-Old Technology

The centenary of the internal combustion engine is presently being celebrated throughout the West. A century is a long time, and it is hardly surprising, therefore, that the automobile is generally regarded as a mature product. To the casual observer, all "family cars" look more or less alike, no matter where they were produced. Even 15 years from today that casual observer will have little trouble recognizing such cars, since most automobiles will still be designed to transport four or five persons and their luggage. Obviously, this primary function will continue to dictate car design for decades. Thus the car will continue to be designed around a body that surrounds the driver, his passengers and their luggage.

Of course, certain technical sub-systems are also needed in any vehicle that should transport both passengers and loads. For example, there must be ways to steer, turn, drive in reverse, and protect the vehicle (and its occupants) from road vibrations. The car must be able to stop within a reasonable distance. It must provide a pleasant climate for its occupants in both summer and winter. There must be a system to light the way in the dark and to signal turns and stops.

A list of basic requirements could be continued in even more detail, but these examples suffice to illustrate what systems engineers call ***demand specifications***. As the primary demands of human beings have not changed substantially in the last hundred years, demand specifications for automobiles have also remained constant. It is hardly surprising that no matter where automobiles are produced, they exhibit certain general design patterns which vary little in form or function from model to model, company to company, or country to country.

The demand specifications enumerated above are all related in some way to the transport requirement and thus indirectly related to the vehicle's occupants. But the occupants also have ***direct*** demands and preferences far exceeding the basic transport function. Automobile producers do their best to satisfy these demands and preferences, a fact which is reflected in today's enormous palette of luxury accessories. It has been estimated that a stripped-down, completely Spartan automobile, which only satisfied the transport function to a safe degree, would cost only half the market price as the same model costs in its standard, fully equipped form. The demands and wishes of potential automobile customers are called *consumer preferences.*

Recent changes in production engineering have provided many new opportunities for satisfying various consumer preferences. The automobile has long been a symbol of personal freedom. Recent production developments are a further step forward in adapting automobiles to meet individual consumer's preferences far beyond the primary transport function. Current trends in four-wheel-drive vehicles and spacious cars for families with many children and pets are examples. One must, however, be careful when comparing the standard "world car" with highly differentiated products. In spite of a worldwide trend towards increasing standardization, the technical components that fulfill basic functions (and that the daily user hardly knows anything about) are becoming progressively complex, yet more standardized. In the discussion about free trade in another part of this report it is observed that free, international exchange of such high technology components is one of the most important conditions for further development in the automobile industry.

If an automobile company wants to succeed on today's intensely competitive market, it must consider all the consumer preferences that could influence the choice and purchase of cars.

In view of the automobile's long-term development potential, it is natural to concentrate on providing a technology capable of meeting individual demands for reasonably priced transport in ways that are acceptable to society as a whole. There will be many outside or *exogenous* demands, such as demands from governments, environmentalists, or other political authorities at various levels on the car and its use.

In summary, we can distinguish four groups of factors, which may end the present tendency towards a standard world car. The first group includes exogenous *technical conditions* in the form of new technologies and possible alternative solutions. The second group is dictated by *changes in the environment* which may suddenly make it difficult or impossible to produce or use the car in its present form, therefore compelling the industry to make technical changes, which may take different directions in different countries. The oil crisis of 1974, which resulted in fuel economy requirements, or the present forest die-off, which dictates catalytic converter legistlation, are examples that come immediately to mind. The third major factor can be labeled *changes in consumer preferences.* New or stricter *demands from the authorities* constitute the fourth group of factors. The Clean Air Act of 1970 in the US, which set strict standards for automobile emissions, offers a good example. *Figure 1* illustrates how the four groups of factors influence technical developments in a broad sense. *Figure 1* also includes the additional dimension of competition between automobile companies, which motivates each company to introduce new technical advantages as quickly as possible.

Competition has another effect: To achieve a maximum margin between market prices and production costs, all automobile companies seek to reduce their costs by rationalizing production. When there is particularly fierce competition, or a high inflation rate, or the currency has been devalued, companies are either forced to decrease their profit margins, or reduce production costs. Thus, there is almost permanent pressure to lower costs.

To achieve higher profits with unchanged products in situations such as those described above, a company must dramatically increase its volume at the expense of its competitors. Naturally, automobile companies also attempt to raise profits by offering buyers certain luxury extras or special model variants. This tactic may enable a company to increase its total value added in spite of continuous rationalization. If such tactics were not possible, the automobile industry as a whole would eventually become the "poor relative" of the industrial sector. Obviously, consumer preferences are not the only motivating force behind the trend towards more generously equipped cars.

1.2. Increased Complexity and Rate of Change

The average driver probably thinks his car is rather simple from the technical point of view, since most cars are adapted to the skill level of average drivers. Early automobile models also seem quite uncomplicated to modern engineers. Although the automobile industry is the largest mass industry in the world today, for many decades it did not enjoy very high status among academicians and engineers – with the possible exception of production engineers. Relatively few engineering graduates or scientists were recruited into car manufacturing, which in turn led to a poor understanding of the automobile industry and its conditions outside the industry.

That picture has since been changed. Heavy components, such as the engine and the transmission, began to attract interest rather early. These components include many applications of mechanical high tech, which was regarded as the core of the engineering art throughout the first half of this century.

After World War II, automobile design became steadily more complex. This tendency has been intensified in the last decade. General technical development, progressively stricter demands from the authorities, and environmental and attitudinal changes caused by the energy crisis during the 1970's, have all spurred development in the same direction. Many systems have been developed around an engine, whose basic function remains unchanged. These are either auxillaries which enable engines to function in particular ways or accessories which fulfill demands for certain extra functions. At the same time, maintenance requirements have have been greatly reduced. Compare for example the heating systems and lubrication schemes for the 1960 and 1978 Saab models shown in *Figures 2A – 2D.*

Developments such as these naturally place great demands on technical engineering competence. There is an interesting theory about the reason behind the phenomenally rapid technical development of the West German and Japanese car industries after World War II. Both countries were forbidden to rearm and forced to suppress all military research. While the engineering elite of other industrial countries was recruited for military research during the times of the "Cold War", gifted engineers in Germany and Japan found jobs in their countries' rapidly expanding automobile industries.

Although a modern automobile is a very complicated product, Swedish technical universities, in comparison with universities in other automobile manufacturing countries, did not offer graduate degrees in automotive engineering until recently. One way of describing the complexity of the modern car is to look at the great number of specialist job titles used by the automobile industry itself. *Table 1* reprints the job titles used in the 1984 edition of the Volvo Car Corporation's internal telephone directory. There are no fewer than 64 different categories. Please note that only technically related job titles have been reproduced.

The trend towards complexity makes it natural to ask if the automobile will survive in the long run. This question was first raised in the 1970's when the automobile industry was confronted with two difficult problems within a short time. The first problem resulted from the discovery that engine emissions contain dangerous substances and the concomitant demands to reduce the emissions of lead, hydrocarbons, carbon monoxide and nitrogen oxides as quickly as possible. The second was the insecurity surrounding long-term fuel supplies, which was intensified by the acute shortages caused by the OPEC embargo in 1974 and the energy crisis in 1979.

The way the automobile industry met these problems shows that automobile technology itself is very sturdy, and that the industry has great potential for adapting quickly to changing conditions and new demands from consumers and authorities worldwide. The process has not always been a painless one, however. For example, many companies had operational difficulties with the first generation of clean exhaust engines, which, due to the legal constraints of the Clean Air Act, were rushed onto the US market before adequate development or testing had been completed. These technically "unripe" clean air engine designs led to accusations that the industry lacked any real capacity for innovation. Actually, innovation capacity has grown considerably, if the increasing number of registered Japanese and American patents is any indication. See ***Figure 3***. Memories of being caught unprepared for the upheavals of the 1970's has motivated renewed interest in research and development throughout the industry in the 1980's. Today new components and parts systems are appearing in a constant stream. After complementary testing and product adaptation, they will be available for use whenever environmental or legal demands make new solutions necessary or desirable. The "technology shelf" is rapidly being filled, offering development engineers and designers an ample supply of optimal solutions for specific needs.

2. THE CREATION OF AN AUTOMOBILE – THE INDUSTRIAL SYSTEM AND ITS CONTROL MECHANISMS

2.1. Planning for Products Fifteen Years in Advance

Having a well-stocked technology shelf does not necessarily mean that it is easy to change an automobile design or introduce and market a radically new product. There are many restrictions and barriers which become involved whenever the technical design of a car is changed. The car is part of a complex structure with many actors whose roles are affected whenever the design of the car is changed. This structure may be described in many ways, and each company chooses whatever best suits their culture and tradition. Thus, it should be pointed out that the approach suggested here is by no means the only possibility. As *Figure 4* shows, one rough division is to separate the ***industrial system***, which creates an automobile via a complex network of raw material and component suppliers, and the ***commercial system***, which markets the automobile and provides certain customer services, including those associated with repairs, spare parts, extra accessories, etc. The automobile as a ***product*** is the central idea here. Product planning controls the product development process, which in turn controls the industrial system.

The need for product planning may be met by various means, ranging from a simple conference between the managers of the responsible systems to the establishment of an independent department for product planning. Product planning aims primarily at stengthening a company's competitive advantage by enhancing its profile and that of its products. Much of the input needed for product planning is feedback from marketing, which is seen as part of the commercial system. "Profile development" may be achieved either by changing the product program, e.g. by ensuring that the company introduces some technical innovation every year, or by exerting direct influence on the commercial aspects of a product, e.g. by offering warranties on body damage, or even by offering customers insurance at favorable rates. As all automobile companies hope to achieve a reputation for high quality, it is essential for product planners to identify quality goals and control methods.

The number of actors is large both in the industrial and the commercial systems. These are themselves and often in sequential order responsible for their part of the complicated process behind the realization of a car. Typically, five to seven years elapse between the conception of a new automobile model and the day the first new car rolls off the series production line. Considering that automobile models must be produced for several years to amortize investment costs, and that the median life expectancy for cars is increasing in all countries (see *Figure 5*), it obviously takes a long time before technological innovations can appear on a majority of the vehicles on the roads.

By international comparison, Swedish cars enjoy an extremely long lifespan. Some domestic models have reached a median of more than 19 years of service. As the Swedish manufacturers are rather slow to introduce new models and then retain them for a long time, we may conclude that more than half of the model generation presently attracting the interest of Swedish product planners will still be on the roads 30 years from now, i.e long after the year 2010. Although Swedish conditions are extreme, the picture is much the same in an international perspective, as can be seen from *Figure 6*.

Why does it take such a long time to introduce a new automobile model? Until the 1960's a kind of "from the bottom up" philosophy was common in the automobile industry. A single designer or a small group of skilled, experienced designers created a new automobile model, working in relatively great freedom, by assembling whatever components they thought suitable. Thus, the final result was often much influenced by chance. As long as cars were simple enough for one person or a small group to have a comprehensive understanding of the whole design, the "bottom-up" method often yielded good results at a reasonable cost. As automobile design became more complex, a hierarchical division of responsibility became necessary, but the basic philosophy remained unchanged. Today the old method – one designer, one model – would be nearly impossible. First, no single designer or group could execute the whole design with such simple means. Second, top management is no longer willing to give that much freedom to a single designer.

2.2. The Role of Pre-Development

The philosophy now in use* was inspired by the systems analysis methods developed by the defence industry. It is characteristic of this method to begin with the product as a whole, then examine the parts and finally return to the whole to ascertain if the desired results have been achieved. This method recurs used in each step along a repetitive chain of design in which the automobile progressively takes shape. The automobile is described by a set of specifications, which become more and more detailed and which function as a means of communication between the many parties involved.

The foundation for the work is laid through detailed market studies. The results of these market studies and long-term policy decisions, which, among other things, consider the difficult notion of the "image" of that particular automobile make, form the basis for the next step: ***pre-development***. A central task in this stage is to make a logically consistent and detailed ***demand structure***, a process which alone may take up to a year. Once done, the demand structure is frozen and becomes the basis for all further development work.

The demand structure is then divided into many groups of characteristics. These could include, for example, appearance, driving comfort, fuel economy, performance, crash safety, sound level, cost of production, and weight. Within each group of characteristics a number of functional demands are specified which refer to the car in its entirety. These demands may be market-related and reflect consumer preferences and changes in the surrounding world. The demands may also be legal demands, dictated by say, traffic authorities, or company demands, designed to support either the company's image or the image of that particular make. The demands may be formulated in quantitative terms or merely express desirable qualities. In the former case, the demands may include a description of a test situation which specifies the quantitative demand.

The demand for crash safety, for example, may be specified for a number of frequently occurring accident types, such as head-on collisions, side collisions, rear end collisions and overturning. The demands may also specify pedestrian protection, e.g. by limiting the aggressiveness and projection of external objects or

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* This chapter and the following one are based on material from a research seminar with Erik Elgeskog from the Volvo Car Corporation.

by regulating the bumper height.

The functional demands must then be transformed into demands which apply to specific components in the car. This is done in many steps. First, a number of sub-systems in the car are identified. In the case of accident safety, three systems can be identified; namely: the structure, inner system, and complete vehicle. For each of the sub-systems the relevant functional demands are subdivided into system demands, which are then further subdivided and applied to the individual components. It should be noted that each individual component is, as a rule, subjected to many demands originating from different groups of characteristics. After each component has been selected from the technological shelf or designed "from scratch" and subjected to the necessary calculations and tests, attention focuses once again on the design in its entirety. The subsystems are evaluated and tested according to previously defined test conditions. Finally, for each group of characteristics, the functional demands for the car in its entirety are verified. *Figure 7* shows the procedure schematically.

Normally, not all the demand requirements can be fulfilled. It may be necessary to repeat the process several times, adjusting the demands until acceptable results are reached. On the other hand, if a first attempt is immediately successful, the demands may have been too cautiously stated. Typically, demand structure is frozen after a year and returned to the marketing department, where it is checked against continuously updated opinions on the expected marketability of the proposed car on different markets. On the technical side, work continues by illustrating in detail the prospects for realizing the agreed upon demand structure.

Since no prototype of the car exists during the development phase, possibilities for testing are extremely limited. Instead simulation programs and other advanced calculation aids must be used. It is important, however, to test under realistic conditions as much as possible, because deviations in the theoretical methods (in the form of calculation errors, test errors, or unforeseen effects) must always be expected. Component testing is, therefore, an especially important method during the pre-development phase. The theoretical method, however, can provide a valuable reference, and the search for explanations for the deviations between the theoretically and practically measured values can be very instructive. By using such a step-by-step application to a specific project theoretical calculations can be performed more reliably, thereby successfully replacing time-consuming and expensive testing.

Characteristically, many demands are in opposition to each other. Fuel consumption and performance, for example, are in open conflict. To a lesser extent, comfort and good running characteristics are also conflicting aims. The demand for low production costs is in conflict with nearly all the other demands. The pre-development phase is thus one of permanent compromise, where the ability to find a unanimous solution is the key to continued success.

2.3. From Development to Series Production

After the pre-development phase, a detailed examination of the project is carried out. Then, the real product *design and engineering* work can begin. As costs for the project increase steeply hereafter, the pre-development phase must provide a good basis for assessing the project's profit potential and technical risk. Extensive calculations of economic risks and results are therefore included in the report. On one hand these calculations rely on sales forecasts for different markets, including price estimates for specific markets, and on the other, on careful calculations of production costs. The costs for the continued development work and the necessary investments in the production plant are therefore an essential calculation element. If the examination yields favorable results, the project has taken a big step forward towards realization.

During the design phase a detailed analysis of the "designability" of the new automobile concept is begun. The final result is a complete design plan, which differs from earlier ones not only in accuracy and exactness concerning the qualities the car will have, but also in more exact production information. This analysis depends on great knowledge of what can be taken from the technology shelf in the form of materials and components from old and new sub-contractors.

When the design plan has been completed, further examinations are conducted. If these show positive results, the project is continued and moves ahead as the flow chart in *Figure 8* shows schematically. The perspective now changes from the car as a *product* to the car as an *object of production* in the manufacturing process. Responsibility now shifts from the designer to the production engineer.

Preparation for production results in a detailed plan for production. To be certain that the plan is realistic, a pre-series of from a hundred to a thousand automobiles, is produced.

After the test results of the pre-series cars have been evaluated and any necessary corrections or investments have been made, and all the other preparations for production have been completed, the magical time of actual series production is finally reached. The technical engineering side of the job, however, does not end when *series production* begins. It is becoming increasingly important for car manufacturers to monitor the technical quality of their products. Quality monitoring involves not only curing the "childhood diseases" that can occur even with careful planning, but also regularly checking and improving the standard product. Quality control has established itself as an important and independent function in close contact with the end user.

2.4. Innovation Capacity and Competitiveness

Of course, new automobile models, need not be designed and produced solely by the method described above. A comparison of e.g., the two Swedish automobile producers shows how differently production development and similar questions can be handled when there are significant differences in competition strategies, even though the two companies rely on the same national engineering community.

A classic way to judge a company's competitiveness is to compare it, according to certain criteria, with the leading companies in that branch. In the automobile industry there are three such criteria. The first is *product technology* or the quickly changing art of designing and constructing a car. *Process efficiency*, which includes both production techniques and the efficient organization of the whole chain of production, is the second factor. The third criterion is *market position*, or the company's ranking within different segments of the market and its chances to capitalize on international markets within prevailing trade restrictions and hindrances. To a great extent, the history of the automobile industry has been formed by the choices made in regard to these criteria and the gap between applied and best practice.

The Japanese superiority in production efficiency is famous. The American automobile manufacturers possess a potential advantage – although they may have difficulties capitalizing on it – through their position in several market segments and geographical areas. Although European producers could be said to be in second place in both the above respects, they do enjoy technical leadership as far as the products themselves are concerned, especially in the production of small cars and prestigious automobiles with outstanding driving qualities.

A similar analysis of competitiveness, which is also of interest when advantages of scale are analyzed, can be derived from four separate criteria. The first of these is the ability *to obtain and analyze information.* In the following part we will discuss the experimental car as an instrument for information gathering. The second criterion is the ability *to use information in product design and engineering.* The third criterion is *production technology* and the fourth, *marketing and sales.* In this section we will consider only the first three criteria as marketing and sales lies outside the technical perspective of this work.

A car model may be expected to enjoy a product lifespan of at least eight years, with perhaps a major change to the exterior after four years. Automobile engine designs normally enjoy a greater product lifespan of approximately twenty years. That is equivalent to the replacement cycle for heavier production equipment. What is it then that determines whether a company when changing models or making large investments in production can achieve the level of innovation necessary for maintaining or strengthening its competitive position? Obviously, it is not enough to be a leader in only one of the above dimensions. *Figure 9* attempts to view innovation capacity from a larger perspective and at the same time to express the Japanese view on the role of technical development.

3. THE EXPERIMENTAL AUTOMOBILE – A TOOL FOR DEVELOPING COMPETENCE

In an automobile company – as in other technology intensive industries – it is difficult to incorporate the most advanced developments in research and technology. Certain preliminary work is imperative since series produced products must be based on tested technology. Even if concentration on internal research and development has grown rapidly, this method alone does not enable a company to keep abreast of all the progress being made. For this reason, experimental cars are built, which generally are not intended for production. Such projects offer ways to develop and maintain large networks of international experts, extending far beyond ordinary contacts. Designing experimental cars provides opportunities to test function and performance data using new, unconventional solutions and components. The opportunities for studying how new solutions and components will work together in the complicated systems of an automobile are no less important.

An experimental car not only provides valuable information about what the technological shelf has to offer, but also provides information about who can offer what, and at what cost. Therefore, an experimental car is also an essential tool in developing contacts with potential sub-contractors.

As a rule, new solutions or components which have been successfully tested in an experimental car must undergo a long re-design and adaptation process before a final design can be found that has all the necessary quality specifications and can be produced in series at low cost.

3.1. A Swedish Experimental Automobile

The Swedish experimental project *LCP 2000* (see *Figure 10)* was conceived at about the same time as the "The Future of the Automobile" Program and was inspired by similar trends. It may therefore be of interest to examine what that project stressed and to take a closer look at the areas it studied and tested.* *LCP* stands for Light Component Project and the number *2000* was chosen to indicate its time perspective. The task was to analyze unprejudicially which production methods, materials, designs, solutions and automobile concepts can be practical and useful in the Year 2000, while giving maximum priority to low energy consumption, and to demonstrate the new ideas and design solutions in experimental cars.

Before real design work started with experimental cars, four studies were carried out. The first aimed at analyzing the type of body, which best conformed to customer wishes and expectations. In order to combat expected energy shortages, the traditional family car, which has space for four or five passengers and luggage, was abandoned in favor of a vehicle that offered space either for a driver and one passenger (and their luggage) or for a driver and three passengers (without luggage). According to design specifications, top speed had to be at least 150 km/h and acceleration from 0 to 100 km/h had to be possible in under 12 seconds. Total weight, excluding the driver's weight, was not to exceed 700 kg.

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* The following facts are taken from Volvo's own presentation broschure, but the commentary is primarily the author's.

The air resistance coefficient was not to exceed 0.3, nor the front area 1.8 kvm. These limitations were regarded as a sufficient contribution to the main goal, namely, that fuel consumption should not exceed 0.4 liter per 10 kms in mixed driving. Furthermore, the experimental cars should be sporty, attractive and able to fulfill all foreseeable legal demands regarding safety and the environment.

In the second part of the project an inventory was made which consisted partly of existing engine and gear box components and partly of components that were still in early stages of development. Testing and evaluation were carried out in cooperation with two different companies, and included not only conventional engines – Otto and diesel – but also gas turbines, hybrid engines, Stirling engines, electrical engines, and steam engines. Both companies arrived at the same result, namely that from a strict fuel economy point of view the best drive line alternative for this type of vehicle is a three-cylinder, turbo-charged, direct injection diesel engine. This solution certainly offers the best fuel economy, particularly if it is also combined with a Stepless Variable Transmission (SVT).

Two different types of three-cylinder, direct injection engines were tested and evaluated. The first is a very light engine with a magnesium cylinder block. The engine has a swept volume of 1279 cc and yields 37 kW (50 hp). The second is a insulated cast-iron engine without a cooling mantle in the cylinder head. Cooling is achieved by circulating engine lubricant around the the cylinder linings, valves and exhaust injectors. During the project, this engine was developed further and outfitted with turbo-chargers and intake air inter-cooling, which increased engine power to 66 kW (90 hp). With a one-hole-injector this engine exhibits good multi-fuel qualities. Preliminary tests have shown that the engine is relatively indifferent to the octane level of the fuel used and can be driven as well on low octane fuel, sunflower or rape oil as on conventional diesel oil. To diminish engine vibrations, especially at low revolutions, a special anti-rotating flywheel was designed. Since the effective speed range for a diesel engine is relatively small, a transmission with 6-7 gears is necessary if the engine is to work efficiently. The project group decided therefore to design a stepless variable transmission with a steel chain and an electronic control system for both the engine and the transmission. Theoretically, this makes it possible to achieve lower fuel consumption than with the five-geared transmission, which was chosen for the experimental cars.

The third initial project was a comprehensive study of materials, both those already in use, and those – primarily lighter materials – that will probably be used in automobile production in the next fifteen years. The purpose of the study was to find additional safe, economical, high quality materials.

One of the main principles in the automobile industry is that a weight reduction of 10 percent yields a 4-5 percent reduction in fuel consumption, but, of course, weight reductions are themselves very expensive. The fourth and last initial study sought to find answers to two questions: What is a reasonable cost for a weight reduction of 1 kg? And how essential is energy efficiency to the consumer? The study created a detailed model for evaluating how the choice of materials affects the market price of a car.

On the basis of preliminary studies, four experimental cars, which made extensive use of light materials, were constructed. Aluminum was chosen for the entire load-carrying structure in the bottom plate and the roof frame. The use of aluminum rather than steel reduced the vehicle's total weight by approximately 115 kg. Aluminium alloys were also used in the steering column, suspension links, brake disks and drums, door parts, and the nuts and bolts. More than one fourth of each experimental car's total weight was that of the aluminum. The load-carrying aluminum structure was glue welded, which reduced the number of welds from around 4000 in conventional cars to only about 500 in the experimental vehicle.

Magnesium is a material with especially interesting qualities. In the experimental cars magnesium was used in the clutch and transmission casing, the rims, the steering gear house, the rear suspension links, the engine suspension frame, and the engine block of one of the engines. In all, there are about 50 kg of magnesium alloys per vehicle, which corresponds to seven percent of the total weight. Since magnesium is an extremely light metal, it has been used extensively in the aerospace industry. It is expensive to produce, but as magnesium can be extracted from sea water, the supply is practically limitless. A cubic meter of sea water yields 1.3 kg of magnesium. The disadvantage of magnesium – other than price – is its tendency to corrode and erode.

The roof, hood and all outer panels of the vehicles were made of heat-tempered plastic. Polycarbonate was used for the side windows. The adjustable pedal stand is made of fiberglass, as are the front and back seats, and the inner panels. Each experimental car contains a total of about 200 kg of plastics, rubber, and textiles, which corresponds to a third of the total weight of the vehicle.

Another example of the choice of an unconventional material is the carbon fiber reinforcement of the door frames. In spite of the extensive concentration on new materials, steel and cast iron still represented a fourth of the total vehicle weight. Many materials, such as ceramics, metalic composites, alloys, and light metals other than aluminium and magnesium, are considered to be of interest for future automobiles, but, according to project researchers, production processes for these materials are not sufficiently developed to allow their use in the experimental cars.

Table 2 shows some of the analyses made of the energy efficiency of the LCP cars. The total energy consumption during the lifespan of the LCP car amounts to 82,500 kWh. Included in this figure is the energy used in the production both of the materials and the vehicle itself, as well as the energy consumed over 10 years of driving a yearly distance of 15,000 km including energy required for normal maintenance. The diagram shows that when the energy saved through re-cycling is subtracted from the total energy consumed (both in production and driving), energy consumption for the LCP concept vehicle is nearly 50% lower than that of an average car. This figure is largely the result of lower fuel consumption, but the higher re-cycling value also makes a significant contribution.

As already noted, one of the values of producing experimental cars lies in the creation of an extended contact network that usually accompanies such undertakings. In the LCP Project this opportunity was used to very good advantage. The project group turned to experts in several countries in its search for ideas and expertise. Many companies were involved, and not only functioned as subcontractors but also financed their own contributions. Several Norwegian companies engaged in the work contributed decisively to the metalurgical development of aluminium, magnesium and different plastics. *Table 3* shows the extent of international cooperation.

Although the LCP 2000 experimental car was never intended for production, it did provide very valuable indications of what technology can bring in the future. LCP 2000 indicates what possibilities and limitations can be expected in the development of light weight, energy efficient cars within the next twenty years. However, since present fuel price and supply predictions until the year 2000 are much more optimistic than those made in 1979, today's car designers are far less concerned with producing extremely light, energy efficient cars than the LCP designers were.

It may now be appropriate to examine how the materials question has been handled in some experimental cars, and to compare these approaches with some independent forecasts about the materials that will be used in future series-produced cars.

3.2. The German AUTO 2000 Project*

In 1978 the West German Federal Government initiated a project to study how different technical solutions for safety, environmental protection and fuel economy could be integrated in real production models. The resulting vehicles were to be used primarily to demonstrate new concepts that could be put into series production. At the same time there was to be room for new technical solutions and ideas. Experimental vehicles were designed in three weight classes: up to 1250 kg, 1250 to 1700 kg, and 1700 to 2150 kg. Volkswagen presented a modified Golf, Audi designed a middle-class vehicle reminiscent of the Audi 100, and Daimler-Benz developed a vehicle based on the design of their S-class sedans. Collaborators from the German universities at Aachen, Berlin, Darmstadt and Stuttgart concentrated on designing an experimental car in the middle weight class.

All four cars were built using existing methods and design principles, which resulted in confining the new ideas to individual components. None of the cars has a body made completely of aluminium or plastic. Audi-NSU presented a pre-assembled chassis of fiber-glass reinforced plastic and a frame-assembled roof element. Both offer examples of technical solutions that could replace conventional design principles. The same can be said about Volkswagen's 100 percent plastic seat. None of these solutions, however, yields any significant weight reduction. Today, the production of these components is extremely labor intensive. Therefore, from a car producer's point of view, such changes are motivated only if they lead to greater integration and fewer parts. The additional costs of painting, assembling and packaging such components must also be considered. Moreover, the manufacturing technology for sandwich elements must be refined and made suitable for mass production.

A common characteristic of these cars was the use of plastics for the hoods and chassis panels, and of aluminium for the main parts of the doors. For maximum energy absorbtion in low speed crashes, polyurethane or polycarbonate plastics were used for the bumpers. The load-carrying and energy-absorbing elements in the car bodies were made of steel, however, in all four designs. Plastic materials already dominate the mass production of interior fittings, so no surprises were presented here. The windshield and adjustable windows were still made of glass, although it was thicker, but polycarbonate or acrylic plastics were used in the stationary windows and headlights. Aluminium was frequently used in body and engine parts. Volkswagen equipped its vehicle with a plastic rear axle which proved to have a short life. Volkswagen's plastic wheel rims also compared badly with the

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* The text in this and the following two sections is primarily a condensed version of Blödorn (1983).

aluminium rims of the other cars because of strength problems at extreme temperatures. No ceramic materials were tested.

3.3. Other Examples of Experimental Automobiles

Most of the other experimental cars presented in recent years have also been based on well-known concepts. In many cases they are simply modifications of mass-produced standard cars. This is largely true for the body designs. A few of the experimental vehicles have had self-supporting plastic bodies. In other cases, all the stressed parts of the vehicle under the body surface were made of high tensile sheet steel. The decision to use steel for such parts was influenced by the similar strength-to-weight ratio of steel as compared with that of the plastics presently available. Of course, aluminium can also be used, but since aluminium is more expensive and consumes more energy in production, the use of aluminium must be motivated by the kind of life cycle analysis which Volvo performed for its LCP 2000, where the savings in operational costs were allowed to compensate for the higher initial cost.

The advantages of traditional design methods are particularly obvious in *Fiat's* experimental car *VSS*. A steel frame provides the skeleton for a flexible, easily formable plastic body. The adherents of plastics see this design as a great opportunity because it allows assembly in component groups. The frame can be produced and painted on a traditionally organized, but highly automated, production line. The plastic components themselves can be pre-assembled and painted as parallel operations. Because of the high tensile steel used in its entire frame, the vehicle can pass all crash tests without requiring additional strength from steel panels in the body. The front and rear bumpers are made of polycarbonate. The luggage compartment door, doors, and side panels are made of Sheet Moulding Compound, which is a fiber carpet impregnated with a prepolymer which hardens into a stiff material when subjected to pressure and heat. A low alloy, high tensile steel was used to strengthen the doors. The hood and roof are made of fiberglass-reinforced polyester foam. The most interesting features are the new methods of production and assembly, and the great variety of materials used in the body – rather than the choice of materials for parts.

An experimental "hand-and-glove" concept car designed by the American company *Minicars* displays similar design principles. Bumpers, hood, luggage compartment, doors and all similar parts are made of plastic and so formed as to cover the entire body. As a result, almost the entire exterior can be dismantled. Here the load-carrying parts of the body are also made of steel, but, to the greatest possible extent, all the hollow areas have been filled with hardened foam. This design approach, which is not new, was motivated by the desire to achieve high energy absorbtion capacity with low weight materials. The question remains whether such costly methods can be adapted to the economic constraints of mass production. It must be remembered that the main goal of the Minicars was to provide maximum safety in a crash, rather than reasonably priced automobiles.

With their *Vera* model, designers at Peugeot did not deviate much from established design solutions, but tried to achieve maximum fuel economy by using an optimal engine, better aerodynamics, and a lightweight design. The Vera body consists mainly of sheet steel. Load carrying parts in safety critical areas were constructed of high tensile steel. The hood, luggage compartment door, wheelhouses and rims were made of various plastics, such as polyurethane, polypropene, acrylnitril-butadine-styrene, fiberglass-reinforced plastic and carbon fiber-reinforced plastic. To facilitate test comparisons, the doors on one side of the car were made of aluminium. Many improvements and changes in the parts were made in an attempt to achieve a significant weight reduction.

An experimental car from the American development company ***Calspan*** offers a further example of a design solution which is a more radical departure from common design principles. The main design criterion for the Calspan vehicle was to achieve a balance between energy expenditure, economy, and the use of natural resources. Changes were made only in those areas where the design goals strongly motivated them. The use of high tensile steel was confined to safety critical areas and parts. To a large extent the designers avoided using metals which are difficult to recover when a car is scrapped. The only significant use of plastics was in the "weak nose" – designed to protect pedestrians – and in the back bumper which had to conform to the Federal Motor Vehicle Safety Standard 215. Because of the project's strict recovery/recycling requirement, aluminium was used only in easily dismantled parts, such as the hood.

The use of interesting or unusual materials is not confined to experimental cars. Unorthodox solutions have always been the rule in racing cars where costs rarely play an essential role. In the rally version of the ***Audi Quattro***, for example, aramide fiber reinforcement was used for certain exposed parts, such as the oil tray. A combination of aramide and carbon fiber was used for the blower console. The inlet tubes, which are exposed to high vibration levels and great temperature changes, were made of carbon fiber reinforced epoxy resins.

The experimental car designs described above were all produced a few years ago. They were motivated primarily by US safety requirements and later, by the anxiety associated with the energy crisis and the dramatic increases in fuel prices. Which design goals are worth pursuing today? Materials technology has developed rapidly and interest in new materials therefore, remains strong. Streamlined designs with low wind resistance coefficients continue to fascinate designers although fears of oil embargos or fuel shortages have subsided. At present, however, interest centers on electronics and vehicle/road communications systems, dashboard computers, microelectronic steering and regulating functions, and audiovisual signals for the driver.

A press notice (Egon Reimertz, GP 1984-11-25) on *Ford's Ghia Vignale TSX-4*, which was unveiled in Turin in November 1984, amply supports the above points.

> *TSX-4* is constructed on the American Ford Tempo bottom plate and has a 2.3 liter, 4 cylinder, 120 horsepower engine, a four wheel drive system developed at Ford, and a five-speed transmission The suspension system features individual springs all around, and the wheels are made of light metal. Extras are becoming more and more important: the *TSX-4* offers not only air conditioning but also a high quality stereo radio and casette recorder, plus television in the back seat. On the dashboard there is a lockable safety compartment with a personal computer and screen.
>
> The *TSX-4*'s exterior is elegantly sculptured, and the glass surfaces are flush with the body. Behind the door openings there is a drip strip running along the sealing. Wind tunnel tests on the *TSX-4* showed a wind resistance coefficient as low as 0.3. Bumper and spoiler are integrated into the low front, and the air inlet and headlights have been incorporated into the body. The back of the body is softly rounded. The maximum load volume with the back seat folded forward is 1000 cubic liters.

Both front and rear seats have grey leather upholstery with contrasting red stripes. The driver can operate most of the controls without removing his hands from the steering wheel (an idea which originated at Citroen). Oil pressure, engine speed, vehicle speed, and other information is displayed in analog numbers on the eliptical dashboard. Ignition is controlled by a push button code system located on the middle console with the controls for the electric windows. Light weight materials have been used throughout to achieve distinctly low fuel consumption.

The experimental car in this shape – at least judging by the above description – seems to function primarily as a means for recording early consumer reactions to the automobile producer's attempt to refine the car beyond the normal transport function. Obviously, technical competence development is not the only reason for building experimental cars. Experimental cars also play a large role in a company's image-building and market-storming.

One development, which until now has only been reported for Japanese experimental cars (Nissan and Honda), is four-wheel steering, which makes parking and maneuvering in small spaces very easy. Four-wheel steering is said to improve the driving qualities very much, but this statement remains to be proved.

3.4. Comparison with Cars Produced in Series

The above discussion shows that few experimental cars include new materials to the same extent as the LCP. The variations in the selection of materials for single components is, however, very large, which indicates how much freedom there is in the way the parts of a car are formed. The assortment on the technology shelf is very large, not only in the choice *among* components, but also in the choice of materials and production methods for *single* components.

Most experimental cars have a relatively conventional design. It is therefore hardly surprising that the predicted use of materials for future series produced cars is rather conservative. *Table 4* reproduces a Japanese prediction which indicates that only very moderate changes can be expected up to 1995. The greatest expected decline will be in cast iron, which supports the prediction that more aluminium will be used for engine parts and in the transmission. The same tendencies can be seen in *Figure 11*, which is taken from the investigation mentioned in the Preface. These trends, however, are not unambiguous. Two crankshafts, the connecting rods and the camshaft of the new 1-liter engine from Fiat, for example, (Maasing, 1984) are made of cast iron. The cylinder block is made of special cast iron according to modern thin-wall moulding principles. The cast iron is never thicker than 4 mm, and at some places it is as thin as 3 mm.

In summary, it may be said that after many attempts to construct car bodies entirely of plastics or aluminium, automobile manufacturers have now become more selective in the use of these materials. Low rates of fatigue strength, stiffness, and energy absorbtion argue against the use of synthetic materials for parts that are subjected to much stress. Significant weight reductions (and adequate safety) can only be achieved in such parts with costly, high tensile composite materials. Until now the possibilities for avoiding rust and for integrating components have not sufficiently motivated the use of such materials for highly stressed parts. Of the light materials available, aluminium and aluminium alloys offer the best potential for possible use. Aluminium's elasticity and specific weight allow important weight reductions, in comparison with steel, without sacrificing stability or energy absorbtion.

Some parts of the car, such as the hood, the doors, the retractable roof, the luggage compartment door and the low-stressed parts of the body, such as the roof, the front and rear end skirts and similar parts, are all candidates for the use of alternative materials. As already noted, the no-rust factor and the possibility of integrating individual components argue more for plastics than weight reduction does, since lower stability must be compensated for by using a greater quantity of plastic. There are still many arguments for using sheet steel in the body panels, including lower costs, proven methods of production, good surface qualities, greater stability and energy absorbtion, adequate supply, and relatively easy repair and recycling.

Especially good alternative materials are available, however, for mechanical components, such as engine parts, chassis parts, links, casings and similar parts. Heavy forged and cast iron parts, as well as molded zinc parts, are especially good candidates for replacement by new materials since changes here could yield really significant weight reductions. However, there can be problems with plastic mechanical parts because of their higher susceptibility to fatique or unsuitable point loads and anisotropy.

Until recently, two-thirds of all the synthetics used in cars replaced traditional materials such as felt and other textiles, wood, conventional insulation and upholstery materials. Only one-third was used to replace metals. Today, synthetic materials already account for two-thirds of the interior fittings in passenger cars.

4. MODULARIZATION AND INTEGRATION – THE ART OF PACKAGING A CAR

4.1. Traditional Design Work

Section 2 examined the long process that precedes the "birth" of a new automobile design. This section focuses on the most critical part of that process, namely the design and engineering phase. It is here that components from the technology shelf are assembled into a new car to meet previously agreed upon structural requirements and thereby, to create the elements of market success. A second and even more important task is to design a car so it can be produced at low social and economic cost. Here, the company's engineering staff must make the decisions. No marketing or finance department can offer any guidance in the critical choice of design solutions and components. The management of the engineering and design department carries the sole responsibility for how well the product fulfills the qualities which marketing research indicates should best secure customer acceptance and make the car competitive. Risk-taking is also at its height during the design phase, as costs can grow rapidly, and there is still no income from sales. ***Figure 12***, for example, shows the development costs for Volvo's 760 model prior to the beginning of series production. The hypothetical graphs in ***Figure 13*** show how essential it is to achieve strong sales quickly and to avoid "childhood diseases" if development costs are to be recovered within a reasonable period.

The last ten years have brought some radical changes in the methods used in the design and engineering phase. These changes have already been discussed in the description of the pre-development phase. The latter is a function which hardly existed earlier, when a series of static design steps between the first design sketches and the final version of the new model were used instead. After specific problems had been identified and overcome one by one, a final version of a new model was approved, which was then sent back to the design department, where more detailed corrections were made, and the special tools or molds needed for series production were designed. The first version of the new model often needed yet further modifications to compensate for problems that arose in series production and/or became apparent only after extensive consumer road use.

Design and engineering took a long time and quality control, production reliability and efficiency often suffered in the process. As a result, the cars were heavy and made little use of available space. Production and labor costs were also unnecessarily high. It was often necessary to improve the product several times, and then to modify the production process according to the

4.2. From Prototype to Mock-Up

The most difficult phase of the job – the very heart of car design – was "packaging", the process of finding space for all the components, interconnecting tubing and cables that are fitted inside the cavities of the car body. Packaging also includes designing the consoles and fastenings. Packaging must be so planned that are no encroachments on the space foreseen for passengers and luggage, and that rapid, ergonomically acceptable assembly is possible. Finally packaging should be so designed that components are reasonably accessible for service, and that no special, highly sophisticated tools are needed for normal maintenance and repair jobs.

Originally, packaging was done by merely building a prototype body around the heaviest components, and then putting in the other components step by step until each part was in place. This work was often relegated to a highly skilled automobile designer with a special talent for the job. Extremely beautifully and efficiently packaged cars can still be found, but, as a rule, they are either custombuilt or experimental models which were never intended for series production.

Later, exterior design became a matter of great importance. Today, instead of first building functioning prototypes, the model department makes mock-ups of plaster, or wood, or other modelling materials. The detailed reproduction of exterior details is stressed. The automotive engineer has moved into the office to find ways to realize the exterior designer's visions by working at a drawing board. Now his job is to adjust the design of the technical components to fit inside the dimensions of the exterior design. Aided by simplified mock-ups, he can determine if the heavier components will have enough space. But the design of the exterior lines has priority and there is no time or place for detailed packaging work until after the exterior work has been finished.

In the past, once the production engineer came into the picture, many details were rejected as unreasonably expensive. Naturally, the resulting redesign work also influenced the packaging. The final solution was often a bad compromise, since so many ad hoc decisions limited manuevering room. As automobile designs became more complicated, it became increasingly difficult to achieve good packaging. Many of the cars produced in series after World War II are frightening examples of badly done packaging. The Saab 9000 (see *Figure 14)* provides a good counter example: its packaging design is so good that even laymen can recognize it immediately when they look under the hood.

4.3. From Mock-Up to Data-Based Mathematical Models

The development outlined above was made possible by growing markets, where long life cycles for the vehicles could be expected. The oil crisis of 1983-84, which followed a period of increasing saturation on the Western markets, radically changed conditions for competition. The length of time needed for designing, engineering and testing a new model until it is ready for mass production, has become a main element of success. The design method introduced in the mid-1970's is based on a new technology that differs greatly from its predecessor. Its most characteristic feature is the use of mathematical models, which describe not only the geometrical shape of the car but also how the various components will interact dynamically when the car is driven under different road and traffic conditions by different drivers. The models are programmed for and run by computers. Already at an early stage, the engineers can adjust the design to conform to customer demands, legal requirements, available industrial facilities, and production technologies.

This method of conceptualizing a car as a computer model has several advantages. It is easy to give everyone concerned access to the same information at the same time, since model descriptions, statistics, and estimates can be quickly printed out or viewed by other project participants on their terminal screens. By comparison, a real model or prototype can only be made available to a few persons at a time, and considerable waiting times are often involved.

With the new design method, development time can be dramatically shortened. A computer model is ready for use as soon as the designer has submitted all the data. Building even a simple mock-up, on the other hand, may take up to several months. Computer models do require great effort in the initial development phase, but once that work has been completed, models can be changed much faster, easier and more economically than new mock-ups or prototypes can be produced.

With mathematical models, designers and the development engineers can interact directly, beginning with the conceptual stage of designing the car. Furthermore, the models are so precise that the construction of the necessary presses, tools and moulding forms can be begun during the early phases of designing the new car. The broad outlines of the production system as a whole can be defined early, thus reducing the time needed to execute any necessary production changes, and increasing the likelihood that the new model designs already incorporate optimal production techniques. Production lines can already assume final shape, and assembly lines can be simulated. When mathematical models are used, as much as 80 percent of all necessary calculations can be made before the first prototype is built. Since all possible restrictions can already be known during the initial development phase, improvements can be made without necessitating changes in the production equipment.

Computer Aided Design is a revolutionary new method, and as such offers so many new possibilities that it will may take a long time before it can be developed to perfection. In itself, CAD represents a form of product development with its own learning characteristics. The first stage of that learning process started in 1974-75, when the method first began to be applied and ended when the first car developed entirely with the CAD method was produced in series. Of course, it is practically impossible to identify a single car model that deserves that distinction. When General Motors presented its "X-Car" in 1979, it was promoted within engineering circles as the first American car to be developed by consistent use of systems engineering methods. The initial development stage had taken a long time, since the method development and product renewal had taken place simultaneously. Later stages of development, of course, went much faster.

A new method in itself is no guarantee that the final product will be good. "X-Car" is not considered a good car, perhaps because the engineers at General Motors concentrated on the design method at the expense of the engineering and designing art. Smaller, more flexible companies were not so quick to abandon traditional design methods after the new method appeared. This is also true of the Swedish car companies, and especially Saab, where development is still performed by a small group of skilled designers. In Japan, the decision to adopt the new design method coincided with a strong drive to recruit university-trained technical personnel in the 1970's. The Japanese car industry suddenly had a whole generation of computer-trained engineers and designers at its disposal who greeted the new method and naturally, found it easy to work with. It is no accident that the development of a new model, which may take up to seven years at Daimler-Benz, can be accomplished at Nissan in three.

Later, the learning process will be discussed in more detail, but first the different parts and ideas of the new design method should be examined. It may be said that computerized design has four parts: Three are concerned with design and engineering and the fourth, with production. All four handle mathematical models with computers, and have CA (for "Computer Aided") as the first element of their American designations.

4.4. Functional and structural analysis

CAE (Computer Aided Engineering) enables the analysts to estimate and simulate a car's reactions and movements during driving, and, by employing structural analysis methods, to estimate mechanical strains in each part of a car. A simulated crash offers a good example. In this case, one must be able to predict how different masses will move in relation to each other, and how various impacts will deform different parts of the car. This information plays an essential role in the safety philosophy, first introduced by Mercedes and further developed by Volvo, that seeks to protect the passengers by encasing them in a stable, crash-proof "cage" with shock and energy absorbing "deformation zones" on all sides.

After a long development phase, the industry has finally solved the problem of when to perform the structural analyses correctly: It should be done between defining the specifications for a new car and constructing the prototypes. Coordinating the design process with the handling of the computer programs is especially important as optimal connections between the various steps in the process can minimize the amount of information handled and thereby save much time and expense. Powerful, specialized program packages are being used that make it easy to divide components into small parts. Such programs also make it possible to choose between analyzing each component individually, a group of components, or the entire vehicle.

Similarly, new methods that facilitate the simulation of vehicle behavior on the road greatly influence the entire design process. Computerized simulation tests using mathematical models permit a more thorough and economical study of a prototype. Normal testing can only be conducted after a prototype has been designed and built. Moreover, real tests are both time-consuming and costly. The ability to draw far-reaching conclusions about the handling and driving performance of a car based solely on computer calculations is very valuable, as it greatly reduces the risks and allows a fast training of the goals in the development work. A change in the professional background of the engineers is partly involved, and can be met either by providing computer analysts with special education in vehicle technology or by recruiting automobile engineers with sufficient computer science background.

In addition to these general tools, there must be computer programs that can deal with specific calculation problems such as the following:

- The introduction of new materials.
- The analysis of complicated dynamic phenonomena which affect driving comfort as well as the fatique of welded assemblies.
- Anelastic behavior in materials which are subjected to large deformations by impacts.
- Acoustic analysis of the interaction between body shape, body panels and engine space.
- Thermal problems in components such as the brakes and in the exhaust system.

4.5. Computer Graphics

The designer's drawing board is rapidly being replaced by the CAD (Computer Aided Design) terminal desk. The body of a new model now takes shape on the computer screen with the aid of programs that project the desired geometrical forms on the screen on command. The transformation of these forms to mathematical models is especially important. These models can provide a three-dimensional description of all the details either individually or in connection with the entire vehicle. The development of such models began with simple, so-called "line models", which describe a detail by approximating its edges with a number of straight lines. The next step was surface models, which work, as the name indicates, by describing the outer surfaces of the detail. Now volume models are being developed and used, which can not only register surfaces but also check whether a particular point lies inside the detail or not. The volume model program also enables the computer to calculate if a line or a surface is covered when it is observed from a certain angle, which in turn enables the computer to make perspective drawings of the detail, which can be rotated, reduced or enlarged according to need. In research laboratories there are already mathematical models that make animated movement possible. The impression of real movement can be further enhanced by varying the color intensity on a lighted surface according to the incoming angle of the light and by showing how the shadow of the detail moves on the ground.

Using models that simulate animated movement, a designer can inspect, for example, how pistons, piston rods and crankshafts will work. Using CAE and CAD simultaneously to create a simulated model is especially interesting. Theoretically, it is possible to ascertain how components will interact dynamically in reality and to present the results in animated form on the computer screen. The animation can be done so realistically that it can hardly be distinquished from a film. This possibility, however, is not practically useful. From the practical standpoint, the most interesting features of CAD-CAE are the possibilities for enlarging details and achieving an accessibility that is difficult to get with real tests. In the above example, the model can be enlarged so that it is possible to observe any play between the piston and the cylinder wall and to decide if the clearance is large enough. The possibility for intentionally exaggerating a particular movement in order to observe some detail better is also of value.

Naturally, the advantages of a model must be seen in relation to its development costs. Moreover, functional safety can seldom be guaranteed unless all the conventional technical tests have also been carried out. Nevertheless, in the long list of engineering problems that must be solved, there are, however, several which can be handled very quickly and easily with this method. One example is a test that checks how air and watertight car doors are while the car is being driven on an uneven road. (The movements that occur in a car body under such conditions are much higher than generally imagined.)

4.6. Experimental Testing

Before the mid-1970's, the testing of prototypes and their driving qualities was quite limited during the development phase, except for separate tests of the engine and transmission. Since then, gradual improvements have led to more extensive testing of separate components and groups of components both in the laboratory and in real driving environments. Most automobile companies have built imposing test tracks where various road environments can be simulated. Sporadic, poorly planned driving tests of a few prototypes have been replaced by systematic, integrated testing programs, which include all the technical systems and components. Naturally, more extensive testing increased the need for computer-aided data processing, which led, in turn, to CAT (Computer Assisted Testing).

CAT has resulted in the development of rapidly growing computer data banks, which can describe various driving environments in great detail, or indicate how components or sub-systems will react in different environments. The CAT data banks are becoming effective tools for calibrating and validating the simulation models being used in design work. These possibilities, in turn, can radically shorten the time needed and thus diminish the development costs for a new model. Predevelopment and actual design work are merging as they are now done in a similar way.

In the long run, the advantages of scale which exist today in the design and engineering of automobiles will largely disappear, except perhaps for those for engines and transmissions.

4.7. Cooperation Between Designers and Manufacturers

By combining CAD, CAE and CAT an abstract world can be created, in which cars can be designed and tested in radically different environments. In principle, computerized design, engineering and testing techniques could be perfected to a level where it would be possible to simulate the car and its environment so realistically that the uninitiated might believe the car actually *did* exist as a physical object in a real environment. However, the large computers and extensive programming needed for such combined applications of CAD, CAE and CAT still make the costs prohibitively high.

The possibility for storing detailed data on an abstract car in computer files for subsequent direct use by the production system has led to an even more dramatic change. The evolutionary development in production has been equally rapid. It started with the introduction of numerically controlled (NC) machine tools, which made use of specially developed electronics to operate lathes, milling machines, or saws by means of data recorded on punched tape. The next step was to have the necessary data generated by the computer, which eliminated the need for manually punched tapes, and paved the way for Direct Numerical Control (DNC). Further development involved combining the computers for design and production into CAM (Computer Assisted Manufacturing), which enables production engineers to receive continuously updated information and basic data for the production of both the prototype components and thetools for mass production via their own terminals.

As noted earlier, the abstraction process makes it possible to combine a great many functions. Instead of performing each task in sequence, which leads to an unacceptably long total development time with a significant risk of something going wrong, all functions work side by side in their own area of responsibility within a uniform CAE-CAT-CAD-CAM system with a common database. Whenever a design change is made, all the data files are automatically updated for all parts of the system, which insures that all development sectors have access to the same, up-to-date information. *Figure 15* is an attempt to illustrate this giant cooperation, which is capable of radically shortening the time needed from the first rough demand specifications to the delivery of series produced cars to the retailer and the consumer.

4.8. Functional Orientation as an Organizational Base for Modularization and Integration

How can such cooperation be structured to facilitate supervision and rational division of labor? There is, of course, no patent solution. Building a car with the aid of computers will remain to large extent an engineering art. There is still a need for a small group of talented, highly skilled key individuals with an intuitive feeling for organizing their work. Some guidance can be obtained by looking at how systems development is being handled in other branches with experience in working with computer design. Since no branch can be expected to have more experience than the computer industry itself, obtaining more experience about computer development practices is a good policy.

The basic philosophy of proceeding from the whole to the parts and then back to the whole again has already been described in Chapter 2. The *functions* that must be incorporated in a car and that characterize the car as a product are identified. Similarly, all the functions that are needed in the the production process are identified. A particular person is appointed and made responsible for formulating operations and implementing the related functional demands. These persons are then involved in an intensive interaction, which can be characterized as a discussion game. The game constantly revolves around the specifications that describe the relation of a particular function to its environment. The process begins by making rough descriptions of the user-related qualities of the car and of the prerequisites given by the organization's competence, financial capacity, production facilities, etc. The next step is to isolate and refine each of the specifications, while simultaneously identifying the systems and components that constitute the design of the car and its production system. As the process continues, responsibility for various groups of functions can be divided step by step and individual designers can be set to work on technically well-defined sub-systems and components.

Obviously, the resulting hierarchy should be as simple and easy to supervise as possible, a requirement which sometimes leads to practical problems. The functional responsibility assigned to one division may partly belong to another division since functions may interrelate in complex ways. Interrelated functions are difficult (if not impossible) to fit into hierarchical structures, and therefore cannot be effectively handled in the hierarchical decision-making process. The solution lies in giving *total* rather than *partial responsibility* to those involved, which also includes identifying how a particular function is related to others. As in many other areas, car design has now become so complicated that no single engineer can possibly supervise the entire process in detail.

How can it be determined if the engineer responsible has defined and isolated a particular function correctly? Every function in the finished car has its counterpart in the form of a number of components. Two indications for how well the engineer responsible has succeeded is 1) *the level of integration* and 2) *the degree of modularization*. The level of integration measures the degree to which several functions have been combined in shared components. A high level of integration means a smaller number of components in a car. A high degree of modularization means that the car has been hierarchically designed around groups of components united by simple connections. In both cases, the packaging of the car will have been greatly facilitated, which, in turn, makes production and service easier. Thus, the packaging of a car indicates how well the design and development work has been done. A high degree of modularization also simplifies the flow of materials in production and creates greater possibilities for sub-contracting the design and development work.

5. SOLUTIONS FOR THE DESIGN OF AUTOMOBILES AND AUTOMOBILE PARTS – SOME RECENT EXAMPLES

5.1. Fiat's New 1-Liter Engine "Fire 1000"*

Fiat, in cooperation with Peugeot, recently developed "Fire 1000", a new one-liter engine with a very simple design. The name is an acronym for Fully Integrated Robotized Engine. In this case, ***robotized*** means that the engine has been especially designed for production on a highly automated, robotized assembly line.

The lubrication unit for the "Fire 1000" engine provides a good example of integrated components. The oil pump, the pressure reduction valve, the oil filter and the distribution lines have all been placed in a metal housing which is then bolted onto one end of the crank case. The fuel pump and the ignition distribution have also been integrated. Both are located on one end of the cog-belt-driven, top-mounted camshaft. Compared with Fiat's old 1050 cubic centimeter engine, the new "Fire 1000" engine has 30% fewer parts and weighs only 69 kg, – i.e., 27 kg less than the old engine.

5.2. Platform design à la LCP

The LCP participants decided to develop the so-called platform concept further. This concept offers great advantages both for production and final assembly. The platform, which forms a structural, load-carrying bottom plate, consists of the floor, girders, the wheel house, and a middle beam. The bottom plate, which is assembled on a separate production line, serves as the base for all the interior fittings, such as seats, panels, dashboard, steering equipment and cable mats. The roof, ceiling and the electric components are added to a separate roof frame.

The bottom plate and roof sections arrive on the assembly line as pre-assembled units. Through the choice of A1-6000 quality aluminium for the structural elements of the bottom plate and the roof section, these parts have already been protected against corrosion. For extra protection, the floor section is spray-coated with polyester to prevent erosion. The bottom plate is positioned at a convenient angle to allow pre-assembled chassis components such as the wheels, wheel suspension, suspension system and drive line to be attached to it.

At this stage the car can be started and all the electrical components can be tested before the car is driven to the wheel adjustment station. All test results are stored in a computer. Quality level checks are carried out, adjusted whenever necessary, and recorded for each of the main operations, bottom plate, roof section and final assembly. The bottom plate and roof sections are then united in an automatic welding jig. Before the outer panels are assembled, all remaining electrical components are tested. Finally, the outer panels, the windshield and side windows, and the doors and rear hatch are assembled on a separate production line.

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* The author is indebted to Maasing (1984) for the information in this section.

In comparison with traditional designs and production methods, this design concept permits the preassembly not only of more chassis and interior fittings, but also of a considerably larger part of the vehicle body. *Figure 16* indicates the order of assembly.

5.3. From Bearings to Bearing Units

Integrated vehicle bearing units (SKF 1982) have undergone rapid development during the last 15 years. Several requirements lay behind this development:

- Both the necessity for frequent service and concomitant maintenance costs should be reduced.
- The life of the bearings should be extended by making closed units which never need to be touched again once the vehicle has left the factory.
- The number of components should be reduced by combining several functions in some components.
- The total weight of the bearing and its components should be reduced.
- The total costs for supply and assembly should be lowered.

For several decades the standard front-wheel drive design has included two conical roller bearings, consisting of a total of eight parts if the lubricant is counted as a separate component. These parts were previously assembled on the spot and lubricated in the factory by the automobile company, which was also responsible for correctly adjusting the bearings. Undriven front wheels were similar in design but had fewer components. The first change came in 1936 when SKF made a pre-adjusted bearing unit for the Citroen Berline. After the war, this unit was developed into "Hub Unit 1" and introduced in several front-wheel driven cars. The "Hub Unit 1" concept achieved a real breakthrough during the 1960's, when Citroen, Peugeot, VW/Audi and Fiat employed it in their new models. It contained a two-row angle contact bearing and was factory adjusted. In the first version of the design, the unit was delivered without sealing material, which meant that it still needed to be lubricated in the factory. Later, permanent sealings were introduced, which meant that the unit then incorporated three functions besides the basic function of the bearing; pre-adjustment, sealant against moisture and dirt, and lubrication for the lifetime of the part. The number of parts for the front-drive wheel had been reduced from eight to two – i.e., the unit itself and a locking ring.

In undriven wheels with a rotating outer ring, a parallel development took place which led to "Hub Unit 2", which has a flange for assembling the brake disk and wheel. This design has now been in use for more than ten years in several cars. Everything indicates that it will become the standard design for undriven wheels.

The interest in the 1970's for compact size and reduced mass gave the signal for further design developments. The result was "Hub Unit 3". Here both the outer and inner rings of the bearing have flanges. The outer ring has been transformed into a stiff bearing part to simplify the shape of the steering spindle house. The hub has been replaced by the rotating inner ring flange. "Hub Unit 3" has simplified design and assembly, and conserves weight and space. Since the two rings are stiff, the bearing geometry cannot be influenced by the components around the assembly. The photos in ***Figures 16-18*** show how the design of the front wheel drive hub was simplified step by step. The most recent applications of Hub Unit 3 and Hub Unit 2 are in the Saab 9000, where designers succeeded in finding a very compact solution for both the front and back axles.

"Hub Unit 4" represents the last step in hub development. The torque from the engine is transferred via the gear box and the cardan to the driving wheels by a number of shafts. In a modern front-wheel driven car with transverse engine, the engine, gearbox and cardan are built together to a compact power plant. Since the wheels move up and down during driving and rotate in the horizontal plane during turns, the driving shafts between the cardan and the wheels must have joints which allow angling of the shaft relative to the power plant and the wheels. Four joints are necessary, two on each side of the power plant. For a long time the drive joints were a problem for front-wheel drive since it was difficult to make them last, especially in cars with strong engines. Because of the short distance between power train and the wheels the angles become large. Therefore, it is necessary to make the joint so that the shaft moves with exactly the same angular speed going in and out, which is not true for a conventional cardan joint. More complicated designs are used instead. A standard joint is the Rzeppa joint which was developed both in the USA and Europe in the 1930's and is based on a 1928 Czech patent. The basic idea in Hub Unit 4 is to integrate the outer driving joint in the bearing unit, which then assumes an additional function. The Formula 1 racing car **Talbot-Ligier** has such a unit, which is shown in cross-section in ***Figure 20***. The Talbot-Ligier unit is an extreme design in which the designers economized on material thickness and made cut-outs in parts not subject to high stress, in order to keep the total weight as low as possible.

The development of bearing units can be seen as proof that sub-contractors can be included in the CAE-CAT-CAD-CAM system. To convince themselves and the automobile industry that the Hub Unit 3 could satisfy the given requirements, SKF built a test rig, which is shown in ***Figure 21***. Since the hub unit also includes the functions of many other components, it is no longer merely a bearing but is classified as a safety critical component, i.e., a component that must never fail, even when the car itself is subjected to extreme driving conditions. The designation "safety critical component" also means that the unit must pass a strict, realistic test program before it can be used in series produced cars.

In this respect, Hub Unit 4 represents a further challenge. It is, of course, already classified as a safety critical component, and its development required large investments of time and money. The process began with function tests with complex equipment for static loads at SKF's Engineering and Research Center. Recordings of real loads from extreme test driving as well as normal driving were used as a basis for the tests. The next phase included dynamic tests of bearings, bearing details and the drive joint. During 1983 dynamic tests with a simulator built especially for that purpose started, as shown in ***Figure 22***. The simulator facility has two powerful computers, which can analyze recordings of wheel vibrations in actual road driving and then use these to produce one or several suitable driving cycles for the test rig. This is then transformed into control signals that are stored in the disk memory of the computer that supervises the test facility through analogue electronics. Some indication of the complexity of the tests can be seen from *Table 4* which defines the six system parameters that can be varied independently of each other during a test. *Table 5* lists 40 different measurement devices, which continuously monitor the test.

Testing equipment of this type can generate enormous amounts of information in a short time. Since the testing equipment is available from a highly specialized sub-contractor who operates on world markets, the information thus gained soon spreads to the entire industry. Of course, the value of such testing devices tends to decrease once the test results have been assimilated and integrated into the abstract world of the CAE-CAT-CAD-CAM system. With the transfer of this information, it becomes possible to test an integrated, safety critical component, such as the SKF Hub Unit 4, even before it actually exists.

6. AUTOMOBILE PRODUCTION – FROM THE DRIVEN LINE TO FLEXIBLE AUTOMATION

6.1. A Short History

This chapter considers the car as an object of production, and begins with some historical observations. The history of the automobile has been greatly influenced by the arts of mass production and design. The car was invented in Europe, but for many decades remained an exclusive article, built by hand for a limited number of wealthy customers and automobile enthusiasts, located primarily in France and Germany.

The turning point came in 1908 when Henry Ford introduced the Model T. Ford combined a number of new ideas in production technology and materials which simplified production and kept costs low. Compared to earlier designs the Model T was also better adapted to primitive road conditions and the necessity for keeping maintenance and repairs simple. The ingenious design of the Model T was improved even further several years later when Ford introduced a new production system, which combined many years of experimentation in two different aspects of production. New handling equipment, which facilitated the continuous flow of materials in the assembly process, was combined with a thorough scientific grasp of how complex work routines could be divided to place well-defined demands on skilled workmen specially trained for particular tasks.

With this new system of social organization and material handling, known today as the "driven assembly line", Ford led the car industry into the era of mass production. Production rose from 10,000 Model T's in 1908, to 30,000 in 1914, when the assembly line was introduced. Further expansion was made possible by repeatedly lowering prices which led in turn to increased sales volume and reductions in the production cost per vehicle. Model T sales reached an all-time high in 1923 when the total American production reached 1,9 million vehicles. That was 44% of total world car production for that year. Other American manufactures, including General Motors, produced an additional 2.1 million vehicles, which made the American automobile industry responsible for 91% of total global car production in 1923. General Motors' rapid growth, which led to production figures exceeding even Ford's, was made possible by Alfred Sloane, who developed the decentralized organizational models which made it possible to manage giant companies in the automobile industry efficiently.

The next dynamic period of development came in Europe in the Fifties and Sixties when increasing prosperity and the removal of many market barriers created favorable conditions for the quickly growing inter-European car market. Because of that expanding market, European automobile companies were finally in a position to take advantage of the economies of scale inherent in mass production. The strong product diversification of European automobile manufacturers, originally motivated by the diversity of their national markets, made European cars competitive with the large, standardized American cars. With its broad palette of small, fuel-efficient cars, the European automobile industry quickly advanced to a leading position worldwide.

The third revolution came with the advance of the Japanese car industry in the 1970's. From a modest start in the 1950's with technically inferior models, the Japanese gradually improved their vehicles until by the late 1970's they had become thoroughly competitive with European and American automobile producers.

Their first successes were based on small cars and later, on middle-sized cars. When the energy crisis came, the Japanese automobile industry was prepared for it with a product palette that was well adapted to the sudden demand for smaller cars with better fuel economy. However, it was not so much the product as the excellently efficient production system which enabled the Japanese to make record export advances during the 1970's.

By the early 1960's the structure of the Japanese car industry, with its solid financial base and strongly interrelated groups of companies, had crystallized. Solidarity within the companies was supported through company-based workers' unions and contracts for lifetime employment. It was further encouraged by "quality circles" and other methods that involved the workers in the success of their companies' products. Two new concepts appeared in the automobile branch, "Just In Time" and "Total Quality", which applied a strictly logical view of production from the flow of materials (from many sub-contractors) to the final assembly of the car. The process included the inculcation of quality consciousness at all levels, and permitted, in principle, no errors. Each sub-contractor was responsible for the quality (ie., the accuracy with which the design demands were executed) of all the components he supplied. This method eliminated both the need for extensive quality control upon receipt of the components and interruptions in production caused by rejected deliveries. "Total Quality" also meant further economies since the small armies of controllors and adjusters, which one still finds in European and American automobile plants, were no longer needed.

These methods and systems developed on a rapidly expanding home market during a phase of strong internal competition between industrial groups, and resulted in a very high productivity for the whole branch and lower per unit costs than those of most car producers in other countries. Characteristically, the superiority of the Japanese industry was achieved through administrative measures. Production technology as such had been adopted from the American and European automobile industries and was still based on the assembly line principle.

The fourth revolution, which is now sweeping the car industry, is dependent on new technology. It is based partly on computerized design, development and production, and partly on the great changes occurring in the production system itself. The long, straight, mechanically driven assembly lines made famous in Charlie Chaplin's *Modern Times* are no longer the obvious starting point for large volume car production. Later in this paper, these tendencies for change will be discussed in more detail, but first, it is necessary to examine traditional automobile assembly.

6.2. Traditional Series Production of Automobiles

Figure 23 shows a typical automobile production system in simplified form. The diagram is based on the classical division into several, often geographically separate production units; one for body production, one for final assembly, and at least one for the production of the engine and transmission. This division has always existed since the materials and production methods used for the drive line were always very different from those in the rest of the car.

The parts for the driving package such as the cylinder block, cylinder head, pistons, crankshaft and crankshaft house for the engine and gear box house, as well as the parts for the suspension of the wheels, such as stiff shafts, steering spindles, and brake disks and a row of smaller details, are made at the *foundry*. Cast iron and steel still dominate, but the use of aluminium is increasing, especially in cylinder blocks and heads. As noted earlier, although magnesium is an interesting material for forged details, it still cannot compete in cost with more traditional materials. The *forge* is used for manufacturing a number of parts which are subject to great stress, for example, the piston rods, and links in the wheel suspension. In many cases, casting and forging are alternative production methods.

In the *machine shop*, the cast or forged parts are refined until all the vital measurements are correct. Cylinder bores, bearing seats and other surfaces with special functions are ground. The cog-wheels for gear boxes and other mechanical components in the driving package are also treated in the machine shop. Cogs and other parts that must be especially hard are tempered in the machine shop. In the *engine shop*, the basic engine and the gear box are assembled. Thereafter, the auxiliary equipment necessary for the function of the engine is assembled onto consoles or directly onto the engines. Engine-driven accessories, a servo-pump, for example, is then assembled onto the engine.

In the *press shop*, the profiles and panels which are the building elements of the body are formed. Large presses which can exert pressures of up to 15,000 kN make it possible for whole sides of the body to be pressed in one operation. In the *body shop*, the outer contures of the car are assembled. The selfbearing body is assembled in a welding operation with alternate spot and arc welding. Finally, the body frame is adjusted, shaped and ground. This work is of great importance for the appearance of the finished car. Automobile producers who strive for a reputation for high quality and fine finishes must invest great effort in this stage of the job.

In the *final assembly* the pre-painted body is equipped with all the hundreds of details which appear on the finished car. Before the car leaves the plant it goes through a *final check* stage where the front end is aligned, the headlights are adjusted and certain functional tests are performed.

Final assembly is the section most closely associated with the classical notion of the driven line. The term *driven line* generally refers to a number of activities performed in series, where each activity includes one or more well-defined operations on a basic object, which then progresses at a previously determined pace to the next station. The continuous mechanical transfer of the basic object, i.e. the car in construction, from one station on the assembly line to the next is the backbone of the complex final assembly. *Figure 24* shows some of the main elements in final assembly. The example used is the same as that in *Figure 23*. (The car being produced is a vehicle with front-wheel drive.) The marriage point at which both back shaft, engine, transmission and front shaft meet the body has been especially emphasized.

For the engine to match the body it is necessary to synchronize the body line and the engine line. If the line is divided into various parts and each part is allowed to proceed at its own pace, a need for buffers is created, both between individual parts of the line and all marriage points affected by the division.

In *Figure 23* the arrows show the flow of large and small components to a great number of points along the line. In Ford's initial system, most assembly work was done in direct connection with the line. As designs have become more complicated. there has been an attempt to integrate and modularize many of the small material flows to certain pre-assembly stations. This development has increased flexibility to a high degree, and conditions have been created that permit some tasks to be done at an earlier stage. Other consequences include the shortening of the final assembly line and the simplification of material handling. For example, many variants can be handled. Pre-assembly can take place near the line, at another place in the same plant, or at another location. In the example used here, engine and body production are in direct contact with each other. In reality, it is more common to find them separated. The possibilities for pre-assembly mean that a larger part of the assembly work can be performed by sub-deliverers.

6.3. Robotization and Flexible Production

Traditional production systems, such as those described above, have been in existance for seventy years. During that time many operations have been mechanized or automated. With the technology previously available each line was designed for a limited number of car models. By the early 1970's the cost for rebuilding production lines for new models had risen so high that it seemed obvious no company would be able to afford more than a small number of large scale production plants at which a few versions of so-called "world cars" would be produced in a never-ending stream. From the beginnings of the industry, production had progressed from individualized, handmade cars, to highly mechanized assembly lines with many semi-automatic operations, to rigid, extensively automated production lines.

The trend towards even more rigidity and the "world car" came to an abrupt end when the rapid growth of computer technology began to offer new possibilities for more flexible automated lines. Industrial robots in the form of mechanical arms have become symbolic of the new trend. These mechanical arms typify the type of robot most often used in car production. ***Robotization*** means however, not only the continued use of such robots, but also of all types of automated production equipment that can be re-programmed for different jobs.

Of course, one of the incentives for mechanization and robotization was, and is, to reduce production costs. Another incentive, which has attracted much attention, is the possibility of eliminating jobs that are dangerous, dirty, extremely hard, monotonous, or somehow unsuitable for humans. The first jobs to be automated in car production were of this type. Later, a third incentive achieved importance: the possibility of achieving a product of even higher quality through the use of robots. As robot technology becomes increasingly refined and robots can work with even greater precision, this argument will become even more important. At present, a break-through with "seeing robots" is occurring. The ***idée fixe*** of always having robots imitate the motion of the human arm has also begun to fade, and many other solutions are evolving. One example is a movement pattern combined with a tool-holding or assembling robot which holds a basic object in a desired position by means of a jig, clamp, or other aid. Another new application is to use small robots to steer heavy traditional handling equipment. By using a robot it is possible to achieve a servo effect, which enables a small, cheap robot to handle enormously large loads with great precision. To imagine the full scope automation may reach – all the combinations and applications of computers and robots which are or will soon be possible – requires much fantasy.

Robotization is now being introduced into all phases of car production. A survey, which was carried out as part of the Future of the Automobile Program (Appel and Hilber, 1984), queried experts in Japan, Sweden, Italy, Germany and the USA about the degree of robot use they expected for the future. Their replies were very similar, although no estimates of the number of robots already in use today were given. ***Figure 25*** shows estimates of how many jobs within different phases of production will be robotized by the year 2000. Nearly all spot welding, for example, will be done by robots. The system for inspecting the quality of welded joints, which is now in experimental phase in laboratories, can be expected to be in general use within a few years. This fact also explains the high degree of robotizing in arc welding. Similarly, "seeing robots" can be expected to play an even greater role in assembly work.

In many cases, of course, production technology will have to be adapted to the special conditions created by robotization. Adaptation will be especially necessary if demand for flexibility is high. One example is the paint shop, which was one of the first areas to be automated because of the health hazards caused by paint fumes. Electrolytic baths replaced spraying as a method for applying the undercoating, which is generally identical for all models and variants produced. For the final finish electrostatic methods using completely robotized operation of the spray nozzles was introduced. This technology, in turn, necessitated new, easy-flowing paints. By attaching different nozzles to the robots' arms, colors can be changed on short notice.

Another factor which contributes greatly to the robots' popularity (with management) is that they need not be taught to work. Once programmed, a robot can perform its job at the same high level indefinitely.

On the other hand, the stabilizing influence and continuous quality control exerted by human operators should not be underestimated. It is not yet fully clear how technical disturbances in a fully automated production should be detected. How should tasks such as those performed by Japanese quality circles be performed in highly or completely automated production units? Isn't industry expecting too much of the the production engineers who program the robots and design the new production lines?

Robots alone cannot offer maximum flexibility. Even in the initial planning stages for new production systems two sorts of investments, ***type-independent*** and ***type-bound***, must be handled separately. Type-independent investments can be used in the production of many different models over periods of many years. For this reason depreciation can be spread over longer periods and great advantages of scale can be realized. By contrast, type-bound equipment is especially designed for each model, and must be constructed so that it can be quickly and easily substituted for a counterpart used for other car models. Furthermore, type-bound equipment is also characterized by a high degree of changeability. Type-independent equipment must be so flexible that it can handle both the changes from one car model to the next, and a growing number of variants of the same model.

Examples of type-independent investments would include computer hardware and non-specific software, autocarriers and other handling equipment, and welding robots. Examples of type-bound investments would be the jigs, and pallets for basic objects or other heavy components, and the software for type-bound robot welding programs. It is obviously desirable to keep type-bound investments to a minimum: They should never represent more than 20% of the investment costs for a production plant.

Flexible production plants offer many advantages in comparison to traditional plants. Type-bound equipment and software can be introduced in a particular order without stopping production, thereby reducing assembly time losses considerably. The use of type-bound equipment permits the production of many different models at the same time. As mentioned, the lifespan of type-bound equipment is no longer coupled with the lifespan of a particular model as it is with type-independent equipment, which means that models can easily be added to or deleted from the production palette.

Type-bound equipment also solves many accessibility and maintenance problems. An important aspect of flexible production plants is that production is modularized. A defective welding robot can be quickly and easily replaced by a reserve robot, for example, or a particular robot can be used at several different work stations, which not only optimizes use, but also leads to significant savings on spare parts. These plants also allow for tasks to be shifted from one work station to another, which means better utilization of both men and machines.

6.4. Production Development and Production Preparation*

According to recent trends, production systems must be designed so that a broad assortment of different bodies can be mounted on the chasssis of a number of basic model designs. These must have a common design to such an extent that considerable advantages of scale can be realized. Such advantages of scale can be achieved by designing models with extremely simple, yet highly standardized mechanical structures that can be "refined" or supplemented later by adding integrated groups of components or pre-assembled modules, produced off-line. The Volvo LCP 2000 and some of the other experimental cars described here were constructed according to the principle that the basic model must permit quick, easy substitutions.

A vertical disintegration of the production system, similar to the above developments, is taking place, in which the line is being increasingly divided into independent sections. Within each section there is a horizontal integration of many types of activities into tasks which are being performed by functionally coordinated groups. How this system works will be examined in detail in the next chapter. Logically, the classical production system can be described as a continuous chain of simple functions which together form a complete, vertical cycle. The new system with its functionally coordinated groups can be described as a number of parallel cycles in which each group produces basic modules which can then be assembled in different ways to satisfy the demands of a constantly changing market.

A key question is how to split production by organizing integrated groups in such a way that each group gets a unique, functionally-based field of responsibility. Of course, this possibility must already be taken care of in the design and development phase. The adoption of the system can result in dramatic changes in the entire organization of production. Instead of a traditional plant which consists of many independent cycles each producing different final products, there is a matrix of production sectors, pressing, body construction, painting, assembly, etc., in which different form or sequences of production activities can be identified for different model variants. *Figure 26* illustrates the differences between the two principles of production in simplified form.

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* Much of the argumentation in this section has been inspired by or taken from Bianchi and Calderale (1984).

The internal design of the different production groups on the shop floor is also changing. Activities, in which the task and the equipment were once dictated by a particular car model being produced, have now been replaced by Flexible Production Systems (FMS). A switch to Flexible Production Systems requires organizational changes in production on two levels if the same economies of scale are to be realized. As noted earlier, the production of each product must be divided into autonomous groups, which are connected with buffers in the form of work-in-process inventories, from which semi-manufactured and pre-assembled components can be distributed to various production groups. Furthermore, each group must be able to introduce different products within a short time by simply and quickly changing the type-bound equipment.

This change in the systems approach can obviously influence the production capacity of an entire plant. The vertically integrated cycle has a well-defined production capacity measured by the number of cars produced in a certain length of time. Since normally only one car model can be produced at any given time, the actual or expected sales volume determines whether the line works at full capacity or not. If demand sinks, there are only two possibilities: 1) stop production for a limited period, or 2) diminish the speed of production. At the same time, demand for other models may become so great that it outstrips production capacity for those models.

In the new production system such situations can easily be handled by allowing different sections to work on alternate models. This means that less demand for one model can easily be offset by more demand for another one. The possibilities for expanding the product palette will be a function of the number of component variants and of how well product flow is organized within the system.

The new system is based on the premise that it is possible to supervise and direct a complex system of production in such a way that new products can be put into production without any loss of time. In economic terms, initial investments for such systems will be greater than those for the one-product systems, but the depreciation period will be longer and the adaptation costs, lower. As already mentioned, such systems also offer a choice between producing all the components in-house, buying some pre-assembled from independent sub-contractors, or pursuing "lego" production.

The system also makes it possible to move certain tasks ahead in the sequence, or to perform them out of sequence. We can thus expect that more variant adaptation will occur at the sales level, and that the industrial and commercial systems will increasingly overlap. Smaller body shops will customize new cars within the commercial system.

The conventional assembly line had to be geared from the outset to the highest production capacity achievable. Although, in principle, changes in capacity could be made, in reality, capacity changes required enormous effort. The new production systems allow capacity to be increased (or decreased, if need be) step by step. With so many good qualities, it seems likely that the new production system will be in use for a long time.

It ought to be stressed that the use of a matrix system with n production groups and m models requires considerable change in the way productivity is measured, as compared with the simple way productivity was measured in earlier, more rigid systems. With the new system it is difficult to ascertain which investments are necessary for a particular product, which makes it impossible to determine the production capacity level. Similarly, it is difficult to evaluate each worker's production level as his work is viewed in terms of *functions* performed rather than in terms of *"pieces"* produced. It therefore becomes necessary to use over-lapping parameters to evaluate the efficiency of the production system. The long-term cost structure is no longer inversely proportional to the production volume but is a result of complex interactions between different operative functions. Similarly, productivity becomes a result of the complex interactions between different elements of the system and its potential for rational management.

6.5. Coordinated Development and Production

As noted in the preceding chapter, the new system encourages preparation for production within the abstract game of designing new car models. Actually, the list of acronyms can be extended to include FAS, where FAS refers to Flexible Assembly System, and CAP for Computer Aided Planning. CAP is a system which aids in the introduction of new products by describing what activities are needed. Instead of a long list of acronyms, we could simply use the term CIM, which stands for Computer Integrated Manufacturing.

By analogy with production development, it can be helpful to divide the preparation for production into various segments and to divide the roles of the production engineer into production development and production preparation. With the aid of simulating models, which describe the type-independent equipment within the production system, combined with simple routines for generating models of the type-bound equipment needed for a particular car model, the production engineer has, in principle, the same possibilities as other engineers to take part in the abstract game of designing a new car model. ***Figure 27*** depicts an integrated development and production system. Here, product development and production are shared and coordinated within the frame of a joint ***development system***. One effort of this collaboration is the creation of resources for detailed design and production preparation at the heart of which is a highly productive computer-aided system – the CIM system proper, which is here referred to as the ***data production system***. This is where the detailed information on products and manufacturing operations is continuously received, created, updated and transmitted. Another major effort of the development system is to create and modify the ***manufacturing production system***, which physically shapes the products. Product planning is partly directed by the development system, which operates on the strategic level through goals and plans, and partly by the data production system, which operates on the tactical level using detailed demand specifications as its controlling input.

To achieve high productivity, new product generation and new production systems must match from the start. Creative, well-informed product development and production engineers are the most important resources for this task. The engineers who are responsible for production preparation must make efficiency and productivity their main goals. They must also show special consideration for the workers, who will keep the production process going. Of course, the change-over to a new, more highly automated production system cannot be completed overnight but must be implemented gradually. Long, complicated negotiations between management and labor unions about how each step will influence the workers involved must be expected. This process will be the subject of the next chapter.

7. THE HUMAN BEING IN PRODUCTION AND AS A PART OF A SOCIO-TECHNICAL SYSTEM

To be able to develop a production system that makes full use of recent technological advances one must proceed in the same way as in production development, ie., functions must be identified and described by means of demand specifications. The method is similar in principle to the one described in *Figure 7*, but differs in the important respect that detailed specifications cannot be introduced solely by and for production engineers. To obtain good results, everyone who has a function in the growing system must be directly represented. It is essential that both labor and management be intimately involved in the process from the very beginning. The reason is easy to understand when the production system is regarded as a socio-technical system as shown in *Figure 28*. The workers must be acknowledged as an interest group, which places the same kinds of clearly specified demands on the company management as the consumer places on a new car, or as the management puts on the production system. One difference lies in the focus of the workers' demands, which are concerned primarily with the quality of the ***work*** rather than the quality of a ***product***.

It is certainly possible (Engström and Sjöstedt, 1984) to combine higher productivity and meaningful work within the new concepts for automated production. There is, however, very little information available about experiences with such systems on an international level. Each system tends to be unique, which makes the transfer of experiences extremely difficult. Many production systems, which were successful in one environment, proved unsuccessful when transferred to different environments, perhaps because local restrictions (labor laws, the local mentality, etc.) were overlooked. One reason for retaining a less advanced system could be lack of information about the technical possibilities or insurmountable difficulties in securing the cooperation of all the parties involved. There may also be communication problems between the two parties of labor and management. Furnishing production engineers with computers and other advanced planning and development tools is not enough to close the gap. Methods that can make the abstract models "live" for all the parties involved, including the line workers, should also be used. Scale models, animated films and other teaching aids can be very persuasive.

In Sweden the long tradition of close cooperation between labor and management has greatly facilitated experiments with new production systems and ways of organizing work. Until now, experiments have been limited to confined trials in a few plants and only a small part of current production work has been involved. To a certain degree, smaller production volume (as compared with those of the major competition) has allowed greater flexibility. These experiments show clearly how important it is to have reached agreement on demand specifications from the start. Developments during the last decade indicate a growing necessity for complex, detailed demand specifications. The responsibility for satisfying the demands must be shared unanimously between the parties. Each party plays two roles; first, to make sure that the demands which are agreed upon during the production planning phase can be accepted as compatible with the party's own interests and second, to make sure that the demands are satisfied when the system has been realized and put into operation. Principal demand specifications for a final assembly sector could, for example, include the following points:

7.1. Examples of Demand Specifications

In the case used here as an example, the specifications were the product of a dialogue between union and management representatives. In the first stage of the dialogue, the union defined its social demands. A proposal resulted which was discussed and modified in a conference. In the next step each party evaluated the results of the discussions. This process was repeated a number of times until both parties reached an agreement. This agreement contained the following statements:

> *Buffer*. There must be a buffer between adjacent sectors of production and areas of responsibility equal to the output of eight hours of production. There must also be a buffer between the six-man groups within a production sector, corresponding to from half an hour to four hours of work.
>
> *Dependence*. No more than two to three workmen may be dependent on each other's work. The degree of freedom should correspond to at least half an hour's work. The work cycle should contain an over capacity of at least twenty percent as long as there are no technical disturbances. Magazine loading should be used whenever it is technically feasible.
>
> *Internal Aspects*. The workers in each group should be so positioned that they can both see and hear each other.
>
> *Weight Restrictions*. The work should not be too heavy; it must be possible for a woman to do the job. No component that must be handled manually should weigh more than six kilograms. The share of heavy components to be handled must not exceed ten to twenty percent of all lifting required.
>
> *Group Rest Areas*. There must be an area near the work station where members of the group can take rest breaks in social groups. The area must be separated from the production area by walls and offer places to sit. The rest area should be located close to the work stations so that workers in the rest area can be easily informed of the situation in their work stations.

7.2. Organization for Working and Learning

Demand specifications of this kind are establishing a foundation for major changes in the way work and production are organized. Even the far-reaching changes demanded by the new production system can be made more easily when a healthy relationship has been established between management and labor. For a particular production group to function smoothly it must have a certain degree of autonomy and be able to absorb the products of other sectors flexibly (whether with a planned, or an unplanned variation of production time). Negotiations may continue and define the function of the group in precise terms according to its working conditions and productivity. In Japanese factories, for example, the production group is responsible for final adjustments and quality control. The central questions have to do with the changing meaning of work, the value placed on skill, the need for complementary competence within the group, and the extension of individual and group responsibility.

There are at least two main reasons why automation is not expected to become total even in the distant future and why some jobs will always require human labor. First, automation very quickly reduces the number of unskilled, unqualified jobs thus, reducing the number of workers needed, a trend which can only be counteracted by creating new jobs.

Second, the growth and size of the indirect work force must be restricted if an increasingly complex production system is to remain manageable and economical. In a situation where it is increasingly difficult to identify the share of direct work for a specific product, it would be, of course, unwise to allow the amount of indirect work to increase. The risk is too great that the division of labor could become too hierarchical and vague. It will become more and more difficult to maintain a sharp division between factory workers and office workers, between "blue collar and white collar" jobs. Occasional discussions about establishing joint unions for for office and factoy workers in certain sectors of industry is evidence of the trend. Furthermore, the role of the manager may eventually be questioned.

Specification of the group's function should be completed by determining which individual skills and competence are necessary in the group. Every increase in the amount of skilled work a group is expected to perform must, as a rule, be accompanied by an increase in the competence of the individuals. Discussions about increasing competence on the individual level usually involve increasing senso-motoric and technical qualifications. This may take the form of a change from a general knowledge of assembly of one or a few components to a broad assembly knowledge of a smaller number of components; the reading of instructions, the know-how for faster methods, proficiency in the use of special tools, etc. In autonomous work groups it is also essential to master the handling of group relations and to have the ability to perform administrative tasks such as planning, manning, budgeting, etc.

To stimulate individuals to accept the division of roles within their group and to provide incentives for developing their own skills and competence, it is necessary to initiate a system of wages which is closely connected to the qualifications required and expected of the group and its level of responsibility. The wage system must also reflect the layout of the production system. As an example, a system for final assembly of trucks has been chosen. In this case, there is an undriven line with many buffers. The wage system permits both individuals and groups to get bonuses, independently of each other, for specific jobs requiring varying levels of competence. To encourage the group's performance there must be a high correlation between the level of responsibility and a bonus for the group as a whole. At the individual level bonuses are primarily given in relation to the number of manual tasks each individual masters. It must be noted that such schemes rapidly lose their appeal and ability to motivate workers and must be revised frequently.

The need for identifying career progress is not confined to production workers, but is relevant to the whole system of product development and production. The need is just as great for those who work within the increasingly abstract world of computer design as for the employees in the physical plants. In Sweden, experienced and qualified design and production engineers have too frequently been promoted to administrative and managerial functions. For the future ways must be created for competent, skilled engineers to have direct responsibility for technical developments and their applications. A three-step career ladder for production engineers has been proposed; the last step of which is an appointment as "specialist". In addition to basic competence in production engineering, the specialist should possess ample knowledge of how systems solutions can be applied in various environments, as well as extensive direct and indirect personal experience in different production systems. Similar career ladders are being proposed for other groups of engineers and technicians.

New jobs and higher levels of competence require additional training. The extremely short cycles of the traditional driven line are being replaced by longer and more varied cycles. Swedish experience shows that if the length of the cycles exceeds fifteen minutes, training can be accomplished ten times faster through so-called functional training and at a very reasonable cost. *Figure 6* offers data that support the functional training idea. Some ways of organizing groups allow individuals to choose difficult tasks instead of easier ones during training periods, which enables a trainee to contribute to the production result even if he is not yet able to perform all the the jobs required in his group. This means that his training involves either no or only minimal costs.

The material handling system can also be designed to facilitate the training process. The final assembly system of a bus chassis in four docks provides a good example. Each dock is assembled in three steps, with three assembly workers assigned to each chassis. The nine assembly workers in each dock form an autonomous group. Unskilled assembly workers can be quickly trained by two other assembly workers in the group who first process the materials for the first step, and then for the other two steps. Assembly systems which have many objects in various stages of completion side by side also give assembly workers better chances for learning their fellow workers' routines on an ad hoc basis, which, of course, also facilitates training. The step-by-step functional training in the above example is shown in *Figure 7*.

7.3. The Renaissance of the Line in Japan*

The first experience with new production systems in Sweden began at Volvo's renown Kalmarverken and the E-plant for diesel engine assembly in Skövde, which were both in operation by 1974. The experiment was primarily motivated by the desire to create a better working environment. Saab-Scania's new layout for diesel engine assembly in Södertälje was motivated by the same wish. At that time the Japanese advance had hardly begun. Since the late 1970's, however, there has been a strong interest in learning from and applying the production methods employed by the Japanese car industry in the hopes of becoming more competitive by using their methods. Streams of travelers have come back from Japan with various formulas, from quality circles to Kanban, which is Toyota's special formula for just-in-time production. There is much the Western car industry can learn from Japan, but an uncritical adoptation of Japanese formulas can pose a number of risks as well. What most foreign visitors to Japan have been permitted to see are the "older" Japanese plants of the 1970's. Only a few travelers have seen the new concepts that are now taking form in Japanese factories. The concepts which are helping the Japanese achieve their enormous international expansion belong to a third revolution in production engineering. This concept is completely based on the driven line and to great extent the automation is rather inflexible.

It should be stressed that it is Toyota's production system which has dominated interest in the West. The other Japanese car producers use different methods. When Toyota's system was presented in Sweden interest was concentrated on a number of principal points. There is a systematic standardization of batch sizes, stock piles, depots, lead times, etc. The plant layout makes it possible to exercise

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* This chapter is mainly based on Berggren, 1983.

visual control of both production and materials. That possibility has been achieved among other things through flow orientation, special packing and simple signal systems. Lead times and planning cycles are short. Through the combination of large production volume, frequent, small deliveries from nearby subcontractors (who are responsible for the transports themselves), minimal buffers and minimal part/component storage in the assembly plant itself, Toyota has succeeded in creating a system that achieves an exceptionally high capital turnover. The adjustment times are also very short. Standardized tool elements are being used and as little as possible of the adjustment work is being done in the machine. By combining a maximum of adjustment work outside the machines, good order, effective maintenance and frequent adjustments, a high degree of training and speed has been achieved. High quality is stressed in each stage and seen as a factor in raising efficiency. The workmen cooperate to a great extent in the rationalization and quality work.

To some degree these these methods incorporate the principles which will be essential foundation stones in the fourth revolution in production technology and its philosophy. This philosophy encompasses, for example, the new view of quality as a factor in production, the advantages of frequent change and the necessity for increasing the workers' skills and training and making maximum use of their knowledge, suggestions and ideas. At the same time, nearly all of these ideas can be compatible with the conventional production systems already in use. In any case, use of the driven line has never been seriously questioned.

One example of a conflict between the evaluation of the third and fourth generations concerns the use of buffers. Inspired by the Japanese system companies over the world tried to increase the speed of their capital turnover by reducing the amount of capital tied up in materials and parts. This attempt inspired the philosophy that all buffers should be eliminated. Another argument was that through the elimination of buffers the weaknesses of the technological system can be easily exposed. When these measures have been taken, further elimination of the buffers makes other weaknesses visible, which can then be corrected. This discussion overlooks the fact that buffers, besides compensating technical weaknesses, often have social functions. If all buffers were eliminated, the technical autonomy and the freedom of functional groups to influence their conditions would disappear. This would undermine the basic idea behind the new ways of organizing production work.

The solution of such conflicts lies in careful analysis of the partial goals of all parties in yet more complex specifications of requirements – i.e., demands in a general sense. The amount of capital tied up in production buffers is usually quite low. In one specific case an economic comparison of the two systems showed that the turnover from a more flexible production system was better and larger than losses due to larger production buffers would have been. This can be explained in part by the way increases in the stability of the system reduce the need for buffers *between* different sections of production. One way of handling the goal conflict is to state explicitly that a step-by-step decrease of the buffer can be carried out for technical reasons. When the responsibility for both types of buffers is invested in an autonomous working group, incentives can be given to the group to attack the causes of the technical disturbances. In another real case, a group was given the responsibility to smooth out the assembly times based on a previously agreed upon total buffer size.

7.4. Line Theory

The advantages of a driven line are evident. However, to a great extent its efficiency is an illusion. The short work cycle creates an illusion of efficiency since the unproductive times within each cycle are so short that they are hardly noticeable. Furthermore, they cannot be accumulated and therefore pass undetected. Not until the development of the series flow production theory in the 1970's, was there any possibility to calculate efficiency, or space requirements and other parameters in different production schemes accurately. During the last decade, the series flow theory has been further developed and refined in Sweden.

There are many reasons for the occurrence of unproductive times on the line. *Balancing losses* result from the fact that the total working time in a series flow can never be divided equally among the number of available stations. All stations, except the most heavily utilized, get less than full work load. When there are many variants of a product, there will also be ***variant losses,*** since more work-intensive variants tend to slow down other variants. ***The system loss*** – in a narrow sense – is due to the distribution intensity at the level of individual workers. Variations exist between individuals concerning their particular work capacities, and for each individual during a particular work cycle as well as during the working day. To compensate for system losses the line is usually equipped with certain functions to control the result of work and to handle mistakes. ***Handling loss*** refers to the time lost in moving materials and tools. The term "handling loss" is, however, unsuitable since handling is a necessary operation that simply requires a certain amount of time. Handling losses increase when the length of a cycle is increased.

7.5. Headlines in Production Development in Sweden

Where do Swedish producers stand today? It is possible to discern roughly three groups of organizational models. The first model is the conventional line with its distinctive series flow, centralized control structure and relatively unskilled labor force. The second model, which may be called the ***modified line,*** has also basically a series flow character, but shorter parallel flow sections are interspersed in the line. Buffers are inserted between separate stations or production sections, and workers are given more flexible roles. Methods that radically depart from the conventional line model and its way of organizing the work and the flow of production fall into a third group of models.

The conventional line still has its adherents within the production management in many companies. There are many reasons for this. The conventional line gives production management an easy, direct method for controlling the flow and working tempo. The line workers are forced to work at the tempo set by the assembly line and that often gives the management the impression that "at least the line is predictable". The line also permits the use of a simple system for supplying materials. Components that are needed on the assembly line can be distributed from one or several supply depots. The line is an administrative system, which is submitted to scientifically tested principles of management, such as detailed division of labor, well-defined specifications, pre-determined work loads and a strict decision-making hierarchy.

The modified line *(Model 2)* aims at increasing the efficiency of the production system and its ability to absorb disturbances without changing its basic principles. In this variation, centralized control of the system is usually maintained, while the work load is expanded horizontally with only marginal improvements in the skill level of the workers. At the same time these changes often mean an increase in working intensity.

The third model includes really significant changes towards creating more flexible, function-oriented systems. Some, if not all, of the following characteristics are typical for production models in the third group. For one, there is ***technical autonomy***, which means there is no mechanical equipment setting the working tempo, and the workers themselves are free to set their own pace. Within the organization of the group, there is ***administrative autonomy***, which makes the group independent in matters such as budget or production plannning. Job content has been increased, the work cycle has been prolonged, and demands for other skills have been integrated in the work. Production administration has been simplified by having fewer "anti-flows," shorter waiting and adjustment times, and decentralized responsibility.

7.6. The Present Situation in Various Production Sectors

The distribution of the three organizational models varies in different production sectors. For press shops there is a positive connection between automation level and new job types. It was not possible to make any changes in the organization until the most monotonous machine operating jobs were eliminated. The degree of mechanization is coupled to the production volume. Therefore, stamping of parts for passenger car bodies has progressed further toward new organizational models than its counterpart in truck production. An example of this development is Volvo's plant in Olofström, where the mechanized press lines are operated by teams responsible for overseeing production, replacing tools and equipment and doing the remaining manual jobs, such as inspecting and packing completed parts. Compared with the previous production system, demands for qualified workers have risen: the new organization model requires more of the individual worker than merely operating one particular machine. Automated production methods, however, do not necessarily lead to the adoption of new ways of organizing the work. There are other plants, where mechanization has not been followed by any changes in the traditional hierarchical divisions in work, labor and management. In some cases, even piecemeal handling of individual parts has been retained.

In the welding sections that produce truck frames and body parts, there has been rather extensive mechanization, but compared with the automobile press shops, there is still a lot of manual work. Handling the pieces, completing and adjusting the welds are all still to a large extent manual jobs. Short-cycled, fragmented work paced by a driven line still dominates that sector. There seems to be little room for organizational change; even the plants that have changed most have only modified conventional systems, by installing buffers, arranging U-shaped flows or parallel single stations, and introducing work rotation within production groups.

In the production of passenger car bodies the robotization process has already progressed far beyond the introductory stage. Examples of the third, most advanced model for organizing work can also be found in that branch of the industry. One example is the spot welding line at Saab-Scania in Trollhättan. There, the foremen and workers took the initiative of forming a matrix organization with four sub-groups each of which includes a special field of expertise; robot maintenance (including programming), adjustment, quality control and welding equipment maintenance. The idea was to develop higher qualifications and skills among the workers and to divide both monotonous and highly qualified work more evenly. Within each group, the workmen rotate between production work, which consists mainly of magazine loading, and their group's specialty. Moreover, each member of a sub-group takes part in the administrative work and functions as the group's contact man for a month at a time. These efforts to increase the level of qualification are severely hampered by the fact that a large part of the skilled tasks consists of maintenance and repair work, which falls under the auspices of an independent organization.

The final steps in body production – additional welding, grinding, fitting, polishing, inspecting, and adjusting – are mainly manual jobs, thus offering a broad margin for different solutions. In the middle of the 1970's, Saab-Scania decided to introduce a parallel layout with a group-based organization. By contrast, Volvo maintained the traditional line in its private car production, but has recently begun to take new steps. One example of this trend is a method which stresses technical and administrative autonomy, work rotation and increased competence. Most of the welding, fitting, etc., is done in parallel two-man stations. A smaller part, mainly loading operations, is mechanically controlled with the traditional short cycle and frozen working positions this involves. A similar system for the production of truck cabins is in use in the workshop Volvo Umeverken at Umeå. Work in the paint shops is being organized according to the model used in the body shops, although with some delay.

Final assembly is still done mainly by hand. There are few fundamental technical changes and those are limited because it is difficult to mechanize assembly work. There are many reasons for this: the complexity of the material flow, the difficult fitting movements that are required, the long list of different joining methods necessary, and the specific demands put on control and function testing. In many cases great advantages could be realized by radically changing the way the work is organized. However, there is no final assembly system for passenger cars which departs radically from the basic assembly line system. Volvo Kalmarverken, which represents a modified elastic line, i.e., Model 2, did not immediately smooth the way for new assembly methods, as it took a long time to evaluate and understand the effect of the different steps, such as the location and size of the buffers, the effect of the prolonged cycle time on the work environment, etc. The new Volvo method did not find any imitators until 1982, when Saab-Scania began to redesign its final assembly at Trollhätten. The new method in Trollhätten was called *Miniline* and included a small section of the final assembly. The system is still in an experimental phase, but good results have been reported. The motivation for innovations in the final assembly have been strongest among manufacturers of heavy commercial vehicles such as buses and trucks. In that sector, there are examples of factories that have replaced the line with parallel flows and groups which enjoy technical as well as administrative autonomy.

7.7. Time and Space Restrictions

It is not often economically possible for the relatively small Swedish automobile companies to build or introduce completely new factories. Lack of space is often a problem when existing assembly methods are to be changed. The conventional line is actually very compact, but a large area is required for adjustment work. The problem is just the opposite for the new production systems with more or less parallel structures. In this case, a changeover creates free space in the adjustment area, which can then be taken over by assembly stations. The problem is that the space only becomes available after the new system has been in operation for some time, which makes the changeover difficult. The brief company vacation time is the only time available for executing the changeover, which also creates limitations. The new system must be introduced step by step and must fit into the corridor areas of the old line. This necessarily shapes linear flows. One positive result is that the design of transport equipment can be simplified. One possibility is to use a small mobile unit, which is attached to the basic object or the undriven vehicle body. A pneumatically driven unit of this type has been developed by a member of the Saab-Scania bus factory in Katrineholm.

TABLES

Table 1: Selective table of specialist job titles as listed in the 1984 version of the internal telephone directory for the *Volvo Car Corporation.* Only two or three job title categories are given. Job titles in the production sector of the organization are not included. *Volvo Car Corporation* is also served by *Teknisk Utveckling* (Central Development), which has its own laboratories and specialists in applied physics, finishing materials and processes, metallic materials for construction as well as a department for standards.)

Quality

- Quality systems
- Quality preparation
- Quality follow-up
- Quality technology
- Legal requirements and product responsibility
- Quality revision

Program and Logistics

- Program
- Long-term programs
- Development of logistics

Project control

- LPM
- Time and resource planning

Product planning

- Product projects
- Industrial analysis
- Commercial analysis
- Technical analysis
- Special projects

Product development

- Administrative and design engineering development
- Special workshops
- Vehicle development
    - Chassis
    - Body
    - Fittings
    - Interior and accessories
    - Body trim – outside details
    - Technology

- Testing for vehicle development

    - Non-metallic materials and corrosion testing
    - Mechanical testing
    - Accident safety testing
    - Aerodynamic and thermodynamic testing
    - Functional vehicle testing

- Complete vehicle testing

    - Vehicles in production
    - New projects
    - Long-term testing
    - Noise and vibration testing
    - Test cars
    - Vehicle workshops
    - Operational reliability technology

- Development of complete vehicle

    - Coordination of preliminary development
    - Functional analysis of complete vehicle
    - Calculation and simulation
    - Preliminary development

- Drive line development

    - Technology
    - Technical analysis of complete engine
    - Basic engine
    - Engine testing
    - Electrical system
    - Drive line testing
    - Transmission

- Product design

    - Design
    - Model design

- Testing techniques

    - Mechanical testing equipment
    - Plant and building preparation
    - Technical photography and photo security
    - Process computer system
    - Electronic laboratory
    - Test track facilities

Technical administration

Product and production preparation

- Product development
- Quality
- Method and test assembly
- Preparation, complete vehicle
- Preparation, body
- Preparation, coating and sealing
- Preparation, final assembly
- Central plants

Total Consumption of Energy (kWh):
Volvo LCP 2000 Compared with an Average Passenger Car

	Volvo LCP 2000	**Average Car**
General Specifications		
Dry weight	645 kg	830 kg
Fuel consumption	.4/mile	.82/mile
Production		
Materials	11,700	10,300
Assembly	2,000	3,000
Processes	2,300	2,100
TOTAL	16,000	15,400
Operation		
Fuel	64,500	118,100
Service	2,000	3,000
TOTAL	66,500	121,000
Total energy consumption	82,500	136,000
Recovered energy	−5,600	−3,600
TOTAL LIFETIME ENERGY NEEDS	77,000	133,000

Both cars are estimated to have a lifespan of ten years and 150,000 km, which is actually quite a conservative estimate for the Volvo LCP 2000. Considering the choice of materials the lifespan ought to increase, thus yielding an even lower energy consumption per year.

Table 2: Comparison of estimated energy efficiency of the *Volvo LCP 2000* and a car of conventional design. Source: *Volvo Car Company*.

International Cooperation	
Denmark	plasma injection (brake disks)
England	models, mock-ups engine suspension system brake system
France	engine cushions headlights
FRG	engine instruments
Italy	sub-frame wheel rims
Norway	bumpers electronic control system steering column pedal stand
USA	detailed design half-scale tests
Sweden	CVT transmission production of experimental cars

Table 3: Examples of international cooperation regarding design and production engineering within the LCP 2000 Project. Source: *Volvo Car Company.*

Material	**Share of weight percentage**					
	1979*	1980	1985	1990	1992**	1995
Common steel	61	65	59	51	54.9	48
High tensile steel		3	7.5	11		11
Cast iron	9.6	8	7.5	7.5	7.7	7.5
Aluminum	3.0	4.5	5.5	6.5	6.3	7.5
Plastics	5.2	5	8.5	9.5	11.1***	9.5
Glass	3.5	3	3	3	3.5	3
Rubber	4.8	11	9	11.5	5.1	13.5
Others	12.9				11.4	
TOTAL				100%		

* 1.51 passenger cars
** FTA forecast
*** Plastics, composite materials and laminated steel

Table 4: Japanese forecast for the use of materials in passenger cars of the future. (Repr. from Apple and Hilber, 1984.)

Loading and Setting Parameters in DYANA	
System parameters	**Definition**
Vertical bearing force	Calculated vertical force from road through center of contact surface between tire and road surface
Lateral bearing force	Calculated lateral force between road and tire width at the end of the rolling radius
Torque	Measured torque in the drive shaft between the car and the outer drive joint
Shake angle	Calculated vertical displacement of the bearing unit
Steering angle	Calculated angle between the projection of the drive shaft onto the horizontal plane and the bearing shaft
Speed	Measured rotational speed of the drive shaft

Table 5: Loading and setting parameters for dynamic tests of bearing units for car wheels in SKF's simulation rig "DYANA". (Repr. from SKF, 1982.)

Supervision signal	**Number of sensors**
Speed	1
Torque	2
Shake angle	1
Steering angle	2
Radial load	8
Lateral load	4
Bearing temperature	4
Drive joint temp.	4
Drive joint angle	2
Material tensions	4
Vibration level of the bearing	4
Thickness of the oil film	4

Table 6: Supervision signals during simultaneous tests of four bearing units in SKF's test rig "DYANA". The signals can be distributed among 32 computer channels. (Repr. from SKF, 1982.)

Empirically Measured Learning Times for Assembly Objects

Object of assembly	No. of assemblers working simultaneously on object	Cycle time in minutes	Working pace MTM	Learning time in weeks
Yacht	2	750	95	1-3
Truck	3	120	115	4-6
Passenger car	3	20	112	3-6
Kitchen stove	1	10	112	1-3

Table 7: Empirically measured learning times for various assembly objects with different cycle times. (Repr. from Engström and Karlsson, 1982.)

Cumulative Functional Learning	
Assembly Proficiency	**Accumulated Time Within Group**
Remember one variant in Stage I	2-5 days
Assemble one variant in Stage I with 90% of full work pace	2-4 weeks
Assemble 75% of all variants in Stage I with 90% of full work pace	4-8 weeks
Master all assembly work in Stage I	7-16 weeks
Master all assembly work in Stage II	7-16 weeks
Master all assembly work in Stage III	7-16 weeks
Master all assembly work within the total three stage work cycle	6 months (approx.)

Table 8: Cumulative functional learning of a two-hour cycle of work divided into three production stages. (Repr. from Kjellberg and Sjösten, 1979.)

FIGURES

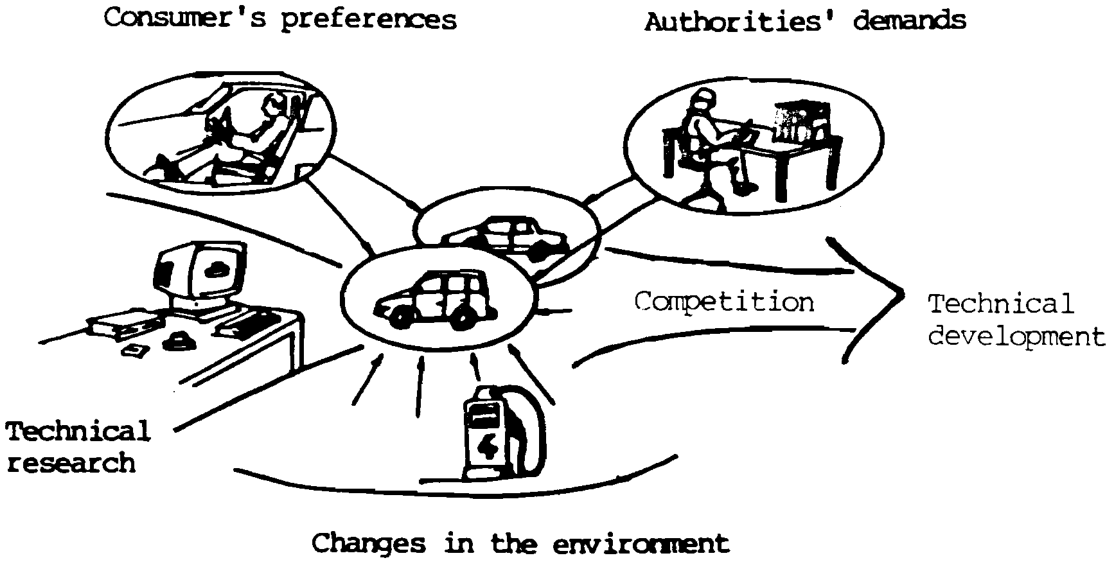
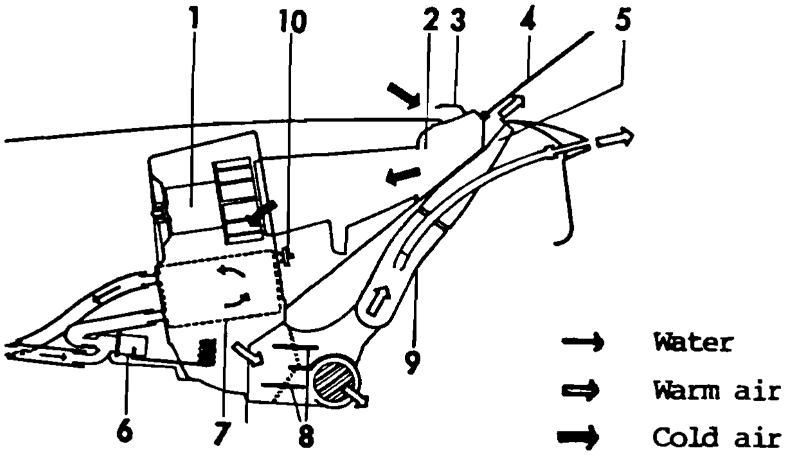
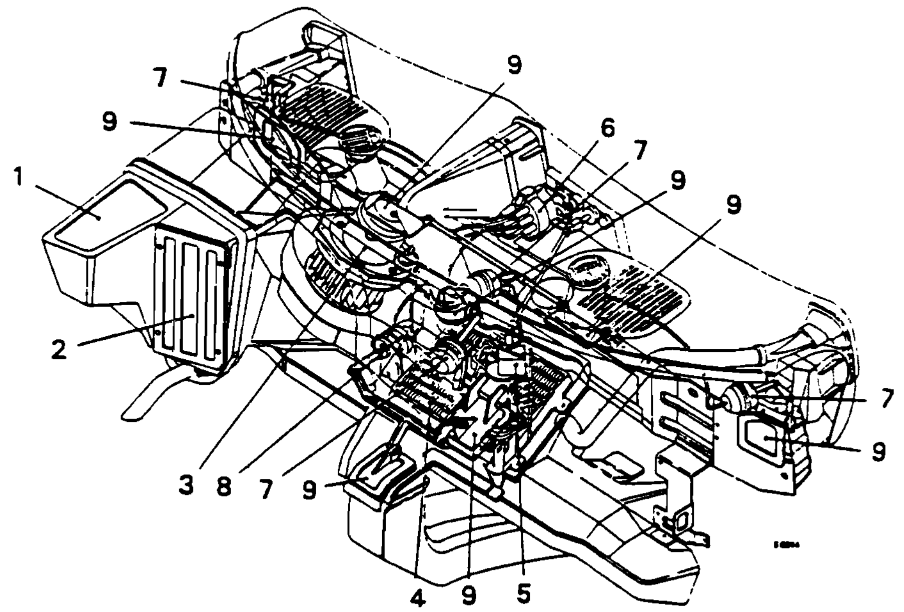


Figure 1: Schematic description of the environment that influences the technical design of a car.



1. Fan with motor
2. Collection box
3. Fresh air inlet
4. Windscreen
5. Defroster nozzle
6. Thermostat valve
7. Heating element
8. Distributor throttle
9. Defroster hose
10. Air nipple

Figure 2A: Principle outline of the heating system of a 1969 Saab. (Repr. from a company manual)



1. Air inlet
2. Filter
3. Fan motor
4. Heating exchange
5. Heat tap
6. Vacuum distributor
7. Vacuum servo, 1st step
8. Vacuum servo, 2nd step
9. Vacuum regulated air flaps

Figure 2B: X-ray view of the heating system of a 1978 Saab. (Repr. from a company manual)

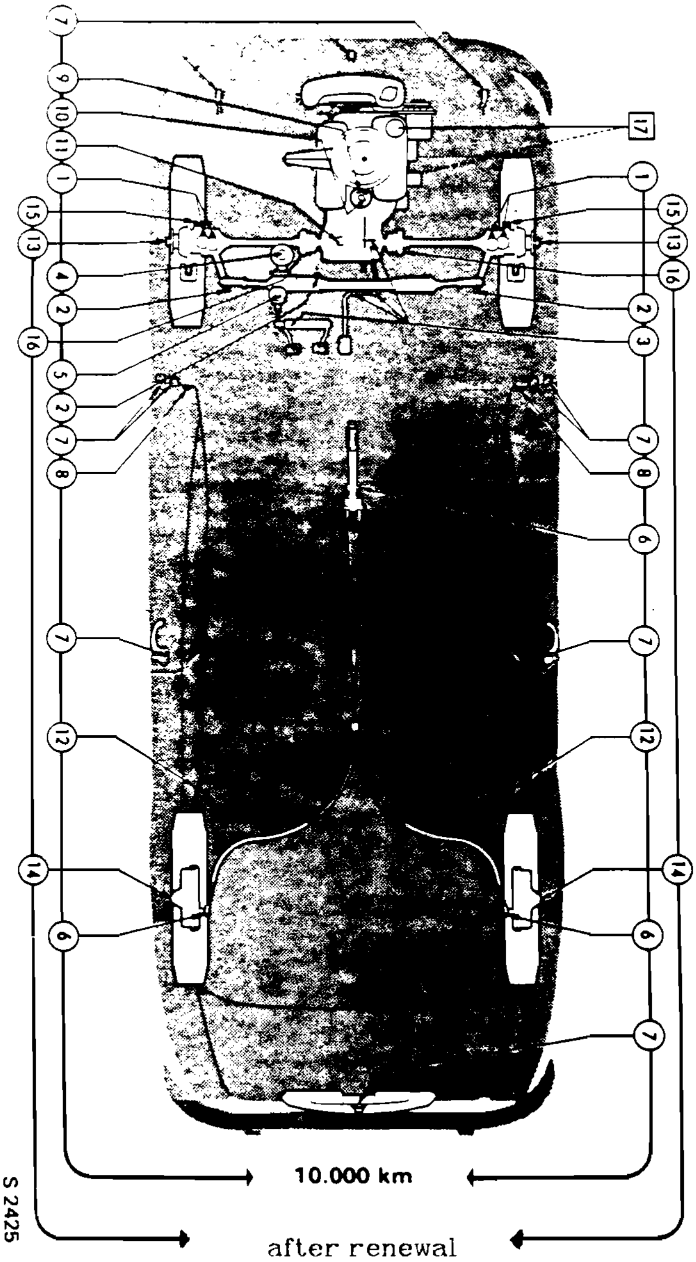


Figure 2C: Collation of lubrication points in a 1969 Saab. (Repr. from a company manual)

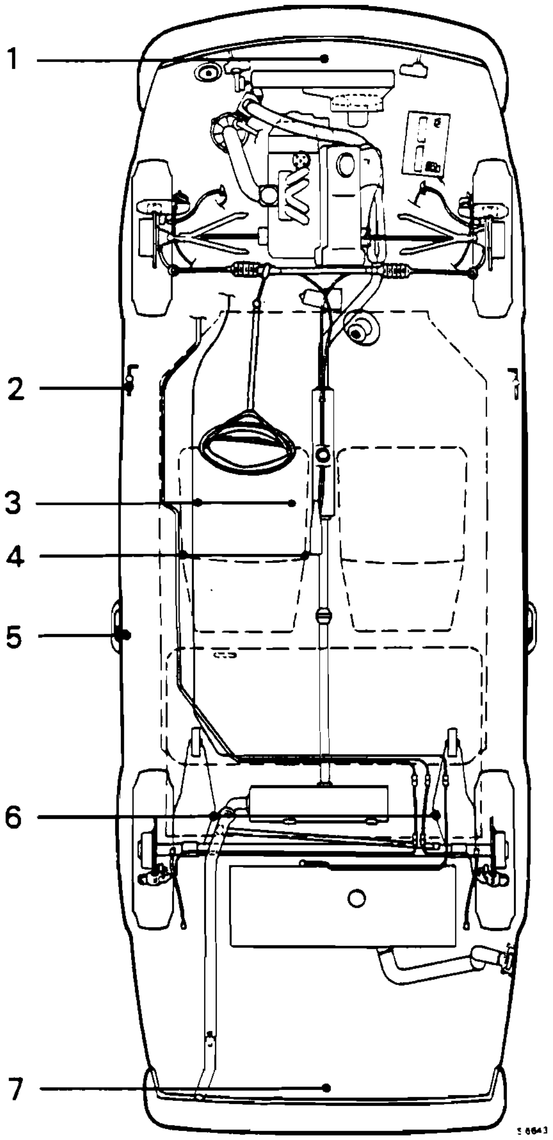


Figure 2D: Collation of the lubrication points in a 1978 Saab. (Repr. from a company manual)

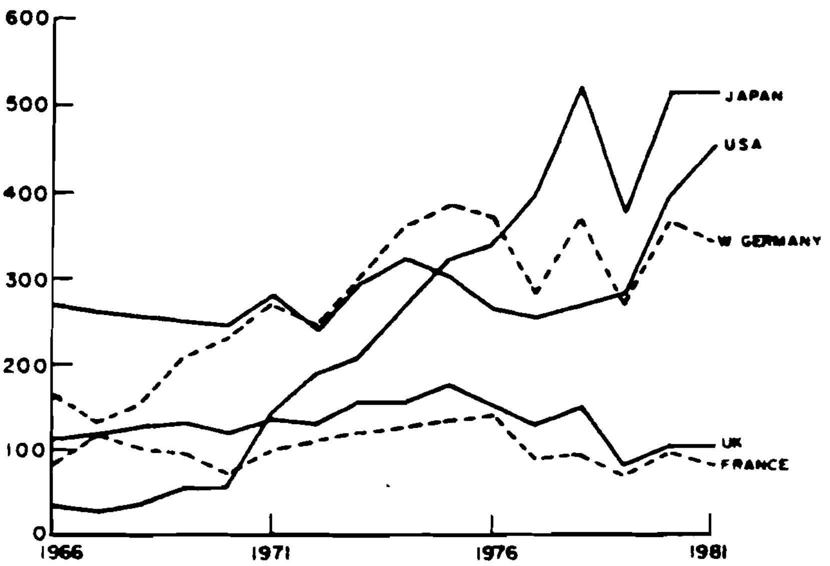


Figure 3: The pattern of motor vehicle patent activity in the USA from 1966 to 1981. The graph shows the number of patents granted per year under the "Standard Industrial Classification 371", concerning motor vehicles. (Repr. from Altshuler et al., 1984)

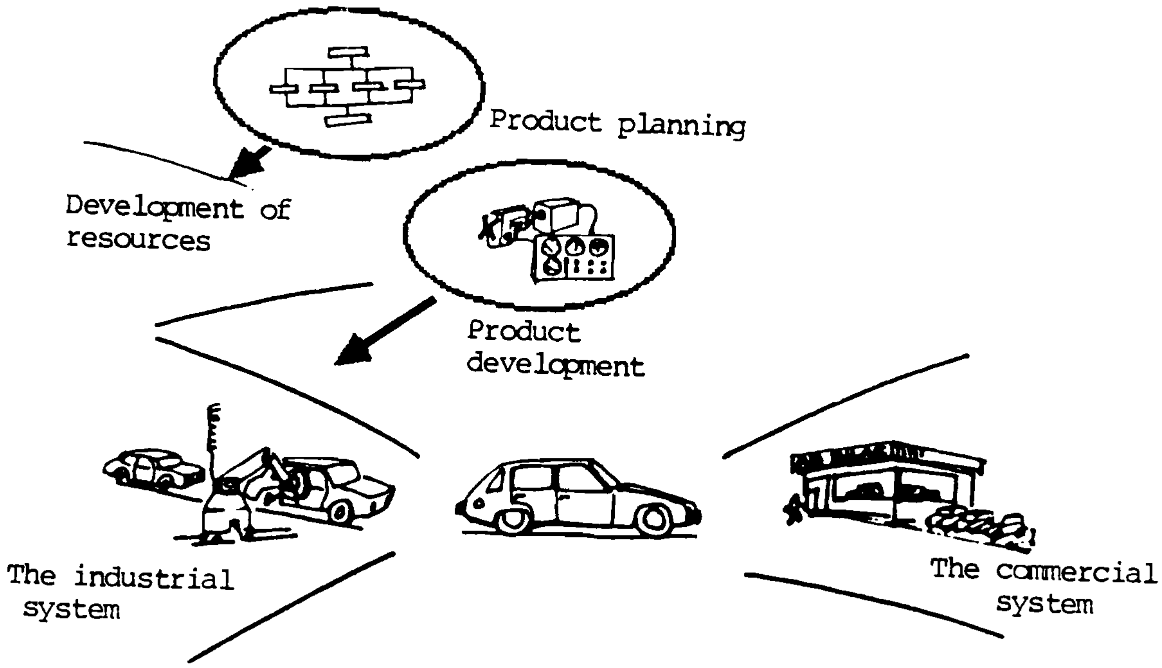


Figure 4: Product planning and development as control functions in an industrial system.

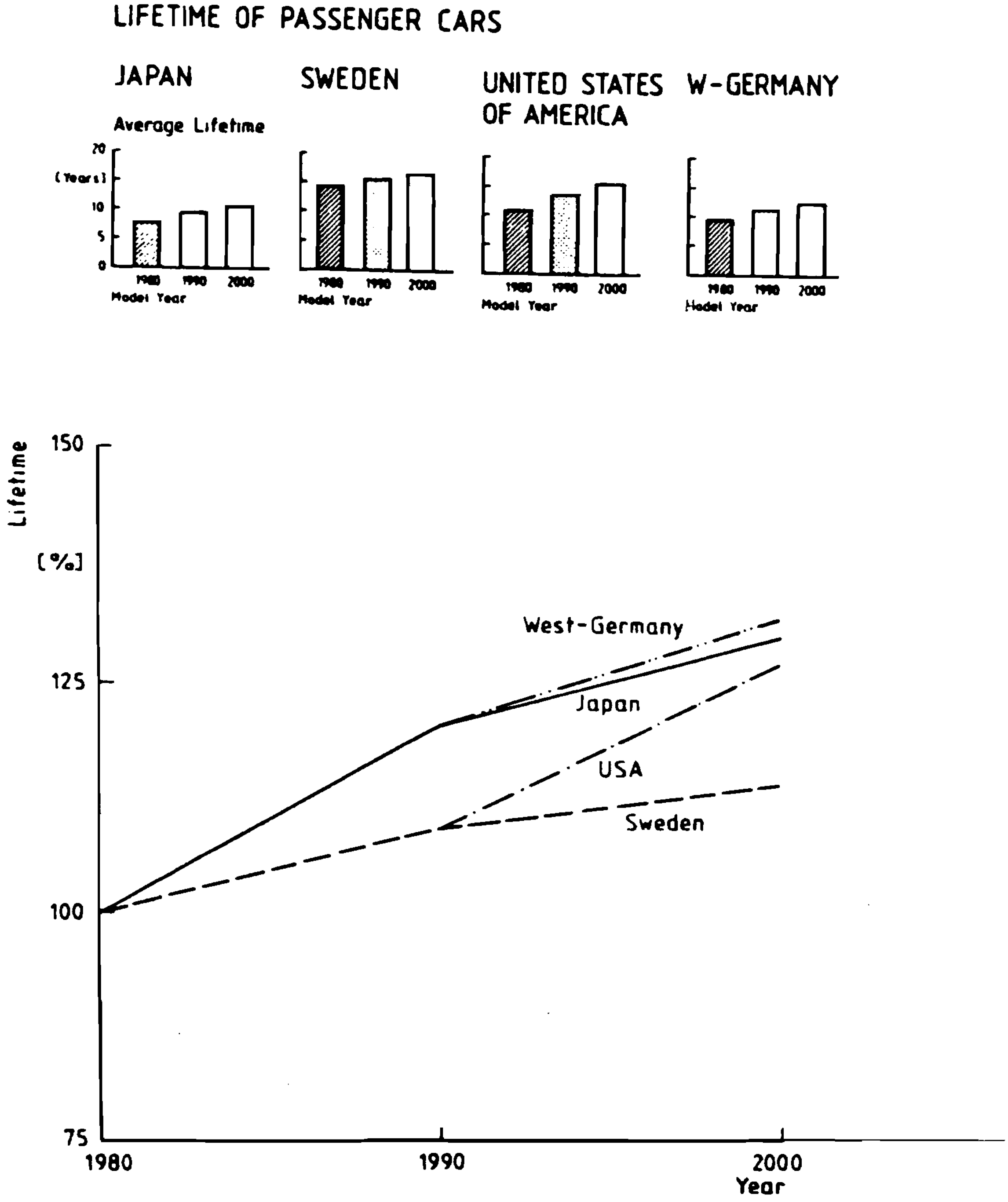


Figure 5: Expected increase in the average lifetimes of passenger cars. (Repr. from Appel and Hilber, 1984)

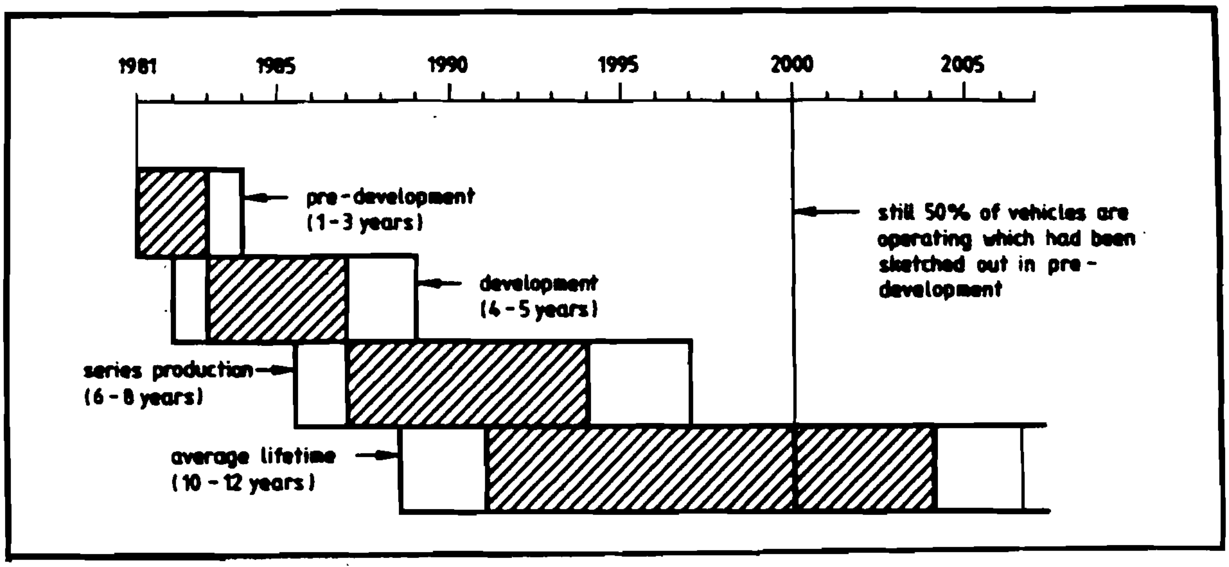


Figure 6: Time needed for development and production and the average lifetime of passenger cars. (Repr. from Lincke, 1984)

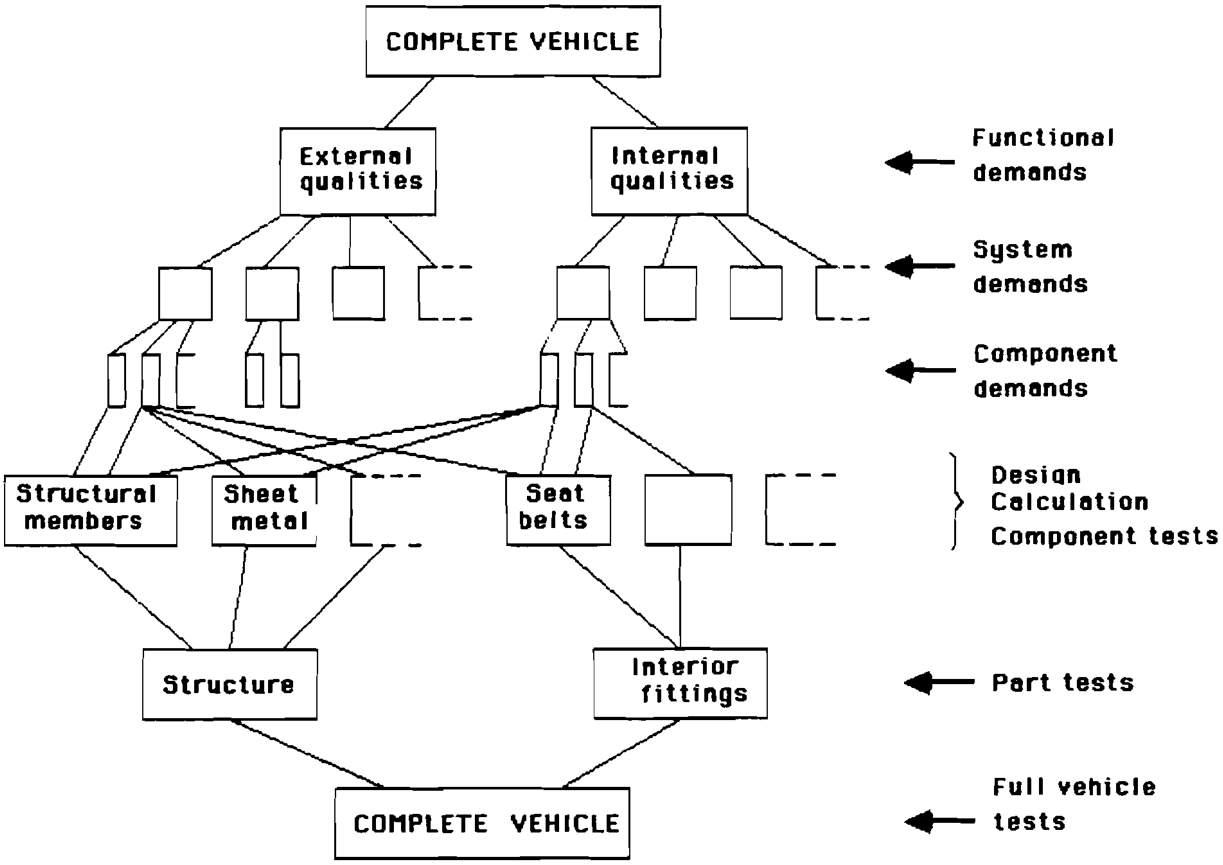


Figure 7: Example of demand structures. (The example chosen deals with crash safety.)

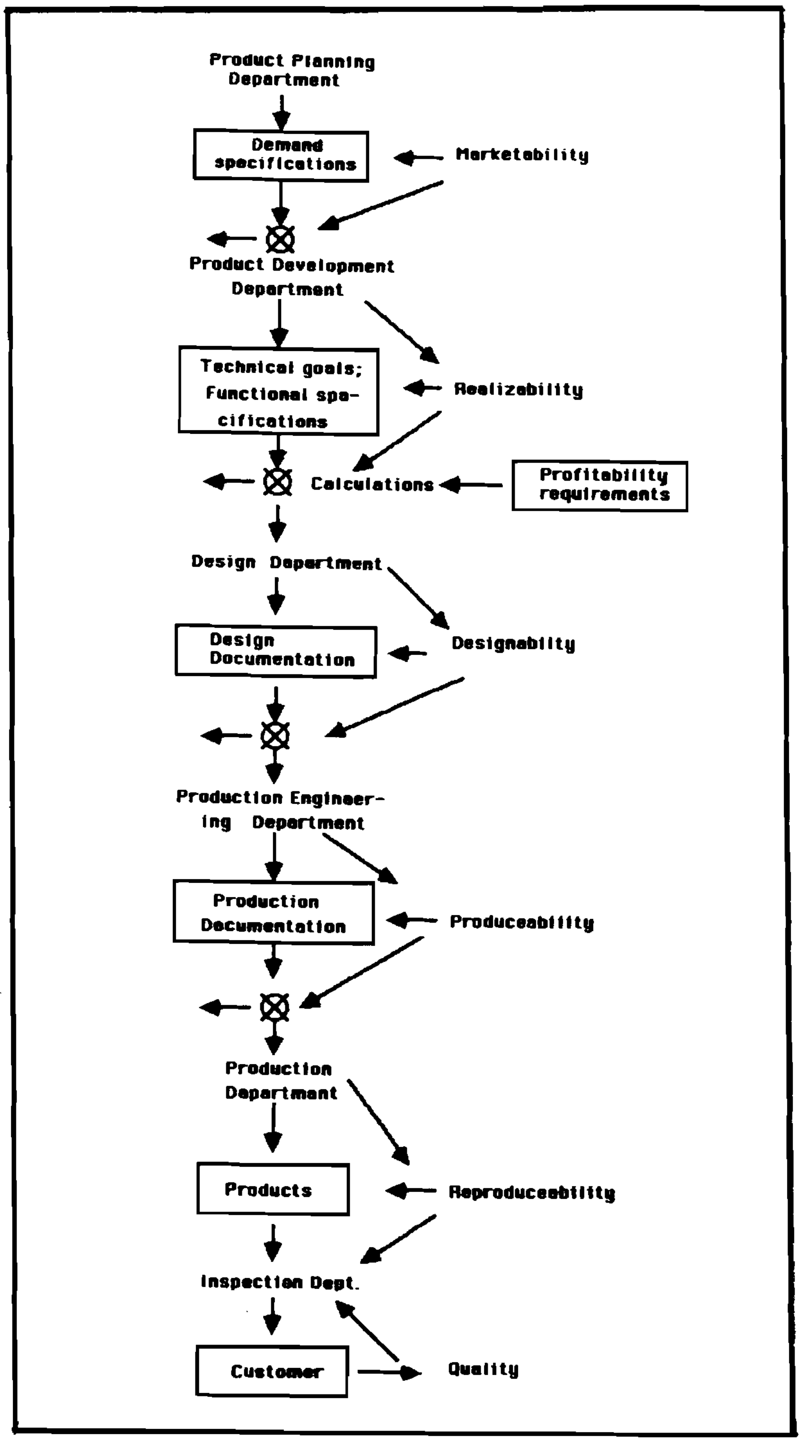


Figure 8: Principle diagram of the process of new car design in the industrial system.

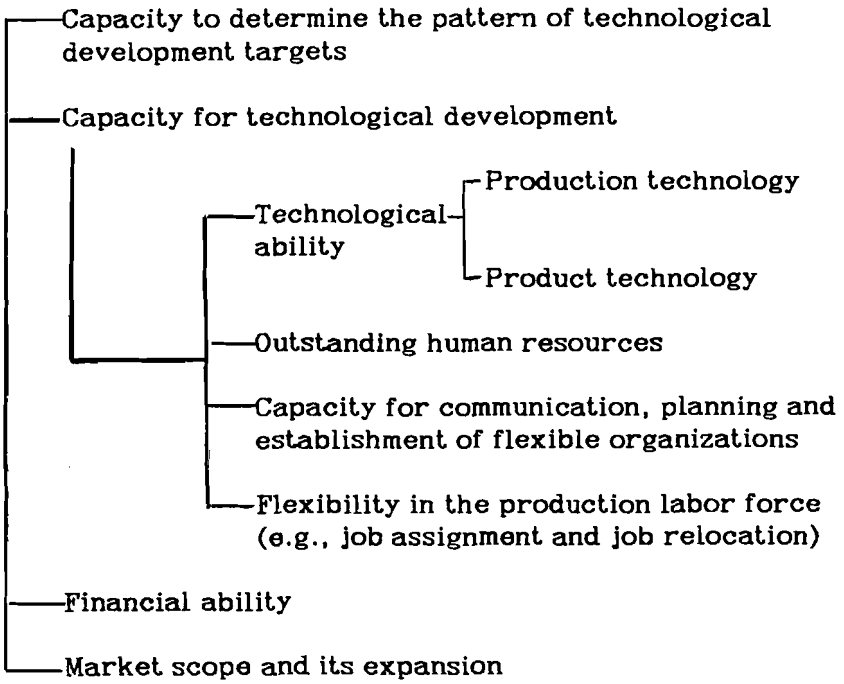


Figure 9: Important conditions of innovation and technical development. Source: Hashiyama, R., Jguchi, M., Nakamura, H., Shimokawa, K.: Technological Development and Its Implication On the Automotive Industry.

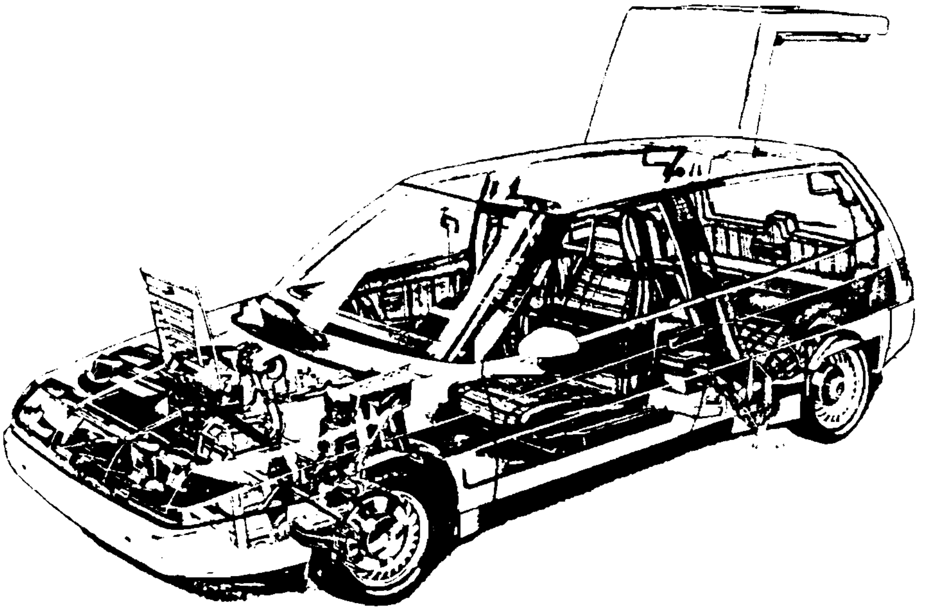


Figure 10: X-ray view of a Volvo LCP 2000. Source: Volvo Personvagnar AB.

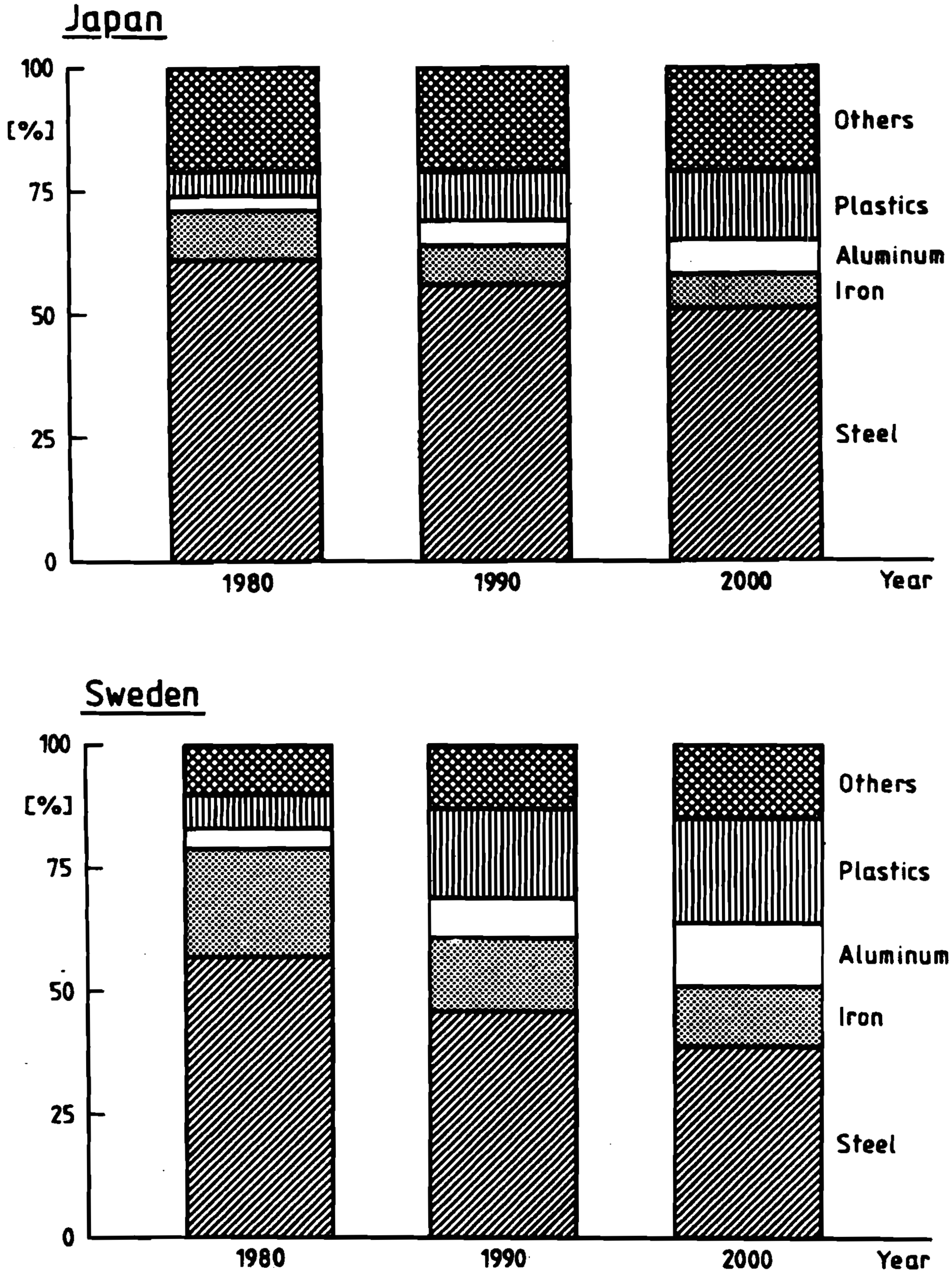


Figure 11A: Projected (1980) use of materials for passenger cars expressed as a percent of weight. (Repr. from Appel and Hilber, 1984)

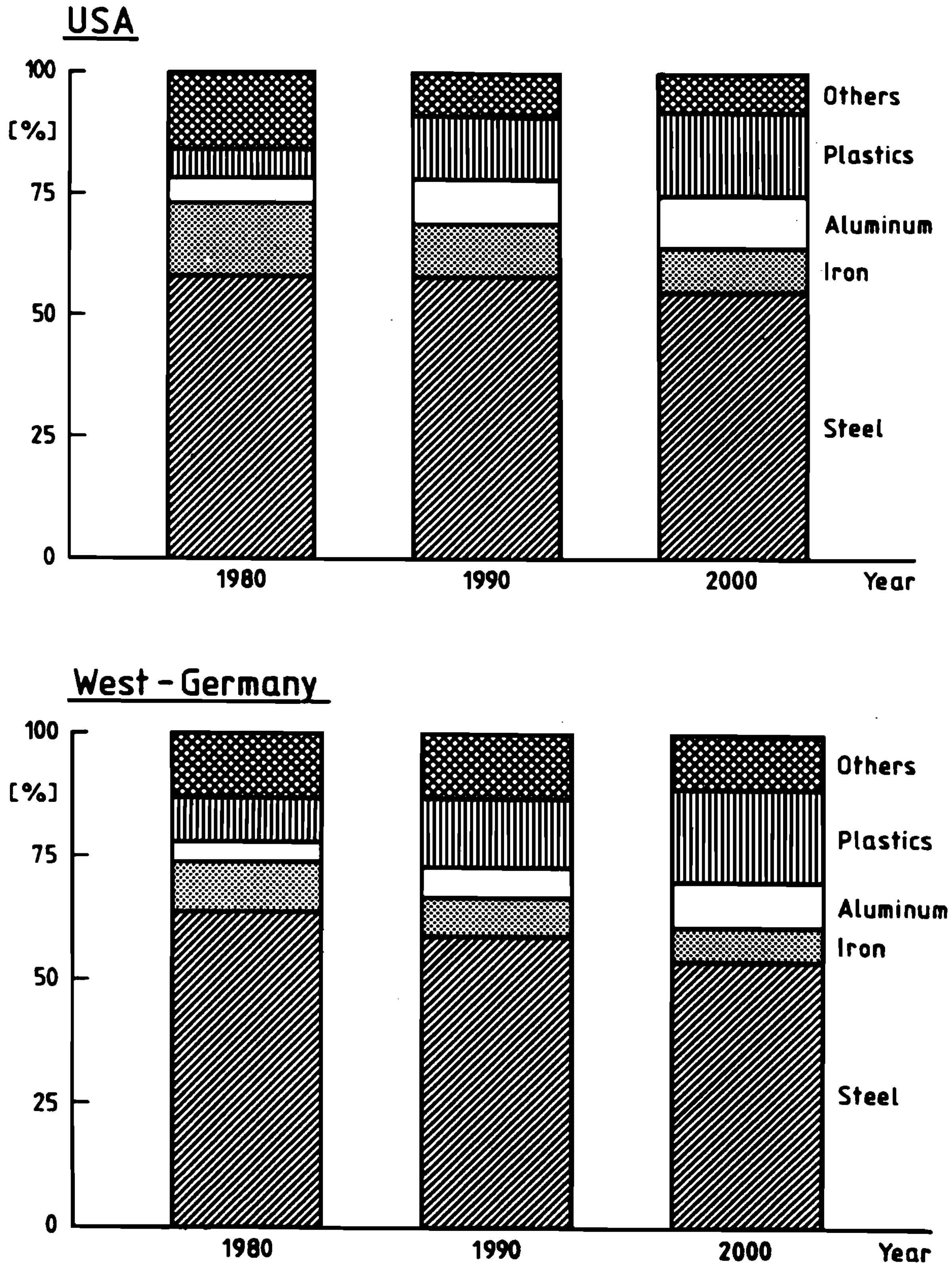
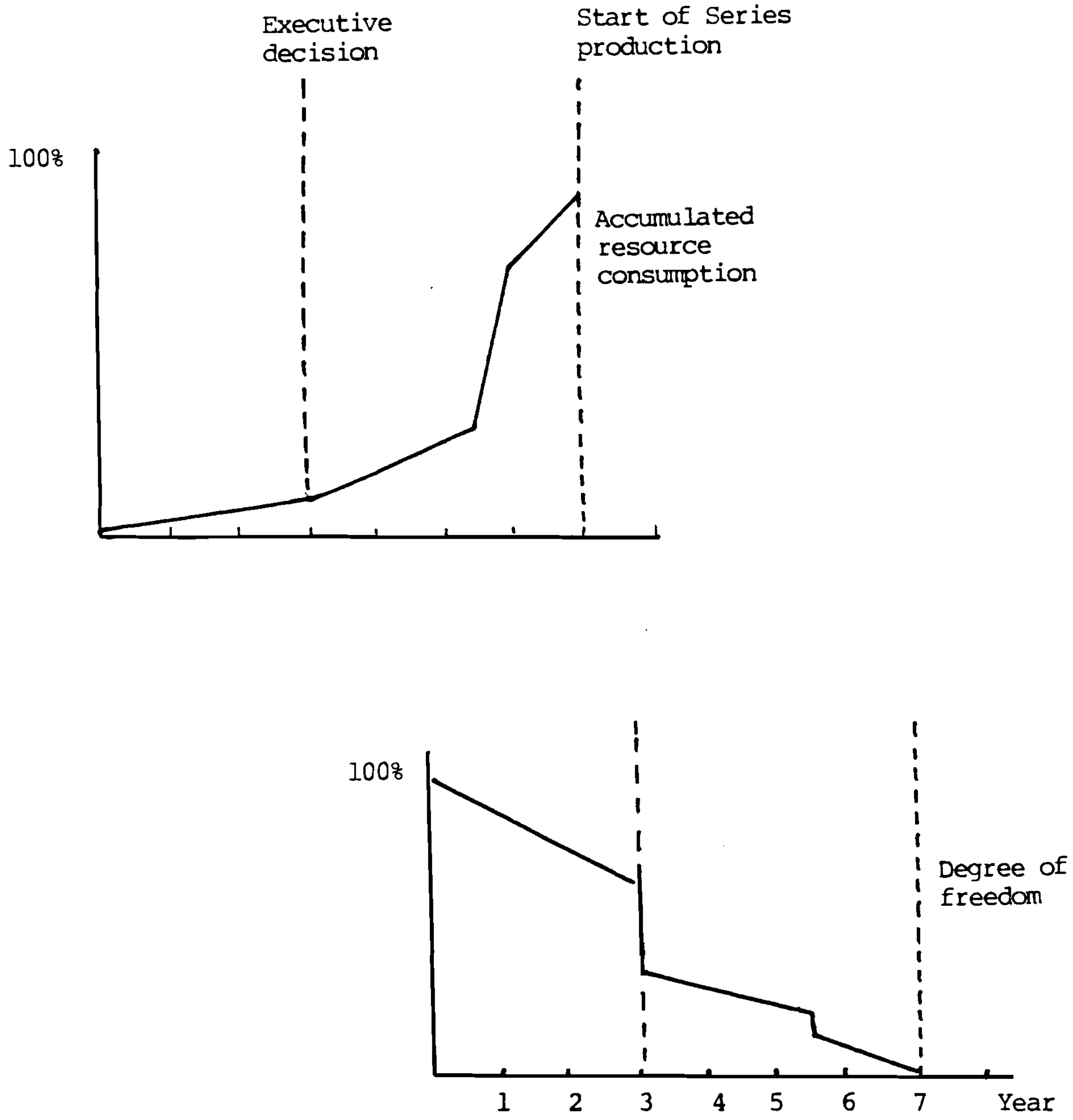


Figure 11B: Projected (1980) use of materials for passenger cars expressed as a percent of weight. (Repr. from Appel and Hilber, 1984)



Figures 12A and 12B: Typical resource allocation and degree of freedom from the beginning of an automobile development project until the initiation of series production.

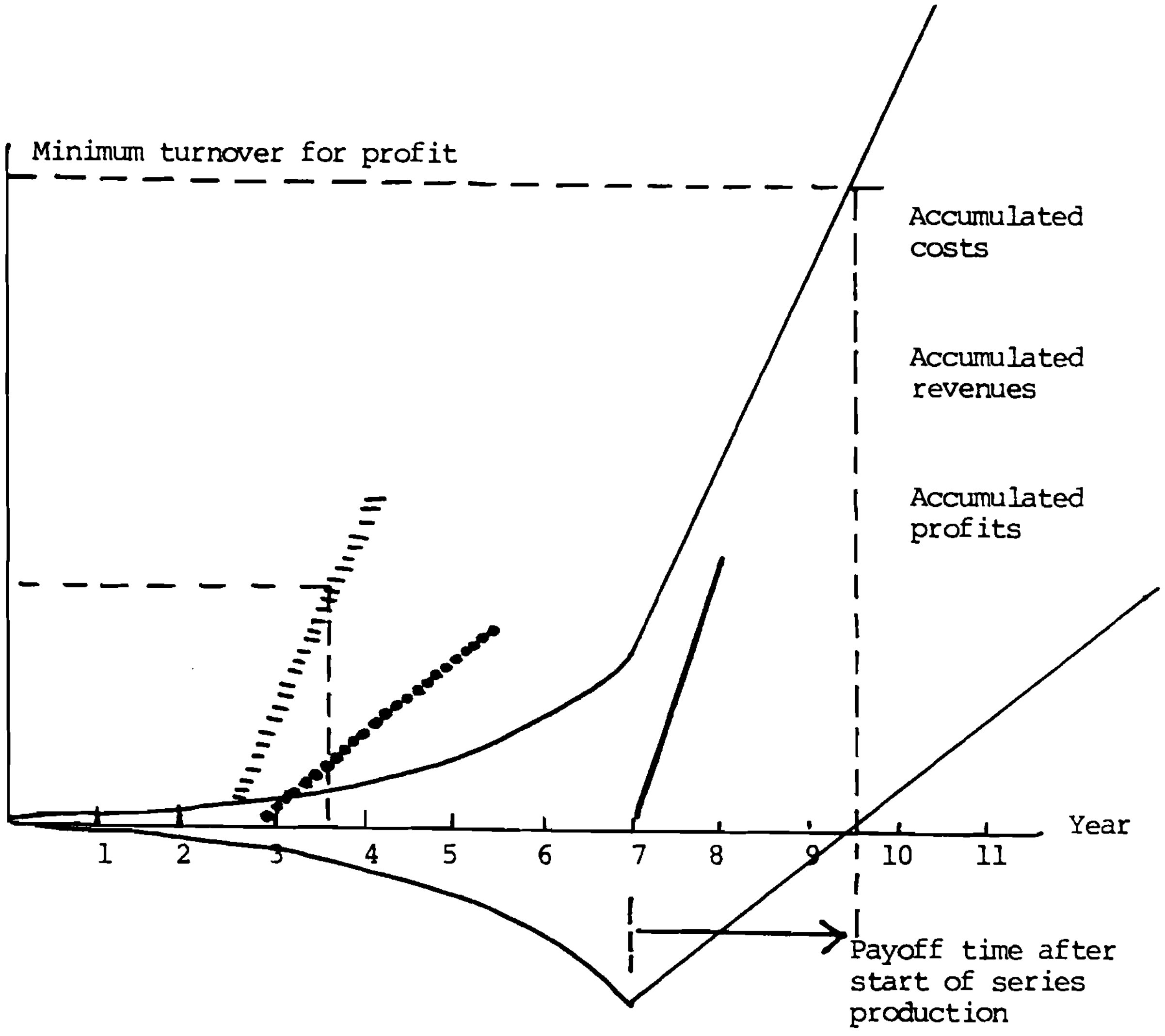


Figure 13: Cost and revenue curves for car production (excluding interest and depreciation periods).

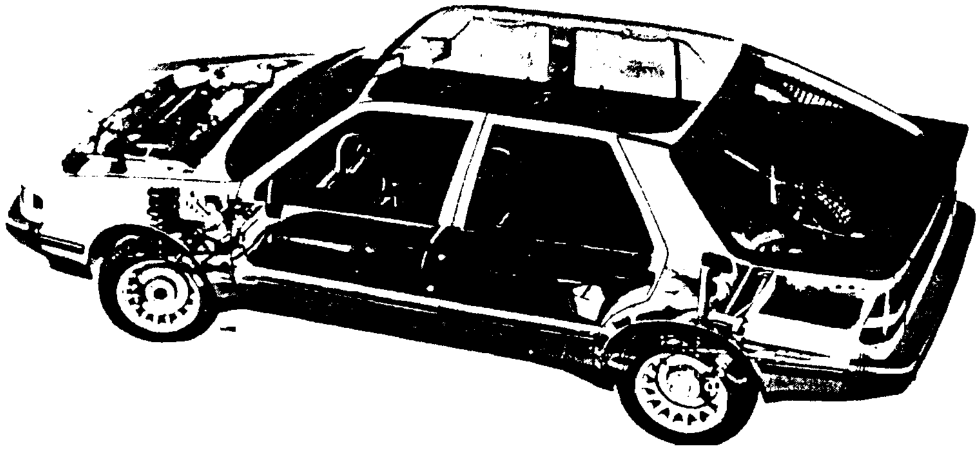


Figure 14: X-ray view of a Saab 9000. Source: Saab-Scania AB.

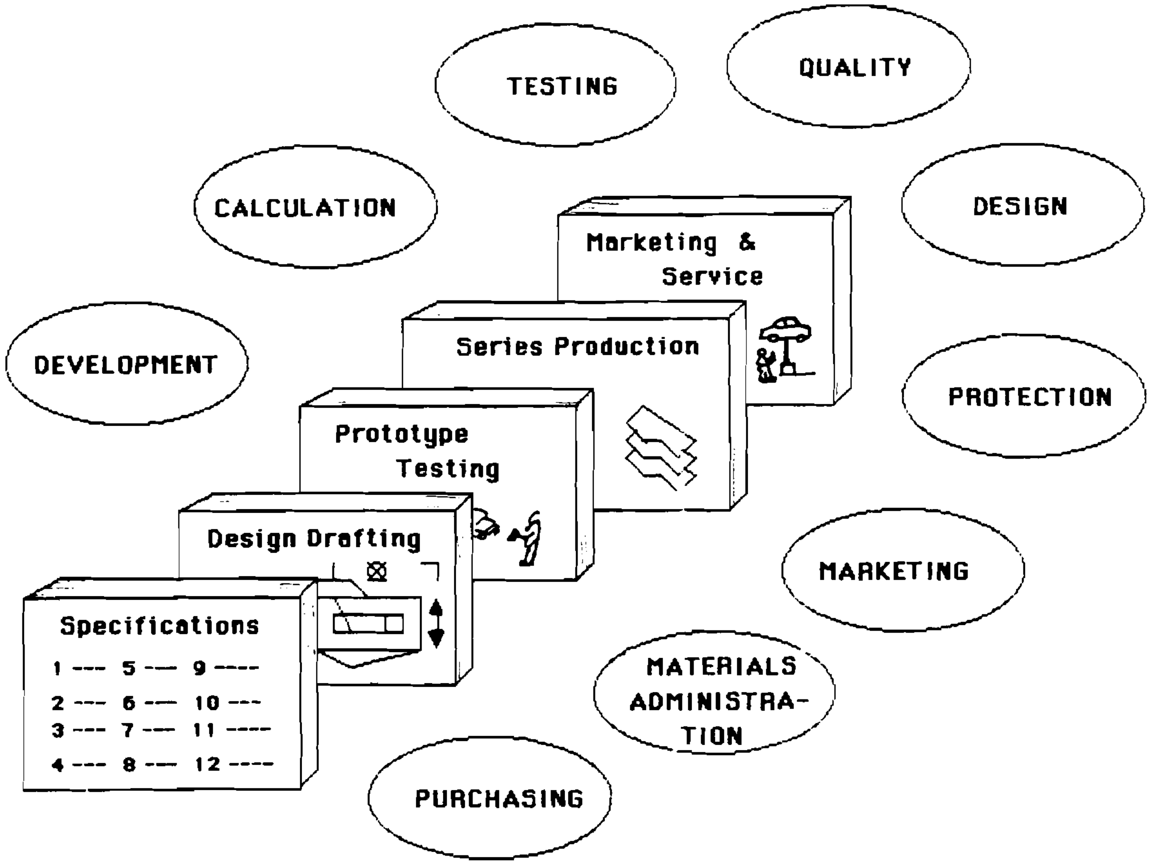


Figure 15: Symbolic representation of the creation of a modern passenger car through integrated team work.

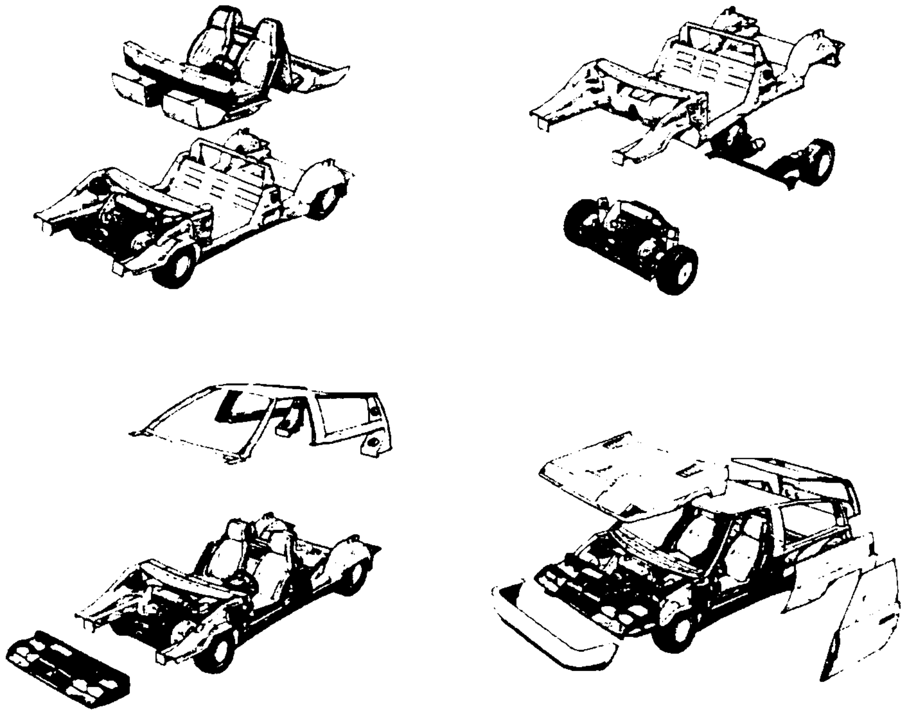


Figure 16: The order of assembly in the conceived production of the Volvo LCP 2000. Source: Volvo Personvagnar AB.

Figure 17: Conventional bearing arrangement for front-wheel drives. (Repr. from SKF, 1982)

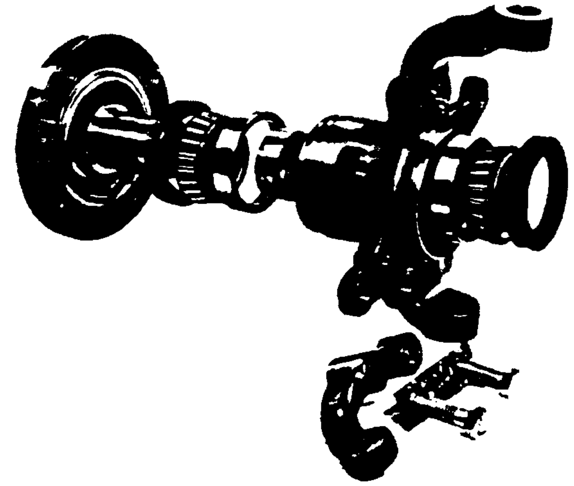


Figure 18: Bearing arrangement for Front-wheel drives using Hub Unit 1. (Repr. from SKF, 1982)

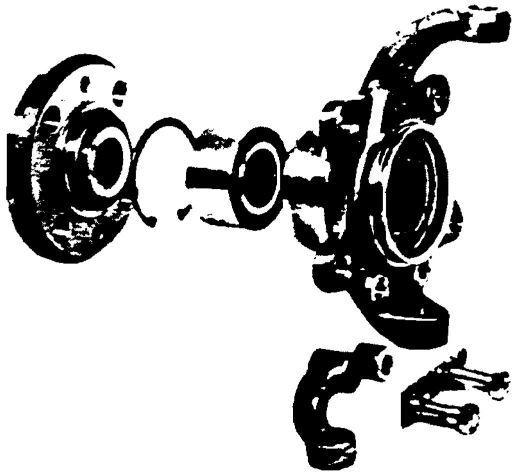
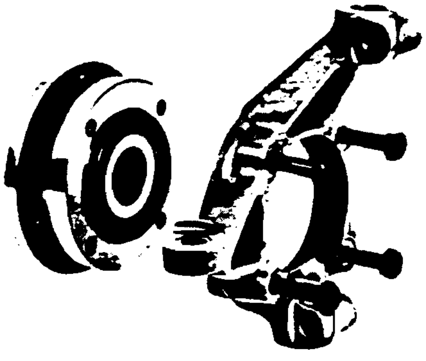


Figure 19: Bearing arrangement for front-wheel drives using Hub Unit 3. (Repr. from SKF, 1982)



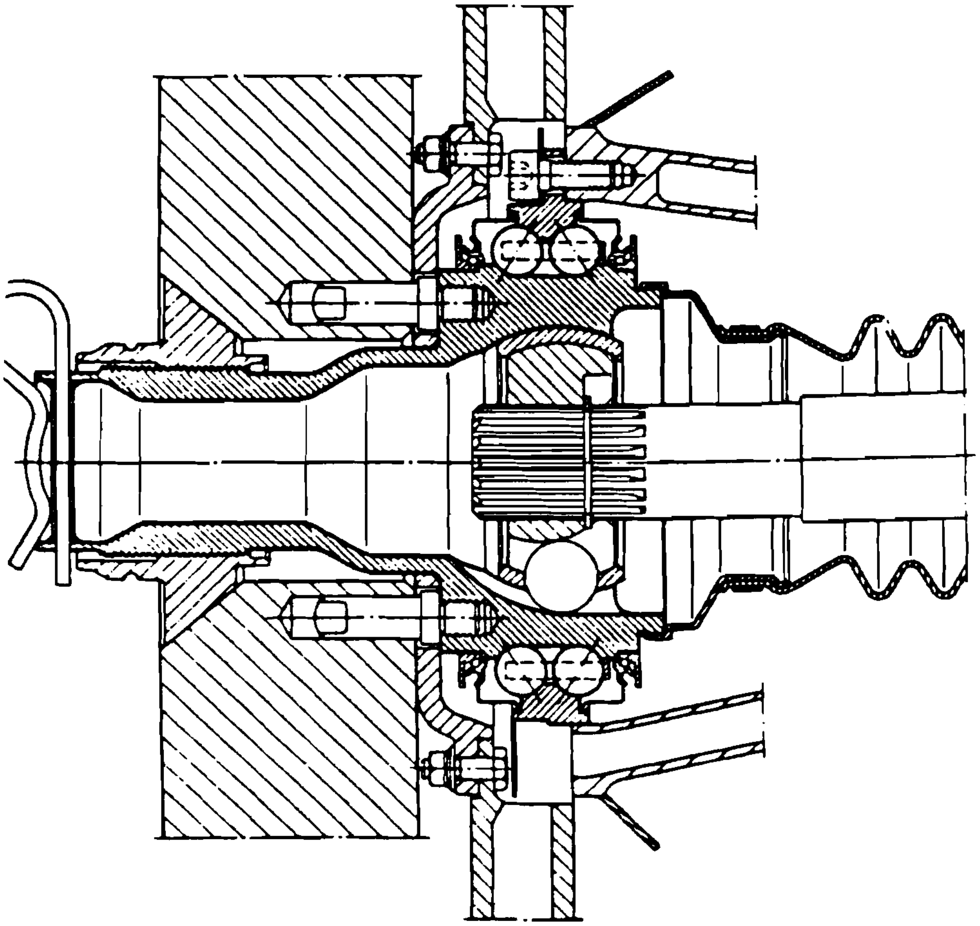


Figure 20: Cross-sectional view of SKF Hub Unit 4 assembled into a Formula-1 Talbot-Ligier. (Repr. from SKF, 1982)

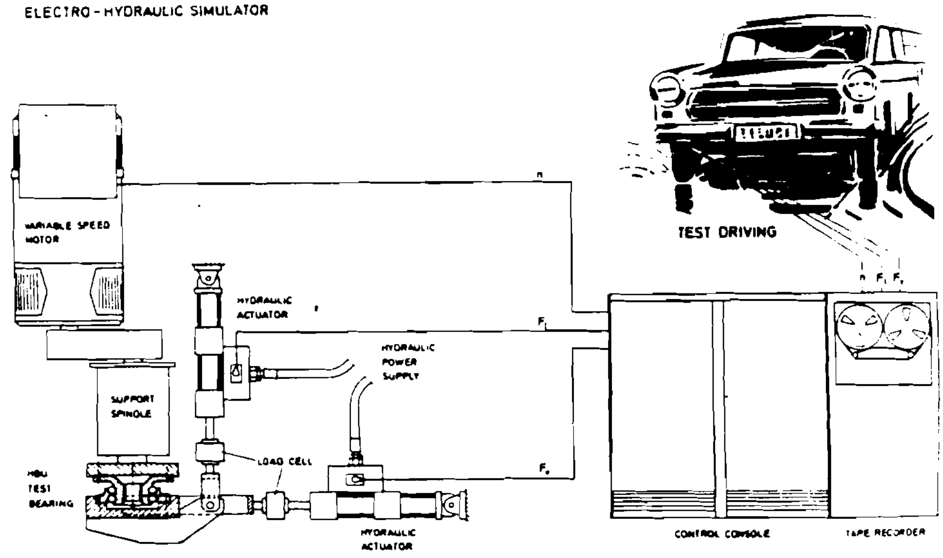


Figure 21: Principle sketch of a test facility for SKF Hub 6, Unit 4 – "Dyana". (Repr. from SKF, 1982)

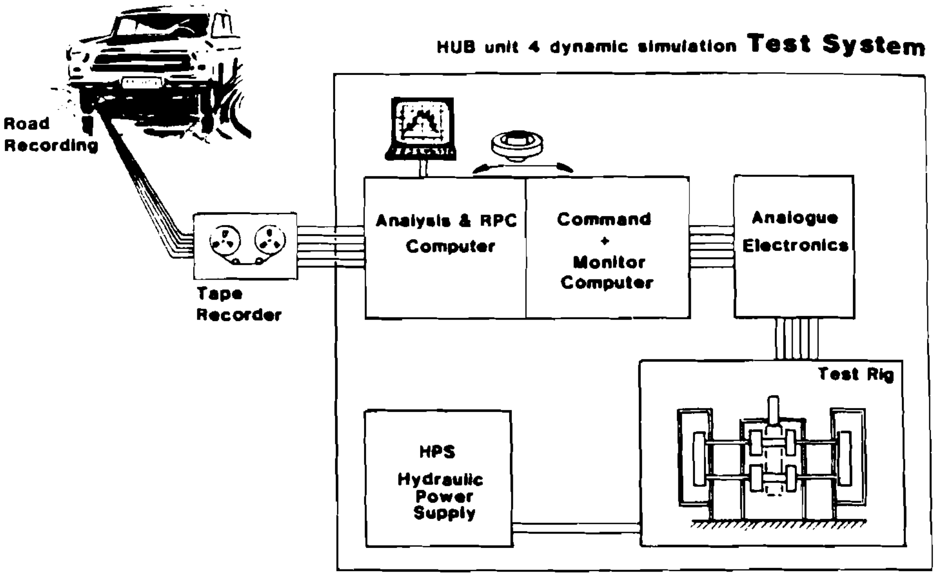


Figure 22: Principle diagram of a test facility for SKF Hub Unit 4, "Dyana". (Repr. from SKF, 1982)

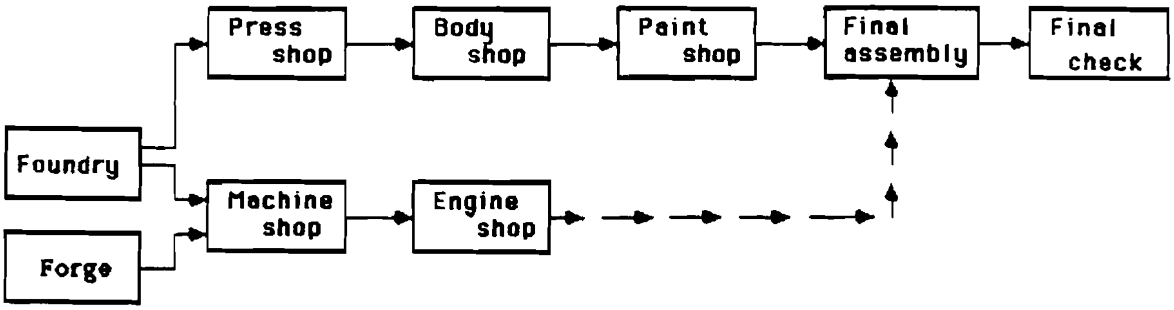


Figure 23: Symbolic representation of a traditional production system for cars.

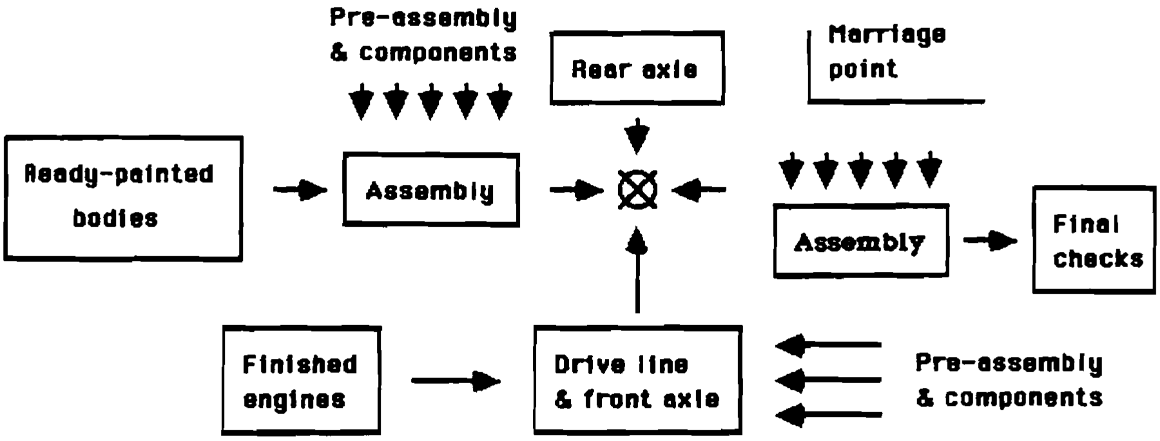


Figure 24: Symbolic representation of the location of final assembly in a production system for passenger cars.

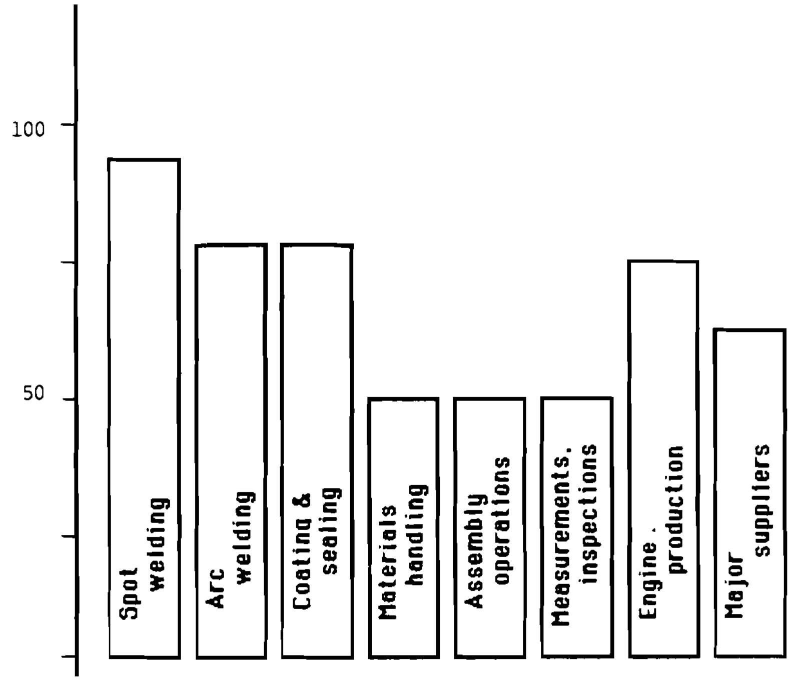


Figure 25: Projected number of automated tasks in different production sections by the Year 2000. (Repr. from Appel and Hilber, 1984)

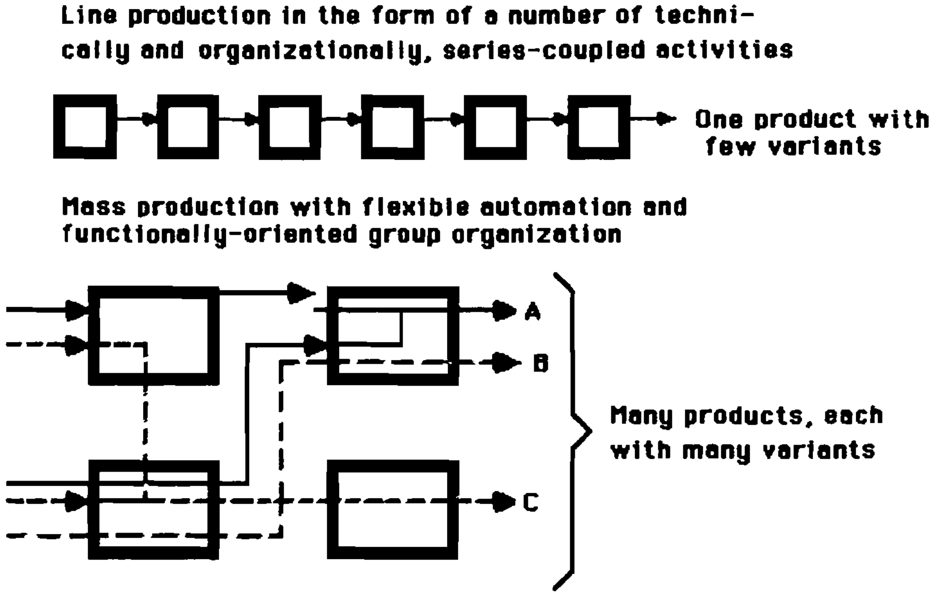


Figure 26: Schematic comparison of a traditional line with many short-cycle production activities and a functionally organized production system with flexible automation.
production

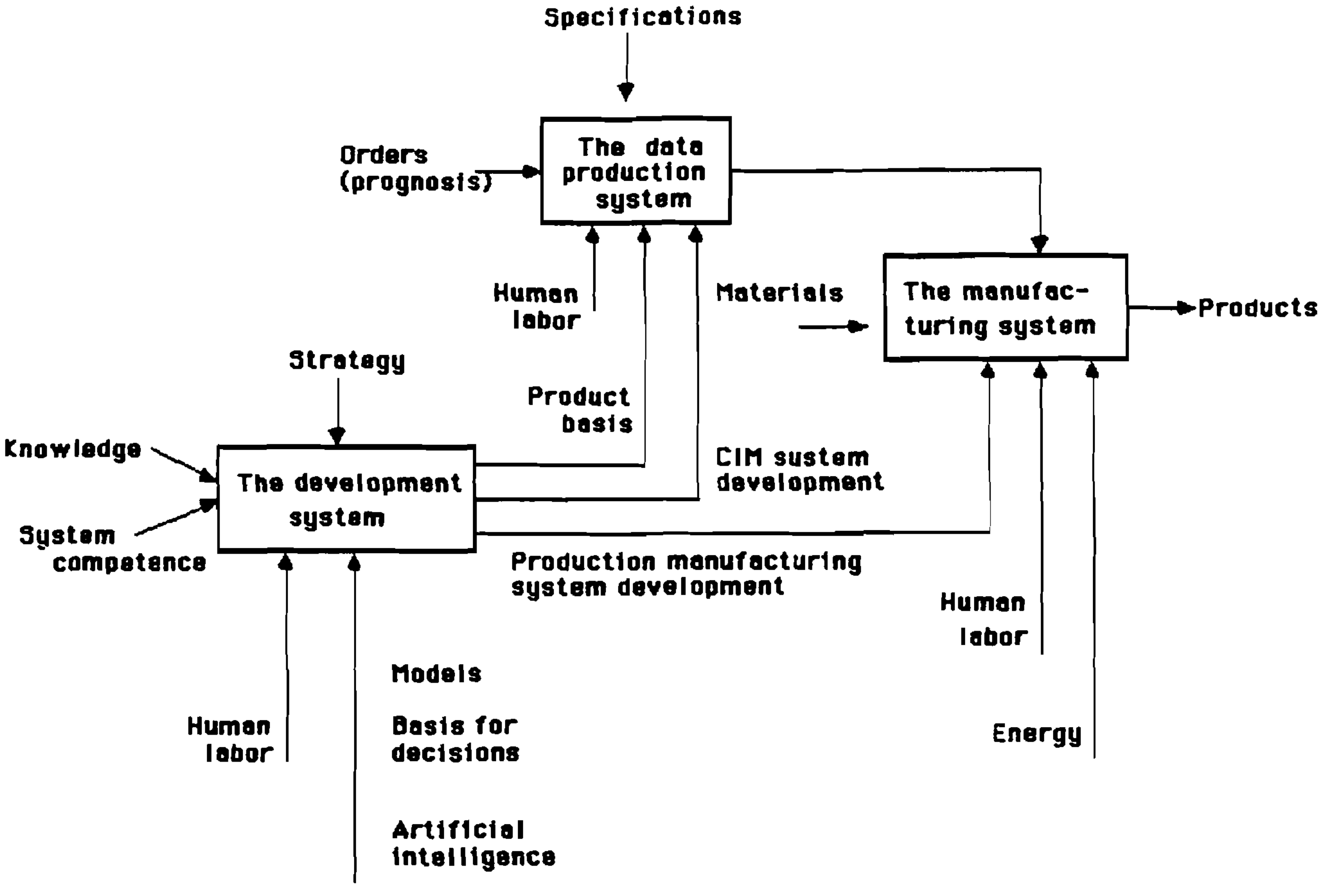
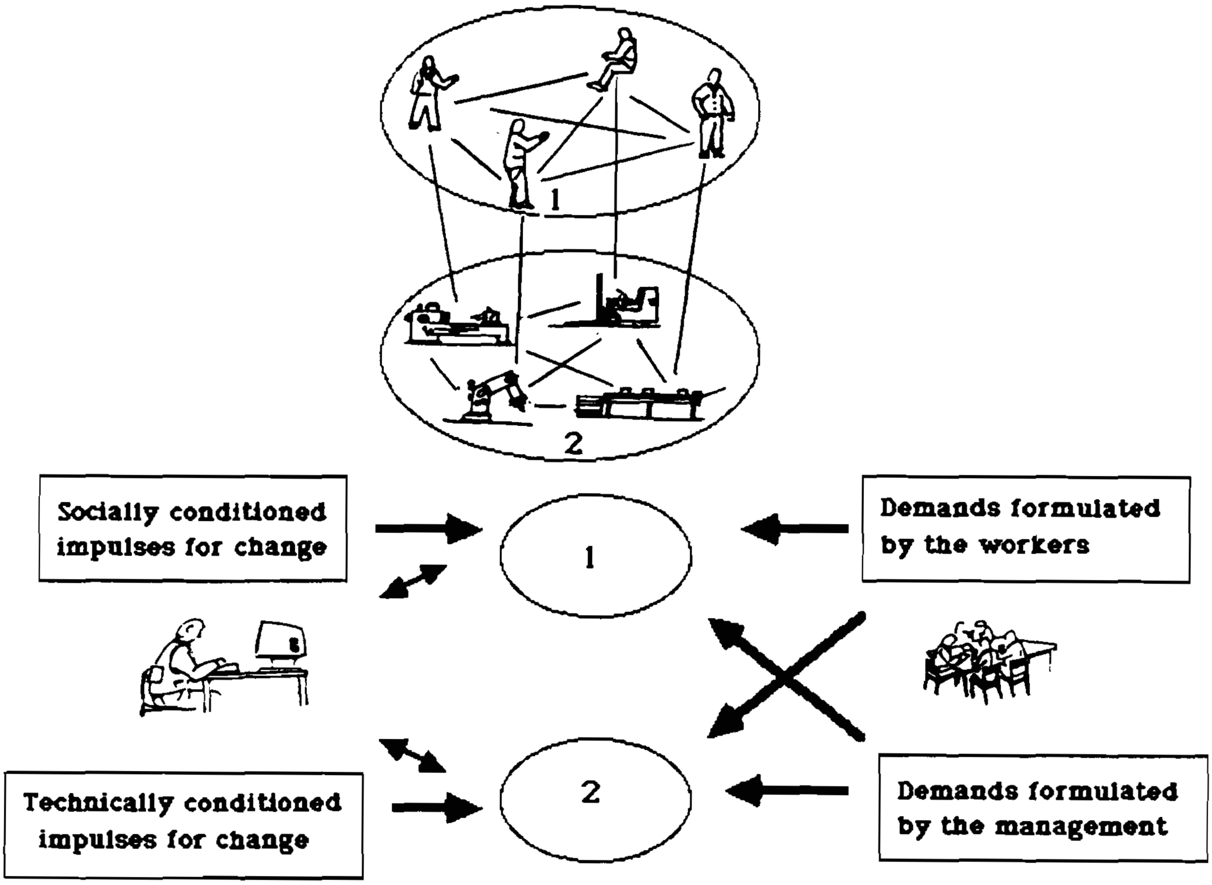


Figure 27: Division of an integrated development and production system into three subsystems. Source: Professor Sohlenius, Royal Institute of Technology, Stockholm.



THE SOCIO-TECHNICAL SYSTEM OF PRODUCTION
.... AND ITS ENVIRONMENT

Figure 28: A production system seen as a socio-technical system. The dual role of the production engineer is to fulfill not only business and economy related efficiency and flexibility demands, but also to fulfill the employees' social demands. (Repr. from Karlsson and Engström, 1983)

REFERENCES

Altshuler, A., Anderson, M., Jones, D., Roos, D. and Womack, J. (1984) *The Future of the Automobile*. London: George Allen & Unwin.

Appel, H. and Hilber, K.-P. (1984) *Product and Production Technology of Future Automobiles*. Berlin: Technische Universität Berlin and Massachusetts Institute of Technology, Report 6 on Cooperative Research.

Bengtsson, B., Sjöstedt, L., Valdsoo, T. and Wedel, J. (1984) *Fuel Supply and Distribution – With and Without Alternative Fuels*. Göteborg: Chalmers tekniska högskola, Inst. för transportteknik.

Benktander, S. (1982) *How the Bearing Became a Bearing Unit*. Göteborg: SKF Technical Forum.

Bergren, C. (1983) *Tio år efter Kalmarverken – Vad händer med arbetsformer och produktionsutformning in bilindustrin*. Göteborg: Chalmers tekniska högskola, Inst. för transportteknik.

Bianchi, P. and Calderale, P. M. (1984) "Flexible Manufacturing and Product Differentiation in the Automobile Industry" in Appel and Hilber (1984).

Blödorn, J. (1983) "Mode of Construction and Materials of Some Recent Research Automobiles". International Policy Forum, Stenungsund, June 13-18.

Engström, T. (1983) *Materialflödessystem och serieproduktion*. Göteborg: Chalmers tekniska högskola, Inst. för transportteknik. Doctoral dissertation.

Engström, T. and Sjöstedt, L. (1984) "Development of Production Design and Organization of Work within the Swedish Automobile Industry" in *Euroforum '84*.)

Euroforum '84 (1984) *The Future of the Automobile Society. Berlin.*

Grant, B. and Gadded, L-E. (1984) *Automotive Component Supply Strategies*. Göteborg: IMIT.

Karlsson, U. (1979) *Alternativa produktionsystem till lineproduktion*. Göteborg: Göteborgs Universitet, Sociologi. Doctoral dissertation.

Kjellberg, H. and Sjösten, K. (1979) *Inlärning av montör för dockmonteringsarbeten*. Göteborg: Chalmers Tekniska Högskola, Inst. för transportteknik.

Liljemark, S. and Pettersson, H-A. (1984) *Elbilen – en system-studie med tonvik på batterier och drivaggregat*. Göteborg: Chalmers tekniska högskola, Inst. för transportteknik.

Linke, W. (1981) "Das Auto in den nächsten beiden Jahrzehnten" in *Umschau* 81, Vol. 13.

Maasing, I. (1984) "Fiats nya 1-litersmotor 'Fire 1000': Tillbaka till naturen" in *Motor*, Nr. 10/84, p. 35.

Sjöstedt, L., Ternryd, C-O., et al. (1985) *Bilen och bilindustrin i svenskt perspectiv – En sammanfattning av svenska forskares bidrag till "The Future of the Automobile". Göteborg: Institute for Management of Innovation and Technology.*

Steen, R. (1984) *Industripolitik och structuranpassning inom bilindustrin.* Stockholm: IIB, Handelshögskolan.

Svidén, O. and Vahlne, J-E. (1984) *Automobile Usage is a Future Information Society.* Linköping: Linköpings tekniska högskola, Ekonmiska institutionen.

Sölvell, O. and Vahlne, J-E. (1984) *Structural Evolution in the Automotive Industry – History and Possible Futures.* Stockholm: Handelshögskolan.

Valdsoo, T. (1984) *Alternative Fuel Introduction: Some Aspects of the Brazilian Experience. Göteborg: Chalmers tekniska högskola, Inst. för transportteknik.*

APPENDIX I

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APPENDIX III – PART-C PAPERS & REPORTS

Part-C related Papers and Reports of the Future of the Automobile Program:

Aldmanm Bertil, Multilingual Research and Development as a Basis for Harmonizing Legislation, Paper presented at the Third International Policy Forum, Stenungsund, Sweden, June 1983.

Appel, Hermann and Hilber, Klaus-Peter, Uni-Car: Academic Exercise for an Integrated Research Vehicle, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982, (MIT-Future of the Automobile Publication FRG-C-82-1).

Appel, Hermann and Hilber, Klaus-Peter, Comparison of Different German Research Vehicles, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982 (MIT-Future of the Automobile Publication FRG-0-82-2).

Appel, Hermann and Hilber, Klaus-Peter, Design and Technology for Future Competition – A Trilateral Comparative Study, Paper presented at the Third International Policy Forum in Stenungsund, Sweden, June 1983.

Bellini, Nicola, Bianchi, Patrizio and Prodi, Romano, Production Cycle and Structural Adjustment in the Automobile Industry, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982.

Bellini, Nicola and Bianchi, Patrizio, New Production Systems and the Relevance of Quality in the Automobile Industry, Paper presented at the Third International Policy Forum, Stenungsund, Sweden, June 1983.

Bengtsson, B., Sjöstedt, Lars, Valdsoo, Thure and Wedel, J., Fuel Supply and Distribution – With and Without Alternative Fuels (in English with some Swedish sections – full English translation planned) Paper S-007.

Berggren, Christian and Engström, Tomas, Future Production Systems, Part I and Part II (in Swedish – English translation not yet decided) Paper S-005.

Bianchi, Patrizio and Calderale, Pasquale Mario, Flexible Manufacturing and Product Differentiation in the Automobile Industry, Paper presented at the Third International Policy Forum, Stenungsund, Sweden, June 1983.

Blödorn, Joachim, Some Aspects of Construction and Materials of Future Automobiles, Paper presented at the Third International Policy Forum, Stenungsund, Sweden, June 1983.

Blödorn, Joachim, Mode of Construction and Materials of Some Recent Research Automobiles, Paper presented at the Third International Policy Forum, Stenungsund, Sweden, June 1983.

Delsey, Jean, Diesel Engine, Conversion of Cars and Techniques for Reducing Their Prospects and Implications, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982 (MIT-Future of the Automobile Publication F-C-82-1).

Engström, Tomas and Berggren, Christian, Influence of Automotive Design on the Production System, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982 (MIT-Future of the Automobile Publication S-C-82-1).

Engström, Tomas and Berggren, Christian, Process, Product and Production System – Trends on the Development of Production Design and Organization of Work within the Swedish Automotive Industry, Paper presented at the Third International Policy Forum, Stenungsund, Sweden, June 1983.

Fraser, Jane, Changes in Production Processes in the Automotive Industry, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982 (MIT-Future of the Automobile Publication US-C-82-1).

Gustafsson, R., Life Cycle Costs for the Passenger Car (In Swedish only) Paper S-006.

Hayashi, Waichero, Energy Consumption by Automobiles in Japan, Paper presented at the Third International Policy Forum, Stenungsund, Seden, June 1983.

Honda, Shoji, What is the Future of the Electric Vehicle? Paper presented at the Third International Policy Forum, Stenungsund, Sweden, June 1983.

Honda, Shoji, Hoshino, Chisato and Ohno, Masakatzu, Electric Vehicles in Japan, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982 (MIT-Future of the Automobile Publication J-C-82-1).

Honda, Shoji, Hoshino, Chisato and Ohno, Masakatzu, Electric Vehicles in Japan, Evaluation, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982.

Iguchi, Masakazu, The Future of Automobile Technology, Paper presented at the Third International Policy Forum, Stenungsund, Sweden, June 1983.

Iguchi, Masakazu, Nakamura, Hideo and Shimokawa, Koichi, Technological Development and Its Implication to the Automotive Industry, Paper presented at the Third International Policy Forum, Stenungsund, Sweden, June 1983.

Iguchi, Masakazu, Shimosaka, Haruo, Yamashita, Tokuo, Kusano, Hiromitsu and Kitoh, Kozo, Future Trend of Passenger Cars in Japan, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982.

Iguchi, Masakazu, Shimosaka, Haruo, Yamashita, Tokuo, Kusano, Hiromitsu and Kitoh, Kozo, The Technological Future of the Automobiles in Japan, Paper presented at the Third International Policy Forum in Stenungsund, Sweden, June 1983.

Inoue, Mitsumasa, Technological Opportunities and Uncertainties Regarding New Types of Engine and Alternative Fuel Engine for Motor Vehicles, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982.

Inoue, Mitsumasa, Several Technical Vicissitudes Regarding the Engines of Recent Passenger Cars in Japan, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982.

Ishiwata, Shoji, Kim, Young Kil and Sugimoto, Takayoshi, Feasibility Study of Alcohol-Blended Gasoline as Automotive Fuels, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982.

Ito, Masashi, Present State and Future Trends of Introducing Robots into the Automobile Industry in Japan, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982 (MIT-Future of the Automobile Publication J-C-82-2).

Japanese Research Team, Comments on the Findings of the International Questionnaire on Product and Process Technology for Future Automobiles, Paper presented at the Third International Policy Forum in Stenungsund, Sweden, April 1983.

Jones, Daniel T., Technology and Competitiveness in the Automotive Industry, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982.

Liljemark, S. and Petterson, Hans-Ake, The Electric Vehicle – System Study with the Emphasis on Batteries, Motor and Drive Line (in Swedish – English translation available) Paper S-008.

Osawa, Makato and Ide,Masashi, Trends of Auto Materials in Japan, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982 (MIT – Future of the Automobile Publication J-C-82-3).

Pettersson, Hans-Ake, Experiments with Electric Vehicles in Sweden, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982 (MIT – Future of the Automobile Publication S-C-82-2)

Suzuki, Nobuo and Fujii, Haruki, Prospect of Communication and Control Technology for Automobile Traffic, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982 (MIT – Future of the Automobile Publication J-C-82-4).

Valdsoo, Thure, Fuel Supply and Distribution – With and Without Alternative Fuels, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982.

Valdsoo, Thure, Alternative Fuel Introduction and Use: Some Aspects of the Brazilian Experience (in English), Paper S-009.

Whitford, Robert K., Federal Involvement in Integrated Vehicle Development – US Experience: A Perspective, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982.

Whitford, Robert K., Results of Survey on Automobile Technology Forecast to the Year 2000, Paper presented at the Third International Policy Forum, Stenungsund, Sweden, April 1983.

Womack, James P. and Jones, Daniel T., The Competitive Significance of Government Technology Policy in the Auto Sector, Paper presented at the Second International Policy Forum, Hakone, Japan, May 1982 (MIT – Future of the Automobile Publication US/UK-82-2).