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United Nations Industrial Development Organization

The Seminar on the Establishment and Development of the Automotive Industry in Developing Countries

Karlovy Vary, CSSR, 14 ~~October - 1 November 1968~~
24 Feb. - 14 March 1969

AUTOMOTIVE RESEARCH AND DEVELOPMENT[1]

by

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1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO.

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SUMMARY

1. The paper discusses the planning, organization and functions of research and development in the automotive industry in terms of system engineering.

2. The duties and functions of product management include research, system engineering and product engineering. Product management formulates the objectives of the company, taking into account the results of marketing research, and prepares designs for the most effective manufacturing.

* This is a summary of a paper issued under the same title as ID/WG.13/8.

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3. The basic duties of system engineering are to formulate and establish company goals, to develop plans for the attainment of these goals and to direct the technical organization in accordance with these plans. Prior to the formulation of company goals, consideration of the future technical, economic and social environment is necessary. Design decisions must be made in the best interest of the complete system, taking into account modern technology. Economic and technical feasibility has to be considered at any stage of technical planning and control.

4. The system engineers can give useful information for the preparation of the budgets for research and engineering.

5. The interrelation of basic and applied research is discussed. Applied research in the automotive industry is mainly concerned with materials, processes, systems and components, safety, and engineering.

6. Requirements for the making of good designs include availability of complete data on improved designs, records on the performance of vehicles and parts, qualified design personnel, and accurate feedback of test results.

7. The paper mentions the new techniques of computerized design which are of great help to advanced product development.

8. The product objectives, subsystems and components, the areas of compromise for physical dimensions ("package"), and the area of fixed and variable cost form a four-dimensional matrix. This matrix illustrates the problems of system design.

9. Product development begins with building and testing of prototypes. The advantages of using simulators are briefly recorded.

10. In the chapter dealing with the significance of automotive research in developing countries, it is found that vehicles built in large volumes in highly industrialized nations are generally not suitable for production in small quantities in the developing countries using less sophisticated technology. The necessary redesigning of parts calls for local research and development. Usually the chassis and body must be changed to match the conditions prevailing in developing countries. In this respect, recent developments of production methods using fibreglass-reinforced plastic for manufacturing cabs are of great interest, since the engineering and tooling costs are considerably

lower than with conservative methods (pressed steel sheet). The organization of an automotive research and development capability in developing countries should be seen as part of an over-all programme for developing a local technological capability.

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Foreword

A discussion of scope and terminology

1. Automotive research and development is concerned with the creation of new and improved product designs, materials and manufacturing processes. Each of these three fields is sufficient to require a complete discussion of its own. This paper will be concerned principally with the creation of new and improved product designs and with materials only to the extent that they bear on the organization and the design. When the work of research and development is complete, the design is ready for the final engineering phase of preparing specifications and detailed drawings on the basis of which the production tooling programme can proceed.

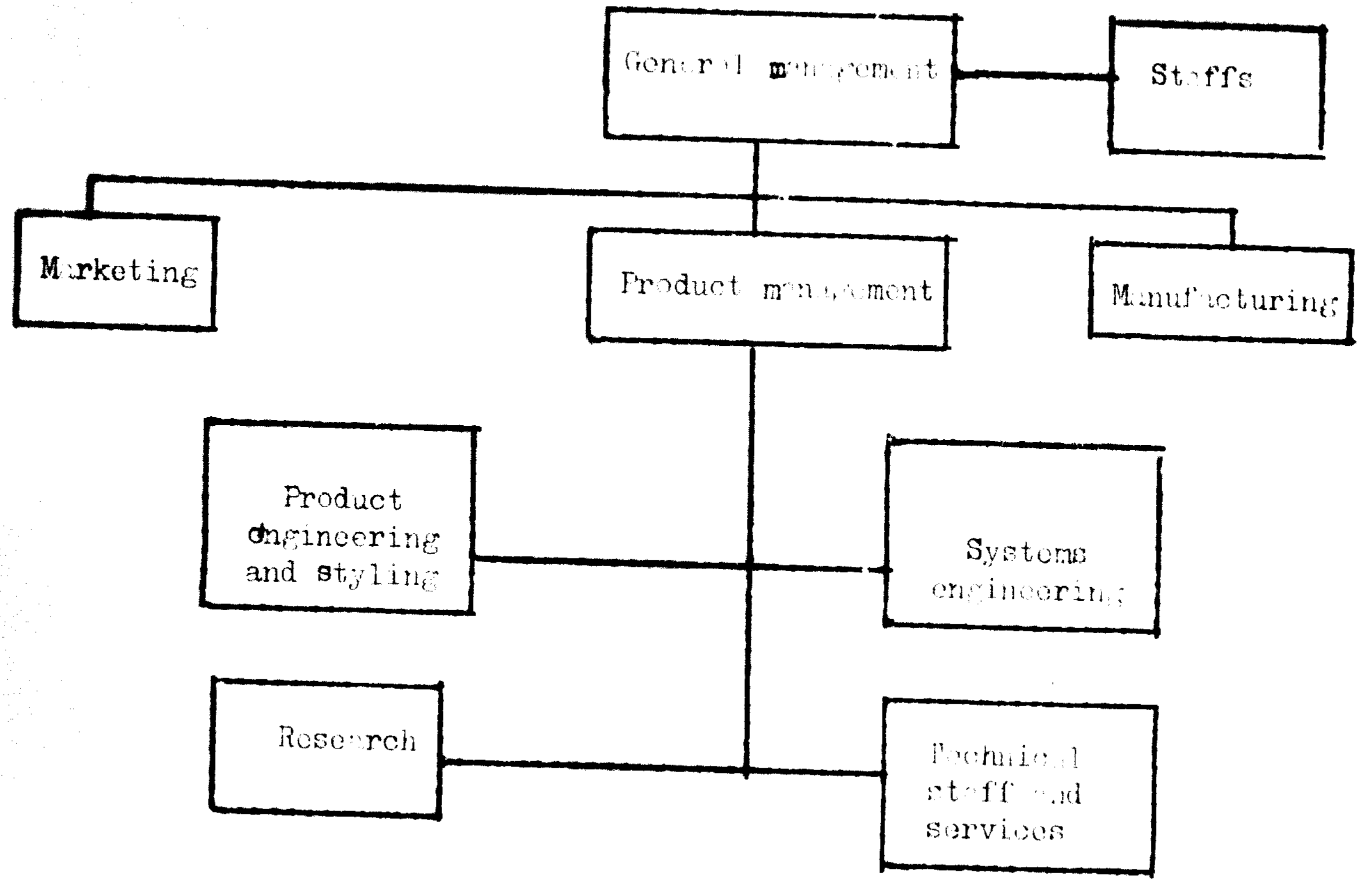
2. It should be emphasized that throughout the following paper the automotive organization will be described strictly in terms of its functions. The paper is not descriptive of any existing automotive organization. The organization and procedures that will be described are in many instances based on what are clearly foreseeable future trends in the industry, rather than on present practices. In some instances these differ materially from existing organizations and functions, all of which necessarily represent in varying degree the pattern of the past.

3. Figure 1 below shows a general management structure with various supporting staffs plus the basic operations which are marketing, manufacturing and product management. This could be applied to a medium-sized automotive organization or to a single division of a large one.

4. It is with product management with which we shall be principally concerned; but with the understanding that all operations must be closely coordinated. None of them work independently of the others. Product management must formulate its objectives with the guidance of the marketing operation, and it must prepare its designs for the most effective utilization of the techniques and facilities at the disposal of the manufacturing operation. Product management includes research, systems engineering, and product engineering, with the necessary supporting technical staffs and services. Systems engineering is responsible for technical and financial planning and control. It also includes scheduling and timing, value analysis and design cost guidance. Product engineering includes industrial design or what is sometimes known as "styling". It also includes both the advanced development and final phases of the engineering programme of which we will be concerned only with the former.

Figure 1

General management structure



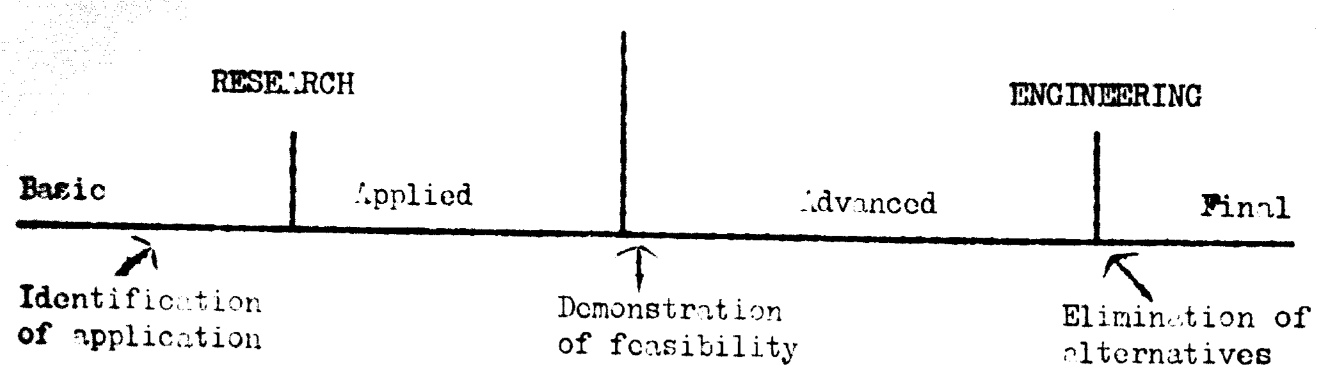
Functions and nomenclature

5. There is much confusion resulting from the fact that such terms as "science", "engineering", "development", "research" are used to describe different kinds of activities in different organizations. In order to avoid this kind of confusion, these terms will be defined as they will be used here. The distinction between science and engineering is primarily a social one. Science looks at the physical world, and its objectives are solely concerned with adding to our fundamental knowledge. Engineering has been defined as "the art and science of directing the forces of nature for the use and benefit of mankind". Engineering looks to the society in which we live both for its direction and for the rewards and satisfaction from its use and benefit to mankind. Popular usage has unfortunately credited to science and scientists the technological advances that are in fact the work of the engineers, so that in the popular mind science and technology tend to be synonymous. One engineer has remarked somewhat ruefully that "whenever the spaceship takes off and goes gloriously into orbit, the great achievement is credited to the scientists. If it falls in the ocean instead, it somehow becomes the work of the engineers". The engineer has the objective of directing the forces of nature for the use and benefit of mankind. He also has the further obligation of doing so at minimum cost. He must accomplish his objectives with the smallest possible expenditure of vital resources of manpower and materials.

6. Figure 2 below shows the spectrum of the technical organization beginning with the basic principle and ending with the final product.

Figure 2

Spectrum of the technical organization



7. Basic research concerns itself only with the basic principles of science. This phase of the evolution of a final product may be said to end with the identification of some application of the basic principle involved. Applied research uses the methods of both science and engineering in developing a product design, material or process. When feasibility has been demonstrated, the work of advanced engineering development begins. In this phase the specific design is evolved with full consideration of required objectives, costs and available facilities. The design is reduced to practice, tested, developed, and modified in the light of tested results. The final milestone is the elimination of alternatives. Up to this point there are more projects and alternative designs being carried forward than are intended to be followed into production. At this point the decision is made which alternatives will be chosen for final production; the rest are then either deferred or dropped. (Subsequent to this point are final engineering and manufacturing engineering which will not be discussed in this paper.)

I. THE PLANNING OF RESEARCH AND DEVELOPMENT

8. Research and engineering planning will be discussed in terms of systems engineering. In this term the word "system" simply means that which is composed of a number of subsystems and components. The automobile is a fine example of a very complex system.

9. In any instance where a complete system is produced there is some individual ultimately responsible for the success of the complete product. This individual is therefore accountable for the success of each component and subsystem of that product, whether or not he has the capability and the authority to control the design of that component or subsystem. Systems engineering is a method of providing to the responsible party the capability he needs to direct the engineering of all subsystems and components in the best interest of the complete system. In other words, systems engineering is a kind of "collective boss" whose business is to know everything about the technical organization and its capabilities. Like any good boss, systems engineering derives its technical capability from its subordinates; it respects them and their views, and it makes sure they understand the reasons for its decisions.

10. The difference between systems engineering and the line operating organizations is not one of knowledge and ability; it is one of objectives. Any large organization must of necessity be divided into smaller organizations whose objectives will differ in some way from those of the entire company. Systems engineering is a means to make certain that the over-all company objectives govern major product decisions. To accomplish this, systems engineering must be able to express those objectives explicitly and in great detail; it must be an arm of the central authority of the organization in order to achieve the objectives.

11. The assumption is made throughout this paper that the most modern techniques of operational research and systems analysis are available and will be used wherever appropriate in the performance of the functions to be described. One of the advantages of modern computerized analysis is the ability to analyse a large number of possible alternatives influencing a decision. However, analysis is of little value unless there are good

alternatives to be chosen; creative synthesis is not out dated by the computer. It is vital that the capabilities be highly developed for the creation of viable alternatives.

12. Arthur D. Hall says, "In major systems work, theoretical studies alone seldom provide all the grounds for decision making. This is because large systems often must satisfy many objectives simultaneously, some of which cannot be reduced to numbers. Even within the smaller area of technical feasibility, many relevant variables lead to an overly complex model. Sometimes the consequence is that a purely verbal description possibly based on experimental results provides a better approach. Generally, the best results come from a combined theoretical-experimental approach; each approach acts as a check on the other. Study of even simple models can be a powerful aid to thought."[2]

13. The author is in agreement with Hall that in the fields with which this paper is primarily concerned the best possible results will come from a combination of theoretical analysis and experiment. Inasmuch as present engineering organizations rely largely on experiment, this concept is much better adapted to their needs than a purely theoretical concept which would share no common ground with the present way of doing things. The modern systems engineer must not only understand the power and flexibility of theoretical analysis as performed with modern facilities, he must also understand what its fundamental limitations are.

14. As soon as it is given the responsibility for advanced planning, systems engineering discovers that the earlier in the spectrum it begins to plan, the more effective are the results. Since every engineering design should be made with the maximum possible benefit of technological progress, it can be seen that the maximum of engineering effectiveness is inseparable from the maximum of capability for innovation. This is to say that research and engineering are directed so as to make the most effective possible use of technological advances; both those which originate within the company's own organization and those which originate elsewhere. This means that systems engineering must know as much as possible about what is new in all aspects of technology that are significant to the company's operations.

2/ Arthur D. Hall (1962) A Methodology for Systems Engineering, Van Nostrand, p. 30.

15. Systems engineering has three basic objectives:

(a) To formulate, specify, and establish company goals;
(b) To develop plans for the accomplishment of these goals;
(c) To direct the technical organization in accordance with these plans.

Each of these objectives will be discussed in some details.

Company goals

16. As has been emphasized, the technical organization works toward broad economic goals, not just technical goals. These goals are formulated by systems engineering. One of the duties of systems engineering is to bring together all relevant considerations of the future technical, economic and social environment as they bear on probable marketing conditions; such as the probable need and use for various concepts of the product, the alternative technical methods of accomplishing the design of such products, and the problems that are involved in the accomplishment of each. The formulation of these goals is a creative job, and there are a number of techniques available for bringing together the many different kinds of information useful in their formulation. One of these techniques is a thorough study of the future in all areas that are relevant. This, of course, is a co-operative venture with contributions from many specialists within the company. The study of the technological future pursued within the organization itself is a valuable tool for the planning of research and engineering.

Studies of future science and technology

17. Studies of the future may aspire to be fairly meaningful over a period of about ten years. Beyond that point there is an increasing probability of being wrong when visualizing the future. The reason for the choice of the ten year period is that this is the length of time it takes a radical new scientific development to become a factor in the technological world. In other words, assume that the technology for the next ten years will be based on the science that we know today, but that after ten years it is highly probable that some basic scientific development, not yet known, will change technology in a way not now foreseen. Surprisingly, the scientists are no better than the engineers in predicting the future. They predict superhuman accomplishments for the engineers, erecting shining towers of technology on the smallest rocks of scientific truth, with the air of saying, "Now we have done the important work, you people can take care of the details". They are singularly unwilling to predict what new discoveries are likely to arise in basic science. A look at the past will show that the really good predictors of the future are the writers of science-fiction and comic strips.

18. There is no better illustration of the difficulty of predicting the future than to go back only thirty years - to 1938 - to a time when nuclear fission and fusion were as yet unrecognized; when the concept of the digital computer was not yet a vision of Charles Babbage; when solid state physics had just recently been recognized as a subject worth pursuing; when the idea of jet propulsion was unkown, while rocketry and space travel were mentioned only in the comic strips.

19. For the planner of engineering and research who has at his disposal a large and capable technical organization, there is a better way to study the future of technology. The technical capability of any good research or advanced engineering organization is based on the capability of the people at the working level. It is they who are the experts, not the managers and directors of laboratories. One of the most effective techniques of surveying the future is to go to each of these experts in turn and say to him, "Please write a paper telling what will be the state of development in your field ten years from now". The responses to such a request would be prompt and voluminous; the asker of the question would find himself buried in an avalanche of authoritative and significant information in many fields of technology. After he patiently read all of these papers, he would find they are inconsistent. He would ask many questions of the writers and would bring the experts together to confront each other. Various kinds of inconsistency between specialized predictions of the future can provide many opportunities for stimulating interaction. After such a lively confrontation each participant would return to his own activity bursting with new ideas of research projects to be planned, and new developments to be pursued. The usefulness of this kind of interaction is much better recognized and exploited in basic science than in engineering. In the pursuit of the original purpose of making a survey of the technological future to be used in formulating company-wide technical goals, planning, engineering and research can effectively be aided by confrontations between experts.

Formulation of company goals

20. It has already been noted that the formulation of goals is a creative assignment. In the words of Frederick R. Kappel, "A business needs goals that are clear and have wide range and reach. Aims must be explicitly stated and they must be of a quality that challenges superior minds."3/

21. The formulating of business goals begins with a clear look at the basic business of the company. What kind of a contribution to society does it conceive to make? What can be done to increase the value of that contribution or to broaden its scope, or to put it within the reach of more people? In what way can this specific contribution take the form of a saleable product?

22. The company goal can be formulated in terms of its ultimate function, recognizing various technological paths for arriving at the goal; or it may be defined in terms of a particular technological system to be developed, recognizing that there are many functions that it can perform. A goal may be defined in terms of improvement of a particular quality in a broad line of products. One of the important needs in the formulation of goals is to state each of them in such a way that each component organization of the company may perceive in that goal the nature and the importance of his own contribution toward the attainment of it. Thus, the goal takes the form of a detailed specification of the component and subsystem requirements of the complete system, with the economic objectives of each.

Establishment of company goals

23. This is a formal procedure but an important one. After the goals have been formulated and have been reviewed by the representatives of various company operations who took part in their formulation, they are ready for presentation to the policy-making body of the company. Once this has been done and the goals have been approved, they become company policy. The very formality of this process gives a consistency to the direction of the technical organization that is likely to be lacking otherwise. Almost all technical organizations are subject to various kinds of short-range pressures. Not all these pressures can or should be resisted. However, the existence of consistent company policy directed towards long-range objectives can force a more careful evaluation of short-range needs, and prevent many erratic technical directions that would otherwise result.

3/ Frederick R. Kappel, (1963) "The System Approach in Science-Based Industry" Bell Telephone Magazine 42(3),2-7.

24. It will be found that the existence of well-formulated company goals, and the practice of reviewing these with the general management, forms an excellent framework in which members of general management who are not engineers or scientists can visualize the operation of the technological organization. This improves, in a very important way, the quality of management and the effectiveness of the technical organization.

Formulation of plans

25. Every goal requires a plan as to how it is to be accomplished. A plan is primarily a schedule that lists all the tasks to be performed, who will perform each task, which tasks await the completion of others before they can be undertaken, and which tasks must be completed before others can be undertaken.

26. There will be points in time at which decisions must be made in the choice of alternative technical means. Certain information must be available for the making of that decision. There will be engineering and development work necessary for the production of that information, and there will be a time at which the engineering and development work will have begun in order to have the information available at the desired time.

27. When there are a great many tasks to be performed in the minimum of time, the job can become very complicated. If it is the kind of job that computers can do better than people, and within the areas that engineering work can be reasonably scheduled, the planning is fairly routine. Since the plan is no better than the estimates of what is needed to perform a task, in advanced engineering planning is less precise, but the general principles apply equally well.

28. It is a favourite statement of engineers and research people that it is impossible to schedule invention. In fact, there is some degree of invention required in all good engineering design and development. This kind of design and development can be, and commonly is, scheduled and planned. It has to be remembered that plans and schedules are no good unless people perform as planned. Engineering planning is not effective unless the planning agency represents the authority to direct the work required.

29. This kind of planning can only be done in those instances where there is no major subsystem or component on which feasibility has not yet been demonstrated. Longer range plans may be set up on the assumption that the desired feasibility will be accomplished by a certain date, or there may be plans in which alternative courses are pursued, one of which is less desirable but feasible, to be chosen only in case the more desirable alternative does not achieve feasibility as originally assumed.

Direction of the technical organization

Design decisions

30. As previously noted, some single individual or company agency is always responsible for the design of the complete product, whether or not is has the capability to direct the design of its subsystems and components. Systems engineering, in assuming in the name of this responsible party the responsibility for subsystem and component design, must recognize two specific rules of operation:

(a) All design decisions must be made in the best interest of the complete system, and not that of the subsystem or component;

(b) All design decisions must be made in the light of the most modern available technical knowledge.

If these appear as platitudes, they are in fact difficult to achieve, and require explicit recognition of the needs and conditions they impose.

31. The first rule means that component design decisions shall not be made solely by those whose function it is to design that component. All engineering designs are subject to some requirement to minimize cost, weight or bulk, and any part of the system that exceeds the total requirements, will penalize the whole system accordingly. If it is assumed, for example, that an automobile should have a useful life of 150,000 miles, it would be pointless to equip it with a major component that would last for 500,000 miles. The purchaser's money would be wasted, as he would be paying for 350,000 miles of component life that he would be unable to use. The designer of the component, however, will have found that the easiest way to keep down complaints is to design a component that will go 500,000 miles. He may not like to face the more difficult problem of designing a cheaper one that will still not cause complaints. Someone outside the organization charged with the design of that component must recognize this condition and demonstrate the feasibility of the alternative approach.

32. The second rule requires that feasibility decisions on new designs shall not be made solely by those responsible for the present designs. Any organization will resist change that comes from outside. It takes less risk and less effort to perform a familiar task than to learn a new one. While change must take place when the interest of the company demands it, systems engineering can do better than simply arbitrarily directing, in the name of centralized authority, that the change be made. One of its major functions is to foresee required changes in time to acquaint the engineering organization before they must be put into effect. By including the responsible engineers in the original planning, and enlisting their ideas and assistance in the new development, it gives them understanding and familiarity, and a share in the pride of accomplishment. These things overcome reluctance to accommodate to change, and reduce the associated risks.

Design cost guidance and planning

33. At every stage of technical planning and control, systems engineering has to consider economic feasibility as well as technical feasibility. The economic value of the function performed by the product must be weighed against the cost of producing that product and some kind of an estimate be made as a basis for proceeding with any plan. The cost of any product can vary enormously depending on its design, this cost-value relationship is the best possible measure of the excellence of a design.

34. How does the designer proceed to keep his cost at a minimum? Oddly enough, the more highly developed are the cost accounting procedures, the more difficulty the designer has in obtaining the guidance that he needs to hold his costs to a minimum. In a complex product built in great volume with elaborate tooling, a long and complicated list of elements must be included in any cost estimate. This involves the cost of tooling, which in turn involves an estimate of volume of production; the cost of material, of fabrication and of assembly. No designer can wait while the great machine of cost accounting grinds through the complicated process needed to produce information of this kind; and if he could wait, the cost of producing the information would weigh heavily against the project. On the other hand, a designer has a clear feel for the essential cost of a design; he can look at the weight and cost of materials, the number of parts, and the number of operations required to assemble the parts. He can get for himself a reasonable index of the relative cost of two alternative designs.

35. The best method of providing cost guidance for designers is to add to this natural designer's ability the help of cost consultants in each engineering activity. These cost consultants are expert on processing and materials, and they have current knowledge of existing facilities. They can tell the designer how he can change his design to save tooling costs or to simplify assembly, to reduce the need for a kind of material that is expensive or difficult to handle, or how he can design a casting in such a way as to reduce the number of cores required in the foundry.

36. In advanced engineering programmes, both functional and cost considerations require that alternative designs be carried forward to the point where an evaluation can be made of the value-cost relationship. The planning of the experimental design and development of these various alternatives is a routine part of the planning of advanced programmes.

Allocation of technical resources; budgeting

37. It is commonly assumed that the total amount that should be spent on research and engineering will establish itself, but there is considerable range in this quantity. Assuming a given level of technical competence on the part of the organization, engineering can be better or worse; the cost of the product can be higher and its ability to perform its function can be lower. Both of these cost money. There is obviously a level below which reductions in the cost of engineering will cost a great deal more than have been saved by other engineering economies. In practice in a large organization it is a difficult lengthy process to establish any meaningful relation between these quantities.

38. In the attempt to find some basis on which proper expenditures for research and engineering can be set, it is common to look at the operations of competitors. Unfortunately, even less information is available for judging the adequacy of a competitor's engineering effort, since less is known about the cost of his operation and almost nothing is known about the adequacy of his advanced programmes. Systems engineering can supply useful information on this subject in line with its assignment to know all there is to know about the technical organization, its capabilities and its expected results. Systems engineering can and should be able to express to management the probable long-term effects both of increases and of decreases in the research and engineering budget. While often a relatively small proportion of the total expenditure is in research and development, the quality and cost of subsequent engineering is based on the effectiveness of the advanced programme.

39. Another area in which engineering costs must be carefully examined is in the speed of development. It is exceedingly expensive to accelerate a programme beyond the normal pace of experimental design and development; and it is important to weigh the costs of acceleration, not only in engineering costs but in quality and cost of product against the value of early product availability. One of the best ways to accomplish early availability is to start early, and this is one of the benefits of systems engineering's careful and systematic examination of future needs and opportunities.

40. The necessity for budgeting is inescapable in advanced engineering or research. Any creative engineer or scientist can think of more good ideas than he will probably have money to pursue. The proper process of budgeting is one of evaluating these ideas as nearly as possible in terms of their anticipated cost, and anticipated return. A major factor in every budget in an advanced engineering and research programme is a decision as to the probable value of the project; its value as an investment in future company profits and its probability of success. Estimating the probability of success is a highly technical job. Unfortunately it cannot be left to the sponsor of the project, who would not be in the business if he were not an optimist.

41. Systems engineering, by taking a long-range view of the company's aims and how they can be accomplished, can add greatly to the content of this pattern and improve by a considerable margin the efficiency with which the company's resources are allocated for the needs of its advanced programmes. It has the full capability of the technical organization at its disposal and can form reasonable estimates of probability of success. It is important to emphasize the need for allocating to each able member and department of the organization, a proportion of its annual budget, free and clear from outside control, to be used for the initial investigation of good ideas.

42. Just as it uses computers for the development of complex schedules, so systems engineering will use computers for multidimensional analysis of complex objectives in the process of estimating the probable value to the company of individual programmes.

43. It has already been indicated how systems engineering can encourage interdisciplinary interaction for the purpose of improving the quality and content of internally formulated budget proposals. It is a mistake to assume, however, that there exists a clear distinction between those proposals that are formulated internally and those which are part of a company plan. There is a great deal of overlap. This is because much of the subject matter of the goals formulated by systems engineering is drawn from the work of the various research areas. What systems engineering does is to make sure that each worthwhile proposal is supported by necessary work in other areas. In this way, in the process of working on systems engineering plans, "A" is doing some work toward objectives that he has formulated himself; other work that he is doing is in support of objectives that have been formulated by "B" or "C". The important thing to remember here is that none of these objectives can be achieved without the accomplishment of the supporting work. The more complex the system, the more necessary are the efforts of systems engineering to see that all objectives receive the support needed from all departments of the technical organization. Research and advanced engineering people will not resent this. They would rather work on one project that they know will be a success as otherwise they receive no support.

II. ORGANIZATION AND FUNCTIONS OF RESEARCH AND DEVELOPMENT

Basic research

44. Only a very few of the largest automotive companies support basic research. Basic research in industry is similar to basic research in institutions of learning. By definition it is entirely subject-oriented, and in principle the pure scientists are entirely unconcerned with the material goals of the company that employs them. Their sole objective is adding to fundamental knowledge. Nevertheless, the basic research laboratory makes important contributions to the industrial organization. Not only can it be expected to develop new scientific principles that will have important application for the future; even more importantly, it is in the best position to be aware of the potential importance of scientific developments that take place elsewhere.

45. In addition to the flow of ideas and concepts along the line of the technological spectrum, there should also be a flow of people and methods. Research should be regarded by the rest of the organization as a potential source of talented people; the scientists make good engineering managers and they bring along with them much needed new attitudes and methods.

46. The basic research laboratory at the Ford Motor Company is the largest of its kind in any automotive organization. It employs 165 people of whom 91 are scientists with doctorate degrees. It has six departments: mathematical and theoretical sciences, physics, metallurgy, chemistry, physical electronics, and cryogenic devices.

Applied research

47. Applied research is the link between science and engineering, and it employs the methods of the scientist as well as the engineer in accomplishing its objectives. Its primary task is to recognize the possible useful application of a scientific principle; and to reduce this application to practice in such a form that its usefulness can properly be evaluated, with judgement as to the probability of its eventual success, and the extent of its contribution to technology. On the basis of such evaluation, decisions can be made regarding further development.

48. Recognizing the diverse nature of the two fields, between which applied research forms a link, the characteristics of the personnel for this department can be accurately specified. They must be drawn from both fields. One of the great advantages of a viable basic research laboratory is that it forms a nucleus and a source for the recruitment of able scientific personnel for applied research.

49. Whenever a scientific development emerges that promises to have useful application, the scientist who is responsible for it often pursues it into the subsequent stages of development, and transfers his allegiance from pure science to applied science. When this occurs, it brings to the project a useful degree of continuity, understanding and enthusiasm, all of which increase the probability of its success. In addition to this, a valuable contribution is made to the economic objectives of the parent organization through the addition of an able member of its applied technical staff. It has previously been remarked that scientists often make good engineering managers; they most often make good applied research scientists as well.

50. Many of the most able and intelligent young people choose to be scientists engaging in pure research rather than applied scientists or engineers. It is true that science is credited in the popular press with many of the technical achievements of engineering, and has about it the glamour that engineering possessed in an earlier generation.

51. There are other reasons however. Many of the ablest people with the most intense creative drives have a fierce desire for independence; a desire to control their own destiny and choose their own tasks. They fear regimentation and organization. Many of them have an idealistic urge to avoid materialistic constraints. All of these things cause them to shun engineering and applied science because of its connection with practical affairs. Many able scientists retain this attitude throughout their lives. Others, once embarked on a career of pure science, perceive the opportunity for service to society. They perceive that leadership is as worthy a goal as independence, and they find that economic constraints are as real outside business as within it. Such people are good candidates for applied research and development. Their intelligence and ability quickly overcome any lack of specialized training, and they become successful members and leaders of the technological organization.

52. As to the engineers, some should have previous experience in design and development, with the ability to bring a project to a state of readiness for those operations. Others are primarily creative design people. This is a good field for young engineers to get their first view of the process of product innovation. Young engineers are trained in the latest engineering techniques, and their creative abilities are at the peak; and at this stage of the process the penalties for the mistakes of inexperience are relatively small.

53. Not all technological innovations have their origin in applied research since not all innovations depend on the new application of scientific principles. Some of the most important however are likely to do so, and for this type of development applied research has a task that is both difficult and important.

54. About half of the work of the applied research organization will be directed towards objectives formulated within the organization; the other half in pursuit of objectives stated for it by systems engineering. The latter include objectives that have been formulated by the organization in support of product needs as well as projects needed to support developments in other departments of the technical organization. Systems engineering is also concerned that developments that are feasible within the applied research organization, are given prompt consideration for incorporation into company goals and engineering plans.

Materials and processes

55. The automobile is dependent on a wide spectrum of materials. Each has an important bearing on durability and reliability, the ability to perform as expected, and the ability to give satisfaction to the user. In varying circumstances there are wide differences in the proportion of these materials that are produced by the automobile manufacturer and those procured from outside sources. In most instances, the procurement from outside sources dominates, and the automotive manufacturer finds that he cannot successfully turn out his product without exerting close control over the sources of his materials.

56. Close control of physical properties is essential to the success of the product. Basic to the automobile is steel. Steel is highly stressed in modern designs for savings in cost and weight. In sheet metal, formability and weldability must be held within close limits, while gauge and hardness control are essential if pressed metal parts are to be within dimensional tolerances. Elastomers are vital parts of the modern automobile. Vibration absorbing mounts for engines and bodies, suspension parts, air and water seals for doors and windows, oil seals and gaskets, hoses for petrol, hydraulic fluid, cooling water, and vacuum assists, diaphrams for petrol pumps and vacuum power cylinders are a partial list of devices that require a wide variety of physical properties all of which must be specified and controlled.

57. A growing number of small parts are molded plastic, and in some instances plastic body panels are used. Plastics and leather, both natural and simulated, for interior trim, electroplating for decoration and corrosion protection must be specified for procurement and controlled in production. Brake and clutch linings must have accurately known friction characteristics and resistance to heat and abrasion. Glass for windshields and windows requires close control of optical and shattering characteristics for safety. Fuels and lubricants relate intimately to the design of the vehicle and its successful performance. These are especially important, since their quality must be assured to the customer, and therefore there is need for the automotive manufacturer to control the quality of a product that he neither makes nor buys.

58. The applied research organization becomes the natural base on which to build the extensive capability required to control this long list of materials. If one examines the automobile of 30 years ago and compares it with today's product, he finds that the improved value and capability are due a great deal more to the more efficient use of materials than to basic differences in design. This fact serves to indicate the relative importance of research in the improvement of materials and the capability for their control. It also indicates the wide range of scientific and engineering techniques and abilities required to conduct this research.

59. The general subject of process development is outside the scope of this paper. However, it must be said that process development is closely linked with product design and material development, and the conduct of research in this field is inseparable from the functions of an applied research organization. It is particularly important under the circumstances so typical of a developing nation that manufacturing processes be developed which are best adaptable to product requirements, to locally available resources and the volume of production, since these processes are quite likely to be entirely different from those that prevail in more highly developed technologies. In the highly developed countries, the product designer is the prisoner of the enormous investments in manufacturing facilities. In the developing nation, the product designer is likely to be the prisoner of local economic limitations.

60. Some examples of improvements in materials and processing that have arisen in the basic research laboratory at the Ford Motor Company and have been reduced to feasibility and practice in applied research are the following:

(a) Titanium carbide cutting tools have about five times the life of tungsten carbide equivalents and permit substantial increases in production output per machine hour through the use of higher cutting speeds.

(b) Ausformed steel has tensile strengths up to 400,000 pounds per square inch and permits comparable increases in metal hardness. This material is particularly useful in highly stressed components and already much used for punches and dies for difficult applications in large volume production. It will eventually be used to reduce the size and weight of suspension springs.

(c) Electrophoretic deposition of corrosion-resistant coatings on metal surfaces is an electrostatic equivalent of the electroplating of metals. This process is valuable because it is self limiting and leaves no conducting metal surface uncoated. It is already in use in the application of corrosion-resistant coating on vehicle underbodies.

(d) Radiation is a method of curing of paints and polymers. In this process, electron radiation produces, in about 30 seconds, a comparable effect in 20 minutes in the bake oven. It permits the application of baked enamel finishes to materials that cannot withstand baking temperatures and will find increasing application in large-scale production where it will save time and space by the elimination of bake ovens. It will permit the use of materials that cannot now be applied to the automobile.

Many other examples may be cited from the experience of Ford and other comparable manufacturers.

Systems and components

61. It is in this area of applied research where many new design concepts take form. The cardinal rule in the design of a complex system such as the automobile is that the system comes first. Its individual components are never regarded as ends in themselves but only as means towards the accomplishment of the central objective. It is often difficult for those who have responsibility for the design of specialized components such as engines, transmissions, suspensions, chassis parts and bodies to accept the rule that their objective is always to build the best possible automobile, and never just to build the best possible component. These objectives are never the same since all design is a compromise. The optimum system and component design will be discussed at greater length in another section of this paper; the concept begins at the beginning, however, and it must guide the conduct of research and development in all its phases.

62. Since the objective of the research organization is the demonstration of feasibility and not the creation of a finished design for a specified product objective, the approach to design in the research organization is therefore more creative, less inhibited, and more governed by the need to conduct experimental design and development as economically as possible. Thus, the parts of an experimental model intended to demonstrate feasibility are likely to be designed quite differently from those intended for production.

63. Because of its concern with the system, the applied research organization requires that there be included in its organization persons who have capability in all design areas. This is true even though the enterprise is not sufficiently large to justify undertaking research in all the areas of specialized component development. The success of an organization is not dependent on its having a large number of people. In these early phases, and indeed in all phases of research and development, a small number of truly able people can produce much more effective results than a large number of people whose abilities are only indifferent.

64. Any organization, large or small, will conceive of more projects and ideas that it has the facilities to carry forward. One of the keys to economical performance of effective research and development, and hence of effective organizational leadership, is early identification of projects with potential for the greatest success and early elimination of unsuccessful projects. It often requires courage and discipline on the part of both leaders and associates in an applied research operation to recognize a negative result, and to put an end to a project originally undertaken enthusiastically in the expectation of success. A useful formal procedure is to conduct a regular technical audit, by senior technical people, of the current projects, the adequacy of the design they represent, and their expectations of success.

Safety and human engineering

65. Safety is not the province of any single department in research and development. Engineering is sometimes defined as the fine art of compromise, but at least in the United States there has never been any degree of compromise that would increase the risk of mechanical failure; this includes chassis and suspension components, wheels, tires, brakes, and lighting. In the United States there are over 60 million cars in daily operation and despite the horrifying total of deaths and injuries in car accidents, the United States is the safest place in the world to drive a car. It has the lowest accident rate per mile travelled of any nation where statistics are kept, and it has the second lowest accident rate per vehicle.

66. The industry has been less meticulous on the whole about the human factors in safety, primarily in the matter of passenger restraint and interior design. Following the cold reception by the public of Ford's initial attempt in 1955 to popularize this aspect of safety, it was generally neglected by the industry until the recent outburst of criticism and government action. Recently the industry has set about to make up for lost time, taking up where Ford left off ten years ago.

67. Unfortunately, ignorant critics have raised great expectations of the potential of "crashproof" automobiles, which are not realizable. The presumptions concerning the possibility of building crashproof automobiles are most generally based on the work of Col. John Stapp, who survived without serious injury a deceleration of 47 g in a carefully controlled sled test with elaborate body restraint and acceleration in a predetermined direction. To withstand such

accelerations, body restraints must distribute the force of acceleration as uniformly as possible over the whole body. Such restraints severely restrict freedom of movement, and their application is a lengthy and difficult process; one which is obviously not applicable to the passengers in an automobile, less than 20 per cent of whom are even willing to endure the slight restraint of a seat belt. Probably the best hope for this kind of passenger protection rests in new inventions, such as airbags designed to inflate in sufficiently short time to absorb the impact of the so-called "second collision", or nets or blankets serving roughly the same function.

68. The concept of the crashproof car is itself fallacious. Probably the ideal effect of a frontal impact is for the front structure of the vehicle to collapse as uniformly and as completely as possible without seriously infringing upon the space of the passenger compartment. This provides the maximum stopping distance. Fortunately this condition is consistent with other design objectives, and most cars now built will collapse in this mode on frontal impact. It is important that there not be too much rigidity or resistance to crushing in the front structure of the car in order to avoid unduly large accelerations of the passenger compartment. It is notable that, of the so-called safety cars that have been designed - and some of them built and shown - there have never been any public reports of the results of a crash test conducted on one of them.

69. The Ford Motor Company is presently destroying about two vehicles per day in systematic crash tests in barrier impact, rollover, side and rear crashes and drop tests. In each test there are extensive measurements of trauma on the dummy occupants, acceleration rates, structural collapse factors and indicated points of occupant injury, for the purpose of establishing optimum design factors for occupant safety. Other United States manufacturers conduct these same tests in comparable numbers. Unfortunately, there are many times this number of vehicles destroyed in customer service, with inadequate information concerning the circumstances and causes of the accident or the causes and extent of the injuries sustained.

70. Other vehicle characteristics must be established primarily on the basis of the human factors. Many of these, such as the operation and location of controls, are also directly or indirectly concerned with safety. The basic dimensions of the vehicles are established by anthropometric data which must be constantly updated because of the rapidly increasing stature of coming

generations. The design and location of operating controls and indicators have received more systematic attention in aircraft than automobiles, but the automotive industry is rapidly catching up in this field. There is growing appreciation of the importance of the subjective factors that play such a large part in total user satisfaction, and the need for developing objective information on which vehicle design can be based.

Engineering development

Factors of good design

71. Since the success of the entire organization is dependent on the quality of designs produced by the research and development organization, some of the basic requirements for the production of good design will be discussed here.

72. The advanced engineering organization begins its responsibility for design, through an ongoing programme of design improvement in each subsystem and component area of the vehicle. Whenever the need arises, anywhere in the organization, to design a new subsystem or component, advanced engineering should have available complete data on improved designs. These must be of demonstrated feasibility, and must embody the lessons of past experience and the full benefit of the most modern developments and materials and processes.

73. The automobiles engineers have designed and developed are built in significant quantities under conditions of the utmost competitive pressure for low cost and product quality, function, and durability. Records of their performance with the ultimate buyer, which emerge only long after the manufacturer has produced a design, constitute an evaluation of the design many times more accurate than any possible prior analysis. No analytical prediction of behaviour is more accurate than the assumptions made concerning the conditions under which the behaviour is expected to take place, and in the case of the mass produced article these conditions can only be inferred statistically from this field experience. In the design of a new product, or a new model of an existing one, there are degrees of uncertainty concerning the extent the conditions derived from the earlier experience can be extrapolated to cover the future one. For reasons of this kind, changes in the design of an existing product entail a risk which is in proportion to the degree of change, and the product can be protected against this risk only through an increase in its cost.

74. Oliver Wendell Holmes Sr. wrote the engineer's ideal specification of optimum design more than 100 years ago in a humorous poem, "The Deacon's Masterpiece, or the Wonderful One Hoss Shay", in which is described a vehicle so carefully built, with each piece exactly as strong as every other, that it went perfectly for 100 years and then collapsed into dust. (Unhappily the Deacon bequeathed to us very little of his design technique.) The point to the story is that a part, which has more durability than it needs in order to live out the life of the product, is one which embodies unnecessary cost for which the buyer must pay but for which he receives no value. Consequently, the engineer is concerned not only to improve those parts which fail to give adequate service, he must be equally concerned to reduce the cost of those which do not fail. In fact, he must do so in order to allow for the cost increases of needed improvements. The accumulation of many years of gradual proving and development, always under the pressure of competition, eventually results in a product approaching the "wonderful one-hoss shay" in the degree to which its components are balanced against one another for durability and value, and have a reliability factor that rivals those products in which cost is no object.

75. A designer constantly strives for the most efficient possible disposition of material, to improve a design through reductions in the cost and weight of material used. He must reduce the total number of separate parts, the complexity of each, and the points of interaction between them. When a design is kinematic, it performs its function with the smallest possible number of separate actions; hence, the smallest possible number of basic components. For example, a three-legged stool is kinematic; each leg performs its own share of the work. A four-legged stool is not kinematic; one leg is almost always not working, and ordinarily two legs do most of the work.

76. The indispensible element in the production of good design is the good designer. Truly able designers are rare, and since one of them has as much value to the organization as any individual in it, no cost or allocation of organizational status is too great to insure his maximum productivity.

77. The qualifications of the able designer are exacting. They include native talent, knowledge, training and experience. Native talent is the ability to visualize the design. If it happens to be a mechanical device, he is able to see it functioning in his mind, and to visualize the spatial relationships of its parts. In the case of an electrical system or circuit, the designer visualizes some kind of analogue. Intuitive thinking is perhaps difficult to discuss but essential to consider. The able designer is likely to be the kind of individual who thinks in terms of pictures and diagrams rather than in words and equations. The designer's intuition is not only important to him in visualizing relationships, but it also forms the basis for a kind of running analytical check which maintains the basic design within limits demanded by a subsequent formal analysis. It is the mark of the work of a good designer that modifications can be contained within the concept originally set down. A good designer does not pursue a concept that embodies a fundamental fallacy.

78. A good designer has strong aesthetic motivations; he is concerned with balance and elegance. Elegance means here what it means to the mathematician; economy, lack of redundance, an element of beauty, an element of the unexpected, a flavour of ingenuity, a lack of the obvious and commonplace. The outstanding designer will try, and reject for such reasons, many concepts, any one of which would have satisfied the journeyman. The resulting differences in cost, weight, function, reliability and durability can be as great as the difference between the success of a product and its failure.

79. The maximum possible freedom to conduct experiment is an indispensable tool for the able designer. A designer must be guided by a constant feedback of experimental trial and verification of various design concepts, if these concepts are to differ in any important way from others already proven. There are very few fields in which analysis is sufficient by itself to enable the designer to proceed with confidence on what might be a promising new idea.

80. New techniques of computerized design are becoming available that greatly assist the process of visualizing spatial relationships. There remain a great many complexities of functional relationships that are inadequately understood by analysis, and require that the designer have access to physical facilities in which he can conduct experimental verification of design concepts. The greater the freedom of access the designer has to such facilities, and the

shorter the time lag between the idea and the experiment, the more creative and the more productive the designer can be. The effectiveness of experimental verification is almost destroyed by formalities and delay: making drawings, approving orders, waiting for parts to be produced in some remote spot. A drawing is only a one-way communication system. The best designer is the one who has at hand the technical facilities to perform his own experiments, to communicate directly with the technician who makes his experimental material. In many instances difficult mechanical and electromechanical problems that defy solution by ordinary methods can be solved by the simple expedient of placing the design engineers in the same room with good facilities for building experimental models.

Product planning and optimum design

81. Existing practices in the automobile industry make it impossible to separate product design and development into an advanced and final phase. In a large manufacturing organization the process of tooling for the production of a new model automobile requires about two years. Ideally, the design should be finalized, developed, tested and proven before a tooling programme is undertaken. In practice this is seldom done. Competitive pressures are such that manufacturers must be free to make design changes in new model programmes at any time prior to tooling. In extreme instances, changes must be made one year before the beginning of production. Obviously under these conditions, the latitude is limited, for any design changes which may be required as the result of testing and development experience (as both the cost and the timing of tooling changes) become critical. The capability of a very short engineering and development schedule concurrent with tooling in a large system is limited to evolutionary change and accompanied by high risk and expense, unless advanced engineering has done a good job of design improvement. Otherwise, the design must be made on such a conservative basis, sufficiently resembling previously employed designs, that all opportunity for design improvement is lost. Despite these complexities in practice, the process of product design and development will be discussed in this paper as though it were entirely separable in time from final engineering release and tooling.

82. In so complex a system as the automobile, the optimum system design is both difficult and important. Product planning cannot be considered here in detail, but the subject of system design cannot be discussed without some introduction to the complex process of planning and specifying the detailed characteristics of the product.

83. A list of typical product objectives which form a framework for the specification and definition of a product can be found in table 1 below. Cost does not appear on this list primarily because it is ordinarily assumed to be an independent variable, arbitrarily established at the beginning. The process of product definition and specification is one of determining the optimum compromise of each of the desired product characteristics that can be obtained within the specified limits of total cost. For purposes of product definition, the list in table 1 must be subdivided into many more items than are shown.

Table 1

Product objectives

Carrying capacity
- Passengers
- Luggage
- Special

Economy
- Operating Cost
  - Fuel
  - Lubricants
  - Maintenance and repair
  - Tires
- Fixed Cost
  - Depreciation
  - Insurance

Durability
- Component life
  - Major components
    - Engine
    - Body
    - Chassis
  - Renewable items
    - Brakes
    - Tires
    - Lamps
    - Fanbelts
    - Fuel pumps
    - Spark plugs
- Maintenance of function
- Maintenance of appearance

Reliability
- Freedom from unscheduled repair
- Starting

Safety and emissions
- Crash injury reduction
  - Structures and fuel tanks
  - Interior design and passenger restraints
- Accident avoidance
  - Brakes
  - Tires
  - Acceleration
  - Suspension and steering
  - Visibility
  - Fatigue reduction
- Air pollution control
  - Exhaust products
  - Crankcase and evaporation

Performance
- Speed
- Acceleration

Table 1 (continued)

Controllability

Steering
Throttle
Brakes
Heating, ventilating, cooling
Windows and doors
Lights
Auxiliaries

Comfort and convenience

Ride, road noise, harshness and shake
Powertrain noise and vibration
Seating comfort and space
Heating, ventilating and cooling
Entrance - egress
Power operated controls
Miscellaneous options

Appearance

Exterior styling and proportions
Interior styling and trim

84. The total problem of system design in the automobile can be expressed in terms of a four-dimensional matrix of which table 1 is one of the dimensions. The second is subsystem and component classifications which a partially sub-divided list includes the following:

Table 2

Vehicle subsystems
(Each subsystem includes from one to twenty component subsystems)

1. Body
2. Frame and mounting
3. Engine
4. Suspension
5. Driveline
6. Brakes
7. Transmission
8. Clutch
9. Exhaust
10. Fuel supply
11. Steering
12. Heating, ventilating, and cooling
13. Gauges and warning devices
14. Electrical system
15. Radio

The third is made up of the areas of compromise for physical dimensions, or what is known in the industry as "package". The fourth is the area of fixed and variable costs.

85. This particular arrangement of total product requirements is well adapted for eventual analysis by computer, although it can never be expected that the computer will make final design decisions on the strength of such an analysis without the exercise of judgement. There is little question that in the future, computer analysis will give important aid in achieving the optimum of these complex relationships. The very act of quantifying the many factors involved provides a useful basis for the exercising of judgement. Computer programmes adapted to solutions of this type of problem will be of such a nature that each programme will be strengthened by the accumulated experience of past programmes. Ideally each programme would be reinforced by feeding in the actual product experience after the event. These will form an invaluable checklist of product and production problems to be avoided in the future.

86. A few examples will be given of the kinds of interaction between matrix elements that complicate the process of system design. Considering the matter of fuel economy for example, this item must be compromised with a number of other product objectives, such as acceleration, engine exhaust emissions and all vehicle objectives involving the addition of weight. The latter includes carrying capacity, comfort and convenience, most divisions of safety and emission, and appearance. In the subsystem and component area, fuel economy involves a wide variety of considerations beginning with the engine; carburetion, manifolding, and valve timing in particular, also transmission and torque converter losses and ratios; axle gear friction and ratios; and rolling friction including tire losses, aerodynamics, and wheel alignment. Each of these component areas bears in turn on other objectives. A similarly complex series of relationships occurs in the package dimension of which the engine compartment forms a typical example. The basic dimensions of the vehicle are to some extent established by the length, width, and height of the engine, which must be related to the front suspension, steering and cooling systems. Engine-driven accessories, such as alternators, air-conditioning compressors, power steering pumps and air pumps for emission controls must compete for space with steering gears, power brake cylinders, engine speed controls, voltage regulators, storage batteries, windshield wipers and washers etc. In this area the demand for compactness conflict sharply with a need for easy access for maintenance and repair.

87. The cost dimension has many subdimensions of its own. The need to conserve investments in tooling and facilities conflicts with optimum design by dictating the use of existing components in place of those newly designed for the purpose. The compromise between fixed and variable cost can be established only by a prior assumption of planned production volumes. Indeed, the entire process of optimum design for a given cost goal depends on the assumed planning volume, since it is always possible to produce more vehicles for the money at large volumes than at small. Also included in the cost, for purposes of this discussion, is the entire area of materials and processing, which is similarly dependent on planning volumes and the chosen ratios between fixed and variable costs. For small volume production, for example, it may be economical to choose a higher cost material and a higher labour content in order to avoid large investments in tooling, as for example in the choice of plastic body components over those of pressed steel.

88. All of these decisions are made in the area of product design. In principle they can be made only after evaluation of each factor of the many dimensional matrix, and each factorial decision should involve a suitable choice of alternatives. In practice this is more a goal to be sought than an end actually achieved; decisions are more likely to be made by the extrapolation of past practices plus the introduction of new design features for the accomplishment of major objectives.

89. The discussion of optimum design would be incomplete without a warning of the dangers of less than optimum design which is an ever present tendency in all large organizations. The following quotation from "Systems philosophy" written by Ellis and Ludwig[4] is offered without further comment:

> "One of the major dangers in optimization of choice amongst several alternative systems or of choice amongst alternative detailed designs of a given system is that of reduction to suboptimization. It may be that in criterion selection one relevant factor is overweighted at the expense of others equally important, or that some subsystem is optimized rather than the overall system. For example, in a business or military organization it is all too frequently found that some organizational subsystem is more concerned with maximizing performance and growth in its own functions than in furthering overall organization objectives ... Unfortunately, experience indicates that in real-world situations suboptimization almost invariably precludes optimization."

4/ David O. Ellis and Fred J. Ludwig (1962) Systems Philosophy, Prentice-Hall, pp.17-18.

In conclusion it may be said that the difficulties in achieving optimum design are formidable but the rewards are substantial.

Product development and testing

90. Product development begins with the building of component prototypes which are tested as much as possible in the laboratory and then assembled into component test vehicles. As nearly as this can be done, bearing in mind the requirements of the complete system, each subsystem and component is tested in a vehicle which has well proven characteristics in other component areas. There is a tendency in the industry to minimize vehicle testing at all phases and to resort instead, as much as possible, to analytical prediction and laboratory testing.

91. Sophisticated equipment is becoming available for the purpose of simulating actual operating conditions in the laboratory; for example, conducting performance and durability testing of complete vehicle powertrains on the dynamometer in which all conditions of engine load, speed and transmission shift positions are controlled by a master tape which has been recorded in an actual road test. Similarly, it is possible to simulate a wide variety of noise and vibration conditions in the laboratory from a recording of power spectral density of noise and vibration over the entire effective spectrum, recorded from many locations in the vehicle over a typical section of road.

92. Testing for durability and reliability can likewise be simulated in the laboratory. In these areas the feedback from actual customer experience is invaluable since no laboratory test can simulate actual conditions of operation quite so accurately as the statistical results of consumer use. For this reason, the design of a product is greatly benefited by the maximum availability of information on vehicle repairs and component replacements with actual length of serviceable life and causes of failure. The accumulation of this kind of information is only one of the many reasons why automobile manufacturers are finding it necessary to become more directly involved in the after-market servicing and repair of the vehicles they sell.

93. The final stage of vehicle development are conducted on prototype vehicles that resemble the production design in every possible respect. The final evaluation of a product is in many ways subjective, and after all theoretical analysis and scientific laboratory testing of components is completed, there is still much left to be proven by the subjective evaluation of the complete vehicle. No matter how many clay models may have been viewed in the studio, the final appearance of the vehicle as it runs on the road surrounded by its competitors and predecessors is always something of a surprise. The final measure of the success of any design programme is the product itself, and the degree to which it fulfills the requirements originally specified for it.

III. THE SIGNIFICANCE OF AUTOMOTIVE RESEARCH AND DEVELOPMENT IN DEVELOPING COUNTRIES

94. In all nations, the automobile plays an important role in both social and economic evolution. It provides transportation of people and goods with unparalleled flexibility. Automotive transportation has not only implemented the growth of the economy in countries where it has been available, but it has revolutionized the lives of the inhabitants.

95. In addition to being a useful instrument of transportation, the automobile has become one of the most highly valued of personal possessions. It provides its owner with freedom of movement over practically unlimited distances. No privilege is more highly prized by the individual than the privilege of travelling where he wishes at whatever time suits him best.

96. The individual values the automobile not only for what it can do for him but also for what it is: a source of pride and aesthetic enjoyment, and a badge of prestige. In its role of prized personal possession, the automobile has acquired additional characteristics that contribute to the ease and luxury, comfort and convenience, pride and aesthetic satisfaction of its owner. Aesthetic purists and economic utilitarians complain that these things are frivolous and uneconomic, and they denounce the producers and designers for them; but we do not live by bread alone and the common man values things differently from the purist and the utilitarian. The demands are the same no matter where the automobile is produced. People have seen the automobiles of affluent and highly developed countries, both in substance and through media of communication. They want the same thing. Thus, the possession of a viable automobile industry is not only a spur and a nucleus for economic development, it is a source of national pride.

Design for local production

97. The local production of automobiles in developing countries, in practically all instances, has evolved with the importation of assembled automobiles from highly industrialized countries. The first step in this evolution is local assembly of components produced abroad. In response to the need to increase output without increasing expenditures of international credit, this has been followed by the local production of an increasing proportion of vehicle components.

The vehicles that were originally imported in the assembled state were designed to be produced in large volume with expensive and sophisticated facilities and tools. Component parts are highly stressed, requiring exacting control of material quality and the use of highly specialized materials. They depend for both their durability and their performance on highly specialized and exacting physical properties of fuels and lubricants. All of these things are either absent or present in much less degree in the developing country where production volumes are small and material suppliers are neither highly specialized nor highly trained. As a consequence, the designs of vehicles which are built in large volumes in highly industrialized nations are not, in general, suitable for production in small quantities under a less sophisticated technology.

98. In practice, because of the evolutionary nature of the change from importation to local production, the designs of locally produced vehicles have derived from those of the previously imported vehicles mainly through a piecemeal substitution of changed component designs. The very fact that these vehicles are being produced successfully is a testimonial to the energy and ingenuity of those who have evolved their design. It is easy to see however that the eventual solution for this problem is the creation of unique designs for local production. This fact highlights the need for local research and development. In the long run, the capability to develop local designs, instead of importing them, will prove to be of as much economic value to a nation as the capability to produce the articles themselves.

99. To cite an example, a commercial vehicle cab is being locally produced in Turkey, where programmes of high local content have recently been initiated. The cab has underbody and structure consisting of imported steel pressings with doors and outer panels locally produced of fibreglass reinforced plastic. It was designed and developed in England by a specialist who also trained a small nucleus of engineers, technicians, and labourers from the Turkish manufacturer who had no previous experience in the production of any kind of plastic components. Prototype components were tested and validated by the parent producer. The cost of the entire programme including tooling was about 2 per cent of the estimated cost of engineering and tooling for volume production of a similar cab of all steel construction. This component passed all the tests to which the all-steel cab is subjected and weighs 35 pounds less.

Design for local product requirements

100. Vehicles designed for operation in highly developed countries are primarily intended for use on excellently constructed roads and require considerable modification to operate successfully on the much more primitive roads that are found in less developed countries. Vehicle structural and chassis components, wheels and tyres must be larger and more rugged; ground clearance must be greater and more protection given to undercar components for the withstanding of accidental impacts; engines, transmissions and driveline parts must be operated at lower ratings to permit the use of less specialized fuels and lubricants.

101. There are many indications that in the future unique vehicle designs will be created to meet the product and manufacturing needs of developing nations, where it has been necessary to have a high percentage of the vehicle locally manufactured. At first glance it would appear uneconomic to engineer a complete vehicle for such limited quantities as most of these markets demand. However, the peculiar requirements of design for local production have already required such extensive vehicle design changes that few of the advantages remain of utilising the designs originally created for large volume production. This is particularly true of chassis and body parts, while less true of complex mechanical components such as engines, transmissions and axles. Since the chassis and body parts are the same parts that require modifications for local product requirements, it may be seen that the pressure for unique product designs for local operating conditions and markets is in the same direction as that for unique product designs for local production and materials. Thus, the creation of locally designed products will not require at the start a capability for the entire spectrum of the vehicle design. The successes of the design changes already made in many of the developing countries demonstrates that the needed capability, to an important degree, now exists.

Building a capability for the future

102. The building of a capability for automotive research and development must be regarded not as an isolated programme, but as part of the over-all programme for the development of a local technological capability. Indeed, the automotive manufacturer draws upon so many segments of industry that its own needs cannot, in the long run, be satisfied without the accompanying development of the wider

technology on which it is dependent. One cannot deal adequately with so vast a subject as the building of a viable technology in so short a discussion as this paper presents. It is possible only to offer a few helpful suggestions on the building of a creative design capability.

103. The most important factor in any technological organization is the quality of the people in it. The need, from the standpoint of those who direct the organization, is that each individual be employed in a manner to give the maximum utilization of his talents. This appears a very simple matter, but in fact it is difficult; and very few organizations make efficient use of the technical talents of the people they have.

104. On the other hand, in the continuing effort to improve the capability of a technical organization, one of the most widespread mistakes is to decree that all the people in it shall meet a high standard of ability and training. This is a mistake, because there are many tasks which do not require these high standards, and there are many individuals who cannot meet them who must be usefully employed. Consequently, one of the objectives is to make sure that people are not under-utilized and that tasks are not over-evaluated.

105. Much is written about creativity and much emphasis is placed on techniques for minimizing the effects of the inhibitions that stand in the way of expressing and acting upon novel and useful ideas. In fact, creativity is not as uncommon as it is often stated to be. What is uncommon is the combination of creativity with an adequate capability for analysis and the self-discipline to use it. An active and creative individual who lacks this important qualification can be an unmitigated nuisance and a disturbing influence in a technical organization. He brings forth a flood of ideas that a moment's analysis would show to be fundamentally fallacious. He will not accept a theoretical demonstration of this, and even the results of an experimental demonstration, he will continue to feel, can somehow be changed by tinkering. Such an individual invariably feels that his talents are not given proper recognition. It is therefore necessary to ask of a creative individual not if he has new ideas, but rather how many of his ideas have resulted in useful technical developments.

106. The foregoing points to another fundamental of successful direction in a research and development organization. This is the requirement that the organization's facilities for theoretical analysis and experimental design and development be most efficiently utilized. There will always be more proposals and more ideas

put forward than the organization has the facilities to carry through. These must be evaluated as carefully and as completely as possible before experimental design and development are undertaken. The ultimate responsibility for decisions as to which projects will be undertaken rests with the director of the organization. Since facilities for theoretical analysis and computer simulation of experiment are not unlimited, it is unavoidable that considerable judgment enters into the making of these decisions. The exercise of this kind of judgment is one of the two most important qualifications of the leader of subsidiary groups within the organization. The other is, of course, the ability to judge the capability of people. In maximizing the capabilities of the organization, both theoretical and experimental, it is of the utmost importance that organizational leaders be able to identify the critical problem inherent in a proposed development, to identify an area to be given extensive analysis, or to design a crucial experiment, the results of which can then determine whether or not to proceed further. This has been called "spending a penny to see if it is worthwhile to spend a dollar". Those who spend their pennies wisely can avoid the needless expenditure of many dollars.

107. The research and development component of the automotive industry is only a part of a larger body whose primary objectives are economic. This fact can never be forgotten by those who are primarily responsible for the direction of the technical organization. They are required to recognize that no objectives can be purely technical. Every technical man has to struggle with this fact and face the need occasionally to turn his back, however reluctantly, on certain projects which would have given results that would have provided great satisfaction for the technical people. On the other hand, those individuals, often non-technical people, who have the larger responsibility, must call upon themselves to accept certain measures which fill important needs for the organization. One of these is the need to reward technical ability with appropriate status and material compensation. Able technical people are too seldom efficient managers and effective entrepreneurs. On this account there is a special difficulty in placing sufficient able technical people in organizational positions where their technical insights and judgements can best be utilized. The manager of a research and development group must have certain abilities as manager and entrepreneur. These abilities are themselves rare enough and in combination with adequate technical ability they are even more rare. Consequently, circumstances often require that managers be appointed who fall short of the ideal combination of the

two. In such circumstances, it is wise to divide the total responsibility for direction between two people, one of whom has ability as manager and entrepreneur, the other the technical judgement and capability. Depending on personal stature, leadership ability and seniority, one of these people would have the major responsibility, the other would be his assistant.

108 There must also be organizational positions for purely technical people at a sufficiently high level to utilize their judgement in the making of decisions, and to allow them to communicate without undue formality with those who have responsibility for important technical decisions. These provisions seem to be expensive and it is often difficult for non-technical general managers to agree that they are justified. However, an organization that has at its disposal the best possible technical judgement can be twice as effective as one that does not. The success of the entire organization in accomplishing its economic objectives is directly dependent on the success of its research and development departments in creating the best possible design. Investments in improved technical capability pay very high dividends.

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