# Long-Range Research and Development Program for Individual Transportation Systems

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A long-range research and development program for individual transportation systems is described. Three phases are outlined: systems analysis, research and development, and prototype testing. The systems analysis phase determines the basic criteria governing the performance of any system of individual transportation and develops a general systems concept. It provides the framework for the other two phases of the program.

The ultimate objective for the total program is the determination of the most promising integrated systems concepts as a basis for completion of the research from which a prototype or prototypes of individual transportation systems can be developed for evaluation. The long-range research and development program for individual transportation systems will not be accomplished in a short period of time or by any one agency. The general plan has been formulated. As the program develops, it is anticipated that there will be participation by States, industry, and other interested groups.

• THE PRESENT highway transportation system is highly effective for individual transportation. It serves the needs and desires of individuals very well. But complacency is dangerous in view of a rapidly changing technology and ever-rising standard of living. The Interstate Highway System, when completed in 1972, is expected to alleviate congestion, decrease travel time between origin and destination, and contribute to an increase in safety, comfort, and convenience for travelers. But it is important to look beyond the completion of the Interstate System. This Nation must keep ahead of the continually changing demands by improving its transportation systems to satisfy individuals needs in the future.

It should be remembered that the Interstate System, as now being constructed, is the culmination of research and development that was started more than a generation ago. To meet the needs of the future, it is necessary to intensify research and development efforts by using new technology in a coordinated and integrated fashion. Hence, the Bureau of Public Roads is proposing the long-range research and development program for individual transportation systems described in this article.

A recent statement by Robert F. Baker, Director of the Office of Research and Development, Bureau of Public Roads, summarized this long-range program well:

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The accelerating requirements of the Nation make clear that a systematic, energetic research and development program is essential if the optimum transportation system to meet these needs is to become a reality. This program will define a range of alternative transportation system concepts that offer substantial improvements over present concepts. Initially, the program will consist of an intensive systems analysis to develop the basic criteria governing the performance of any system of individual transportation. The ultimate objective of the program will be to determine the optimum integrated systems concepts and to perform the research needed to develop prototypes for field evaluation.

To initiate the first phase of the program, the systems analysis, a set of specifications has been prepared by the Bureau of Public Roads after consideration of the many alternatives suggested by industry, university, and other transportation specialists. The long-range research and development program for individual transportation systems will not be accomplished in a short time or by any one agency. Public Roads has formulated the general plan and proposes to undertake the initial phases of the program. As the program develops, it will broaden to include participation by the States, industry, and other interested groups.

## NEED FOR PROGRAM

The program described has been evolved from an examination of individual transportation; that is, systems designed for individuals to move themselves or their possessions under their own control. This examination was especially related to the ways in which individual transportation may significantly change to meet the needs and requirements of a society that is itself undergoing rapid change. The program was developed because of the recognition that no transportation system can be permitted to drift, with the hope that it will be adequate indefinitely. No society so dependent on personal mobility can afford such luxury. Hence, this program is concerned with the long-range future of individual transportation.

It is obvious from any examination of the highway transportation system that the purposes for which it exists do not depend on the peculiar physical characteristics of that system. Highway transportation arose out of random invention and has developed as a system in large measure by trial and error. The ultimate reason for the dominance of the highway transportation system over other transportation systems lies in the fact that it better meets the needs of people for movement today. Highway transportation offers the individual the freedom to (a) adapt his travel to a set of time criteria determined by himself, (b) expand the area that he can use to satisfy his particular needs, and (c) schedule travel according to his own plan and order of priority. Therefore, regardless of the mechanical methods employed, the objective of any system of individual transportation is to provide maximum freedom of movement so that the greatest possible number of people may satisfy their independent and individual needs for travel and for movement of goods.

## MANY CONCEPTS POSSIBLE

It should be recognized that highway transportation is only one possible system concept of a tremendous variety of possible concepts that can be employed for individual transportation. Figure 1 shows it to be only one system of a surface-space transportation concept. An air-space concept, of which the ground-effects systems are an example, also is possible, as is a time-space concept, of which closed-circuit television is an example. In addition, there may be other concepts that have not been considered, as well as systems formed of combinations of all. Consideration of these concepts poses questions as to whether (a) systems embodying them are technologically possible; (b) how the alternatives are to be defined; and (c) how determinations can be made as

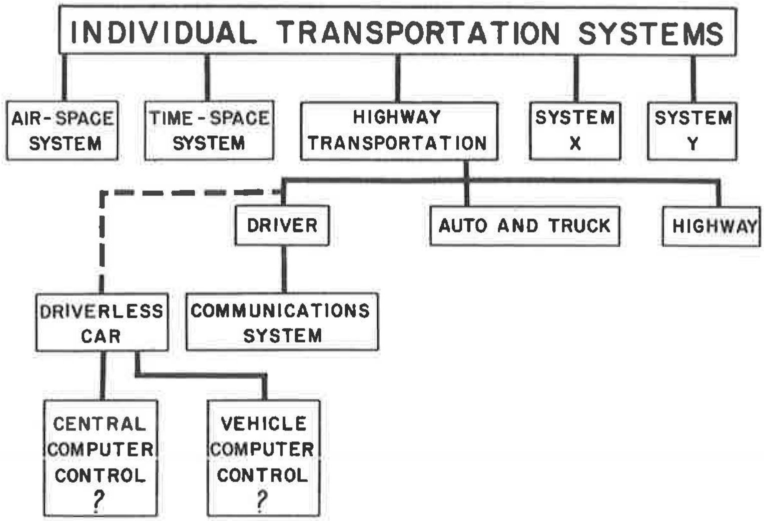


Figure 1. Highway transportation—one system for individual transportation.

to the feasibility of these concepts, and whether the resultant transportation systems would offer measurable improvement over the highway transportation system now available. Many answers to these questions have been and are being suggested. Most, although not all, suggest modifications of the present highway transportation system. Some of the other answers include suggestions for pallet systems or ground-effect systems.

Highway transportation, which may be considered as a system because it operates as the result of the interaction of the three elements of driver, vehicle, and highway, has stimulated suggestions interesting because of their emphasis on one aspect. Almost all suggested modifications have pertained to the driver or, stated more generally, the control mechanism. Suggestions have ranged from driverless automobile systems to complex communication systems.

Although improvement of the existing system by use of sophisticated electronics or mechanical means in the control subsystem is necessary, it is frankly not known whether simply superimposing various devices on highway transportation can ever meet the long-term needs for individual movement. For example, is the control of the vehicle now so poor that new control systems must be added? If so, what kinds of systems? Shall there be a large central computer, which controls groups of vehicles by telemetry, or a small one located in the vehicle? Technologically, use of any of these techniques is possible, but which is the most efficient technique and how can efficiency be defined? Which technique is most reliable and how is its reliability to be measured? Which technique is the safest and how can its safety be proved?

Further, can an optimum solution to the problem be obtained without consideration of the design of other aspects of the highway transport system? What of the vehicle? Can the existing vehicle be modified or can a novel one be substituted that could be controlled more easily or more economically? Can the highway be designed to eliminate control problems? Each of these separate questions may be answered in more than one way. However, it is becoming increasingly obvious that over the long run, a significantly improved system cannot be obtained by treating its parts separately. To achieve a radically improved system of individual transportation, a complete and integrated system must be conceived, designed, and developed. This cannot be done by arbitrarily pursuing any one particular electronic or mechanical technique. Although this approach has been the historical precedent, such a procedure precludes valid comparisons and objective choices among the many possible alternatives.

## LIMITATIONS OF ARBITRARY APPROACH

The limitations of pursuing one electronic or mechanical technique become very evident from a brief analysis of some proposed solutions to the control problem. For example, as shown in Figure 2, induction radio has been developed and is being suggested as a means for transmitting control information to the driver or his equivalent. Another suggested solution involves a system of detector units placed in the roadway that would form electronic blocks for the location of vehicles. However, it should be obvious that to use either of these devices in this manner would imply that a whole set of decisions had been made about the nature of the control problem and its solution. Thus, the use of induction radio techniques would imply a decision to use a system of radio frequency for information transmission rather than some kind of pavement-coding system. It would also imply that a decision has been made about telemetry and radar. In addition, a decision to use induction radio rather than a specialized central computer system would indicate a conclusion that in-auto computers are the way to solve the control problem. Finally, all of these decisions clearly would assume that electronic methods should be used to resolve the control problem.

However, within current limits of understanding of the true nature of the control problem, can mechanical methods of solution be ruled out? Further, can the current solution to system control—the human—be ruled out? After all, the human has capabilities that are difficult to rival mechanically. For example, the human can detect angular velocities as low as $5 \times 10^{-5}$ radians per sec; he can discriminate differences in frequency to an accuracy of 0.2 percent; he can estimate position relative to himself with an accuracy of 1 percent. These capabilities not only are unusually good but cost nothing to produce.

This discussion of just one aspect of the highway transportation system shows the tremendous complexity of the problem and the dangers that may arise from the arbitrary choice of one type of solution. This danger obviously applies to all the other aspects of the system. To operate in this arbitrary fashion would minimize the chances of ever knowing whether an efficient system had been selected.

The problem of individual transportation can be resolved only through a systematic

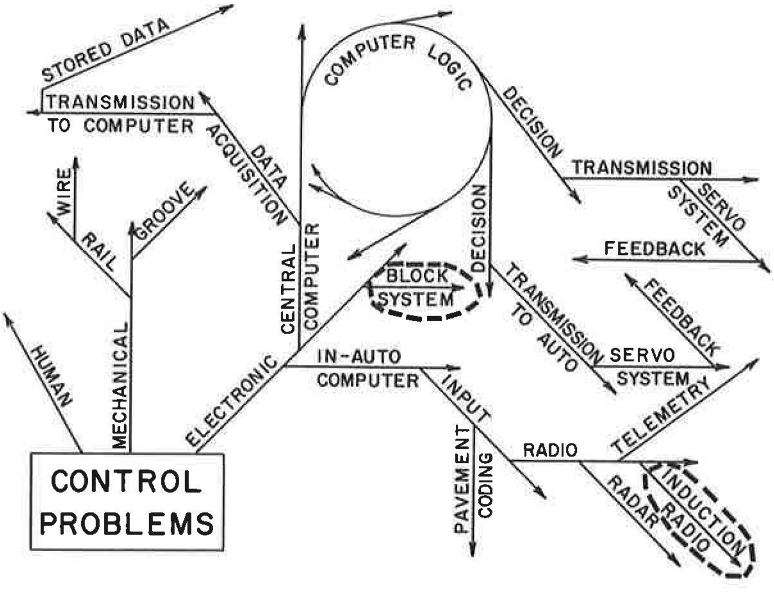


Figure 2. Possible solutions to control problems.

analysis that starts from the essential requirements that any system must have to meet the objectives of individual transportation. Only from such an objective analysis can measures be developed to evaluate alternative physical means rationally so that the most effective systems may be selected. To achieve this selection a comprehensive and integrated program of research and development is required. Such an approach, which is the modern systems engineering approach, is the one that the Bureau of Public Roads proposes to use in the solution of the long-range problems in individual transportation.

## THE PROGRAM

The proposed program consists of three phases as shown in Figure 3. The first phase is a systems analysis, which will provide a framework for the next phase—an intensive research and development effort which is aimed at producing in the third phase one or more prototypes for testing. The initial phase of the program, the systems analysis, is a procedure for defining a complex problem in operational terms. In this way, the problem may be stated in analytical terms, thereby permitting the precise definition of alternative systems, which can be designed and evaluated. Thus, the systems analysis will form the framework for the research and development phase.

The research and development phase of the program will encompass investigations of the various components of each of the alternative systems, particularly, their interaction. A continuing process of evaluation will be used to determine whether the alternative systems selected meet the required performance criteria. Among other matters, economic considerations and questions of reliability and public acceptability of the systems will be investigated. After evaluation and research have been done, an intensive development effort is expected to make it possible to provide one or more prototype systems for testing.

Research, development, and evaluation will be a continuous and simultaneous process and considerable interaction is expected among these activities. From these feedback processes, it becomes apparent that the research and development phase will be modified as the systems analysis proceeds. Likewise, the systems anlaysis will provide a general but flexible framework for the research and development phase.

The third phase of the over-all program will consist of testing one or more prototypes that have been produced during the research and development phase. This testing will be undertaken on a proving ground before the prototype is subjected to field tests. Again, there will be feedback between proving ground and field tests.

Similarly, the three phases of the over-all program are interdependent; and, as mentioned earlier, the research and development phase will undoubtedly be modified from that which is initially selected. Thus, the systems analysis will, in effect, be modified as research and development proceeds. Similarly, modification also will occur from research and development to prototype testing. It is, therefore, conceivable that feedback from prototype testing to the systems analysis could revise the initial systems concept.

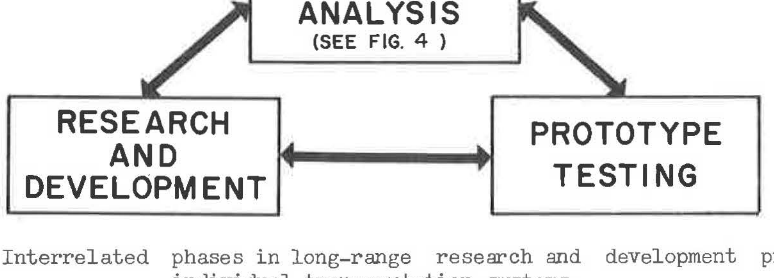


Figure 3. Interrelated phases in long-range research and development program for individual transportation systems.

## SYSTEMS ANALYSIS

The first phase in fulfilling the objective of this long-range program is to conduct an intensive systems analysis. Systems analysis is described as the definition of a problem in operational terms, which then permits formulation of a systems concept. The problem is individual transportation, and the goal is to define this transportation system, formulate requirements for it, evaluate and select the most promising systems concepts, and plan for the subsequent phases.

This systems analysis will be essentially a theoretical, analytical effort by a team of engineers and systems analysts. It will not involve physical hardware or its application. It will involve the general or abstract principles of individual transportation. It will formulate mathematical models that present a clear, systematic picture of individual transportation.

This will be the first time that such a comprehensive systems analysis of a transportation system has been undertaken. Its output will provide a better understanding of the over-all problem, a logical grasp of the most promising concepts, and identification of critical areas of needed research.

Figure 4 shows that the analysis will consist of three parts: a definition of performance requirements that the system must meet, the formulation of a generalized system concept, and a description of the alternative systems that may be derived from the generalized concept. The first two steps will constitute a purely theoretical study. The general model or concept of individual transportation to be formulated will be the most important, single product of this effort. The alternative systems shown at the bottom of Figure 4 will then follow.

At this point it should be added that the relevant user categories that one thinks of today will be considered in the systems analysis. These categories are the transportation of individuals; the mass transportation of people, covering also the movement from origin to the mass transport vehicle and from such a vehicle to a destination; and the transportation of freight together with the special characteristics that such transportation requires.

### Performance Requirements

As the first step — definition of performance requirements — a preliminary set of system requirements must be drafted in the early stages of this analysis. Such requirements will be the "guide posts" for the basic evaluation of proposed systems. It should be understood that they are preliminary, however, for they will be continually modified

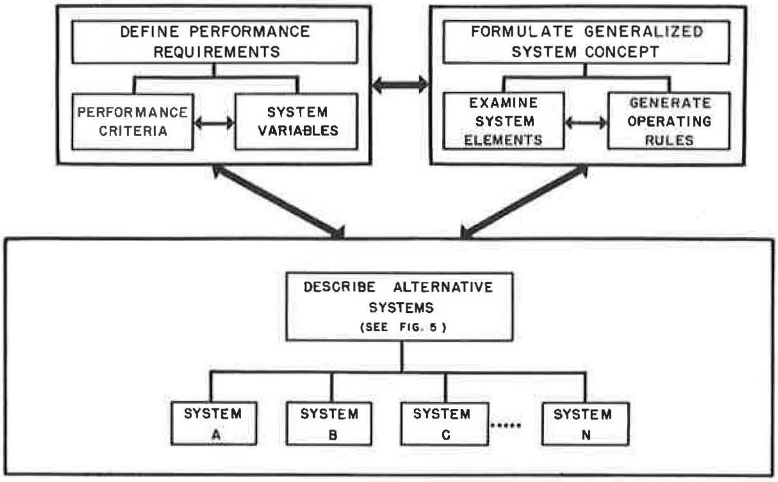


Figure 4. Outline of systems analysis for individual transportation.

as the program progresses. Experience has shown that formulation of these requirements is a process of achieving a harmonious balance between practical means and ideal goals. A sound requirements statement is therefore an end product of the systems analysis even though in preliminary form it is used for guidance of the study itself.

The statement of performance requirements will define performance criteria that are the measures by which individual transportation can be judged. It will also define the variables or quantities of such a system and their range of values. Some examples of criteria might be the probability of collision, the predictability of position, or the travel time between origin and destination. There may be many others similar to these. There may be other ways of specifying them. However, the criteria must define the system on a complete and rational basis. The variables, and their operating ranges may include such items as speed, flow rate, and size of vehicle. Again, these are only examples of the qualities that describe the operation of a generalized concept.

As to the formulation of the generalized system concept, it should be noted that this concept is still completely theoretical and will be based on the performance requirements to be developed.

First, an examination will be made of the essential elements or components of any transportation system. These components include the vehicle, an operating medium, the control logic, and the human. The human, of course, must be considered both as a part of the control logic and as a system user. In each, there are various alternatives that might be listed in the light of present and future technology. The interaction of these four elements is highly critical.

Then, operating rules will be generated. These are to be the bases by which the characteristics of individual transportation may be specified in terms of the performance criteria and system variables. These are the theoretical expressions of a generalized systems concept. The operating rules may be expressed as a set of equations and the variables could then be related in such a way as to meet the defined performance criteria. Thus, it could be that a description of individual transportation would be stated as a set of mathematical functions.

Once this generalized framework for individual transportation has been developed, any combination of vehicle, operating medium, and control logic can be tested. Ultimately, one or several of the possible combinations that best satisfy these equations will be chosen for more intensive analysis. This is not a simple, straightforward procedure; there must be feedback and interaction among the various steps. The generated operating rules and the several alternative solutions will point to the competence of the original performance requirements. Conversely, the continuous refinement of this performance statement must be accurately reflected in the operating rules.

Because this feedback process is of such vital importance to a systems analysis, the analysis can become extremely complex, particularly when dealing with a system so encompassing as individual transportation. Moreover, the systems analysis will form the basis for the entire long-range research and development program. Hence, it is evident that the systems analysis should be done as a single operation in order to provide a solid framework around which all succeeding steps can be taken.

Precaution must be taken to avoid initial error, because any concept adopted and implemented would undoubtedly involve a significant portion of the national effort. To prevent hasty judgment and preselection of the most obvious (or any other) form of individual transportation as the "only" solution, it is desirable to explore all alternative concepts that could possibly meet the same objectives. Therefore, the systems analysis must investigate feasibility from broad viewpoints and determine the detailed technical concepts worthy of further research, development, and evaluation. It will define various alternative system concepts, bring them into a common analytical frame of reference, and compare their relative effectiveness.

One result of the systems analysis, incidentally, might be to indicate that modification of the existing system is the optimum way to proceed in the research and development phase. But, if this is the case, it will be clearly established that other alternatives have been investigated and rejected, and the reasons for such rejection will be detailed. Thus, it has been shown that by a systems analysis of the criteria, the variables, and the components, one arrives at a theoretical expression of individual transportation. For the first time there will be a comprehensive model of a major transportation medium from which to select optimum solutions. This generalized concept will permit the preliminary testing of many individual system combinations and the selection of those that best satisfy the general expressions.

## Alternative Systems

Figure 4 shows that the three interdependent operations comprise a theoretical systems analysis. A general procedure was outlined for defining the performance requirements and formulating a generalized system. Now the third operation, the description of alternative systems, is discussed. However, these three operations are interdependent and must therefore be undertaken as a carefully coordinated effort.

By way of definition, an alternative system is the combination of operating components that will accomplish a given objective in an acceptable manner. In this case, describing an alternative system means proposing a complete solution to the problem of improving individual transportation. By this process, several alternative systems, not just one, may evolve. But, a properly conducted systems analysis will produce the minimum number of maximum efficiency systems. Each system will be complete and can be accurately described.

These alternative systems, as shown in Figure 5, obviously cannot be named at this time. However, they might include such systems as the often-mentioned but so far vaguely described "automated highway." One system might be a conveyor belt highway and another might be some form of pneumatic tube transport. Or, with visions on the horizon of the possibilities of the future, one system may utilize airborne vehicles guided by laser beams and propelled by the energy received from the lasers. Other systems concepts will complete some unknown number of alternatives.

Figure 5 shows that there will be a description of the operating characteristics of each alternative system, which will describe how the components within that system interact. The subsystems of which any system must be comprised will be described from all aspects. In this description, consideration of the environment will include

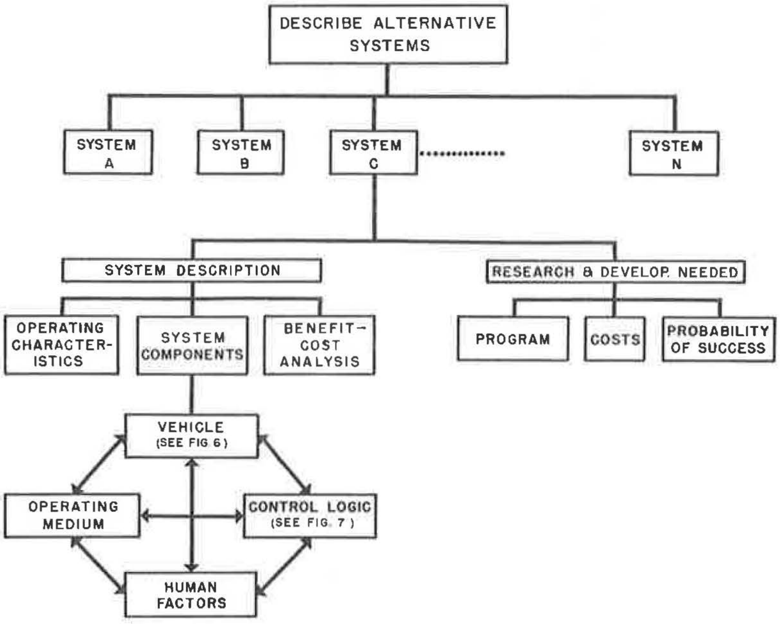


Figure 5. Description of alternative systems including research and development needed.

analyzing the features of the areas through which the system itself will operate, such as the land areas of the business district, the city, the suburbs, and the rural areas. It will also include solutions for those problems of entrance, exit, and storage of vehicles within the system. And, of course, it will describe the effects of environmental problems such as weather.

The subsystems will be described from the viewpoints of the various user groups. Of these, the largest group will consist of those who are desirous of improved personal transportation. But full consideration will also be given to that group of individuals who wish to join with others to share improved mass transportation; and to a third group, which will include those individuals who desire to improve the movement of freight. There will also be a description of the probability of acceptance of each given alternative system. This may well be based on a description of its comparability with the present highway system or it may use some other datum for evaluation. It will, of course, include a complete description of the readjustment necessary in the economy to accept the new and proposed systems.

Figure 5 also shows the four categories of basic components in any transportation system: the vehicle, the operating medium, the control logic, and the human. Close interconnection must exist among all four of these component categories. It is not feasible to develop one of the components without full consideration of the others.

The vehicle will be considered as a container for that which is to be transported. In each alternative system the vehicle will be comprised of some combination of power sources and propulsion techniques, as shown in Figure 6. This 2 by 2 matrix shows some existing and familiar vehicles. But many other vehicles could be placed in the

**VEHICLE**

| POWER AND PROPULSION MEANS | | | |
|---|---|---|---|
| | | PROPULSION | |
| | | SELF | EXTERNAL |
| POWER | SELF | AUTOMOBILE<br>DIESEL TRAIN<br>GROUND EFFECTS MACHINE | ? |
| | EXTERNAL | TROLLEY<br>ELECTRIC TRAIN | CONVEYOR BELT<br>IMPELLER SYSTEM<br>SKI LIFT |

Figure 6. Various combinations of vehicle power and propulsion.

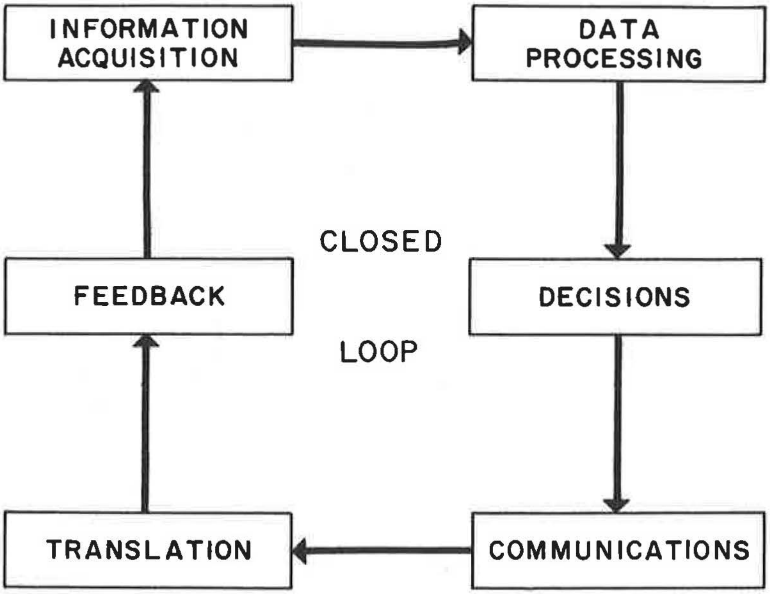


Figure 7. Control logic considered as closed loop process.

matrix. The self-powered, externally propelled vehicle does not exist at present. However, a systems analysis would generically describe new and unique vehicles that in concept may make use of such techniques, and it is entirely possible that such a vehicle could be developed. The systems analysis will describe the useful characteristics of the proposed vehicles and contrast them with undesirable characteristics such as air pollution. From such descriptive comparisons of vehicles, the usefulness of each as a system component will become evident. These will be generalized rather than detailed, technical descriptions.

The operating medium of any alternative system in this systems analysis will be described by its features as a "highway." The term highway is used in the sense of the AASHO definition, "A general term denoting a public way for purposes of vehicular travel, including the entire area within the right-of-way." As has been mentioned, the operating medium of an alternative system may well be the conventional highway, with or without some modification. However, unconventional media such as the ground pathway, various types of structures, air, and many others need to be considered and compared for the description of alternative systems. Different subsystems possibly will require different media to promote the most efficient movement of traffic in each particular area. The description of the operating medium will also indicate what provision must be made for such foreign objects as pedestrians, animals, and debris.

The control logic of a system is that combination of techniques and devices employed to regulate the operation of that system and is outlined by the closed loop diagram shown in Figure 7. For each system, the analysis will show what information needs to be acquired and how it will be obtained. The conception and design of the processing and analyzing equipment that will be necessary to convert these data into operational decisions can then be described. The best means of communicating these decisions to the mechanical equipment or the human, which will translate them into the necessary action, can be specified. The control logic loop is closed by including the reaction, or feedback, which will detect and correct the performance errors. The description of the control logic will also include such things as the handling of nonconforming vehicles, failures in the logic itself or in other parts of the system, and the accommodation of personal emergencies.

It is also evident that as each alternative system is described, the role of the human must be considered both as an active system element and as a rider. No analysis need assume the preconceived notion of complete automation. The amazing ability of the human to accomplish perceptive and control tasks has been previously pointed out. The capabilities and limitations of the human will be studied and the results of these studies will determine the areas where he may be utilized in guidance and control. The human may well be the monitor of an automated system; or the alternative system may be designed for human control that is to be automatically monitored. The factors of fatigue and vigilance also will be completely studied and described in each alternative system.

The human as a rider in the system will have great bearing on the acceptability of the system. Studies of the tolerance of the human to motion and to changes in motion in all directions will, of course, need to be made. Also, it will be necessary to specify the training that will be required to fit the human to each new system. These and other human characteristics will bear equally with the other components on the utility and acceptability of any system to the potential user.

Finally, a benefit-cost analysis will complete each alternative system description. It is evident that in all areas it will not be possible to indicate these items in terms of dollars. However, where it is not possible to estimate an exact cost in one alternative, the same base of comparison will be extended to the other alternatives. Of principal importance, however, is that the comparative cost between alternative systems be properly made. These costs, of course, can be categorized as initial, operating, and maintenance, and the benefits can be identifiable in each system. Those benefits which cannot be expressed in dollars and cents will be expressed in such terms as comfort and convenience to the potential user.

Thus, out of the systems analysis will come a description of alternative types of systems that meet the requirements for individual transportation. In addition, the systems analysis will define the research and development needed to produce a prototype, as shown in Figure 5. Included will be a complete description of the research and development program needed to determine the feasibility of and the design requirements for a prototype system. In addition, the cost of the research will be included and the probability of success in producing a prototype for testing will be estimated. It is recognized that some aspects of such a program will be only broadly identified in the systems analysis phase but will be detailed as research and development proceeds.

From this discussion, it can be seen that the systems analysis is a logical approach to the challenge of today; namely, to lay the foundations for the rational evolution of individual transportation systems of the future.