WHY DO WE NEED COORDINATION OF AUTOMATION SYSTEMS?

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I seriously question both the need and the advisability of trying to achieve coordination of automation systems all the time. A review of one example demonstrates how too much attention to coordination can lead to voluminous computer printouts that are worthless.

In the 1940s, the maintenance control section concept was developed to serve as a common reference base for all highway location data in a number of planning and management areas. Control sections were initially used to evaluate the adequacy of the road system in relation to existing and projected traffic burdens. The sections were defined to provide segments of the road system within which the existing road character and the traffic served were reasonably uniform. The control sections accomplished this; however, for more sophisticated economic evaluations, it was concluded that road section maintenance costs should be established and that the incidence of accidents should be related to the road sections. Consequently, many highway departments established maintenance cost reporting systems that related all maintenance expenditures to control sections, and many departments grouped accidents by the control section in which they occurred. Because these analyses were computerized, it appeared that maintenance data handling could be expedited and a valuable coordination of output provided.

For years, the use of control sections provided the basis for effective analysis of priority needs in the development of highway programs in several states through a procedure called sufficiency ratings. From time to time, they also provided the basis for the objective development of total highway needs estimates by procedures largely developed by the Automotive Safety Foundation and pursued strongly by the Bureau of Public Roads.

It was in the maintenance cost area that control sections were used most extensively. Most departments that established maintenance cost reporting systems continued the daily recording of maintenance work by control sections and maintained cost summaries. For highway safety analysis in planning, accidents were recorded by control sections and much experimentation was undertaken to try to relate accidents and highway features by use of this device.

The use of control sections, therefore, seemed to have a great future as a sound basis for coordinating inputs into several analyses; however, this future never materialized. Although control sections were useful in needs analyses, their use in maintenance cost analyses proved to be almost a dead loss. There was almost no worthwhile use of the voluminous computer output from maintenance reporting systems in many states. The maintenance data were found to be too unreliable for coordination with other needs study data. Furthermore, it was found that sampling data or generalized maintenance estimates served the needs purpose adequately. Some highway departments made summary reports of the data and distributed these presumably so that maintenance managers would examine their costs in relation to other managers' costs and use the unit-cost data for budgeting. However, the lack of validity of the data was too easily recognized for the summaries to be useful for either purpose.

The traffic safety area is another area where control section reporting proved meaningless. This was not immediately apparent in that some safety improvement programs were being structured on the basis of where the most accidents were occurring—except that it was difficult to count the spots on the accident spot maps. As researchers further analyzed traffic accidents, however, they found that the location of accidents by control section was not sufficiently refined to provide the values needed for pertinent identification and cost-effective correction of high-accident locations.

As a coordinating device, therefore, control sections that once seemed to provide a sound basis for coordinating all highway location data for various analytical purposes have proved to be of little value. Even in the needs study area, control sections, although they proved to be a valuable basis for reporting and analyzing location data and are still used in some places, are now a completely dispensable tool.

What can we learn from this history of control sections that is pertinent to our discussion of coordination in automation systems? I believe we can learn at least three lessons, and, from these lessons, we can establish three principles that should guide us in any coordination of systems we undertake in the future—automated or otherwise.

The first lesson is that coordination of systems may not always be a worthwhile objective. Control systems proved valuable in the area of needs measurement even though they failed to work out for the other two purposes that they initially were conceived to serve.

The second lesson is that we should review periodically where we are going with our systems. We are in business to accomplish things; a complex system that produces useless maintenance cost output for 20 or 25 years may not be the only mistake that highway departments have made in coordinating data systems of a similar nature.

The third lesson is similar to the second but may not be reflected as such in the control section experience. It is that systems—automated or otherwise—should be designed backward from decision input needed to achieve well-defined basic objectives of the organization. Reviews of systems, continually made in the regular management process and occasionally made in depth, should concentrate initially on how well the system provides decision input data. Further, the objective toward which design of a system of any kind is directed should never be systemization itself. Systemization should be viewed only as a means to an end; the end should be the achievement of the organization's basic objectives more efficiently or more cost effectively. If we had learned this better in connection with control sections, we would have reviewed maintenance reporting systems in terms of obtaining worthwhile maintenance cost and accident data that could help in decision-making.

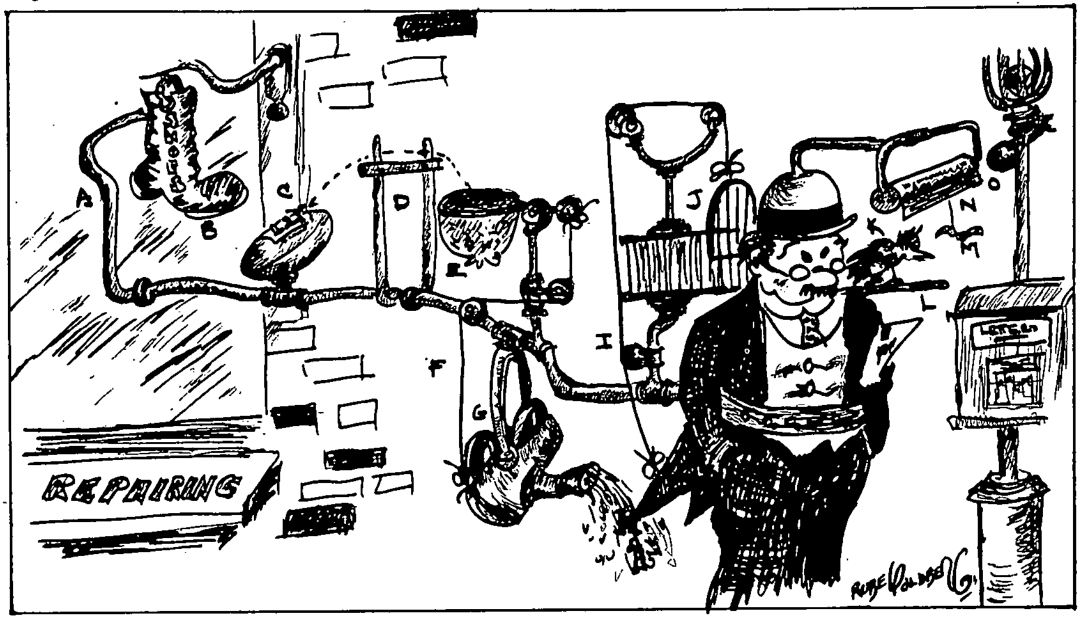
The principles that we can relate to these lessons are as follows:

1. The design and subsequent review of any system or combination of systems should begin with defined decision input needed to achieve basic objectives.
2. There should be continual management review and occasional in-depth study of all systems to see how their output relates to the provision of needed decision input.
3. Efficiency and cost-effectiveness in providing needed decision input should be the sole criterion of whether, and how much, systems should be coordinated.

In connection with the first of these principles, a great cartoonist, Rube Goldberg, amused us for a number of years by designing complex systems for accomplishing insignificant things (Fig. 1). Is a complex computer system that produces worthless output any less humorous than Professor Butts' system? From the standpoint of a noninvolved observer, it may be. From the standpoint of a stockholder or taxpayer, I doubt that it would be. Regardless, there is a very real danger of producing this kind of automation system if we fail to observe the first principle: to design systems exclusively to provide needed decision input for the achievement of basic objectives.

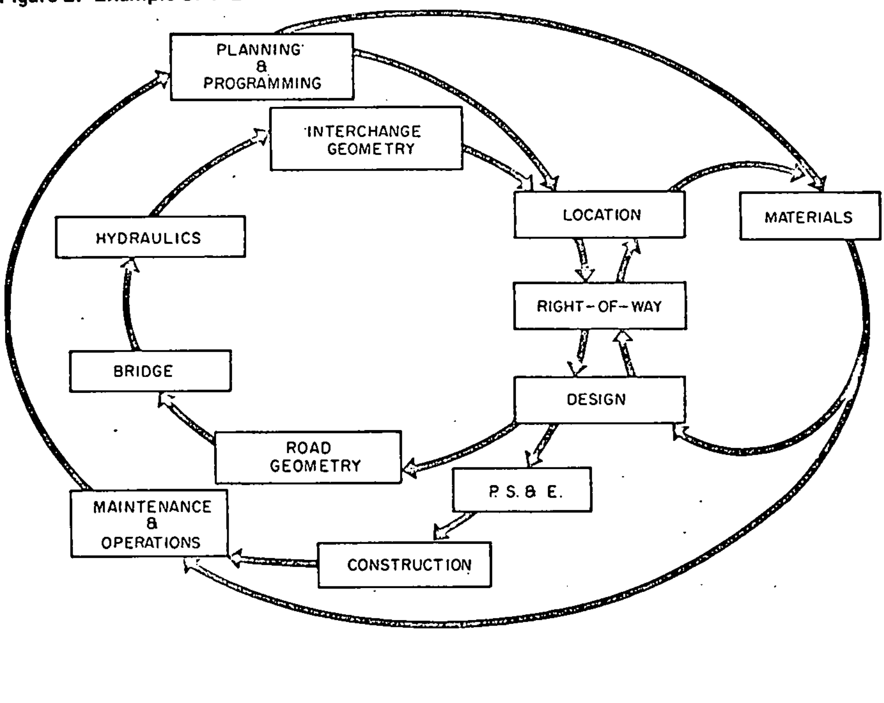
How does this relate specifically to the coordination of automation systems? It means that coordination of automation systems should be designed backward from decision input. This would rule out, for example, the concept that a central data bank can be structured to contain provisions for all data conceivably needed for most analytical functions in a highway department and to adequately provide a system of linkages to deliver needed data to any user on demand. This concept would be ruled out because, designing backward from decision inputs, we would first design the systems providing the basis for the decisions before we identified the data input required for these systems. Even with current systems, we need to go this route because all of our current systems may not be right. Furthermore, as is commonly known, it is an unprofitable task to obtain summary data that are outside of the data linkage design from a data bank of this kind.

Figure 1. Professor Butts mails a letter.



PROFESSOR BUTTS GETS CAUGHT IN A REVOLVING DOOR AND BECOMES DIZZY ENOUGH TO DOPE OUT AN IDEA TO KEEP YOU FROM FORGETTING TO MAIL YOUR WIFE'S LETTER.
AS YOU WALK PAST COBBLER SHOP, HOOK (A) STRIKES SUSPENDED BOOT (B) CAUSING IT TO KICK FOOTBALL (C) THROUGH GOAL POSTS (D). FOOTBALL DROPS INTO BASKET (E) AND STRING (F) TILTS SPRINKLING CAN (G) CAUSING WATER TO SOAK COAT TAILS (H). AS COAT SHRINKS CORD (I) OPENS DOOR (J) OF CAGE ALLOWING BIRD (K) TO WALK OUT ON PERCH (L) AND GRAB WORM (M) WHICH IS ATTACHED TO STRING (N). THIS PULLS DOWN WINDOW SHADE (O) ON WHICH IS WRITTEN, "YOU SAP, MAIL THAT LETTER." A SIMPLER WAY TO AVOID ALL THIS TROUBLE IS TO MARRY A WIFE WHO CAN'T WRITE.

Figure 2. Example of TIES.



If, on the other hand, analytical systems are designed to provide specific input needed for decisions and are found to utilize the same basic data, then it is obviously sound to specifically develop a data bank structure that will efficiently provide the source data for these systems and, perhaps, to these systems through automation processes. There would be no limit to the number of systems a data bank could serve on this basis. However, a data bank structured in this way would need to be quickly adaptable so that new data arrays could be provided when the analytical system is changed because of new or improved technologies.

It is unrealistic to expect that an automation system can be designed practically to carry through the analytic processes from planning to construction or planning to maintenance on the computer with input from engineers being made at different points along the way. Figure 2 (1) is not very meaningful in indicating procedural or data interchange relationships among the various highway department functions shown. In fact, many times there is no continuous procedural flow. Planning, for example, employs a completely different type of procedure than that utilized in location, and the procedures in right-of-way acquisition are another set. True, there is a point in time when planning procedures result in identification of a project and, at that point, there is an interface between planning and location. True, location of a project provides a basis for right-of-way acquisition, and right-of-way factors are important in location. True, there are many common data needs. However, needs for various data far exceed needs for the same data. The analytical processes are completely different for each function, and the type of decision-making and even the decision-makers are different. Any system that tries to provide for some of these things simultaneously (and several should be conducted simultaneously) and for others sequentially (and several should be conducted sequentially) would be very complex indeed. Fortunately, the figure does not include financial management and scheduling and control areas, which apparently are expected to coordinate differently or perhaps not at all.

More recent diagrams of systems similar to the Total Integrated Engineering System (TIES) have shown pie-like divisions that represent major "engineering" functions and contain more detailed functional breakdowns, with a data bank core at the center. These diagrams are no more descriptive of the actual relationships involved than the one we have chosen for illustration. The data bank idea does not contribute much to a conceptual definition because we have already discussed the impracticality of data being provided to all systems from an unstructured data bank. In a structured data bank, data content and form of entry are arranged specifically to provide efficient data input into one or more analytical systems which, in themselves, are designed specifically to provide the necessary information for a management decision.

To determine how best to provide the information needed to arrive at a management decision, one must decide whether a computerized routine for a particular analysis should be provided. The objective should not be to get everything on the computer. In some cases, computerization or automation of an analytical process will not be cost-effective. Generalized examples are (a) when application frequency is low, (b) when the analytical processes are not stable, i.e., new developments occur and change computer program requirements frequently enough to destroy the aggregate advantage of computerization, and (c) when the results of the program cannot be specifically detailed in advance in terms of the information needed for management decisions. It is certainly desirable to have research projects on computer systems, but there should be no doubt, in advance, that the projects do constitute research that may have successful, partially successful, or unsuccessful outcomes.

At least two basically different kinds of management systems that present different demands on and opportunities for automation must be recognized in structuring practical automation systems in highway departments. First, there is the preconstruction project production line; second, there is the management support system group consisting of such functions as planning, budgeting, programming, scheduling, personnel management, financing, controlling, and, possibly, maintenance.

The production-line group, consisting of location, materials analysis, design, and right-of-way acquisition, appears to present the largest potential for full-scale automation. Functions in the group have these characteristics in common: (a) Within the limits of periodic change, the analyses are largely routine; (b) computerized applications already are available for many of the analyses; (c) the functions interface sequentially, with data and decision output from one providing data and decision input to another; and (d) most use common source to some extent. They also represent functions that are susceptible to a single programming, scheduling, and control system, which also can be computerized or automated.

These functions provide the real target for TIES and other integrated engineering systems. Several so-called subsystems have been developed (or largely developed) for TIES such as a hydraulic design subsystem, a road design subsystem, and a bridge engineering subsystem. In addition, several state highway departments and other agencies working apart from TIES have developed in conjunction with their own integrated system concepts full or partial systems for road design, bridge design, hydraulic design, location, and right-of-way acquisition. Generally these systems have been developed function by function, and in the area of common data utilization or machine interfacing little has been accomplished. There has been considerable progress, however, in the development of a production-line system. The use of common data utilization or machine interfacing is worthwhile only when it results in a cost-effective benefit such as speeding the preconstruction phase, reducing the number of personnel, or providing a better design product.

The same principle applies to what we have called the management group of systems. For the most part, these systems do not represent sequential steps in a basically single-target process. In general, they have little in common with the production-line system and with each other.

Planning systems are directed toward providing bases for the production line, but the direct inputs, for the most part, are identified projects. This is not altogether true because a clear distinction is not made between processes that are called planning and those that are called location or design. Also, processes such as location and design utilize some planning data. Where there is this utilization, there obviously ought to be coordination of systems, whether they be computerized or not, to arrange for transfer of data with maximum efficiency.

The production programming, scheduling, and control system—sometimes considered as a planning function—is a candidate for extensive automation. However, there is no obvious reason for coordinating this system with the systems in the production line; they do not use the same data at all. There is reason for some coordination of this system with the budgeting system and the personnel management system; however, it is not at all certain that data transfer through machine processes would be advantageous in any way.

There are other developed or partially developed automation systems as well as potentials for new automation systems in planning. Simulation and other analytical models are available for such things as traffic systems analyses, continuous highway needs analyses, environment planning analyses, and certain economic analyses. There is some interfacing and desirable interchange of analytical procedures among these models, and there is considerable sharing of common data. It would be profitless, however, to try to arrange for transfers of data or common machine processing without being highly selective in the determination of where these interfaces should occur.

Selective coordination may also be desirable between maintenance and planning systems, maintenance and other production-line systems, and maintenance and budgeting systems. Automation systems for maintenance management are largely self-contained, however, and need no extensive interface with other automation systems. There are uses for some road inventory data gathered for general purposes, and maintenance uses should be taken into consideration in gathering and filing these data. However, in general, it looks as if maintenance should largely rely on independent systems.

The principle of selective coordination applies not only to automation systems and potential systems for the functions mentioned but also to systems and potential systems in financial and personnel management, communications, and other highway department operations. It applies equally to systems applicable to a larger field of transportation such as departments of transportation. The principle of backward design (from management decision input) also applies to all automation systems or combination of automation systems regardless of where they may be used.

If we follow these principles, we will be better able to avoid the following examples of bad automation systems:

1. An automated system of work-reporting or cost-accounting that produces summary output for which there is no practical use;
2. An automated system that produces diagrams of highway features that are only used, when they are used, because the users are ignorant of other sources that are available at much less cost;
3. A computerized bridge design system that is used for only one or two design applications;
4. A scheduling system that is not effective either in scheduling or in controlling production;
5. A complex, comprehensive data retrieval system that is of little practical use in any of the processes of highway planning, engineering, or management because data retrieval is based on complex linkages that must be established in advance and thereafter are rigidly inflexible;
6. Any kind of a system that produces voluminous data, such as equipment usage and maintenance reports, that are never actually used;
7. Systems that never seem to be completely developed as the developmental expenditures mount up; and
8. System conversions that do not function as well as the old system.

That both principles are also applicable in general business and industry should be evident from an article that appeared recently (2). In general, the article documented instances in industry where computerized systems, during the last decade, have failed to live up to the expectations of the purchasers. Most of these instances involved automation systems used in large companies in Britain and the United States. According to the article, the systems were (a) too expensive to install, operate, and repair and (b) ineffective in producing satisfactory results.

After analyzing the underlying problems, largely through conversations with executives both in the affected companies and in the computer industry generally, the authors of the article made the following conclusions:

1. The current capability of computer systems has been oversold by the industry—particularly the hardware companies;
2. Lack of standardization, adequate training, and control and shortages of trained personnel have created large technical deficiencies in the computer programming area;
3. Managers have inadequate understanding of the use and capabilities of computers and computer systems;
4. Low-level personnel, such as the head of a data processing division, are left to make basic decisions about computer installations and systems; and
5. Those associated with computers and computer systems are often more interested in and aware of the complex electronic functions of the machines than they are of company objectives.

Some of these conclusions may be superficial or even misleading. For example, what managers may need to know about computers and computer systems is (a) that electronic computers are only machines that combine the attributes of an extremely fast desk calculator and a filing case; (b) that they can only process data to obtain answers to calculations or chains of calculations built into them and retain or provide the raw data and answers in initial or summary form; and (c) that computers are not even very efficient in performing calculations, just very fast.

The idea of man-machine systems, where the electronic computer performs all of the routine calculations of dozens of people while a professional sits back conceptualizing and feeding in decisions at key points, is largely a pipe dream.

Executives would be better managers if, instead of trying to understand computers, they would take a close look at any proposition to automate existing or new procedures and answer the following questions: Is the system designed to supply specific needed output for management decisions? Is there any likelihood that it might not achieve this specific result? What problems are likely to be associated with it? Does it have cost-effective advantages over current systems?

The more obvious aspects of coordinating automation systems apply only when it is rationally decided that coordination is needed on the basis of the principles we have stressed. For example, where better efficiency and cost-effectiveness may be served by machine transfers of data from one system to another, it is obvious that attention should be given to compatible formats of one subsystem's output and another subsystem's input. If summary final values are the only data to be transferred, then coordination with respect to these values is all that needs to be considered. If there are to be transfers of basic data content or sharing of basic processes, considerations need to be extended to more complete compatibility of data formats and compatibility of program language.

Other obvious considerations in coordinating automation processes may relate to potential variances in basic computer needs and applications such as between different highway department processes. It is quite possible that maximum automation and computer use in some processes may not demand the machine capacity that minimum automation and usage may demand in others. Obviously, coordination is needed to ensure rental or purchase of a computer with optimum capacity. Types of computer applications vary among processes. Computer applications for maintenance are quite different from those for bridge design. Specific computer systems have been designed for different types of applications, including different hardware. Once more, coordination obviously is needed to ensure rental or purchase of adequate hardware.

There is no basic reason why computer programs need to be written in the same computer language when they apply to unrelated applications. When it is anticipated that the output of one program will be used as the input for another, efficiency may be increased by using the same language for both programs. Use of a common data bank is facilitated by using one language. The additional training necessary to equip programmers to write in more than one language is also worthy of consideration. Of course, the days of computer language problems may be numbered as we approach the development of a universal computer language.

Figure 3 shows a planning system that can be automated to excellent advantage. Perhaps the most extensive potential for automation is in the plan cost analysis and program through work plan and implementation steps shown in Figure 3. Plan cost analysis differs from the conventional needs study by providing for continuous evaluations of the entire highway plan and potential or actual modifications of the plan. It is used continually in the planning process to evaluate changes in concepts of such things as specific routings, design standards, and levels of traffic service.

The program through work plan and implementation procedure has already been discussed to some extent; it combines programming and the scheduling and control processes. In this case, the procedures can be carried out effectively through a sequential coordination of subsystems.

Figure 4 shows how an automation system for processing maintenance work records can be directed toward management decisions needed for the effective scheduling and control of maintenance operations.

Figure 5 shows a central core data system as related to analytical systems in a multiagency traffic safety program. It shows one basic group of data that can be used to serve many purposes. The data are structured in such a way as to be readily available for several subsystem analyses, largely automated. The subsystems are designed to provide needed management decision input. Because the subsystem analyses require more data than those included in accident reports, nonreport data are also made part of the central core record and are conveniently arranged such that all subsystems can have immediate access to them in the required format. How the data are arranged in the central file is not particularly important so long as they can be supplied immediately on demand. There are no useless data in this file.

REFERENCES

1. Tennent, R. C. TIES Subsystems. Proc., Conf. on Improved Highway Engineering Productivity, U. S. Dept. of Commerce, Bureau of Public Roads, 1965, p. 569.
2. The Accident-Prone Miracle—A Survey of the Computer Industry. Economist, Feb. 27, 1971.

Figure 3. Recommended planning system.

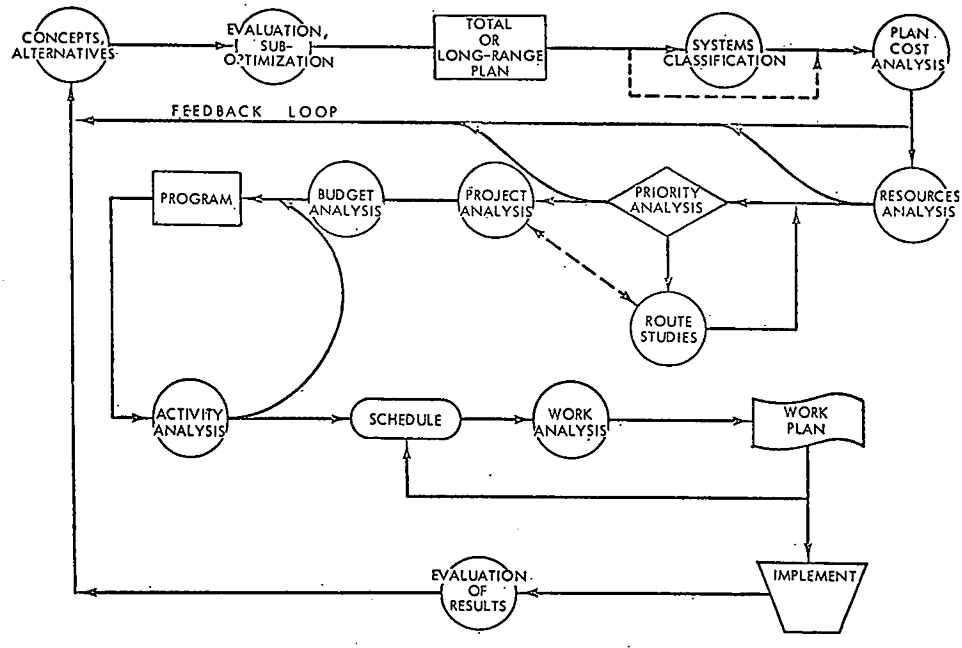
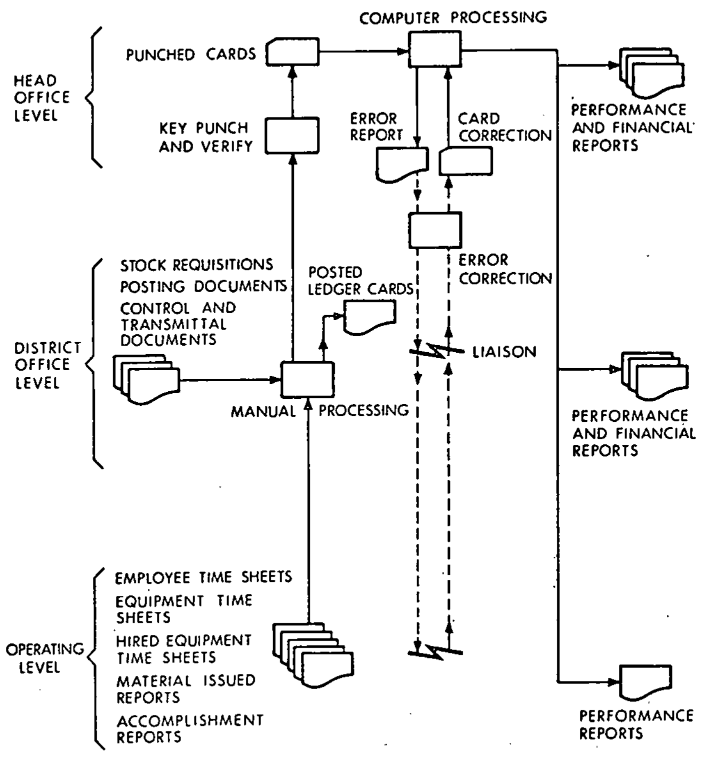


Figure 4. Recommended maintenance management system flow.



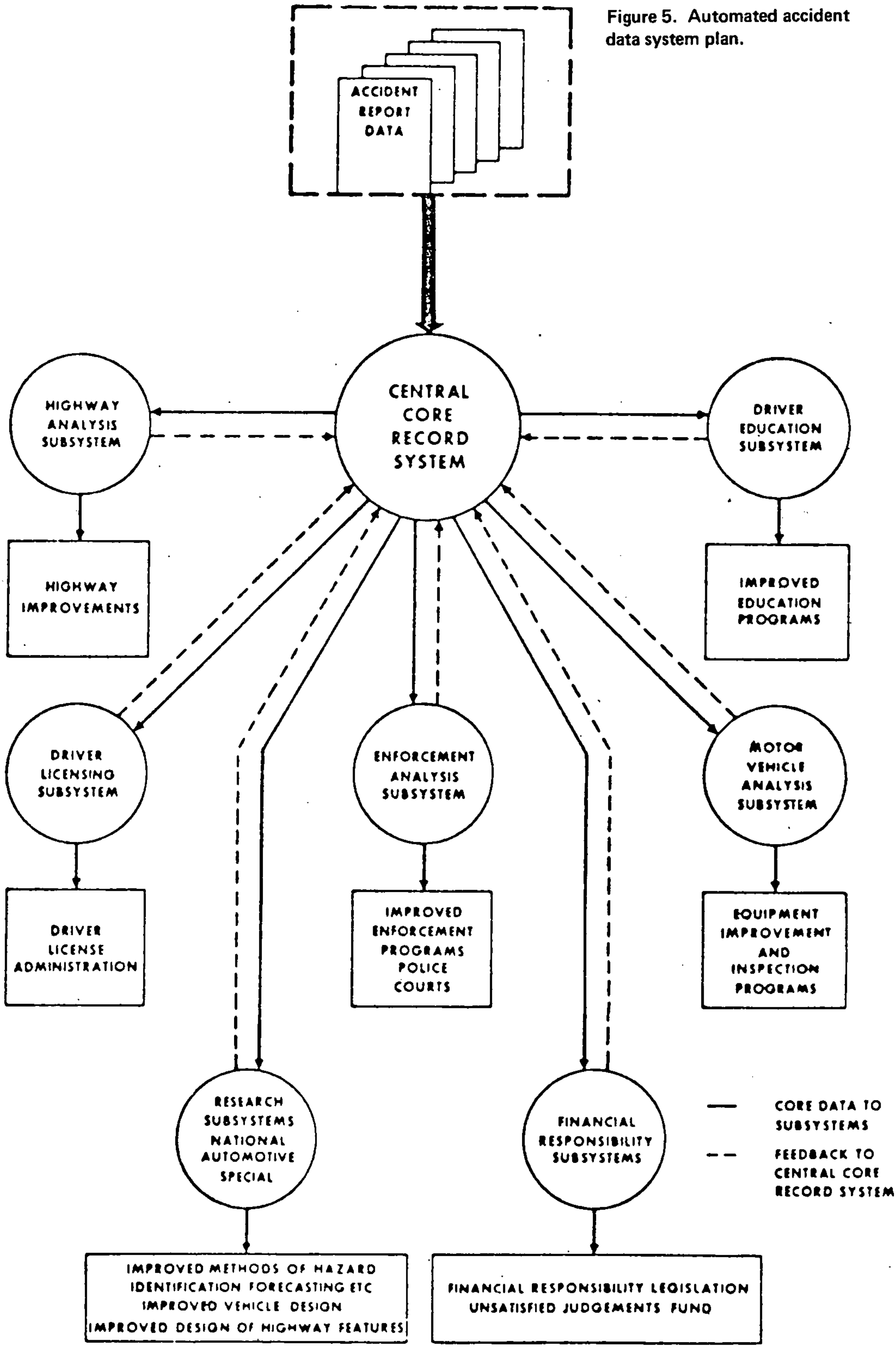


Figure 5. Automated accident data system plan.