The Design of Highway Interchanges: An Example of a General Method for Analyzing Engineering Design Problems

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This interim report describes the application of a set-theoretic decision method to the problem of highway interchange design. The paper is one of a continuing series reporting the development of this approach to the analysis of engineering design problems.

A design problem can be described by a list of misfits, or ways in which the design can be "wrong," and by a list of the pair-wise interactions among the misfits. Description in this form makes it possible to associate a linear graph with every problem. A set-theoretic criterion is used to obtain a hierarchical decomposition of the graph. The result is a program for developing a solution to the design problem.

This paper introduces the method, and describes the shortcomings of the AASHO manual as a design program. It also describes the preparation of the interchange problem for analysis and discusses the results of a preliminary analysis of the problem. A program for the design of a highway interchange is presented and some partial solution attempts are described.

•THERE is no systematic approach to problems of engineering design. Present methods of design are largely ad hoc, they are based on trial and error, and they are influenced more by the forms which have been found as solutions to old problems, than by the specific nature of the problem in hand.

These methods are inefficient and expensive. The physical forms they lead to seem comparatively economical as far as the cost of their design goes. But they are actually much more expensive than they need be because their imperfections lead to long-range diseconomies.

ANALYSIS OF A HIGHWAY INTERCHANGE DESIGN PROBLEM

If we look at the number of possible types of interchange available to a practicing engineer today, we see what looks at first like a rather rich variety (1). If we look a little closer though, and think about these designs, we realize that to a large extent they are really nothing but variations on one basic idea. In fact, when the engineer faces the task of designing interchanges he is under tremendous cognitive constraints, in the sense that it is very hard indeed to escape from these habitual patterns or stereotypes, without being deliberately and willfully "different."

However, once we realize just to what extent the engineer is constrained by nothing better than habit, it occurs to us that possibly these interchanges are not even particularly well suited to the task they perform. Even if they were suitable at the time of

Paper sponsored by Committee on Geometric Highway Design and presented at the 43rd Annual Meeting.

their invention, they may be the hung-over formalism of a past task, like the horseless carriage, whose shape changed only long after the horse dropped off.

To find out whether this is in fact so, we must invent some way of explicitly getting around our cognitive bias, something which allows explorations unfettered by the conventionally accepted forms; but at the same time, something not based, like "brainstorms," on wild association, but related in a sensible and significant way to the problem at hand. Present methods lead to imperfect designs, because they do not take the structure of the design problem into account.

When confronted by a complex design problem, we automatically try to reduce its complexity by organizing it according to certain invented categories. Thus for instance, in the case of a highway design problem we begin by saying that one must consider economic factors, safety factors, and aesthetic factors. This assumes, tacitly, that the structure of the problem is such as to permit this subdivision, and that it makes some sort of sense to think about economics, safety, and aesthetics separately. But note that this subdivision has been generated purely by the words which happen to be at our disposal, not by the specific structure of the problem which confronts us.

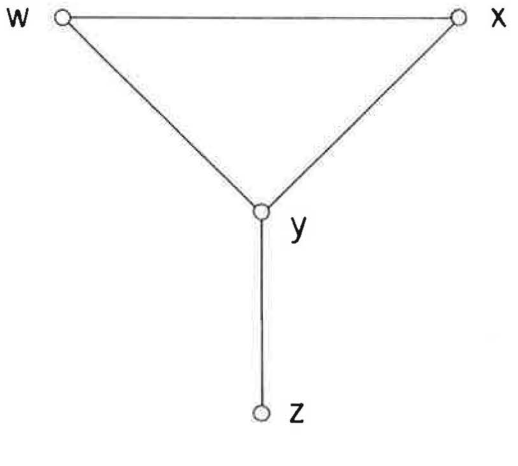
Designers do not deliberately disregard problem structure. But the way in which they naturally think out problems forces them to think in terms of categories, and whether such categories are derived from past experience, or self-consciously invented, they are still governed by the verbal labels now available in English. There is no reason to suppose that these are appropriate to the problem in hand.

Instead of superimposing irrelevant or misleading verbal labels on it, we have to find some way of letting the problem generate its own structure. To do this we must abstract from all the issues which crop up in a design problem some representation which we shall call the structure of the problem. Once we have this structure, it can be manipulated to gain insight into the problem itself, to improve the organization of the process of design itself.

Graph

The structure we shall use to represent problems is a special kind of topological complex known as a graph. It is uniquely defined by two sets, V and L. V is a set of points, or vertices; L is a set of unordered point-pairs, or undirected links. (Of course L must be a subset of the set of all possible links, $v \times V$.)

Thus, if the set V contains the points (w, x, y, z), L might contain (wx), (wy), (xy), (yz), and V and L would then define the graph:



Such a formal structure, simple though it is, allows us to represent the essential features of any design problem, no matter how complex.

Every problem of designing a physical form has these two fundamental characteristics:

1. There are certain requirements which the form must meet.
2. Many of these requirements conflict with one another.

The objective of any design process is to find a form which manages to meet all the requirements, in spite of the conflicts. We call the process of inventing any such form "solving the design problem."

Given any list of requirements and a list of the conflicts between pairs of requirements, we can associate with every requirement a vertex, and with each interaction between requirements a link between the corresponding pair of vertices. The graph so defined completely summarizes the structure and the difficulties of the problem. The whole of the analysis which follows is based on this correspondence between design problems and abstract graphs.

If the defining requirements were all independent, then any problem could always be solved, no matter how many requirements it contained, because we could specify the physical characteristics of the form which each separate requirement demanded, and be sure that these characteristics would not conflict. The solution to the problem could then be found by simply aggregating the relevant physical characteristics.

Of course, this usually cannot be done, because the desirable physical characteristics are to some extent mutually exclusive, so we have to compromise. It is just wherever this happens that we speak of a conflict between requirements.

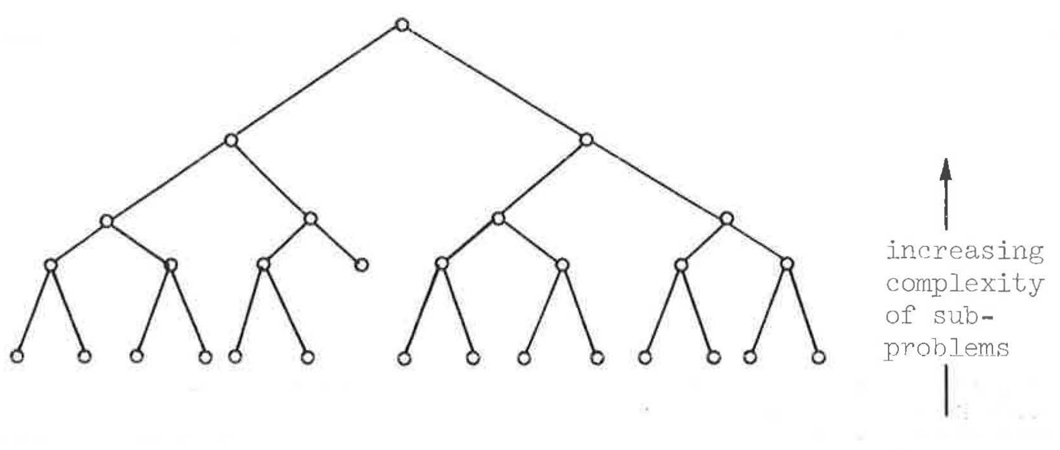
When there are such conflicts, the conflicting requirements must be juggled until we find a satisfactory solution. This is exactly what the designer does during the course of a day's work. But under circumstances where the requirements can no longer simply be solved one by one, the number of requirements and requirement interactions to be dealt with simultaneously begins to be critical.

In our opinion, it is just the cognitive limits on the number of interactions a designer can manipulate, which make the unaided designer obsolete in the face of the large complexes of requirements he meets today.

If this is so, the purpose of any analysis must be to bring the design task within cognitive limits generally available to all designers. This calls for careful control of the conflicts and requirements they try to deal with at any one time.

To achieve this kind of control, we have first to outline a systematic procedure which can take the place of the present confused process (called design), and we shall call such a systematic procedure a design program.

A kind of program which is known to be effective in solving complex problems is one which first solves simpler subsidiary problems (2, ch. 6; 3; 4). By solving simple subproblems, combining their solutions to form solutions to more complicated ones, and so on, hierarchically, we can buildup a solution to problems of great complexity:



Program

To construct such a tree or sequence we must first ask whether we actually know any simpler problems we can solve. The answer is clear. Any problem can be made easier by leaving out some of the requirements it contains. The more requirements left out, the easier the problem is. Any subset of the set of requirements is therefore a simpler problem.

Ideally, we would like to break the problem up into a number of smaller sets of requirements which constitute simpler problems, find a solution for each of these small sets of requirements independently, and then somehow "add" the solutions to one another.

The objection to this procedure is clear. While the small sets of requirements are themselves indeed simpler to solve, the problem of integrating the solutions to them is so great that it defeats the whole purpose of the procedure. Small sets of requirements are not in general independent of one another, but interact just as single requirements do. If there is interaction between the sets of requirements to begin with, the various subsidiary solutions will also interfere with one another when we try to aggregate them.

This difficulty is brought out very clearly in the graph chosen to represent the problem. If the points of G are divided into two mutually exclusive sets, the requirements represented by these sets will not in general be independent: there will be many links between the two sets, and the interactions these links stand for make the aggregation of two independently found solutions very difficult. In fact, the only way of escaping this difficulty altogether would be to find some way of dividing the points into two sets such that no point of either set is linked to any point of the other. In this case there would be no interaction between the two sets of requirements, we could solve each set independently, and we should then be free to combine these independently found solutions as we wished.

A solution to a set of requirements is a specification of certain aspects of form. It may specify quantifiable aspects of the form (such as road width and concrete thickness) or nonquantifiable geometrical aspects which can be represented diagrammatically. For every solution to the full set of requirements, there is a large class of forms which satisfy any subset of that set. In solving such a subset we specify just those aspects of the forms which uniquely identify this class.

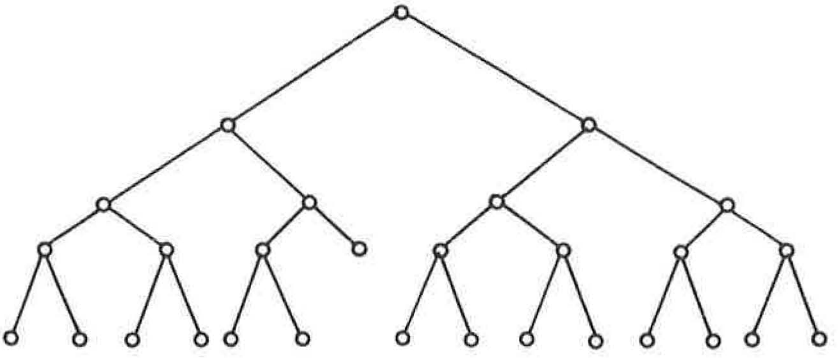
Thus, in finding a solution to any subset of requirements, we determine only certain aspects of the physical form—we do not determine it completely. When we find solutions to two such subsets, we have two different sets of specifications for aspects of the form—one set of specifications per set of requirements. If the two sets of requirements are completely independent, then the two corresponding solutions do not conflict; i.e., if two sets of specifications for the aspects of a form are derived from nonconflicting requirements, the specifications (the solutions) are themselves nonconflicting.

This means that these two sets of specifications may be combined without contradictions; or put another way, there exist forms which satisfy both sets of specifications, and these forms naturally satisfy both sets of requirements. Thus, if the solution to one set of requirements specifies the road width, for example, the solution to the other set, if it is independent, either does not specify any road width, or if it does, it specifies some road width compatible with the specification of the first solution. Under these circumstances, the two solutions can always be combined.

In practice it turns out that almost no problem can be divided into two such completely independent parts. That is, every practical problem must be represented by a connected graph, whose set of points cannot be divided into two subsets which are not linked to one another. In this case the best we can do is to find some way of dividing the set into subsets which are as independent as we can make them.

To do this we use a measure of independence, to evaluate each possible way of subdividing the problem (2, Appendix 2). Then, where there are n requirements, and so 2^{n-1} possible ways of dividing the set of requirements in two, we pick that way for which this measure of independence is greatest. The two sets which result from this subdivision are both simpler than the original problem, and because they are defined according to their independence, it will be relatively easy to combine their solutions.

Once we are able to divide a problem into its most independent parts, we can repeat the procedure, always operating on each of the two subsets derived from the previous operation. This process of subdivision, if used iteratively, allows us to break the original set into a number of distinct sets as small as we like. We can indicate this by a tree, in which each subset stands above the most independent subsets it in turn contains.



This tree is our design program. If we start at the lowest level of the tree, solving subproblems which contain only a few requirements, we can proceed to solve problems higher and higher in the tree. Because the pairs of subproblems we take together are always as independent as they can be, we can solve all the subproblems in turn, and then finally the original problem itself, provided we do so in the order prescribed by the tree.

Solution

Of course, in a sense, this is what the designer does already. He looks first at the component parts of a problem, then at larger and larger components, until finally he manages to achieve a synthesis which encompasses everything the problem demands. But such hierarchical programs can only work successfully if all the component problems at any level are independent of one another, and can therefore be put together without interference. It is only under these conditions that the designer can proceed systematically from one level of the hierarchy to the next.

The difference between what we propose and what usually happens is that we derive our component problems from the problem graph's structure in such a way that those components at any one level of the program are independent of one another and therefore capable of integration, while as a rule the designer selects the problem's components according to rather arbitrary conceptual schemas.

This can be made clear by referring to the specific case of the highway interchange problem which we have chosen to analyze. In this case, the schemas most often used by design engineers are those found in the AASHO manuals (5, 6). Of course, the AASHO manual (5) makes no claims to be a program. However, it does offer a conceptual framework within which to solve the problem of highway interchange design, since it is an organized statement of the issues which have to be considered, grouped under various headings and subheadings (Fig. 1).

We find that, in spite of the non-programmatic intention of the AASHO manual (5), it in fact does contain a hierarchy (Fig. 2) that is superficially very like the kind of hierarchical program we have in mind. The major design issues are laid out for consideration according to a conceptual framework which is intended, in virtue of its organization, to help the engineer overcome the cognitive limits which otherwise restrict his design ability.

Although we doubt the adequacy of this schema as a program, it is perfectly possible that it might be useful in designing highway interchanges. The chief trouble is that as

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etc.

Figure 1. Table of contents of an AASHO manual, A Policy on Geometric Design of Rural Highways.

it stands we can have no confidence in it, because it is too confused conceptually. We wish to know whether its organization is appropriate to the problems it is intended to solve. To do this we at least have to be able to state explicitly just what organization the schema has; that is, we have to be able to describe the arrangement of its elements and the relations between those elements. Although the AASHO schema has a hierarchical structure, it contains elements of many different logical types. Because its elements are not clearly classified we have no way of knowing just what the relations between them are. In other words, we have no way of estimating just what organization the manual has, and therefore no way of deciding whether it is appropriate to the problems in hand.

In brief, to decide whether a program is a valuable one, we must first see it in terms of elements which are classified so that their interrelationships are clear. Then we can determine what the organization of the program is, and then whether or not it is relevant to the structure of the design problem.

We have already pointed to two kinds of element which play an important part in engineering decisions: requirements, and the interactions between requirements. Of course, these two elements alone will not describe all the ramifications of design problems. But we suggest that everything about an engineering design process can be expressed in terms of five elements: the two already mentioned, and performance standards, data, and solution.

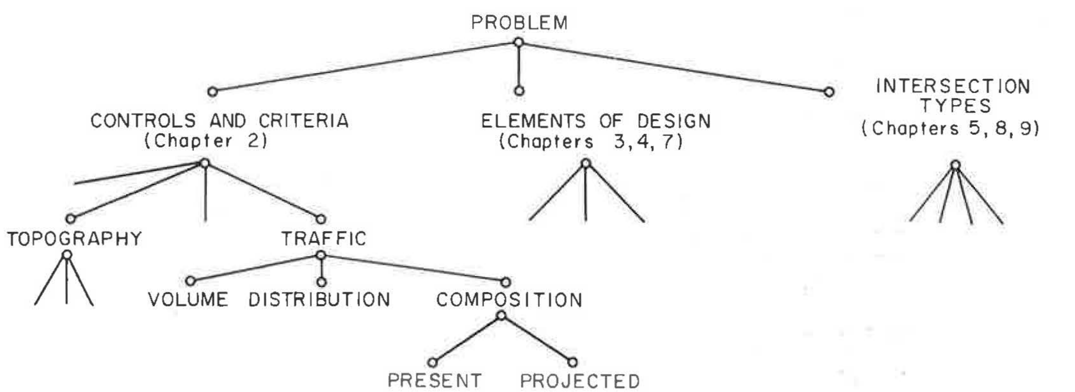


Figure 2. Hierarchical structure of an AASHO manual.

These elements are all discernible in everyday engineering practice, and in particular in the pages of the AASHO manual. But as things are at present, these five kinds of element are not clearly distinguished, there is no clear pattern to their arrangement, and the relations between them are not consistently expressed.

We have shown a part of the table of contents diagrammatically (Fig. 2) to bring out its hierarchical structure. But the elements of the hierarchy are very confused. Some of them, like SAFETY and UNINTERRUPTED FLOW, express requirements which the interchange must satisfy. Some elements, like VEHICLE CHARACTERISTICS, give information about the interaction, or possibility of conflict, between certain requirements. (For instance, VEHICLE CHARACTERISTICS tells us about the interaction of the two requirements, "grade not excessive" and "adequate vertical sight distance.") Other elements, like TOPOGRAPHY AND PHYSICAL FEATURES, refer to data; others (e.g., SPEED) refer to performance standards, and others, like DESIGNS WITH THREE INTERSECTION LEGS, are solutions.

The schema of the AASHO manual contains all five types of element, but treats them all alike, as though they were of the same logical type. But they are not—requirements affect the design process in a manner different from the effect of data, etc. Each kind of element plays a different role in the process of design.

DRAINAGE CHANNELS AND SIDE SLOPES

Modern highway design recognizes the desirability of the "streamlined" cross section. Safety, good appearance, economy in maintenance - and frequently in construction - are the direct benefits of flat side slopes, broad drainage channels, and liberal warping and rounding. These features avoid obsolescence and invite favorable public reaction.

Drainage Channels

Where terrain permits, roadside drainage channels built in earth** should have side slopes not steeper than 4:1 (horizontal to vertical), and a rounded bottom at least 4 feet wide. Minimum depth should vary from about 1 foot in regions of low rainfall intensity to about 3 feet in regions with substantial rainfall intensity. Channel depths of 2 feet or more usually are needed to keep the roadway above ground level. Drainage channels of these dimensions have the advantages given in the following paragraphs. More critical dimensions may be necessary because of terrain or limited right-of-way.

There is reasonable safety from overturning to the motorist who accidentally drives into a flat sloped drainage channel. Slopes of 3:1 are less advantageous than 4:1 slopes in this regard but are satisfactory when economics or lack of width dictate their use. In open country of northern regions, slopes of 5:1 and 6:1 are preferable in that they do not cause snowdrifts as do the steeper slopes.

The broad flat drainage channel provides a sense of openness that is of material benefit in relieving driver tension. With a slope of 4:1 from a 10-foot shoulder (or possibly 3:1, depending upon the shoulder slope and superelevation), the whole of the drainage channel is visible to the driver from a normal position on the traveled way. This lessens the feeling of restriction and adds measurably to the driver's willingness to utilize the area in emergencies.....

**footnote omitted in quotation.

Figure 3. Excerpt from AASHO manual, A Policy of Geometric Design (pp. 209-210).

Not only are these different kinds of element confused at this broadest level of analysis, but the confusion also extends to the most detailed discussion in the text (Fig. 3). In a few sentences elements of all five kinds are discussed, without any explicit reference to the fact that they are being treated differently.

For instance, the first paragraph mentions requirements ("safety, good appearance, economy in maintenance") and what seems to be a solution: " 'streamlined' cross section" consisting of "flat side slopes, broad drainage channels, and liberal warping and rounding." The solution is made more detailed in the next paragraph by specification of "side slopes not steeper than 4:1 . . . and a rounded bottom at least 4 feet wide," but confused by data: "where terrain permits . . . channels built in earth." In the third paragraph, we find that what we thought was a solution becomes a performance standard qualifying a requirement: in other words, "slopes of 3:1" is now treated as a standard for deciding whether the requirement "reasonable safety from overturning" is met. In the same paragraph, there is conflict between the two requirements, "economics" and "lack of width." Nowhere in the passage is there any clear distinction between the different parts these five elements are to play in the designer's decisions, nor are the single elements themselves treated from any consistent point of view.

Although our five-part classification of elements is based on engineering practice, it could be argued that it is an arbitrary invention. Undoubtedly the authors of the AASHO manual did not have these particular elements in mind when they wrote the text, and there is no reason why they should have had. We do not condemn them for failing to use just the kinds of elements we happen to have chosen. Our objection to the manual is that it looks as though its authors did not have any clearly distinguished kinds of elements in mind when they developed it, which makes its organization meaningless.

An example of the use of the most important two elements, "requirements" and "requirement interactions," in an analysis of the problem of highway interchange design follows.

PROCEDURE IN ANALYZING THE PROBLEM

Before discussing interchange design at all, we must be able to say how we would decide that a particular design is good or bad. A simple way of deciding is with a checklist of performance standards associated with the requirements. However, it is not always possible to see every aspect of a design problem in terms of quantitative performance standards; there is a danger that the checklist fails to account for many requirements which we know to be important, but cannot quantify.

For this reason the checklist which follows is not simply a list of measurable standards, but a list of all aspects of an interchange which could be said to have "gone wrong." To make this list of requirements comprehensive, it contains such items as "lack of consistency in signs," for which there is no quantifiable standard, as well as items like "traffic lanes too narrow" which can very easily have quantities associated with them. In this fashion each item on the list describes some way in which a design can fail to meet our approval.

Each item refers to a way in which an actual design can fail to fit its specification: these "misfits" are the requirements which we must satisfy.

This list of requirements is our third. Briefly, the procedure was as follows: We made up a list of words which suggested problems in the design of interchanges (e.g., "safety," "construction costs," and "snow removal"). Then we refined this list, trying to make it as complete as possible, and trying to get as little overlap between requirements as we could. Accordingly, requirements were not listed as separate, if they referred to substantially the same physical aspects of the form. And then we recombined them to provide as parsimonious a description of the problem as possible. For example, at one state we had these three:

a. Erosion of the side slopes excessive,
b. Water and water-borne debris are carried on to roadway, and
c. Stones can roll off side slopes on to roadway.

These three issues refer essentially to two aspects of the interchange: the resistance of the side slopes to erosion, and the protection of the roadway from water, stones and debris. Therefore, the new list of misfits includes the two items 64 and 66 instead of the three a, b, c.

In addition to the list of requirements, we also need to identify the interactions between them. When we say that there is a link between misfits 46 and 89, we mean that decisions which we make about the form of the intersection when we try to satisfy only misfit 46 will probably affect those we make when we consider misfit 89 as well. We call the link "negative" if the attempt to satisfy one conflicts with the attempt to satisfy the other. We call the link "positive" if the two complement each other. (It is assumed that links are not directional, i.e., if 46 is linked to 89, then 89 is linked to 46.) In the analysis, it is not necessary to distinguish positive interactions from negative interactions—both are represented by unsigned links.

It was decided not to attempt a definitive enumeration of the links in this first preliminary analysis. Since there are 112 misfits in the final list, the number of possible links is $112 \times 111 \div 2$, or about 6,000. Allowing any significant amount of time (even five minutes) to decide whether or not a link exists between each pair of misfits would have taken too long. Therefore, we decided to make the link decisions very quickly.

We sat at an IBM card punch, reading down the list of misfits, and punched the data deck directly as each link decision was made. Each link decision was made twice, once for each side of the diagonal in the 112×112 matrix corresponding to the set of possible links. The computer program used (7) corrected the data to produce a symmetric matrix, by eliminating all those links which were not defined twice, i.e., from A to B and vice-versa.

The average time taken for each link decision was (20 hours)/(12,000 decisions), or about 5 seconds per decision. The solution, or tree, which was obtained is all the more remarkable evidence of the power of the method, therefore, because it is thoroughly reasonable, in spite of the very rapid definition of links.

The listing of links which follows is this corrected version.

<u>Misfits—List No. 3</u>

1. Lanes too narrow.
2. Lanes too wide.
3. Vertical sight distance not sufficient.
4. Horizontal sight distance not sufficient.
5. Inadequate acceleration distance.
6. Insufficient lateral clearance to the right.
7. Inadequate deceleration distances.
8. Superelevation, radius, and design speed and material are not consistent with safety.
9. Excessive downhill slope on roads entering the intersection or within it.
10. Downhill slope too long.
11. Curves too long.
12. No waste of land; every square foot used to the maximum.
13. Not enough length of roadway to merge.
14. Not enough length of roadway for weaving when preparing to diverge.
15. Visibility at point of entry is dangerously low.
16. Insufficient illumination.
17. Lack of consistency in signs.
18. Drivers do not receive adequate information as to how they should proceed to destination.
19. Too much information for the driver to take in (number of signs or information per sign).
20. Distance between successive signs too small for adequate reactions.
21. Too much stimulation (advertising, flickering, lights, visual noise).
22. Driver does not know what other drivers in his own traffic stream are doing (movement patterns are inadequately defined and controlled).
23. Driver does not know what course of action he should take (movement patterns inadequately defined and controlled).

24. Driver does not know what drivers in other traffic streams are doing (movement patterns inadequately defined and controlled).
25. Movement paths are counter-intuitive (because they are not oriented towards their ultimate destinations and are misleading in their functions as signals).
26. Median acts as lateral obstruction (psychological crowding).
27. Median provides insufficient separation of traffic.
28. Excessive headlight glare from comfort and safety.
29. Sun in your eyes.
30. Too many driver actions required.
31. Too few driver actions required—monotony dangerous.
32. Lack of consistency in actions demanded of the driver.
33. Access for police and emergency vehicles to all possible accident and breakdown points is not assured.
34. Power line, emergency telephone, etc., connections are not accommodated.
35. No access to service facilities.
36. Paths for pedestrian movement through interchange area are not defined.
37. Pedestrians and animals are not safely separated from vehicles.
38. Vehicular access to adjoining land is upset by the interchange.
39. Through flow on existing roads is upset by the intersection.
40. Process of construction interferes with traffic over existing facilities.
41. Construction periods too long financially—capital tied up, and prices liable to change.
42. Design of intersection is not standardized and so does not allow the use of standard or prefabricated components.
43. Traffic flow gets interrupted by regular events (pedestrians, traffic signals, policemen, swivel bridges, unlimited access).
44. Speed of interchange inconsistent with highway in speeds.
45. Number of lanes in interchange inconsistent with number of lanes on highways.
46. Location and arrangement of interchange disturbs linear continuity of intersecting highways.
47. Bridge structures disturb linear continuity of the roadways.
48. No provision for emergency breakdown—so that a driver does not interrupt traffic flow.
49. No provision of service facilities—gas, food.
50. Peak-hour congestion unacceptable.
51. No parking provided for service area.
52. Travel time too great.
53. Interchange interferes with watercourses on surrounding land.
54. Transitions between paths of different horizontal curvature and too abrupt.
55. Change of radius is so gradual as to deceive the driver.
56. Water falling on to roadway cannot drain.
57. User costs (wear and tear on the vehicles, and gas and oil) are too high.
58. Total cost of material too high.
59. Total construction cost (man and equipment hours) too high.
60. Cost of land too high (including the cost of litigation, etc.).
61. No rest area provided.
62. Cost of design too high (specialized work: skew bridge design, etc.).
63. Design does not permit maximum use of facility under variable traffic conditions.
64. Wind, water, and gravity-borne debris can get onto the roadway.
65. Internal stability of earthwork sideslopes is not assured.
66. Surface stability (erosion, etc.) of earthwork sideslopes is not assured.
67. Cost of replacement and renewal (pavement materials, etc.) is too high.
68. Cost (to maintenance department) of clearing snow, vegetation, garbage, etc., is too high.
69. Operation of snow clearance itself interferes with the operation of the highway.
70. Snow removal is too slow and leaves highway obstructed for long periods.
71. Maintenance of paint and pavement markings (channel markings), vegetation control, etc., sign changes and re-painting obstruct traffic.

72. Time for which road is closed for pavement renewal is excessive.
73. Process of pavement renewal itself interferes too much with operation of the highway.
74. Original load-carrying capacity too low.
75. Wear and tear on structure due to weathering (heat, water, ice, cold, wind, etc.) reduces original load-carrying capacity too quickly.
76. Loads carried themselves reduce original load-carrying capacity too quickly.
77. Surface too rough for comfort.
78. Surface such that it retains an excessive film of water.
79. Material of surface too highly reflectant, causes sun and headlight glare.
80. Possibility of improvements in terms of changed design standards, technological innovations, etc., is hampered.
81. Expected life is too long for its role in regional development.
82. Facility does not meet demands of expected future use.
83. Boundaries for administrative responsibilities (maintenance, policing, liability, etc.) are not clear.
84. Too few visual stimuli along roadside to avoid monotony.
85. Path of road pavement ahead of vehicle does not hold drivers' attention.
86. Road path unrelated to the topography.
87. Road path unrelated to buildings and distant objects.
88. Destruction of existing trees, vegetation, top-soil.
89. No coordination (simultaneous or sequential) of horizontal and vertical movements.
90. Physical presence of interchange (or of some part of it) is objectionable to social, political, or cultural institutions.
91. Some specific movement not provided for.
92. Intersection would be a greater benefit to regional economics in a different location.
93. Too many high embankments.
94. Too many deep cuts.
95. Number of lanes does not accommodate desired traffic volume and composition.
96. Interchange fails to provide for bus-bus and bus-auto transfer, if buses occur in the traffic composition, and for connection to rail transit.
97. Maneuver areas do not accommodate desire volume at design speed.
98. Conflicting movements are possible.
99. Rate of change of grade too great—causes oscillation (2nd derivative).
100. Rate of change of superelevation too great—causes oscillation (2nd derivative).
101. Vertical clearance in underpasses is too little.
102. Inadequate ventilation of exhaust from semi-closed spaces—underpasses, deep cuts, etc.
103. Uphill grades are too long for trucks.
104. Snow drifts dangerously on to roadway.
105. Fog can build up—dips in roadway, valleys, etc.
106. Windborne smoke can interfere with driver vision.
107. Sudden changes in wind pressure are dangerous, especially at high speed.
108. High cross winds a nuisance.
109. No opportunities for vehicles to change order (for instance, as in passing).
110. Actions demanded of driver are not well articulated—no rhythm, driving not a structured pattern of action.
111. No way in which a driver can rectify a wrong turn.
112. Interchange does not have unique identifying character.

RESULTS OF ANALYSIS

The list of 112 misfits and the list of links (see Appendix) representing pair-wise interactions among the misfits described the structure of the interchange problem as a linear graph. This information was punched on IBM cards and used as input to a computer program, HIDECS 2, which was run on the IBM 709 at MIT and the IBM 7090 at the Smithsonian Observatory in Cambridge.

The result of each computer run was a hierarchical decomposition of the graph, which yielded an arrangement of the requirements into clusters in a tree (Fig. 4). As previously described, this tree can be used as a program for the design of a highway interchange. The tree which is presented here was obtained as output from these computer analyses.

It is important to note that the results of each of the three runs were identical as far as the third level of the hierarchy. In view of the well-known difficulties associated with hill-climbing analyses (7), this indicates a remarkable degree of stability. We take it as evidence that the structure of the problem really does have the character described by the analysis, in some very deep sense. The slight differences from run to run, which appeared in the lowest levels of the tree, were reconciled by hand. (See 7.)

In the following pages, a number of clusters of requirements, as identified by the analysis, are discussed. Each cluster has specific implications for the design of an interchange; these implications are presented graphically and are discussed in text. Unfortunately, we have not had time to make these diagrams in detail, or to work them out for all the sets of requirements, or to demonstrate the process of combination developed in the higher levels of the program. (See 8.)

THE TREE

The "Tree" (Fig. 4) is presented on pages 60-66. To reconstruct this diagram use two copies or trace pages 61, 63, and 65 and follow diagram of complete chart shown on page 66.

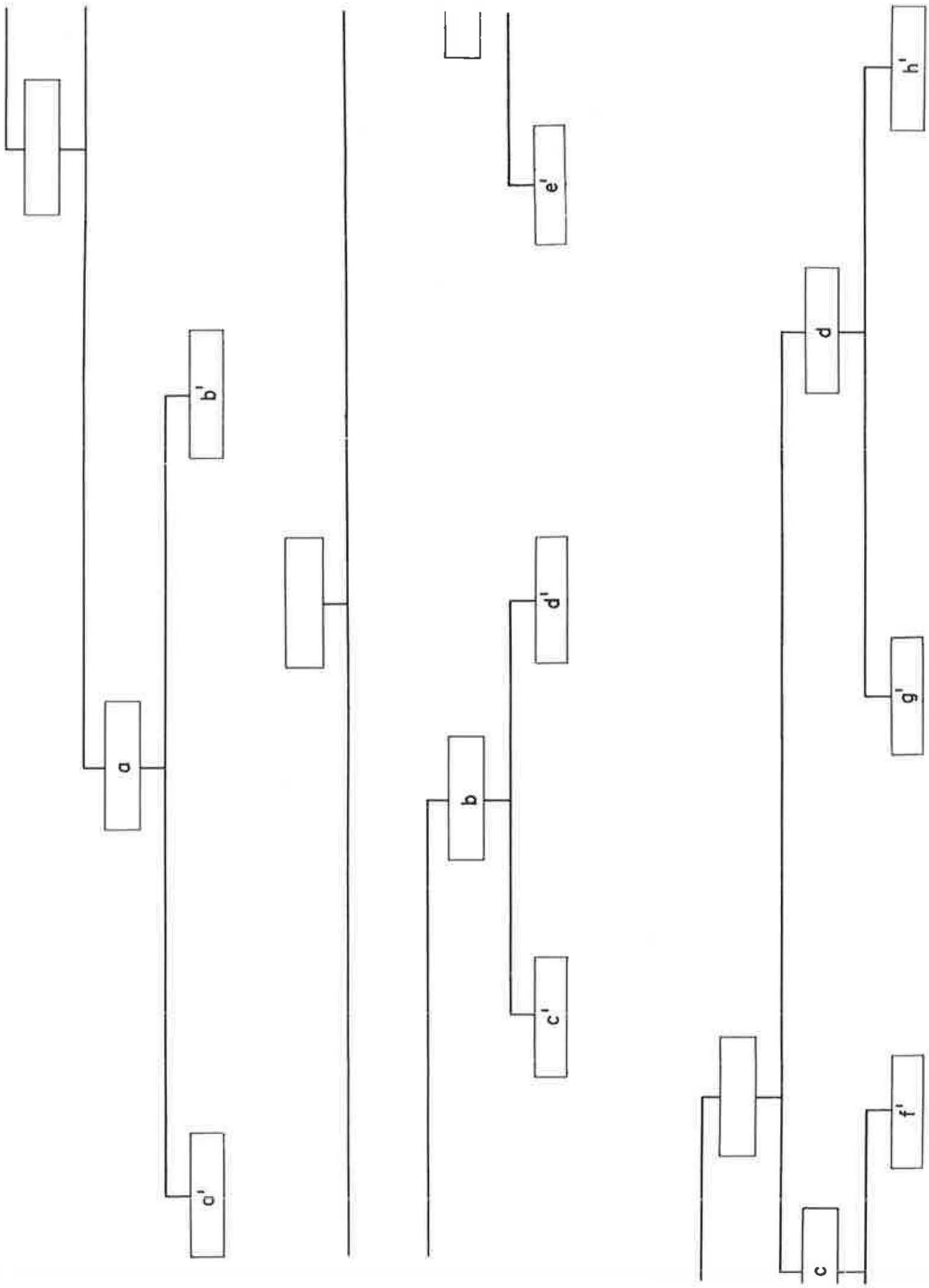
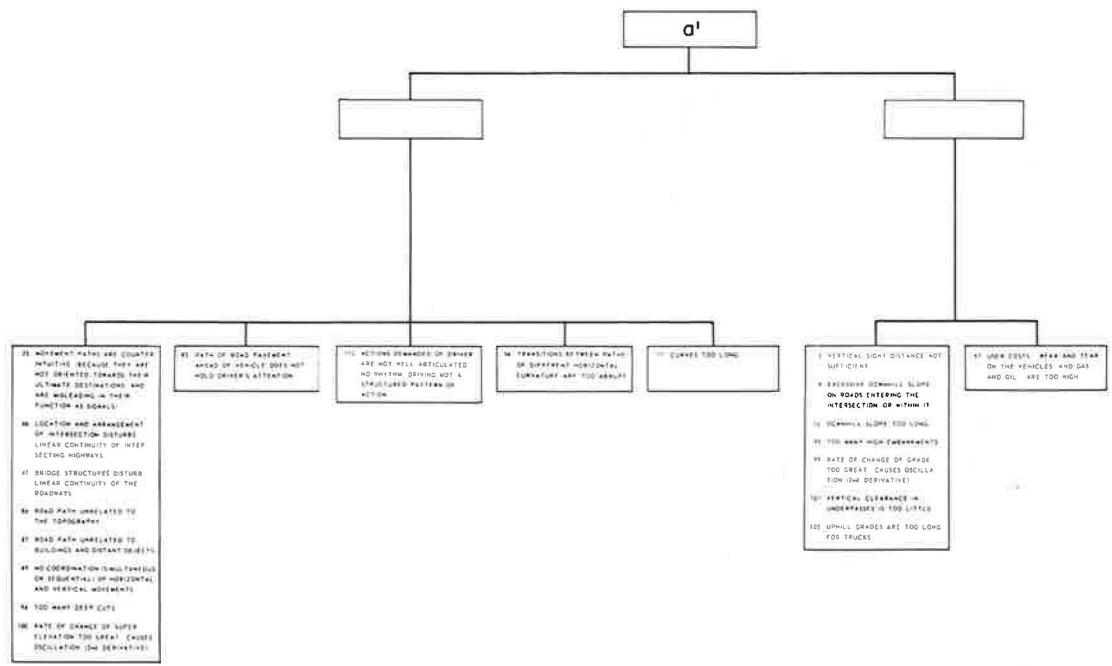
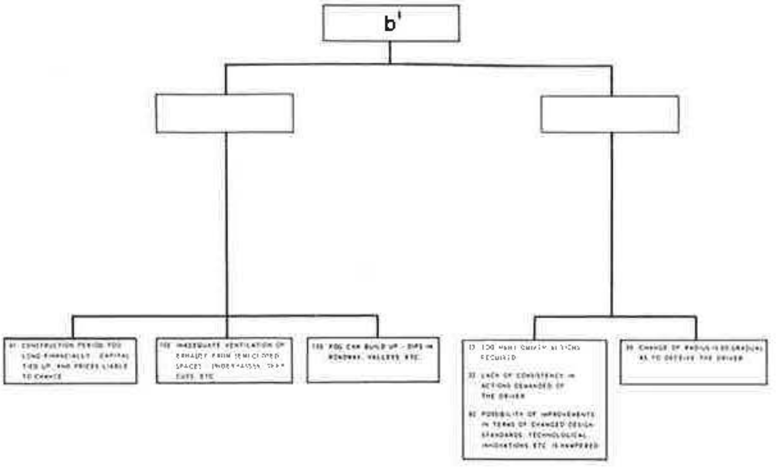
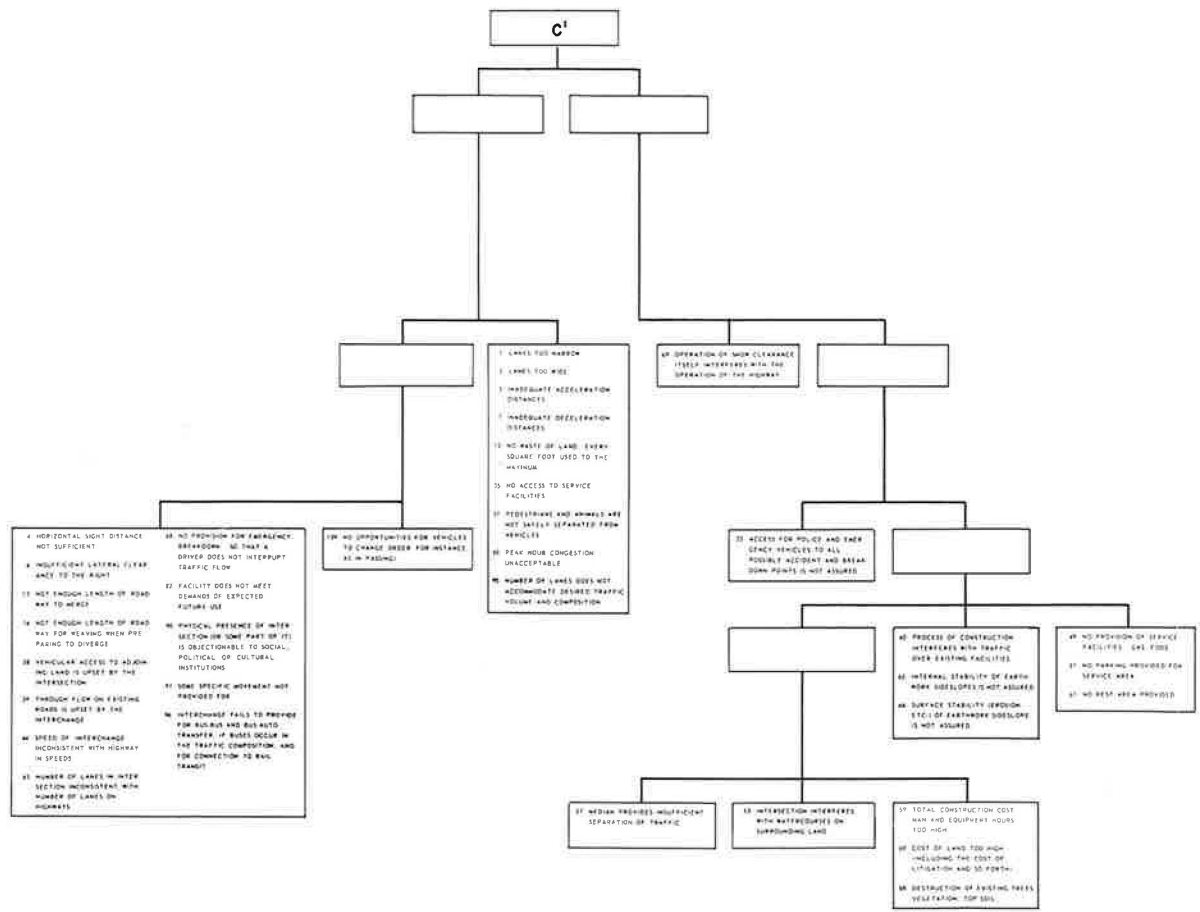
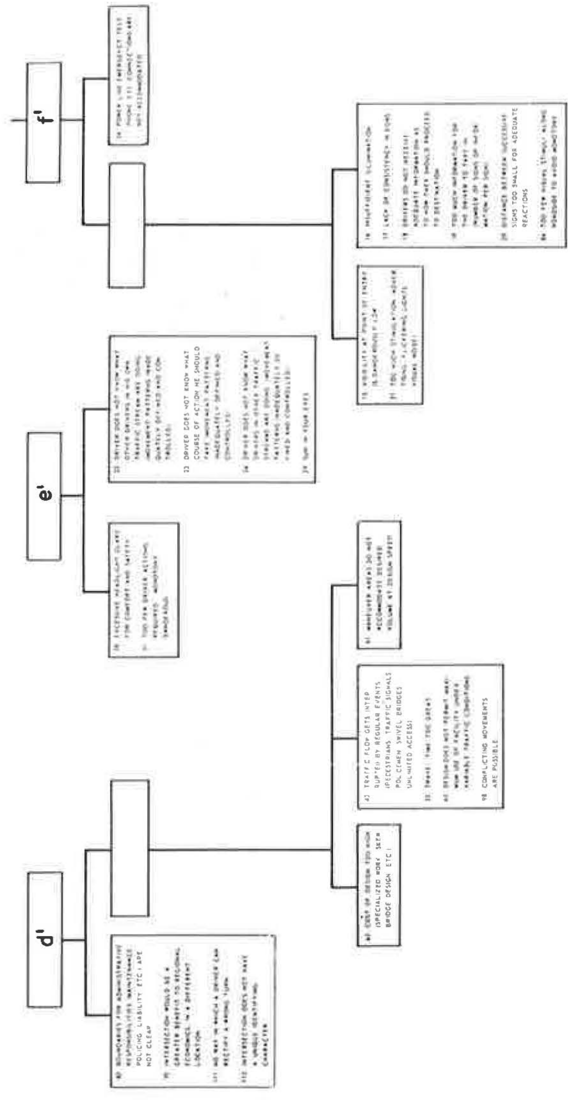


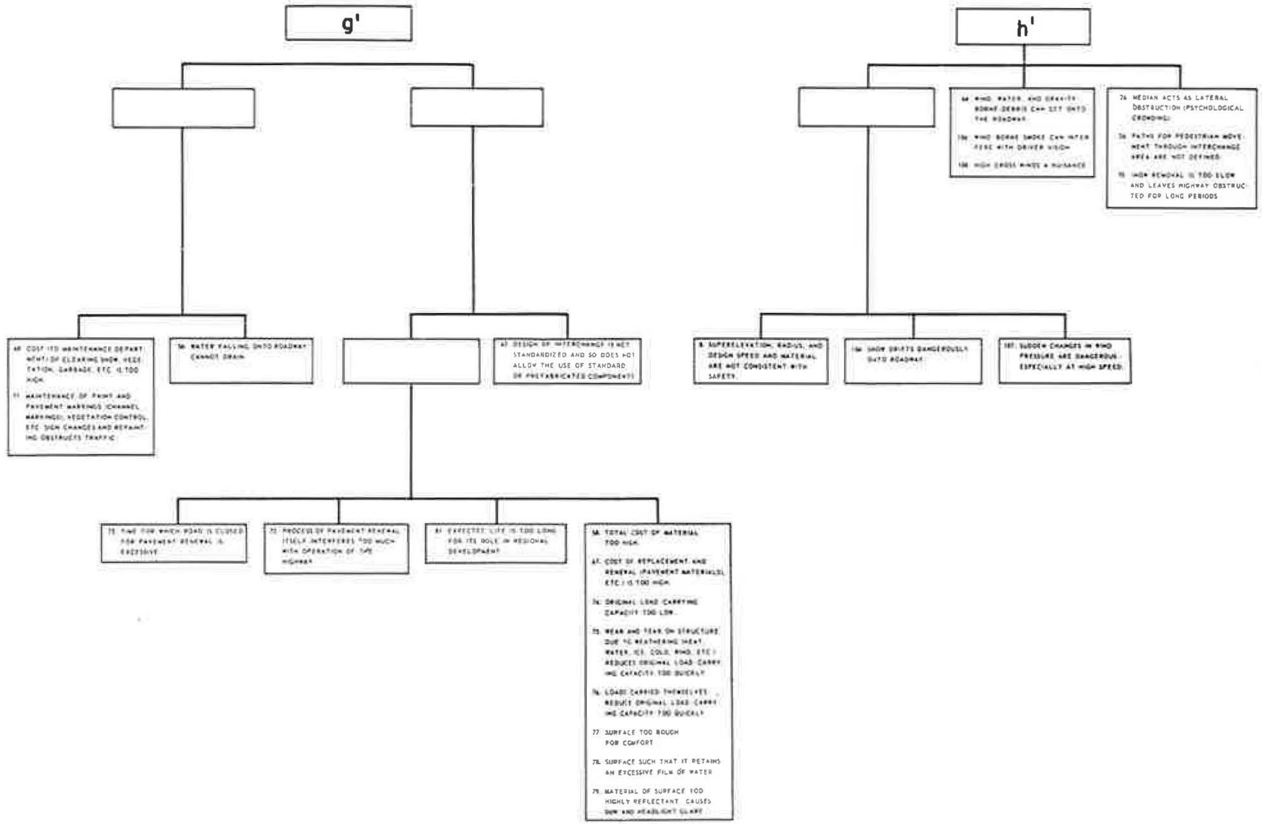
Figure 4. Structure of the highway interchange design problem.

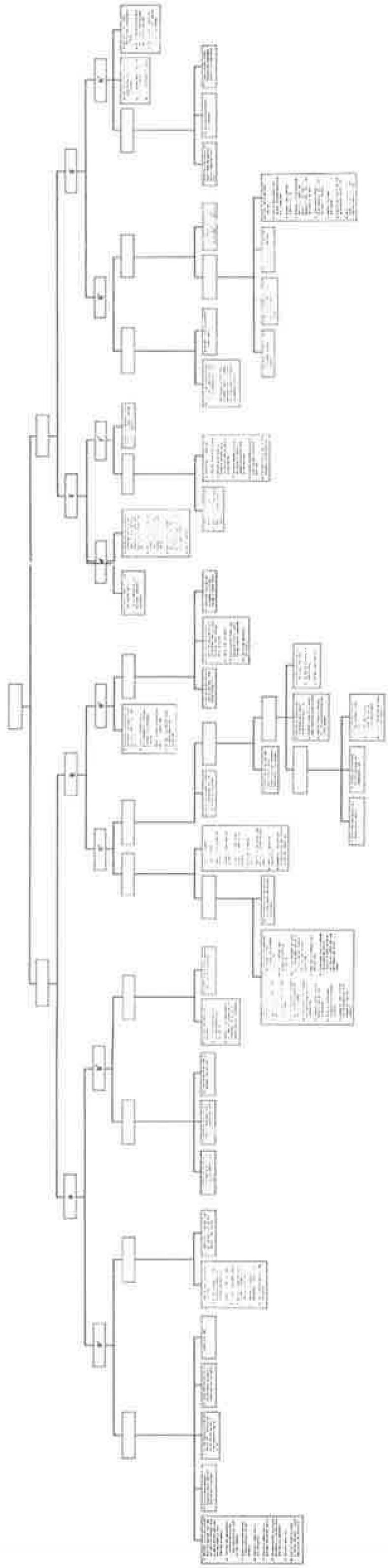

a'
LINEAR CONTINUITY OF INTER
SECTING HIGHWAYS
47 BRIDGE STRUCTURES DISTURB
LINEAR CONTINUITY OF THE
ROADWAYS
ARE NOT WELL ARTICULATED
NO RHYTHM, DRIVING NOT A
VERTICAL SIGHT DISTANCE NOT
SUFFICIENT
ON ROADS ENTERING THE
INTERSECTION OR WITHIN IT
99 RATE OF CHANGE OF GRADE
TOO GREAT CAUSES OSCILLA
TION (2nd DERIVATIVE)
105 UPHILL GRADES ARE TOO LONG
FOR TRUCKS
ON THE VEHICLES AND GAS
AND OIL ARE TOO HIGH


b'
CONSTRUCTION PERIOD TOO LONG FINANCIALLY: CAPITAL TIED UP, AND PRICES LIABLE TO CHANGE
INADEQUATE VENTILATION OF EXHAUST FROM SEMICLOSED SPACES: UNDERPASSES, DEEP CUTS, ETC.
FOG CAN BUILD UP - DIPS IN ROADWAY, VALLEYS ETC.
LACK OF CONSISTENCY IN ACTIONS DEMANDED OF THE DRIVER
POSSIBILITY OF IMPROVEMENTS IN TERMS OF CHANGED DESIGN STANDARDS, TECHNOLOGICAL INNOVATIONS ETC. IS HAMPERED
CHANGE OF RADIUS IS SO GRADUAL AS TO DECEIVE THE DRIVER


C'
4 HORIZONTAL SIGHT DISTANCE NOT SUFFICIENT
WAY FOR WEAVING WHEN PRE
PARING TO DIVERGE
INCONSISTENT WITH HIGHWAY
IN SPEEDS
DRIVER DOES NOT INTERRUPT
TRAFFIC FLOW
82 FACILITY DOES NOT MEET
DEMANDS OF EXPECTED
IS OBJECTIONABLE TO SOCIAL,
POLITICAL OR CULTURAL
INSTITUTIONS
SQUARE FOOT USED TO THE
35 NO ACCESS TO SERVICE
FACILITIES
PEAK HOUR CONGESTION
UNACCEPTABLE
SEPARATION OF TRAFFIC
59 TOTAL CONSTRUCTION COST
MAN AND EQUIPMENT HOURS
TOO HIGH

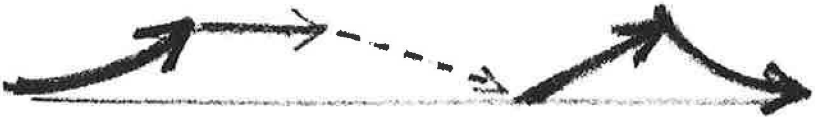

d'
e'
f'
POLICING LIABILITY ETC) ARE
NOT CLEAR
(SPECIALIZED WORK SKEW
BRIDGE DESIGN ETC)
43 TRAFFIC FLOW GETS INTER-
RUPTED BY REGULAR EVENTS
(PEDESTRIANS TRAFFIC SIGNALS
POLICEMEN SWIVEL BRIDGES
UNLIMITED ACCESS)
98 CONFLICTING MOVEMENTS
ARE POSSIBLE
22 DRIVER DOES NOT KNOW WHAT
COURSE OF ACTION HE SHOULD
SIGNS TOO SMALL FOR ADEQUATE
REACTIONS


g'
h'
WATER FALLING ONTO ROADWAY CANNOT DRAIN
DESIGN OF INTERCHANGE IS NOT STANDARDIZED AND SO DOES NOT ALLOW THE USE OF STANDARD OR PREFABRICATED COMPONENTS
TIME FOR WHICH ROAD IS CLOSED FOR PAVEMENT RENEWAL IS EXCESSIVE
PROCESS OF PAVEMENT RENEWAL ITSELF INTERFERES TOO MUCH WITH OPERATION OF THE HIGHWAY
EXPECTED LIFE IS TOO LONG FOR ITS ROLE IN REGIONAL DEVELOPMENT
TOTAL COST OF MATERIAL TOO HIGH
COST OF REPLACEMENT AND RENEWAL (PAVEMENT MATERIALS, ETC.) IS TOO HIGH
ORIGINAL LOAD CARRYING CAPACITY TOO LOW
77 SURFACE TOO ROUGH FOR COMFORT
SURFACE SUCH THAT IT RETAINS AN EXCESSIVE FILM OF WATER
MATERIAL OF SURFACE TOO HIGHLY REFLECTANT CAUSES SUN AND HEADLIGHT GLARE
26 MEDIAN ACTS AS LATERAL OBSTRUCTION (PSYCHOLOGICAL CROWDING)
PATHS FOR PEDESTRIAN MOVEMENT THROUGH INTERCHANGE AREA ARE NOT DEFINED
SNOW REMOVAL IS TOO SLOW AND LEAVES HIGHWAY OBSTRUCTED FOR LONG PERIODS
WIND BORNE SMOKE CAN INTERFERE WITH DRIVER VISION
HIGH CROSS WINDS A NUISANCE
SUPERELEVATION, RADIUS, AND DESIGN SPEED AND MATERIAL ARE NOT CONSISTENT WITH SAFETY.
SNOW DRIFTS DANGEROUSLY ONTO ROADWAY
SUDDEN CHANGES IN WIND PRESSURE ARE DANGEROUS, ESPECIALLY AT HIGH SPEED.



DIAGRAMS FOR SOME CLUSTERS OF REQUIREMENTS

Diagram A: Requirements 110, 136, 12.



Actions demanded of driver are not well articulated: no rhythm, driving not a structured path of action.

We identify five stages in changing roads in an interchange:

1. Preparation for exit from first major road,
2. Exit,
3. Transition—passage between major roads,
4. Preparation for entrance onto second major road, and
5. Entrance.

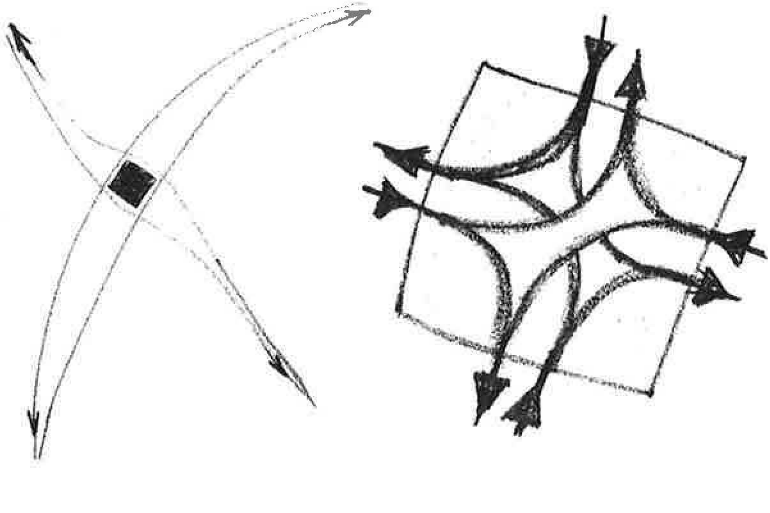
In each of these five stages, there are particular kinds of things which the driver should be doing:

1. Slowing down to prepare for turning off;
2. Controlled exit-slower speed than main road or transition road;
3. Transition roadway is fairly indeterminate as to speed and control;
4. Low relative speed, maximum control to allow driver adequate inspection of stream into which he is merging; and
5. Maximum buildup of speed to obtain zero relative speed for actual merge.

These stages have implications for the vertical profile of a path through the intersection which are expressed in Diagram A. The slowing-down required in the preparation stages 1 and 4 call for upgrades: the maximum buildup of speed required in stage 5 calls for a downgrade; the turning movement of stage 2 calls for a level roadway, and stage 5, the transition, is indeterminate insofar as grade is concerned.

In addition to grade, other physical devices might have been used to achieve this articulation: textures in the roadway (rumble strips), exaggerated superelevation, etc. However, manipulation of grade seems to be the most effective, and grade is a more basic feature of the interchange than the others.

Diagram B: Requirements 25, 46, 47, 86, 87, 89, 94, 100.



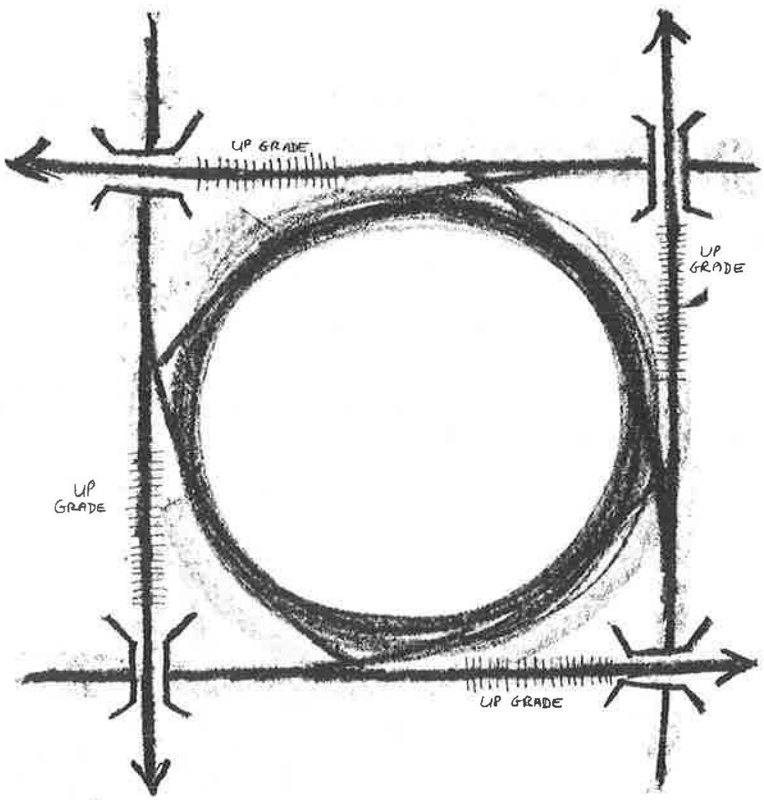
Requirements 46 and 89 suggest strong separation of that part of the interchange dealing with turning movements from the roadways which carry the main streams of traffic straight through the interchange (illustrated in the left-hand part of Diagram B).

Requirement 25 states that movement paths should not be counter-intuitive; this calls for designs in which movements to roadways heading left of the main roadway should be entered with left turns, straight-through movements should be made without major turns, etc. Together with 100, 25 also states that zig-zag movements should be avoided.

Requirement 46 requires that the occurrence of the intersection not cause the main roadways to deviate markedly from their general paths toward their ultimate destinations. This does not require dogmatic adherence to a straight path, only that the path have a general trend toward its ultimate destination, without zig-zags, as 25 suggests. It may even be a good idea for these paths to sweep clear of the mixing and turning functions, as illustrated in the left-hand diagram.

In the right-hand part of Diagram B, these mixing functions are shown in detail. Once the through paths are removed, this is made of two independent sections. If we interpret the diagram of the mixing functions as a bridge structure, we avoid extensive cuts (94). Although this may be expensive in its use of bridges, note that the requirement concerned with bridge costs (59) is not included in this set.

Diagram C: Requirements 3, 9, 10, 93, 99, 101, 103.

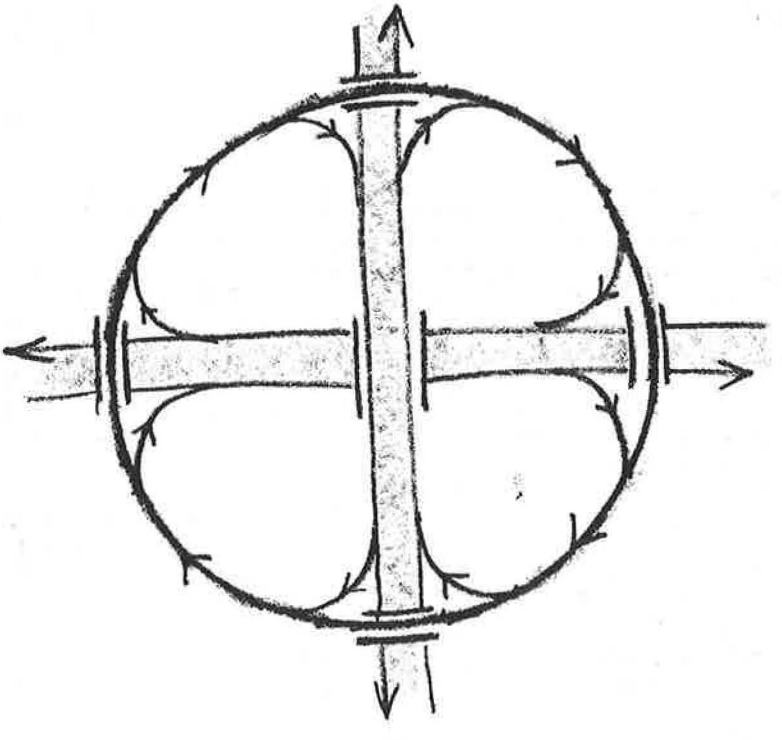


This group of requirements deals principally with grades. Ideally, it calls for a solution with no grades or bridges. Examples of such a form would be a rotary or an at-grade intersection. However, 57, user costs, calls for as little starting and stopping as possible, and makes these solutions unacceptable. Also, clearly, other requirements are going to call for bridges and grades, and make it important to study the less extreme implications of 3-103.

It is not imperative for the through roads to be level. It is the turning maneuvers which are especially dangerous if they contain grades; and 3-103, therefore, do call for an interchange in which all the turning takes place at one level. We solve this, in the Diagram C, by interlacing the four main roadways in "basketweave" fashion. This means that each roadway, as it comes out from under the first bridge, is "down." If the turning movements provided by the rotary all connect to this point, on the four roadways, respectively, the turning movements can all be at the same level.

The set of requirements has another interpretation: all these kinds of restrictions about grades, clearances, etc., call for a form which is not too "tightly packed." For instance, the same general form as the basketweave diagram shows might have this kind of flexibility, if the distances between the overpasses is of the order of 1,000 ft. Then, the grades and clearances of the main through roads can be adjusted independently over a fairly wide range, and the same form is adaptable to a variety of topographic conditions.

Diagram D: Requirements 4, 6, 13, 14, 38, 39, 44, 45, 48, 82, 90, 91, 96.



The number of requirements in this cluster is large (13). It is therefore interesting that a diagram was developed which satisfies almost all of these.

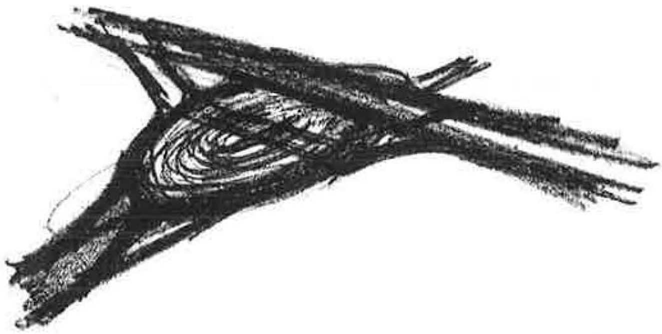
The single ring for all turning movements makes it easy to provide sufficient space on all roadways for emergency breakdowns (48), and for bus-auto transfer points (96). In this simple design, the fact that all turning movements use the same wide ring path makes less critical the possibility that the predicted volume for some particular movement may actually turn out to be very wrong (82). All movements can be provided for equally easily (91).

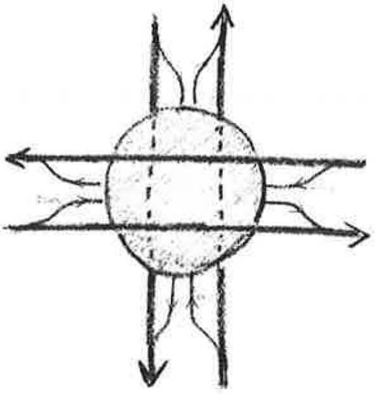
The design provides great flexibility with regard to grades. If the loop is elevated, instead of the through roads, accessibility to land uses within the loop can be preserved (38), and there can be a minimum disruption of through traffic on existing roads (39).

In this design, all exit movements are at opposite ends of the interchange from the point at which the roadway enters the interchange area. This allows the full crosswise length of the interchange to be used for acceleration and deceleration in merging and diverging movements. Similarly, although the ring volumes are high, the length of the ring allows adequate merging and diverging distances (13, 14).

The main through roadways have the same speed and number of lanes within the interchange as without, retaining their straight-through character (44, 45).

Diagram E: Requirements 1, 2, 5, 7, 12, 35, 37, 50, 95.



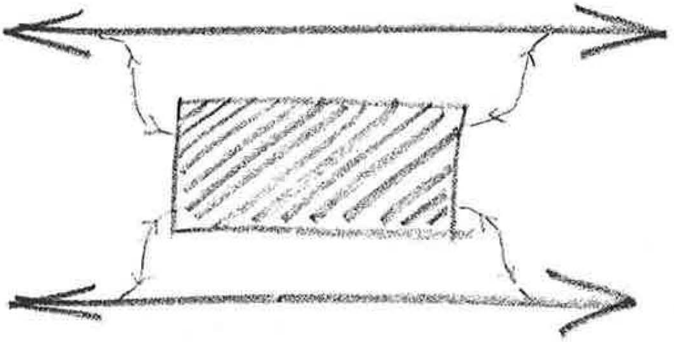


Requirement 12 calls for the maximum use of land—no waste. In making a diagram for this set we come to a point that has not, perhaps, been given sufficient attention in current highway design practice. If the speed of the individual highways is very great, we must expect to slow down in making the transition from one to another. We do not expect to transfer from a limousine to an airplane at high speed. Similarly, we feel that the transition from one highway to another should not necessarily be possible at high speed.

If we accept this premise, it becomes possible to reduce the amount of land used, drastically (Diagram E). A horizontal circular platform is built, above one roadway and below the other. All transition between the roadways comes straight to this platform, where flow stops almost dead. Circulation on the platform will probably be rotary; slow speeds allow a very tight radius.

This solution allows lanes of any desired width (1, 2); and provides ample acceleration and deceleration, since this can be tucked between the opposing paths of each roadway, where the median usually is (5, 7). Service facilities can be provided most simply in the middle of the transition zone; note that this is almost impossible on a cloverleaf (35). Congestion of this zone will only occur if opposing types of turn occur simultaneously (50). At peak hours this rarely happens; flow in one direction will predominate—and can be given priority by traffic-light control, etc., in the transition zone.

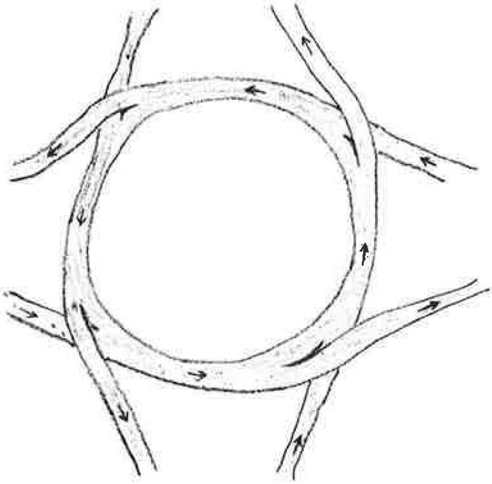
Diagram F: Requirements 83, 92, 111, 112.



Requirements 83, 111 and 112 call for a neutral zone, intermediate between the two main highways. This neutral zone will contain everything (including turning movements) which does not belong explicitly and functionally to one of the highways or the other. It will clarify administrative responsibility (83), and will give the interchange a substance capable of identifying it (111, 112).

The need for regional development (92) calls for an easy way of obtaining access to the interchange. Because of weaving distances, present designs such as cloverleafs make it very hard to provide access from the nearby land to the interchange itself. The neutral zone, however, allows it easily.

<u>Diagrams G and H:</u> Requirements 43, 52, 62, 63, 97, 98



Requirement 43 calls for steady flow without interruption. Requirements 63 and 97 call for a design which is homogeneous and continuous with the main roadways, and contains no narrow, tightly-curved connecting roads which are liable to bottleneck and slow maneuvering.

Diagram G is conceived on the basis of a single centrifugal flow, in which entering movements come in to the center, and all weaving is outward, away from the center. This satisfies 98, though not ideally, since it still makes for weaving which contains conflicts; 62 is not resolved. It is worth observing that it occurs just here, where skew bridges suggest themselves naturally.

A much better solution, derived from this one, is based on the need to avoid conflicting movements completely (98). Conflicting movements occur at places where merging precedes diverging. To avoid it, we must insure that diverging always precedes merging. The use of this principle leads to Diagram H. For the sake of clarity, it is shown without the right-hand turns, which are easily added.

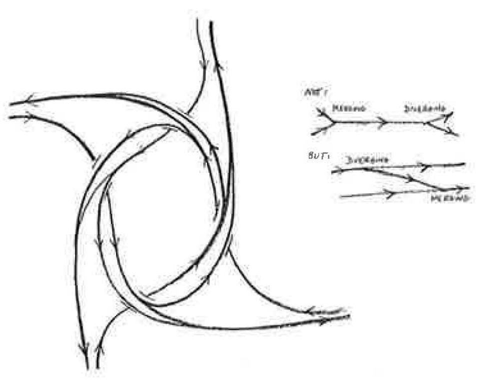
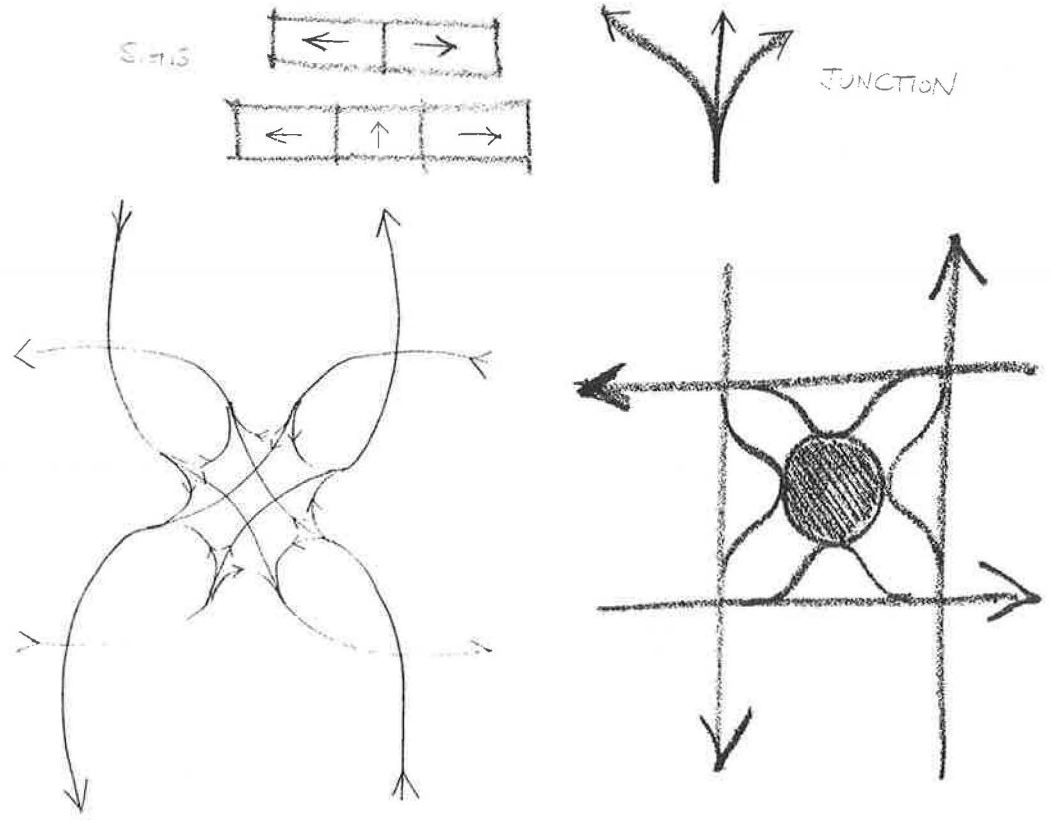


Diagram I: Requirements 16, 17, 18, 19, 20, 84.



This set of requirements deals principally with the fact that the driver has to find out where he is going as he drives through the interchange. The principal conflict which needs resolution is that between 18, 19, 20. On the one hand, 18 calls for as many signs and destination names as possible; on the other hand, 19 and 20 call for as little information as possible, so that it should not confuse the driver who can, after all, only digest a limited amount of information without slowing down. The resolution of this conflict suggests two things.

First of all, the information on the signs should be reduced to a minimum, and a parking place provided in which the driver may consult maps for further details.

Second, in view of this limited information, the signing for the left-hand turn and the right-hand turn should be presented to the driver simultaneously—if possible, also at the same time as the signs for the through path. Otherwise, when looking for an unfamiliar name, the driver may pass one exit, only to find, when he gets to the other, that it was the first he wanted.

These two matters, as shown in the bottom Diagram I, call for a form which contains a central parking space, from which any exit may be made, and for an interchange in which all possible turns are presented simultaneously, so that signs may be presented as shown at the top of the diagram.

CONCLUDING REMARKS

Some Comments on Design

These notes summarize the major ideas which we have been able to develop to date. Although we have by no means solved the interchange design problem completely, we can see emerging a possible solution in the diagrams described here.

The dominant theme seems to be the use of a central space or neutral zone, between the major through roads, for the mixing function, for transition between the through routes, and for information, emergency and service facilities. This represents a highly efficient use of the land usually wasted between turning roadways, and offers flexibility with regard to possible changes in traffic and in transportation technology (automatic control, rapid transit, ground-effect vehicles, etc.).

It is also important that this neutral mixing area can support regional development by providing access to surrounding land. Where two limited-access highways meet, weaving problems do not allow further interchanges for access to nonlimited-access roads. Therefore, for an area of several square miles about the interchange of the limited-access highways, potential growth is hampered by the distance traffic must go to get access to either of the roads: a pocket of dead land is created, and the great potential of the major highway interchange as a power in economic development is reduced.

We should perhaps mention the standard and widely used cloverleaf pattern. This type of interchange is cheap to build, does not consume too much land, and is easy to construct over an existing facility. Where cost and land are the major considerations, this type of interchange may still be a wise choice.

However, the cloverleaf has many noticeable defects. It provides very bad weaving, and offers only short acceleration and deceleration lanes. Its turns, which involve simultaneous change of grade and direction, are dangerous. It offers no opportunity to rectify a wrong turn, and yet presents the driver who wants to turn off with two sequential decisions, so that he does not know until he comes to the second one, which one was right; at that, the left-hand turn is counter-intuitive, and makes a 270° turn. It tends to waste the land inside its turning circles; and also tends to make access to neighboring land difficult, if both intersecting highways are of the limited-access type. Expansion is difficult (since inner turns cannot easily be widened) and opportunities for connection with other types of transportation, as part of a wider system, are non-existent.

SOME CONCLUSIONS FOR ENGINEERING PRACTICE

The computer analysis indicated that the highway interchange design problem had four major components. As a result of our attempts to diagram the implications of several of the subsystems of this problem, these four components can be described as follows:

1. The roadways in the interchange. Each of the roads in the interchange has characteristics as a path—both plane and vertical profile, in general and in relation to the topographical surface. Most of the kinds of things with which these requirements are concerned are characteristic of highways in general, and are not peculiar to interchanges alone.

2. The interchange as a system with particular characteristics and functions. These requirements describe the interaction of the interchange with its environment—its ecology: the relation to the system of vehicular flow—the properties of streams of vehicles; the demand for movement—various forces in the socio-economic system as expressed in terms of flow patterns; the ecology of the natural environment—trees, watercourses, weather; the interaction with the administrative structure of society—maintenance, control, emergencies, etc. These become explicit in the physical part of the interchange which carries on its unique functions—the mixing area.

3. The interchange as it concerns the driver. The driver's perception of where he is, where he is going, his place in the stream of vehicles—the provision of adequate information, comfort including avoidance of monotony, a clear view, provision for emergencies, etc.

4. The material structure of the interchange. These requirements concern the elements of the physical system which require local treatment. In a sense, they do not concern the basic functional organization (though they may have implications for it), but the gingerbread, the trimmings: decisions about materials, cross-sections and details of construction—the barriers to keep off snow, water, debris, wind, smoke;

the wearing surface and its base courses; etc. They are the kinds of things one would find dealt with in a table of specifications for standard designs.

By way of conclusion, we return again to the theme with which we introduced this discussion: the AASHO manual. Although this analysis is only preliminary, it has resulted in a way of looking at the interchange design problem which is distinctly different from the approach taken by the AASHO manual. The discussion of the diagrams and of the principal components of the problem have illustrated this. As we expected, even this preliminary analysis has suggested the way in which a manual for the design of interchanges should be constructed. For example, a division of the manual into four major sections, corresponding to the four major components of the problem outlined above, is not only theoretically justified (by our analysis) but also seems to make good sense on an intuitive basis, now that the analysis has pointed it out. Of course, the way in which each of these four sections is broken down into subsections should also reflect the structure of the problem as revealed by an analysis such as this; however, the analysis so far accomplished is not detailed enough to provide any well-founded basis for such further subdivision.

We do not plan to rewrite the AASHO manual; this is a task which is best handled by those who have had long experience with the detailed problems of designing real interchanges. Our analysis here has not been extensive, and should be considered only a first experiment. We have, however, demonstrated the kind of approach which we believe should be used to write a manual.

ACKNOWLEDGMENTS

The research of which this report is a part was supported by the Bureau of Public Roads of the U.S. Department of Commerce and by the Massachusetts Department of Public Works. Computer and associated facilities were made available by the M.I.T. Computation Center.

This work was performed at the Civil Engineering Systems Laboratory at M.I.T. The authors gratefully acknowledge the suggestions and criticism freely offered by Professors A. Scheffer Lang, Charles L. Miller, and Paul O. Roberts; however, full responsibility for all statements made herein remains with the authors.

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Appendix

LINKS AMONG THE REQUIREMENTS

```
REQUIREMENT     001 IS CONNECTED TO--
  0  2  0  4  5  6  7  8  0  0 11 12 13  0  0  0  0  0  0  0  0  0 23  0  0 26 27  0  0 30  0  0 33  0 35  0
 37 38 39  0  0  0  0 44 45  0  0 48  0 50  0 52 53  0  0  0 57 58  0 60  0  0  0  0 65 66  0  0 69  0 71  0
 73  0  0 76  0  0  0 80  0 82  0  0 85  0 87 88  0  0  0  0  0 94 95 96 97  0  0  0  0  0  0  0105  0107108
109110  0  0

REQUIREMENT     002 IS CONNECTED TO--
  1  0  0  4  5  6  7  0  0  0  0 12  0 14  0  0  0  0  0  0  0 22 23 24  0  0 27  0  0 30  0  0  0  0 35  0
 37 38 39 40  0  0  0 44 45  0 47 48  0 50 51  0  0  0  0 56 57 58 59 60  0  0  0  0 65 66  0 68  0 70  0  0
  0  0  0  0  0  0  0  0  0 82  0  0 85  0 87  0  0 90  0  0  0 94 95 96 97  0  0100  0102  0  0105  0  0108
109110  0  0

REQUIREMENT     003 IS CONNECTED TO--
  0  0  0  0  5  0  0  0  9 10  0  0 13 14 15  0  0  0 19 20  0 22  0 24  0  0  0  0 29  0  0  0  0  0 35  0
  0 38 39 40 41  0 43 44  0 46 47 48  0  0  0  0 53  0  0  0  0  0 59  0  0  0  0  0 65  0  0  0  0  0  0  0
  0  0  0  0  0  0  0 80  0 82  0 84 85 86 87  0 89 90 91  0 93 94  0 96  0  0 99  0101102103  0  0  0  0  0
109  0  0  0

REQUIREMENT     004 IS CONNECTED TO--
  1  2  0  0  5  6  7  0  0  0 11  0 13 14 15 16  0  0 19  0  0 22  0 24  0  0  0 28 29  0  0  0  0  0 35  0
 37 38 39 40  0  0 43 44 45 46 47 48 49  0  0 52 53 54 55  0  0  0 59 60  0  0  0  0 65  0  0  0 69  0  0  0
  0  0  0  0  0  0  0 80  0 82  0 84 85 86 87 88 89 90 91  0  0 94 95 96 97  0  0  0  0102  0104105  0  0  0
109  0111  0

REQUIREMENT     005 IS CONNECTED TO--
  1  2  3  4  0  6  7  0  0  0 11 12 13  0 15 16  0  0  0  0  0  0 23  0  0  0  0  0  0 30  0  0 33  0 35 36
 37 38 39  0  0  0  0 44 45 46 47  0  0 50  0 52  0 54 55 56 57  0 59 60 61  0 63  0 65 66  0 68 69  0 71  0
  0  0  0 76  0  0  0 80  0 82  0  0  0  0  0 88  0  0 91  0 93  0 95 96 97 98  0  0  0  0  0  0  0  0107  0
  0110  0  0

REQUIREMENT     006 IS CONNECTED TO--
  1  2  0  4  5  0  7  0  0  0  0 12 13 14 15  0  0  0  0 20 21  0 23  0  0 26 27 28  0  0  0  0 33 34  0 36
 37 38 39 40 41  0  0 44 45 46 47 48 49 50 51  0  0  0 55  0  0  0 59 60  0 62 63 64 65 66  0  0 69 70 71  0
  0  0  0  0  0  0  0 80  0 82  0 84  0  0  0 88  0 90 91  0  0 94  0 96  0  0  0  0  0102  0104105  0107  0
109  0  0112

REQUIREMENT     007 IS CONNECTED TO--
  1  2  0  4  5  6  0  0  9 10 11 12 13 14  0 16  0  0  0 20  0  0 23  0  0  0 27  0  0 30  0  0  0  0 35 36
 37 38  0 40  0  0  0 44 45  0 47 48 49 50 51 52  0 54 55 56  0 58 59 60 61  0 63  0 65 66  0 68  0 70 71  0
  0  0  0  0  0  0  0 80  0 82  0  0  0 86 87 88 89  0 91  0 93 94 95 96 97  0  0  0  0  0  0  0  0  0107  0
  0110  0  0

REQUIREMENT     008 IS CONNECTED TO--
  1  0  0  0  0  0  0  0  0  0 11  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0 39  0  0  0  0 44  0  0 47  0  0  0  0  0  0  0  0  0  0  0 59  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0 76 77 78 79  0  0  0  0  0  0 86 87  0 89  0 91  0  0  0  0  0  0  0  0100  0  0  0  0  0  0107108
109  0  0  0

REQUIREMENT     009 IS CONNECTED TO--
  0  0  3  0  0  0  7  0  0 10 11  0  0  0 15  0  0  0  0  0  0  0  0  0 25  0  0  0 29  0  0  0  0 34 35  0
  0 38 39 40  0  0 43 44  0  0 47  0  0  0  0  0 53  0  0  0 57 58 59 60  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0 85 86  0  0 89 90 91  0 93  0  0  0  0  0 99100101  0103  0  0  0  0  0
109  0111112
```

```
REQUIREMENT    010 IS CONNECTED TO--
  0  0  3  0  0  0  7  0  9  0 11  0  0  0  0  0  0  0  0  0  0  0  0 25  0  0  0  0  0  0  0  0  0 35  0
  0 38 39  0  0  0  0  0  0  0 47  0  0  0  0 52  0  0  0  0  0 58 59  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0 85 86 87  0 89 90 91  0 93 94  0  0  0  0 99  0101102103  0  0  0  0  0
109  0111112

REQUIREMENT    011 IS CONNECTED TO--
  1  0  0  4  5  0  7  8  9 10  0  0  0  0  0  0  0  0  0  0  0  0  0  0 25  0  0  0  0  0 31  0  0  0  0  0
  0 38 39  0  0  0  0 44  0 46 47  0  0  0  0  0  0 54 55  0  0 58 59 60  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0 85 86 87  0 89 90  0  0  0 94  0  0  0  0  0100  0  0  0  0  0  0  0  0
109  0  0112

REQUIREMENT    012 IS CONNECTED TO--
  1  2  0  0  5  6  7  0  0  0  0  0 13 14  0  0  0  0  0  0  0  0  0  0 25  0 27  0  0  0  0  0 33  0 35 36
 37 38  0  0  0  0 43 44 45 46  0 48 49 50 51  0  0  0 55 56  0 58 59 60 61 62  0  0  0  0 67 68 69  0  0 72
 73 74  0  0  0  0  0 80  0 82  0  0  0  0  0 88  0 90 91 92  0  0 95  0 97 98  0  0  0  0  0  0  0  0  0  0
109  0  0  0

REQUIREMENT    013 IS CONNECTED TO--
  1  0  3  4  5  6  7  0  0  0  0 12  0 14 15  0  0  0  0  0  0  0  0  0  0  0 27  0  0 30  0  0  0  0  0  0
 37 38 39 40  0  0 43 44 45 46 47 48  0 50  0  0 53 54  0  0 57 58 59  0  0  0 63  0  0  0  0 68  0  0  0  0
  0  0  0 76  0  0  0  0  0 82  0  0  0  0  0 88 89 90 91  0 93 94 95 96 97  0  0  0  0  0103  0  0  0  0  0
  0110  0  0

REQUIREMENT    014 IS CONNECTED TO--
  0  2  3  4  0  6  7  0  0  0  0 12 13  0  0 16  0  0  0 20  0  0  0  0  0  0  0  0 30  0  0  0  0 35  0
 37 38 39 40  0  0  0 44 45  0  0 48  0 50  0 52 53  0  0  0 57 58 59  0  0  0 63  0  0  0  0  0  0  0  0  0
  0  0  0 76  0  0  0  0  0 82  0  0  0  0  0 88 89 90 91  0  0 94 95 96 97  0  0  0  0  0  0  0  0  0  0  0
  0110  0  0

REQUIREMENT    015 IS CONNECTED TO--
  0  0  3  4  5  6  0  0  9  0  0  0 13  0  0 16 17 18  0  0 21 22  0 24  0  0  0  0 30  0  0 33  0  0  0
 37  0  0  0  0  0  0  0  0  0  0  0  0 50  0  0  0  0  0  0  0 58  0  0  0  0 63  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0 84  0  0  0 88  0 90  0  0  0  0  0  0 97  0  0  0101  0  0  0  0106  0  0
  0  0  0  0

REQUIREMENT    016 IS CONNECTED TO--
  0  0  0  4  5  0  7  0  0  0  0  0  0 14 15  0 17 18 19 20 21 22  0  0  0  0  0 28 29  0  0  0  0 34  0  0
 37  0  0  0  0 42  0 44  0  0  0  0  0  0  0  0  0  0  0  0  0 58  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0 84  0  0  0  0  0  0  0  0  0  0  0  0 97  0  0  0  0  0  0  0  0  0  0  0
  0  0  0112

REQUIREMENT    017 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  0  0  0  0  0  0 15 16  0 18 19 20  0  0 23  0  0  0  0  0  0  0  0 32  0  0  0  0
  0  0  0  0  0 42  0  0  0  0  0 48  0  0  0  0  0  0  0  0  0 58  0  0  0  0 63  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0 82  0 84 85  0  0  0  0 90  0  0  0  0  0  0 97 98  0  0  0  0  0  0  0  0  0  0
  0  0  0112

REQUIREMENT    018 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  0  0  0  0  0  0 15 16 17  0 19 20 21  0 23  0 25  0  0  0  0 30  0 32  0 34 35  0
  0  0  0  0  0  0  0  0  0  0  0  0 49  0  0  0  0  0  0  0  0  0 59  0  0 62 63  0  0  0  0  0  0  0 71  0
  0  0  0  0  0  0  0 80  0 82  0 84  0 86 87  0  0 90  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0111112
```

```
REQUIREMENT    019 IS CONNECTED TO--
  0  0  3  4  0  0  0  0  0  0  0  0  0  0  0 16 17 18  0 20  0  0  0  0  0  0  0  0  0  0  0 32  0  0  0  0
  0  0  0  0  0 42  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 58  0  0  0 62 63  0  0  0  0  0  0  0 71  0
  0  0  0  0  0  0  0  0  0 82  0 84 85  0  0  0  0 90  0 92  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0111112

REQUIREMENT    020 IS CONNECTED TO--
  0  0  3  0  0  6  7  0  0  0  0  0  0 14  0 16 17 18 19  0 21  0 23  0 25  0  0  0  0 30  0 32  0  0  0  0
 37  0  0  0  0 42  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 63  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0 80  0 32  0 84  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0110  0112

REQUIREMENT    021 IS CONNECTED TO--
  0  0  0  0  0  6  0  0  0  0  0  0  0  0 15 16  0 18  0 20  0  0  0  0  0  0 27 28  0  0  0  0  0  0  0  0
  0  0  0  0  0  0 43  0  0  0  0  0 49  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0 79 80  0  0  0 84  0  0 87  0 89  0  0  0  0  0  0  0  0  0 99  0  0  0  0  0  0  0  0  0
  0  0  0113

REQUIREMENT    022 IS CONNECTED TO--
  0  2  3  4  0  0  0  0  0  0  0  0  0  0 15 16  0  0  0  0  0  0 23 24  0  0  0  0 29  0 31 32  0  0  0 36
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 54  0  0  0  0  0  0  0 62  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 89  0  0  0  0  0  0  0  0 98  0  0  0  0  0  0  0  0  0  0
109110  0  0

REQUIREMENT    023 IS CONNECTED TO--
  1  2  0  0  5  6  7  0  0  0  0  0  0  0  0  0 17 18  0 20  0 22  0 24 25  0  0  0 29 30  0 32  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 63  0  0  0  0 68  0  0  0  0
  0  0  0  0  0  0  0  0  0 82  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0105  0  0  0
109110111112

REQUIREMENT    024 IS CONNECTED TO--
  0  2  3  4  0  0  0  0  0  0  0  0  0  0 15  0  0  0  0  0  0 22 23  0 25  0  0 28 29 30  0 32  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 63  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0 82  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 98  0  0  0  0  0  0105  0  0  0
109  0  0  0

REQUIREMENT    025 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  9 10 11 12  0  0  0  0  0 18  0 20  0  0 23 24  0  0  0  0  0 30 31 32  0  0  0  0
 37 38 39 40 41  0  0  0 45 46 47 48 49 50  0  0 53 54 55  0  0 58 59 60  0 62  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0 84 85 86 87 88 89 90 91 92 93 94  0 96  0 98 99100101  0103  0105  0  0108
  0110111112

REQUIREMENT    026 IS CONNECTED TO--
  1  0  0  0  0  6  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 27 28  0  0  0  0 33 34  0 36
  0  0  0  0  0 42  0 44  0  0  0 48  0  0  0  0  0  0  0  0  0  0 60  0  0 63  0  0  0  0  0 69 70 71 72
 73  0  0  0  0  0  0 80 81  0  0 84 85  0  0  0  0  0 91  0  0  0 95 96  0  0  0  0  0  0  0  0  0106107  0
  0  0111112

REQUIREMENT    027 IS CONNECTED TO--
  1  2  0  0  0  6  7  0  0  0  0 12 13  0  0  0  0  0  0  0 21  0  0  0  0 26  0 28  0  0  0  0 33 34  0  0
  0  0 39 40  0  0  0 44 45  0 47 48  0  0 51  0 53  0  0  0  0  0 59 60 61  0 63  0 65 66  0 68  0  0 71 72
 73  0  0  0  0  0  0 80  0 82  0  0  0 86  0 88  0 90 91  0 93 94 95 96  0  0  0  0  0  0  0104  0  0  0108
  0  0  0  0
```

```
REQUIREMENT   028 IS CONNECTED TO--
  0  0  0  4  0  6  0  0  0  0  0  0  0  0  0 16  0  0  0  0 21  0  0 24  0 26 27  0  0 30 31  0  0  0  0  0
  0  0  0  0  0  0  0 44  0 46 47  0  0 50  0  0  0 54 55  0  0  0 59 60  0  0 63  0 65  0  0 68  0  0 71  0
  0  0  0  0  0  0 79  0  0 82  0 84  0  0  0 88  0 90 91  0  0  0  0 96  0  0  0  0  0  0  0  0  0  0107  0
  0  0  0  0

REQUIREMENT   029 IS CONNECTED TO--
  0  0  3  4  0  0  0  0  9  0  0  0  0  0  0 16  0  0  0  0  0 22 23 24  0  0  0  0  0  0  0  0  0  0  0  0
 37  0  0  0  0  0  0 44  0 46  0  0  0  0  0  0  0 54 55  0  0  0  0 60  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0 79  0  0  0  0 84  0 86  0 88  0  0 91  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0

REQUIREMENT   030 IS CONNECTED TO--
  1  2  0  0  5  0  7  0  0  0  0  0 13 14 15  0  0 18  0 20  0  0 23 24 25  0  0 28  0  0  0 32  0  0  0 36
  0 38 39 40  0  0 43  0  0 46 47 48  0  0  0  0  0 54  0  0 57  0 59 60  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0 79 80  0  0  0  0 85  0  0  0 89  0  0  0  0  0  0 96  0 98  0  0  0  0  0  0  0  0  0  0
109110111  0

REQUIREMENT   031 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  0  0 11  0  0  0  0  0  0  0  0  0  0 22  0  0 25  0  0 28  0  0  0 32  0  0  0  0
  0  0 39  0  0  0  0  0  0 46  0  0 49  0  0 52  0 54  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0 81  0  0 84  0 86 87  0 89  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
109110  0  0

REQUIREMENT   032 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 17 18 19 20  0 22 23 24 25  0  0  0  0 30 31  0  0  0  0  0
 37 38 39  0  0  0 43  0 45 46 47 48 49  0  0  0  0  0 55  0  0  0  0  0  0 62 63  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0 80  0 82  0  0  0 86 87  0  0  0 91  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
109110  0  0

REQUIREMENT   033 IS CONNECTED TO--
  1  0  0  0  5  6  0  0  0  0  0 12  0  0 15  0  0  0  0  0  0  0  0  0  0 26 27  0  0  0  0  0  0  0 35  0
 37 38 39 40  0  0 43  0 45  0  0 48 49 50 51  0  0  0  0  0  0 58 59 60 61 62 63 64 65 66  0 68 69 70 71 72
 73 74  0 76 77 78  0 80 81 82 83  0  0 86  0 88  0 90 91  0 93 94 95 96  0  0  0  0  0102  0  0  0  0  0  0
  0  0111  0

REQUIREMENT   034 IS CONNECTED TO--
  0  0  0  0  0  6  0  0  9  0  0  0  0  0  0 16  0 18  0  0  0  0  0  0  0 26 27  0  0  0  0  0  0  0  0  0
  0  0  0 40  0  0  0  0 45  0  0  0 49  0  0  0 53  0  0  0  0  0  0  0  0  0  0  0  0 66  0  0  0  0 71  0
  0  0  0  0  0  0  0 80  0  0  0  0  0  0  0 88  0 90  0  0 93  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0

REQUIREMENT   035 IS CONNECTED TO--
  1  2  3  4  5  0  7  0  9 10  0 12  0 14  0  0  0 18  0  0  0  0  0  0  0  0  0  0  0  0  0  0 33  0  0  0
 37 38 39 40 41  0 43  0 45  0 47 48 49 50 51  0 53  0  0  0  0  0 59 60 61  0 63  0  0  0  0 68  0  0  0  0
  0 74  0 76  0  0  0  0  0  0  0  0  0  0  0 88 89 90 91 92  0  0 95 96  0  0  0  0  0  0  0  0  0  0  0  0
  0  0111112

REQUIREMENT   036 IS CONNECTED TO--
  0  0  0  0  5  6  7  0  0  0  0 12  0  0  0  0  0  0  0  0  0 22  0  0  0 26  0  0  0 30  0  0  0  0  0  0
  0  0  0  0  0  0  0 44 45  0  0  0  0 50  0  0  0  0  0  0  0  0  0  0  0  0  0 64 65 66  0  0  0 70 71 72
  0  0  0  0  0  0  0  0  0 82 83  0  0  0  0  0  0  0  0  0  0  0  0 96 97  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0
```

```
REQUIREMENT     037 IS CONNECTED TO--
  1  2  0  4  5  6  7  0  0  0  0 12 13 14 15 16  0  0  0 20  0  0  0  0 25  0  0  0 29  0  0 32 33  0 35  0
  0 38  0 40 41  0 43 44 45 46 47 48  0 50  0  0 53  0  0 56  0  0 59  0  0  0 63 64 65 66  0 68 69 70 71 72
  0  0  0  0  0  0  0  0 81 82 83  0  0 86  0 88 89 90 91  0  0  0 95 96 97 98  0  0  0  0  0  0  0  0107  0
109  0111112

REQUIREMENT     038 IS CONNECTED TO--
  1  2  3  4  5  6  7  0  9 10 11 12 13 14  0  0  0  0  0  0  0  0  0  0 25  0  0  0  0 30  0 32 33  0 35  0
 37  0 39  0  0  0 43 44 45 46 47 48 49 50 51  0 53 54  0  0  0 58  0 60 61  0  0 64 65 66  0  0 69  0  0 72
  0 74  0  0  0  0  0  0 81 82 83  0  0 86 87 88 89 90 91 92 93 94 95 96 97 98 99  0101  0103104  0  0107  0
109  0111112

REQUIREMENT     039 IS CONNECTED TO--
  1  2  3  4  5  6  0  8  9 10 11  0 13 14  0  0  0  0  0  0  0  0  0  0 25  0 27  0  0 30 31 32 33  0 35  0
  0 38  0 40 41  0 43 44 45 46 47 48 49 50 51 52 53 54 55  0 57 58 59  0  0 62  0  0 65 66  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0 82  0  0 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99  0101  0103  0105  0107  0
109110  0  0

REQUIREMENT     040 IS CONNECTED TO--
  0  2  3  4  0  6  7  0  9  0  0  0 13 14  0  0  0  0  0  0  0  0  0  0 25  0 27  0  0 30  0  0 33 34 35  0
 37  0 39  0 41  0  0  0 45  0 47 48 49  0  0 52 53 54  0  0 57  0 59 60  0 62 63  0 65 66  0  0  0 70  0  0
  0  0  0  0  0  0  0 80  0 82  0  0  0 86 87 88 89 90 91  0 93 94 95 96  0  0 99  0101  0  0  0105  0107  0
109  0111112

REQUIREMENT     041 IS CONNECTED TO--
  0  0  3  0  0  6  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 25  0  0  0  0  0  0  0  0  0 35  0
 37  0 39 40  0 42 43  0  0  0  0  0  0  0  0  0 53  0  0  0  0 58 59  0  0  0  0 65  0 67  0  0  0  0  0  0
  0 74  0 76 77 78  0 80 81  0  0  0  0 86 87  0 89  0 91 92 93 94  0 96  0  0  0  0  0102  0  0  0  0  0  0
  0  0  0  0

REQUIREMENT     042 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 16 17  0 19 20  0  0  0  0  0 26  0  0  0  0  0  0  0  0  0  0
  0  0  0  0 41  0  0  0  0 46  0  0  0  0  0  0  0  0  0 56  0 58 59  0  0 62  0 64  0 66 67  0  0  0 71  0
  0 74 75 76 77 78  0 80 81 82  0  0  0  0  0  0  0  0 91  0  0  0  0 96  0  0  0  0  0102  0  0  0  0  0  0
  0  0  0  0

REQUIREMENT     043 IS CONNECTED TO--
  0  0  3  4  0  0  0  0  9  0  0 12 13  0  0  0  0  0  0  0 21  0  0  0  0  0  0  0  0 30  0 32 33  0 35  0
 37 38 39  0 41  0  0 44  0  0  0 48  0 50  0 52 53  0  0  0 57  0 59  0  0 62 63  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0 82 83  0  0 86 87 88 89  0 91  0  0  0  0 96 97 98  0  0  0  0  0  0  0  0  0  0
109  0111112

REQUIREMENT     044 IS CONNECTED TO--
  1  2  3  4  5  6  7  8  9  0 11 12 13 14  0 16  0  0  0  0  0  0  0  0  0 26 27 28 29  0  0  0  0  0  0 36
 37 38 39  0  0  0 43  0 45  0 47 48  0 50  0 52 53 54 55 56  0  0 59  0  0  0 63  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0 80  0 82  0  0  0 86  0  0 89 90 91  0 93 94 95 96 97 98  0100101  0103  0  0  0107108
109110111112

REQUIREMENT     045 IS CONNECTED TO--
  1  2  0  4  5  6  7  0  0  0  0 12 13 14  0  0  0  0  0  0  0  0  0  0 25  0 27  0  0  0  0 32 33 34 35 36
 37 38 39 40  0  0  0 44  0  0 47 48 49 50  0  0 53 54 55 56  0  0 59 60 61  0 63 64 65 66  0  0  0  0 71 72
 73  0  0  0  0  0  0 80  0 82  0  0  0 86 87 88 89 90 91  0 93 94 95 96 97 98  0  0  0  0103104  0  0107108
109  0  0112
```

```
REQUIREMENT     046 IS CONNECTED TO--
  0  0  3  4   5  6  0  0  0  0 11 12 13  0  0  0  0  0  0  0  0  0  0  0 25  0  0 28 29 30 31 32  0  0  0  0
 37 38 39 40   0 42  0  0  0  0 47 48 49  0  0  0 53 54  0  0  0 58 59 60 61  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0   0  0  0 80  0 82  0 84 85 86 87 88 89 90 91  0 93 94 95 96  0  0 99100101  0  0  0  0  0 0108
  0110  0112

REQUIREMENT     047 IS CONNECTED TO--
  0  2  3  4   5  6  7  8  9 10 11  0 13  0  0  0  0  0  0  0  0  0  0  0 25  0 27 28  0 30  0 32  0  0 35  0
 37 38 39 40   0  0  0 44 45 46  0  0  0  0 51  0 53 54 55  0  0  0 59  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0   0  0  0 80  0 82  0  0 85 86 87 88 89  0 91  0  0 94  0  0  0  0 99100101102  0  0  0  0 0108
  0110  0  0

REQUIREMENT     048 IS CONNECTED TO--
  1  2  3  4   0  6  7  0  0  0  0 12 13 14  0  0 17  0  0  0  0  0  0  0 25 26 27  0  0 30  0 32 33  0 35  0
 37 38 39 40   0  0 43 44 45 46  0  0 49 50 51 52 53  0  0  0  0  0 59 60 61  0 63  0 65 66  0 68 69  0  0 72
 73 74  0  0   0 78  0 80  0 82  0  0  0 86  0 88 89 90 91  0  0  0 95 96 97  0  0  0101  0  0  0  0  0  0  0
109  0  0112

REQUIREMENT     049 IS CONNECTED TO--
  0  0  0  4   0  6  7  0  0  0  0 12  0  0  0  0  0 18  0  0 21  0  0  0 25  0  0  0  0  0 31 32 33 34 35  0
  0 38 39 40   0  0  0  0 45 46  0 48  0  0 51  0 53  0  0  0 57  0 59 60 61 62 63  0  0 66 67  0  0  0  0  0
  0  0  0  0   0  0  0  0 81 82 83 84  0 86 87 88 89 90  0 92 93 94 95 96  0  0  0  0  0  0  0  0  0  0  0  0
  0110111112

REQUIREMENT     050 IS CONNECTED TO--
  1  2  0  0   5  6  7  0  0  0  0 12 13 14 15  0  0  0  0  0  0  0  0  0 25  0  0 28  0  0  0  0 33  0 35 36
 37 38 39  0   0  0 43 44 45  0  0 48  0  0  0 52  0 54  0  0  0  0  0  0 61  0 63  0  0  0  0  0  0 70  0  0
 73  0  0  0   0  0  0  0  0 82  0  0  0  0  0 88 89 90 91 92  0  0 95 96 97 98 99  0101102103  0105  0  0  0
109  0  0112

REQUIREMENT     051 IS CONNECTED TO--
  0  2  0  0   0  6  7  0  0  0  0 12  0  0  0  0  0  0  0  0  0  0  0  0  0  0 27  0  0  0  0  0 33  0 35  0
  0 38 39  0   0  0  0  0  0  0 47 48 49  0  0  0 53  0  0  0 57  0 59 60 61  0 63  0 65  0  0  0 69  0  0  0
  0 74  0  0   0  0  0  0 81  0  0  0  0  0  0 88  0 90 91  0  0  0  0 96  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0112

REQUIREMENT     052 IS CONNECTED TO--
  1  0  0  4   5  0  7  0  0 10  0  0  0 14  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 31  0  0  0  0  0
  0  0 39 40   0  0 43 44  0  0  0 48  0 50  0  0 53 54  0  0 57  0 59 60  0 62 63  0 65  0  0  0  0 70  0  0
  0  0  0  0   0  0  0  0  0 82  0  0  0 86 87 88 89 90  0  0 93 94  0 96 97 98  0  0101  0  0  0  0  0  0  0
109110111112

REQUIREMENT     053 IS CONNECTED TO--
  1  0  3  4   0  0  0  0  9  0  0  0 13 14  0  0  0  0  0  0  0  0  0  0 25  0 27  0  0  0  0  0  0 34 35  0
 37 38 39 40  41  0 43 44 45 46 47 48 49  0 51 52  0 54  0 56 57 58 59 60 61 62  0  0 65 66  0 68 69  0  0  0
  0  0  0  0   0  0  0  0  0 92 93  0  0 86 87 88 89 90 91 92 93 94 95  0  0  0 99100101  0103  0  0  0  0  0
109  0111112

REQUIREMENT     054 IS CONNECTED TO--
  0  0  0  4   5  0  7  0  0  0 11  0 13  0  0  0  0  0  0  0  0 22  0  0 25  0  0 28 29 30 31  0  0  0  0  0
  0 38 39 40   0  0  0 44 45 46 47  0  0 50  0 52 53  0 55  0 57  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0   0  0  0 80  0  0  0  0  0 86 87 88 89  0 91  0 93 94  0  0  0  0  0100  0  0  0  0  0  0  0  0
  0110111112
```

```
REQUIREMENT     055 IS CONNECTED TO--
  0  0  0  4  5  6  7  0  0  0 11 12  0  0  0  0  0  0  0  0  0  0  0 25  0  0 28 29  0  0 32  0  0  0  0
  0  0 39  0  0  0  0 44 45  0 47  0  0  0  0  0  0 54  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0 80  0 82  0  0  0 86 87 88 89  0  0  0  0  0  0  0  0  0 99100  0  0  0  0  0  0  0  0
  0110  0112

REQUIREMENT     056 IS CONNECTED TO--
  0  2  0  0  5  0  7  0  0  0  0 12  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 37  0  0  0  0 42  0 44 45  0  0  0  0  0  0  0 53  0  0  0  0 58 59  0  0  0  0 64 65 66  0 68 69  0  0 72
 73  0  0  0  0 78  0  0 81  0  0  0  0  0  0  0  0  0 91  0  0 94  0  0  0  0  0100  0  0  0  0  0  0  0  0
109  0  0  0

REQUIREMENT     057 IS CONNECTED TO--
  1  2  0  0  5  0  0  0  9  0  0  0 13 14  0  0  0  0  0  0  0  0  0  0  0  0  0  0 30  0  0  0  0  0  0
  0  0 39 40  0  0 43  0  0  0  0  0 49  0 51 52 53 54  0  0  0 58 59  0  0 62  0  0  0  0  0  0  0  0  0
  0  0  0  0 77  0  0  0  0 82  0  0  0 86 87 88  0 90  0 92 93 94  0 96 97  0 99100101  0103  0  0  0  0  0
  0110  0  0

REQUIREMENT     058 IS CONNECTED TO--
  1  2  0  0  0  0  7  0  9 10 11 12 13 14 15 16 17  0 19  0  0  0  0  0 25  0  0  0  0  0  0  0 33  0  0  0
  0 38 39  0 41 42  0  0  0 46  0  0  0  0  0  0 53  0  0 56 57  0  0  0  0  0  0 64  0 66 67  0 69  0  0 72
 73 74 75 76 77 78 79 80 81 82  0 84 85  0  0  0  0 90 91  0 93  0 95 96 97  0 99  0101  0  0104  0106107108
109  0  0112

REQUIREMENT     059 IS CONNECTED TO--
  0  2  3  4  5  6  7  8  9 10 11 12 13 14  0  0  0 18  0  0  0  0  0  0 25  0 27 28  0 30  0  0 33  0 35  0
 37  0 39 40 41 42 43 44 45 46 47 48 49  0 51 52 53  0  0 56 57  0  0 60 61  0  0 64 65 66  0 68 69  0 71 72
  0 74 75  0 77 78 79 80 81 82  0  0  0 86 87 88 89 90 91 92 93 94  0 96  0  0 99100101102103104105  0  0108
  0110111112

REQUIREMENT     060 IS CONNECTED TO--
  1  2  0  4  5  6  7  0  9  0 11 12  0  0  0  0  0  0  0  0  0  0  0 25 26 27 28 29 30  0  0 33  0 35  0
  0 38  0 40  0  0  0  0 45 46  0 48 49  0 51 52 53  0  0  0  0  0 59  0 61  0  0  0 65 66  0 68  0  0  0  0
  0  0  0  0  0  0  0  0  0 82  0  0  0 86 87 88 89 90 91 92  0 94 95 96 97  0 99  0101  0103  0  0  0  0  0
109  0111  0

REQUIREMENT     061 IS CONNECTED TO--
  C  0  0  0  5  0  7  0  0  0  0 12  0  0  0  0  0  0  0  0  0  0  0  0  0  0 27  0  0  0  0  0 33  0 35  0
  0 38  0  0  0  0  0  0 45 46  0 48 49 50 51  0 53  0  0  0  0  0 59 60  0  0  0  0  0  0  0 68  0 70  0  0
  0  0  0  0  0  0  0  0 81 82  0  0 85  0 87 88  0  0 91  0  0  0 95 96  0  0  0  0  0  0  0  0  0  0  0  0
109  0  0112

REQUIREMENT     062 IS CONNECTED TO--
  0  0  0  0  0  6  0  0  0  0  0 12  0  0  0  0  0 18 19  0  0 22  0  0 25  0  0  0  0  0  0 32 33  0  0  0
  0  0 39 40  0 42 43  0  0  0  0  0 49  0  0 52 53  0  0  0 57  0  0  0  0  0 63 64 65 66 67  0 69  0  0  0
  0 74 75 76  0  0  0 80  0 82  0  0 85  0  0  0 89 90 91  0  0  0  0 96  0 98  0  0  0  0  0  0  0  0  0  0
  0110  0  0

REQUIREMENT     063 IS CONNECTED TO--
  0  0  0  0  5  6  7  0  0  0  0  0 13 14 15  0 17 18 19 20  0  0 23 24  0 26 27 28  0  0  0 32 33  0 35  0
 37  0  0 40  0  0 43 44 45  0  0 48 49 50 51 52  0  0  0  0  0  0  0  0  0 62  0  0  0 66  0 68  0  0  0  0
  0  0  0  0 77  0  0 80  0 82  0  0  0  0  0  0  0  0 91 92  0  0 95 96 97 98  0  0  0  0  0  0105  0  0  0
109  0  0112
```

```
REQUIREMENT    064 IS CONNECTED TO--
  0  0  0  0  0  6  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 33  0  0 36
 37 38  0  0  0 42  0  0 45  0  0  0  0  0  0  0  0  0  0 56  0 58 59  0  0 62  0  0 65 66 67 68 69 70 71 72
 73  0  0  0  0  0  0  0  0  0 83  0 85  0  0  0  0  0 91  0  0 94 95  0  0  0  0  0  0  0  0104105106107108
  0  0  0  0

REQUIREMENT    065 IS CONNECTED TO--
  1  2  3  4  5  6  7  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 27 28  0  0  0  0 33  0  0 36
 37 38 39 40 41  0  0  0 45  0  0 48  0  0 51 52 53  0  0 56  0  0 59 60  0 62  0 64  0 66  0  0 69 70 71  0
  0  0  0  0  0  0  0  0  0  0 83  0  0 86  0 88  0  0  0  0 93 94 95  0  0  0  0  0  0  0  0104105  0  0  0
109  0  0112

REQUIREMENT    066 IS CONNECTED TO--
  1  2  0  0  5  6  7  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 27  0  0  0  0  0 33 34  0 36
 37 38 39 40  0 42  0  0 45  0  0 48 49  0  0  0 53  0  0 56  0 58 59 60  0 62 63 64 65  0  0 68 69  0 71  0
  0  0  0  0  0  0  0  0  0  0 83  0 85 86  0 88  0  0  0  0 93 94 95  0  0  0 99  0  0  0  0104  0  0  0  0
109  0  0112

REQUIREMENT    067 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  0  0  0 12  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0 41 42  0  0  0  0  0  0 49  0  0  0  0  0  0  0  0 58  0  0  0 62  0 64  0  0  0  0  0  0 71 72
 73 74 75 76 77 78 79  0 81 82  0  0 85  0  0  0  0  0  0  0 93  0  0 96  0  0  0100101  0  0  0  0  0  0  0
  0  0  0  0

REQUIREMENT    068 IS CONNECTED TO--
  0  2  0  0  5  0  7  0  0  0  0 12 13  0  0  0  0  0  0  0  0  0 23  0  0  0 27 28  0  0  0  0 33  0 35  0
 37  0  0  0  0  0  0  0  0  0  0 48  0  0  0  0 53  0  0 56  0  0 59 60 61  0 63 64  0 66  0  0 69 70 71 72
  0 74 75  0 77 78  0  0  0 82  0  0  0  0  0  0  0  0  0  0 93  0  0  0  0  0  0  0101  0  0104  0  0  0  0
  0  0  0  0

REQUIREMENT    069 IS CONNECTED TO--
  1  0  0  4  5  6  0  0  0  0  0 12  0  0  0  0  0  0  0  0  0  0  0  0  0 26  0  0  0  0  0  0 33  0  0  0
 37 38  0  0  0  0  0  0  0  0  0 48  0  0 51  0 53  0  0 56  0 58 59  0  0 62  0 64 65 66  0 68  0  0  0  0
 73  0  0  0 77 78  0 80  0 82  0  0  0  0  0  0  0  0 91  0  0 94  0 96  0  0  0  0101  0  0104  0  0  0  0
  0  0  0  0

REQUIREMENT    070 IS CONNECTED TO--
  0  2  0  0  0  6  7  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 26  0  0  0  0  0  0 33  0  0 36
 37  0  0 40  0  0  0  0  0  0  0  0  0 50  0 52  0  0  0  0  0  0  0  0 61  0  0 64 65  0  0 68  0  0  0  0
  0  0  0  0  0 78 79  0 81 82  0 84  0  0  0  0  0  0  0  0 93  0 95  0  0  0  0  0  0102  0  0  0  0  0108
109  0  0112

REQUIREMENT    071 IS CONNECTED TO--
  1  0  0  0  5  6  7  0  0  0  0  0  0  0  0  0  0 18 19  0  0  0  0  0  0 26 27 28  0  0  0  0 33 34  0 36
 37  0  0  0  0 42  0  0 45  0  0  0  0  0  0  0  0  0  0  0  0  0 59  0  0  0  0 64 65 66 67 68  0  0  0 72
 73  0 75 76  0  0  0 80  0 82  0  0 85  0  0 88  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
109  0  0  0

REQUIREMENT    072 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  0  0  0 12  0  0  0  0  0  0  0  0  0  0  0  0  0 26 27  0  0  0  0  0 33  0  0 36
 37 38  0  0  0  0  0  0 45  0  0 48  0  0  0  0  0  0  0 56  0 58 59  0  0  0  0 64  0  0 67 68  0  0 71  0
 73 74 75 76 77 78 79 80  0 82  0  0  0  0  0  0  0  0  0  0  0  0 95  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0111  0
```

```
REQUIREMENT     073 IS CONNECTED TO--
   1  0  0  0  0  0  0  0  0  0  0 12  0  0  0  0  0  0  0  0  0  0  0  0  0 26 27  0  0  0  0  0 33  0  0  0
   0  0  0  0  0  0  0  0 45  0  0 48  0 50  0  0  0  0  0 56  0 58  0  0  0  0  0 64  0  0 67  0 69  0 71 72
   0 74 75 76 77 78  0  0 81 82  0  0  0  0  0  0  0  0  0  0  0  0 95  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0

REQUIREMENT     074 IS CONNECTED TO--
   0  0  0  0  0  0  0  0  0  0  0 12  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 33  0 35  0
   0 38  0  0 41 42  0  0  0  0  0 48  0  0 51  0  0  0  0  0  0 58 59  0  0 62  0  0  0  0 67 68  0  0  0 72
  73  0 75 76 77 78 79 80 81 82  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 109  0  0112

REQUIREMENT     075 IS CONNECTED TO--
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0 42  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 58 59  0  0 62  0  0  0  0 67 68  0  0 71 72
  73 74  0 76 77 78 79  0 81 82  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0104  0  0  0  0
   0  0  0  0

REQUIREMENT     076 IS CONNECTED TO--
   1  0  0  0  5  0  0  8  0  0  0  0 13 14  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 33  0 35  0
   0  0  0  0 41 42  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 58  0  0  0 62  0  0  0  0 67  0  0  0 71 72
  73 74 75  0 77 78 79  0 81 82  0  0  0  0  0  0  0  0  0  0  0  0 95  0 97  0 99100  0  0  0  0  0  0  0  0
 109  0111  0

REQUIREMENT     077 IS CONNECTED TO--
   0  0  0  0  0  0  0  8  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 33  0  0  0
   0  0  0  0 41 42  0  0  0  0  0  0  0  0  0  0  0  0  0  0 57 58 59  0  0  0 63  0  0  0 67 68 69  0  0 72
  73 74 75 76  0 78 79  0 81 82  0  0 85  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0103  0  0  0107  0
   0  0  0112

REQUIREMENT     078 IS CONNECTED TO--
   0  0  0  0  0  0  0  8  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 33  0  0  0
   0  0  0  0 41 42  0  0  0  0  0 48  0  0  0  0  0  0  0 56  0 58 59  0  0  0  0  0  0  0 67 68 69 70  0 72
  73 74 75 76 77  0 79  0 81  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0

REQUIREMENT     079 IS CONNECTED TO--
   0  0  0  0  0  0  0  8  0  0  0  0  0  0  0  0  0  0  0  0 21  0  0  0  0  0  0 28 29 30  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 58 59  0  0  0  0  0  0  0 67  0  0 70  0 72
   0 74 75 76 77 78  0  0 81  0  0 84  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0

REQUIREMENT     080 IS CONNECTED TO--
   1  0  3  4  5  6  7  0  0  0  0 12  0  0  0  0  0 18  0 20 21  0  0  0  0 26 27  0  0 30  0 32 33 34  0  0
   0  0  0 40 41 42  0 44 45 46 47 48  0  0  0  0  0 54 55  0  0 58 59  0  0 62 63  0  0  0  0  0 69  0 71 72
   0 74  0  0  0  0  0  0 81 82 83  0  0  0 87 88 89  0 91  0 93 94  0 96 97  0 99100101102  0  0  0  0  0108
 109110  0112

REQUIREMENT     081 IS CONNECTED TO--
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 26  0  0  0  0 31  0 33  0  0  0
  37 38  0  0 41 42  0  0  0  0  0  0 49  0 51  0  0  0  0 56  0 58 59  0 61  0  0  0  0  0 67  0  0 70  0  0
  73 74 75 76 77 78 79 80  0 82 83  0 85  0  0  0  0 90 91 92 93 94 95 96  0  0  0  0  0  0  0  0  0  0  0108
 109  0111112
```

```
REQUIREMENT     082 IS CONNECTED TO--
  1  2  3  4  5  6  7  0  0  0  0 12 13 14  0  0 17 18 19 20  0  0 23 24  0  0 27 28  0  0  0 32 33  0  0 36
 37 38 39 40  0 42 43 44 45 46 47 48 49 50  0 52 53  0 55  0 57 58 59 60 61 62 63  0  0  0 67 68 69 70 71 72
 73 74 75 76 77  0  0 80 81  0 83  0 85 86  0  0 89 90 91 92 93 94 95 96 97 98  0 0101 0103  0  0  0  0  0
109110111112

REQUIREMENT     083 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 33  0  0 36
 37 38  0  0  0  0 43  0  0  0  0  0 49  0  0  0 53  0  0  0  0  0  0  0  0  0  0 64 65 66  0  0  0  0  0  0
  0  0  0  0  0  0  0 80 81 82  0  0  0  0 87  0  0 90 91 92  0  0  0 96  0  0  0  0  0  0  0  0  0  0  0  0
109  0111112

REQUIREMENT     084 IS CONNECTED TO--
  0  0  3  4  0  6  0  0  0  0  0  0  0  0 15 16 17 18 19 20 21  0  0  0 25 26  0 28 29  0 31  0  0  0  0  0
  0  0  0  0  0  0  0  0  0 46  0  0 49  0  0  0  0  0  0  0  0 58  0  0  0  0  0  0  0  0  0  0  0 70  0  0
  0  0  0  0  0  0 79  0  0  0  0  0  0 86 87 88 89  0  0  0  0 94  0 96  0  0  0  0  0  0  0  0  0 0107  0
  0110  0112

REQUIREMENT     085 IS CONNECTED TO--
  1  2  3  4  0  0  0  0  9 10 11  0  0  0  0  0 17  0 19  0  0  0  0  0 25 26  0  0  0 30  0  0  0  0  0  0
  0  0 39  0  0  0  0  0  0 46 47  0  0  0  0  0  0  0  0  0  0 58  0  0 61 62  0 64  0 66 67  0  0  0 71  0
  0  0  0  0 77  0  0  0 81 82  0  0  0 86 87 88 89 90  0  0 93 94  0  0  0  0 99100  0  0  0  0  0  0  0  0
109110  0112

REQUIREMENT     086 IS CONNECTED TO--
  0  0  3  4  0  0  7  8  9 10 11  0  0  0  0  0  0 18  0  0  0  0  0  0 25  0 27  0 29  0 31 32 33  0  0  0
 37 38 39 40 41  0 43 44 45 46 47 48 49  0  0 52 53 54 55  0 57  0 59 60  0  0  0  0 65 66  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0 82  0 84 85  0 87 88 89 90 91  0 93 94  0 96  0  0 99100101  0103104105106107108
109110111112

REQUIREMENT     087 IS CONNECTED TO--
  1  2  3  4  0  0  7  8  0 10 11  0  0  0  0  0  0 18  0  0 21  0  0  0 25  0  0  0  0  0 31 32  0  0  0  0
  0 38 39 40 41  0 43  0 45 46 47  0 49  0  0 52 53 54 55  0 57  0 59 60 61  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0 80  0  0 83 84 85 86  0 88 89 90 91  0 93 94 95 96  0  0  0100101  0103104105106107108
  0110111112

REQUIREMENT     088 IS CONNECTED TO--
  1  0  0  4  5  6  7  0  0  0  0 12 13 14 15  0  0  0  0  0  0  0  0  0 25  0 27 28 29  0  0  0 33 34 35  0
 37 38 39 40  0  0 43  0 45 46 47 48 49 50 51 52 53 54 55  0 57  0 59 60 61  0  0  0 65 66  0  0  0  0 71  0
  0  0  0  0  0  0  0 80  0  0  0 84 85 86 87  0 89 90 91  0  0 94 95  0 97 98 99100101  0103104  0  0  0  0
109  0111112

REQUIREMENT     089 IS CONNECTED TO--
  0  0  3  4  0  0  7  8  9 10 11  0 13 14  0  0  0  0  0  0 21 22  0  0 25  0  0  0  0 30 31  0  0  0 35  0
 37 38 39 40 41  0 43 44 45 46 47 48 49 50  0 52 53 54 55  0  0  0 59 60  0 62  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0 80  0 82  0 84 85 86 87 88  0 90 91  0 93 94 95  0  0 98 99100  0102103  0105  0  0  0
  0110  0  0

REQUIREMENT     090 IS CONNECTED TO--
  0  2  3  4  0  6  0  0  9 10 11 12 13 14 15  0 17 18 19  0  0  0  0  0 25  0 27 28  0  0  0  0 33 34 35  0
 37 38 39 40  0  0  0 44 45 46  0 48 49 50 51 52 53  0  0  0 57 58 59 60  0 62  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0 81 82 83  0 85 86 87 88 89  0 91 92 93 94  0 96  0  0  0 0101 0103  0  0  0  0  0
109110111112
```

```
REQUIREMENT     091 IS CONNECTED TO--
  0  0  3  4  5  6  7  8  9 10  0 12 13 14  0  0  0  0  0  0  0  0  0  0 25 26 27 28 29  0  0 32 33  0 35  0
 37 38 39 40 41 42 43 44 45 46 47 48  0 50 51  0 53 54  0 56  0 58 59 60 61 62 63 64  0  0  0  0 69  0  0  0
  0  0  0  0  0  0  0 80 81 82 83  0  0 86 87 88 89 90  0 92 93 94 95 96 97 98 99100101  0103  0  0  0  0  0
109110111  0

REQUIREMENT     092 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  0  0  0 12  0  0  0  0  0  0 19  0  0  0  0  0 25  0  0  0  0  0  0  0  0  0 35  0
  0 38 39  0 41  0  0  0  0  0  0  0 49 50  0  0 53  0  0  0 57  0 59 60  0  0 63  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0 81 82 83  0  0  0  0  0  0 90 91  0 93  0  0 96  0  0  0  0101  0103  0  0  0  0  0
  0  0111112

REQUIREMENT     093 IS CONNECTED TO--
  0  0  3  0  5  0  7  0  9 10  0  0 13  0  0  0  0  0  0  0  0  0  0  0 25  0 27  0  0  0  0  0 33 34  0  0
  0 38 39 40 41  0  0 44 45 46  0  0 49  0  0 52 53 54  0  0 57 58 59  0  0  0  0  0 65 66 67 68  0 70  0  0
  0  0  0  0  0  0  0 80 81 82  0  0 85 86 87  0 89 90 91 92  0 94 95  0  0  0 99100101  0103  0  0  0107108
109  0111112

REQUIREMENT     094 IS CONNECTED TO--
  1  2  3  4  0  6  7  0  0 10 11  0 13 14  0  0  0  0  0  0  0  0  0  0 25  0 27  0  0  0  0  0 33  0  0  0
  0 38 39 40 41  0  0 44 45 46 47  0 49  0  0 52 53 54  0 56 57  0 59 60  0  0  0 64 65 66  0  0 69  0  0  0
  0  0  0  0  0  0  0 80 81 82  0 84 85 86 87 88 89 90 91  0 93  0 95  0  0  0 99100101102  0104105  0107  0
109110111112

REQUIREMENT     095 IS CONNECTED TO--
  1  2  0  4  5  0  7  0  0  0  0 12 13 14  0  0  0  0  0  0  0  0  0  0  0 26 27  0  0  0  0  0 33  0 35  0
 37 38 39 40  0  0  0 44 45 46  0 48 49 50  0  0 53  0  0  0  0 58  0 60 61  0 63 64 65 66  0  0  0 70  0 72
 73  0  0 76  0  0  0  0 81 82  0  0  0  0 87 88 89  0 91  0 93 94  0 96 97 98  0  0  0102103  0  0  0  0  0
109  0  0  0

REQUIREMENT     096 IS CONNECTED TO--
  1  2  3  4  5  6  7  0  0  0  0  0 13 14  0  0  0  0  0  0  0  0  0  0 25 26 27 28  0 30  0  0 33  0 35 36
 37 38 39 40 41 42 43 44 45 46  0 48 49 50 51 52  0  0  0  0 57 58 59 60 61 62 63  0  0  0 67  0 69  0  0  0
  0  0  0  0  0  0  0 80 81 82 83 84  0 86 87  0  0 90 91 92  0  0 95  0 97 98  0  0101  0  0  0  0  0  0  0
109  0  0112

REQUIREMENT     097 IS CONNECTED TO--
  1  2  0  4  5  0  7  0  0  0  0 12 13 14 15 16 17  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 36
 37 38 39  0  0  0 43 44 45  0  0 48  0 50  0 52  0  0  0  0 57 58  0 60  0  0 63  0  0  0  0  0  0  0  0  0
  0  0  0 76  0  0  0 80  0 82  0  0  0  0  0 88  0  0 91  0  0  0 95 96  0 98  0  0  0  0  0  0  0  0  0  0
  0110111112

REQUIREMENT     098 IS CONNECTED TO--
  0  0  0  0  5  0  0  0  0  0  0 12  0  0  0  0 17  0  0  0  0 22  0 24 25  0  0  0  0 30  0  0  0  0  0  0
 37 38 39  0  0  0 43 44 45  0  0  0  0 50  0 52  0  0  0  0  0  0  0  0  0 62 63  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0 82  0  0  0  0  0 88 89  0 91  0  0  0 95 96 97  0  0  0  0  0  0  0  0  0  0  0
109110111112

REQUIREMENT     099 IS CONNECTED TO--
  0  0  3  0  0  0  0  0  9 10  0  0  0  0  0  0  0  0  0  0 21  0  0  0 25  0  0  0  0  0  0  0  0  0  0  0
  0 38 39 40  0  0  0  0  0 46 47  0  0 50  0  0 53  0 55  0 57 58 59 60  0  0  0  0  0 66  0  0  0  0  0  0
  0  0  0 76  0  0  0 80  0  0  0  0 85 86  0 88 89  0 91  0 93 94  0  0  0  0  0100101102103  0105  0  0  0
  0110  0112
```

```
REQUIREMENT    100 IS CONNECTED TO--
  0  2  0  0  0  0  0  8  9  0 11  0  0  0  0  0  0  0  0  0  0  0  0  0 25  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0 44  0 46 47  0  0  0  0  0 53 54 55 56 57  0 59  0  0  0  0  0  0  0 67  0  0  0  0  0
  0  0  0 76  0  0  0 80  0  0  0  0 85 86 87 88 89  0 91  0 93 94  0  0  0  0 99  0101102103  0105  0  0  0
  0110  0  0

REQUIREMENT    101 IS CONNECTED TO--
  0  0  3  0  0  0  0  0  9 10  0  0  0  0 15  0  0  0  0  0  0  0  0  0 25  0  0  0  0  0  0  0  0  0  0  0
  0 38 39 40  0  0  0 44  0 46 47 48  0 50  0 52 53  0  0  0 57 58 59 60  0  0  0  0  0  0 67 68 69  0  0  0
  0  0  0  0  0  0  0 80  0 82  0  0  0 86 87 88  0 90 91 92 93 94  0 96  0  0 99100  0102103104105  0  0  0
  0110111112

REQUIREMENT    102 IS CONNECTED TO--
  0  2  3  4  0  6  0  0  0 10  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 33  0  0  0
  0  0  0  0 41 42  0  0  0  0 47  0  0 50  0  0  0  0  0  0  0  0 59  0  0  0  0  0  0  0  0  0  0 70  0  0
  0  0  0  0  0  0  0 80  0  0  0  0  0  0  0  0 89  0  0  0  0 94 95  0  0  0 99100101  0103  0105  0  0  0
109  0  0  0

REQUIREMENT    103 IS CONNECTED TO--
  0  0  3  0  0  0  0  0  9 10  0  0 13  0  0  0  0  0  0  0  0  0  0  0 25  0  0  0  0  0  0  0  0  0  0  0
  0 38 39  0  0  0  0 44 45  0  0  0  0 50  0  0 53  0  0  0 57  0 59 60  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0 77  0  0  0  0 82  0  0  0 86 87 88 89 90 91 92 93  0 95  0  0  0 99100101102  0  0  0  0  0  0
109110  0  0

REQUIREMENT    104 IS CONNECTED TO--
  0  0  0  4  0  6  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 27  0  0  0  0  0  0  0  0  0
  0 38  0  0  0  0  0  0 45  0  0  0  0  0  0  0  0  0  0  0  0 58 59  0  0  0  0 64 65 66  0 68 69  0  0  0
  0  0 75  0  0  0  0  0  0  0  0  0  0 86 87 88  0  0  0  0  0 94  0  0  0  0  0  0101  0  0  0105  0107  0
109  0  0  0

REQUIREMENT    105 IS CONNECTED TO--
  1  2  0  4  0  6  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 23 24 25  0  0  0  0  0  0  0  0  0  0  0
  0  0 39 40  0  0  0  0  0  0  0  0  0 50  0  0  0  0  0  0  0  0 59  0  0  0 63 64 65  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0 86 87  0 89  0  0  0  0 94  0  0  0  0 99100101102  0104  0  0  0108
  0  0  0  0

REQUIREMENT    106 IS CONNECTED TO--
  0  0  0  0  0  0  0  0  0  0  0  0  0  0 15  0  0  0  0  0  0  0  0  0  0 26  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 58  0  0  0  0  0 64  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0 86 87  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0108
109  0  0112

REQUIREMENT    107 IS CONNECTED TO--
  1  0  0  0  5  6  7  8  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 26  0 28  0  0  0  0  0  0  0  0
 37 38 39 40  0  0  0 44 45  0  0  0  0  0  0  0  0  0  0  0  0 58  0  0  0  0  0 64  0  0  0  0  0  0  0  0
  0  0  0  0 77  0  0  0  0  0  0 84  0 86 87  0  0  0  0  0 93 94  0  0  0  0  0  0  0  0  0104  0  0  0108
109  0  0  0

REQUIREMENT    108 IS CONNECTED TO--
  1  2  0  0  0  0  0  8  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 25  0 27  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0 44 45 46 47  0  0  0  0  0  0  0  0  0  0 58 59  0  0  0  0 64  0  0  0  0  0 70  0  0
  0  0  0  0  0  0  0 80 81  0  0  0  0 86 87  0  0  0  0  0 93  0  0  0  0  0  0  0  0  0  0105106107  0
109  0111  0
```

```
REQUIREMENT    109 IS CONNECTED TO--
  1  2  3  4  0  6  0  8  9 10 11 12  0  0  0  0  0  0  0  0  0 22 23 24  0  0  0  0  0 30 31 32  0  0  0  0
 37 38 39 40  0  0 43 44 45  0  0 48  0 50  0 52 53  0  0 56  0 58  0 60 61  0 63  0 65 66  0  0  0 70 71  0
  0 74  0 76  0  0  0 80 81 82 83  0 85 86  0 88  0 90 91  0 93 94 95 96  0 98  0  0  0102103104  0106107108
  0110111112

REQUIREMENT    110 IS CONNECTED TO--
  1  2  0  0  5  0  7  0  0  0  0  0 13 14  0  0  0  0  0 20  0 22 23  0 25  0  0  0  0 30 31 32  0  0  0  0
  0  0 39  0  0  0  0 44  0 46 47  0 49  0  0 52  0 54 55  0 57  0 59  0  0 62  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0 80  0 82  0 84 85 86 87  0 89 90 91  0  0 94  0  0 97 98 99100101  0103  0  0  0  0  0
109  0111112

REQUIREMENT    111 IS CONNECTED TO--
  0  0  0  4  0  0  0  0  9 10  0  0  0  0  0  0  0 18 19  0  0  0 23  0 25 26  0  0  0 30  0  0 33  0 35  0
 37 38  0 40  0  0 43 44  0  0  0  0 49  0  0 52 53 54  0  0  0  0 59 60  0  0  0  0  0  0  0  0  0  0  0 72
  0  0  0 76  0  0  0  0 81 82 83  0  0 86 87 88  0 90 91 92 93 94  0  0 97 98  0  0101  0  0  0  0  0  0108
109110  0112

REQUIREMENT    112 IS CONNECTED TO--
  0  0  0  0  0  6  0  0  9 10 11  0  0  0  0 16 17 18 19 20 21  0 23  0 25 26  0  0  0  0  0  0  0  0 35  0
 37 38  0 40  0  0 43 44 45 46  0 48 49 50 51 52 53 54 55  0  0 58 59  0 61  0 63  0 65 66  0  0  0 70  0  0
  0 74  0  0 77  0  0 80 81 82 83 84 85 86 87 88  0 90  0 92 93 94  0 96 97 98 99  0101  0  0  0  0106  0  0
109110111  0
```