Identification, Analysis, and Correction of High-Accident Locations in Kentucky

Charles V. Zegeer*       Kenneth R. Agent†
Ronalds L. Rizenbergs†

*University of Kentucky
†University of Kentucky, ken.agent@uky.edu
‡University of Kentucky

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by

Charles V. Zageer
Former Research Engineer

Kenneth R. Agent
Research Engineer Chief

and

R. L. Rizenbergs

Kentucky Transportation Research Program
College of Engineering
University of Kentucky
Lexington, Kentucky

in cooperation with
Department of Transportation
Commonwealth of Kentucky

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not reflect the official views or policies of the University of Kentucky nor of the Kentucky Department of Transportation. This report does not constitute a standard, specification, or regulation.

August 1981
**Identification, Analysis, and Correction of High-Accident Locations**

The first step in the highway safety improvement process involves reporting and summarizing accidents by location. Once the high-accident locations are identified, field investigations and analysis follow. Locations are ranked on the basis of potential for accident reduction. Safety improvements are then scheduled and implemented. Finally, improvements are evaluated in terms of accident reduction.

This report compiles, in detail, the process involved in arriving at safety improvements in the high-accident spot-improvement program. References are made to information and methodologies developed in earlier reports by the Division of Research of the Kentucky Department of Transportation. Most of the background information and analysis techniques used to develop the methodologies are not included here. The methods, instead, are cited as they fit together in the total process. The procedures are shown as they fit into the total safety improvement process developed and implemented by the Division of Traffic of the Kentucky Department of Transportation.
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Introduction

The process of improving highway safety on a statewide basis requires considerable engineering planning and judgment. In Kentucky, the state-maintained highway system consists of approximately 25,000 miles (40,000 km) of roads. Funds for safety improvements are available for all types of roads. The goal of the Kentucky Department of Transportation (KYDOT) is to improve safety of the highway system in such a way as to provide the greatest benefits to road-users. Methodologies have been developed for every step in the process of implementing safety improvements. The first step involves reporting and summarizing accidents by location. Once the high-accident locations are identified, field investigations and analyses follow. The locations are ranked on the basis of potential for reducing accidents. Safety improvements are then scheduled and implemented. Finally, improvements are evaluated in terms of accident reduction. A flow chart of the process is given in Figure 1.

The process of selecting safety improvements is compiled in detail in this report. References are made to information and methodologies developed in previous reports by the Division of Research of the KYDOT. Most of the background information and analyses reported before are not included here. The methods are fitted together into a total process implemented by the KYDOT Division of Traffic.

Accident Reporting System

In 1976, the Kentucky Legislature enacted a law requiring copies of all reportable traffic accidents be sent to the state police headquarters in Frankfort. A reportable accident is one that involves at least $200 in property damage or an injury. A Uniform Accident Report (UAR) form was developed and is being used by all police agencies in Kentucky. The UAR form, as shown in Figure 2, provides information pertaining to the drivers and vehicles and a description of the accident. Space for an accident diagram and comments from the investigating officer is also provided. A cover sheet is also used (Figure 3). This is basically a code sheet for completing the report. Currently, about 150,000
Figure 2. Kentucky uniform traffic accident report.
1. Going Straight Ahead
2. Making Right Turn
3. Making Left Turn
4. Making U Turn
5. Starting From Parking
6. Starting In Traffic
7. Slowing Or Stopping
8. Stepped In Traffic
9. Entered Parked Position
10. Plowed
11. Avoiding Object in Roadway
12. Changing Lanes
13. Overskidding
14. Sign Post
15. Tree
16. Shoulder/Barrier
17. Curbing
18. Fence
19. Bridge Structure
20. Culvert/Head Wall
21. Guard Rail
22. Snow Embankment
23. Earth Embankment/Rock Cut/Ditch
24. Fire Hydrant
25. Other Object* NON-COLLISION —
26. Overturned
27. Fire/Explosion
28. Submergence
29. Carrying Off Roadway (Only)
30. Other* APPARENT CONTRIBUTING FACTORS (VEHICULAR)
1. Brakes Defective
2. Tires Defective
3. Mud Flaps Defective
4. Other Lighting Defects
5. Staining Failure
6. Tire Failure/Inadequate
7. Other
8. Other**
9. Other***
10. None Detected
APPARENT CONTRIBUTING FACTORS (ENVIRONMENTAL)
1. Animal's Action
2. Grille
3. View Obstructed/Limited*
4. Debris in Roadway
5. Impaired/Non-Working Traffic Controls* 6. Shoulder Defective
7. Holes/Deep Ruts/Bumps
8. Road Under Construction/Maintenance
9. Improperly Parked Vehicle(s)
10. Fixed Object(s)
11. Slipping Surface
12. Water Puddle
13. Other
14. None Detected

Table of Apparent Contributing Factors (Human)
1. Unsafe Speed
2. Failed To Yield Right Of Way
3. Following Too Close
4. Improper Passing
5. Disregard Traffic Controls
6. Turning Improperly
7. Alcohol Involvement
8. Drug Involvement
9. Inclement Weather
10. Fall Asleep
11. Loss Of Consciousness
12. Driver Instability*
13. Driver Intoxication*
14. Physical Disability*
15. Other*
16. None Detected

Table of Apparent Contributing Factors (Vehicular)
1. Brakes Defective
2. Tires Defective
3. Mud Flaps Defective
4. Other Lighting Defects
5. Staining Failure
6. Tire Failure/Inadequate
7. Other
8. Other**
9. Other***
10. None Detected

Table of Apparent Contributing Factors (Environmental)
1. Animal's Action
2. Grille
3. View Obstructed/Limited*
4. Debris in Roadway
5. Impaired/Non-Working Traffic Controls* 6. Shoulder Defective
7. Holes/Deep Ruts/Bumps
8. Road Under Construction/ Maintenance
9. Improperly Parked Vehicle(s)
10. Fixed Object(s)
11. Slipping Surface
12. Water Puddle
13. Other
14. None Detected

Total Traffic Units Involved

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<tr>
<td>Motor Vehicle</td>
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<tr>
<td>Witness</td>
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Total Lanes in Major Trafficway

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<td>Industrial</td>
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<td>Private Property</td>
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Roadway Surface

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<td>Dry</td>
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<td>Wet</td>
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<td>Snow</td>
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</tr>
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<td>Sleet</td>
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<tr>
<td>Mud</td>
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Weather

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<td>Rain</td>
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<td>Snow</td>
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</tr>
<tr>
<td>Sleet</td>
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<tr>
<td>Fog</td>
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Probability of Collision

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<td>Low</td>
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<tr>
<td>Medium</td>
<td>30</td>
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<tr>
<td>High</td>
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</tr>
<tr>
<td>None</td>
<td>5</td>
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Traffic Control

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<tr>
<td>Stop Sign</td>
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<td>YIELD</td>
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<tr>
<td>Flash</td>
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</tr>
<tr>
<td>Speed</td>
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Light Conditions

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<td>Daylight</td>
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<tr>
<td>Dusk</td>
<td>30</td>
</tr>
<tr>
<td>Dawn</td>
<td>10</td>
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PEDESTRIAN ACTION

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<td>Pedestrian Actions</td>
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</tr>
<tr>
<td>Bicyclist Actions</td>
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</tr>
<tr>
<td>Motor Vehicle Actions</td>
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</table>

Traffic Accident Report Cover Sheet

Figure 3. Kentucky uniform traffic accident report cover sheet.

Department of Transportation, where location information is verified and added. Reports are then returned to the Data Processing Center of State Police for coding and storage of all pertinent accidents are reported annually.

After accident reports are received by the Division of Traffic, they are processed by their Division of Traffic Records. Later, they are sent to the Division of Traffic,
accident information on computer tape. Copies of the tape are provided to various agencies, including the Department of Transportation.

Information taken from the UAR form includes over 1,000 numerical columns for each accident. An example of coded information that is useful to the traffic engineer is the directional analysis used to prepare collision diagrams and to perform other types of analysis. A revision of this code was adopted, beginning January 1, 1980, to give more detailed information about each accident. Accidents are classified and coded according to Table 1. The major categories include intersection, nonintersection (roadway sections and midblock, and bridge), interchange ramp, and miscellaneous accident types.

The distribution and use of computerized information is monitored for the Department of Transportation by the Office of Highway Safety. To aid the processing and summarizing of approximately 150,000 accident reports annually, the Kentucky Accident Reporting System (KARS) was developed. The KARS periodically generates reports such as detailed listings of accidents by location, contributing environmental factors, highway system, and rural-urban designation. A unique feature of KARS includes summary reports for 11 jurisdictions such as highway district, police district, area development district, etc. A statewide traffic volume file, created by the Divisions of Research and Traffic is being used in combination with KARS to compute accident rates. A summary of the reporting features available through KARS is given in APPENDIX A.

As an aid in the analysis of accident records, the Office of Highway Safety also maintains the "Records Analysis for Problem Identification and Definition (RAPID)" software package. This package provides a means of obtaining summaries of the accident data for a large number of variables. In-depth summaries of accident data can be obtained using the RAPID programs. A list of the variables available through RAPID is given in APPENDIX B. Also included in RAPID are an Area Identification Module (AIM), which can be used to find and analyze high accident locations, and an Area Criticality Technique (ACT), which can determine priorities among political subdivisions.

Table 1. Directional Analysis Codes (Revised 1/1/80).

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>00</td>
<td>NOT STATED</td>
</tr>
<tr>
<td>01</td>
<td>ANGLE ACCIDENT - BOTH VEHICLES GOING STRAIGHT</td>
</tr>
<tr>
<td>02</td>
<td>ANGLE ACCIDENT - ONE VEHICLE TURNING LEFT</td>
</tr>
<tr>
<td>03</td>
<td>ANGLE ACCIDENT - ONE VEHICLE TURNING RIGHT</td>
</tr>
<tr>
<td>04</td>
<td>ANGLE ACCIDENT - OTHER</td>
</tr>
<tr>
<td>05</td>
<td>REAR END - ONE VEHICLE STOPPED</td>
</tr>
<tr>
<td>06</td>
<td>REAR END - BOTH VEHICLES GOING STRAIGHT</td>
</tr>
<tr>
<td>07</td>
<td>REAR END - ONE VEHICLE TURNING LEFT</td>
</tr>
<tr>
<td>08</td>
<td>REAR END - ONE VEHICLE TURNING RIGHT</td>
</tr>
<tr>
<td>09</td>
<td>REAR END - OTHER</td>
</tr>
<tr>
<td>10</td>
<td>OPPOSITE DIRECTIONS - ONE VEHICLE TURNING LEFT, ONE GOING STRAIGHT</td>
</tr>
<tr>
<td>11</td>
<td>OPPOSITE DIRECTIONS - BOTH VEHICLES GOING STRAIGHT</td>
</tr>
<tr>
<td>12</td>
<td>OPPOSITE DIRECTIONS - OTHER</td>
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<tr>
<td>13</td>
<td>COLLISION WITH A FIXED OBJECT (SINGLE VEHICLE)</td>
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<tr>
<td>14</td>
<td>NON-COLLISION ACCIDENT (SINGLE VEHICLE)</td>
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Table 1. Directional Analysis Codes (Revised 1/1/80) (continued).

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<td>COLLISION WITH A BICYCLE</td>
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<tr>
<td>17</td>
<td>VEHICLE BACKING</td>
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<td>18</td>
<td>COLLISION WITH A NON-FIXED OBJECT OR ANIMAL</td>
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<tr>
<td>19</td>
<td>SAME DIRECTION - SIDESWIPE</td>
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<tr>
<td>20</td>
<td>OTHER INTERSECTION ACCIDENTS</td>
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II. NON-INTERSECTION ACCIDENTS

ROADWAY SECTIONS AND MID-BLOCK

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<tr>
<td>24</td>
<td>REAR END IN TRAFFIC LANE - ONE VEHICLE STOPPED</td>
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<td>25</td>
<td>REAR END IN TRAFFIC LANE - BOTH VEHICLES MOVING</td>
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<td>REAR END ON SHOULDER</td>
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<td>OTHER ACCIDENTS ON SHOULDER</td>
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<td>28</td>
<td>HEAD ON COLLISION</td>
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<td>29</td>
<td>SIDESWIPE ACCIDENT - SAME DIRECTION</td>
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<td>30</td>
<td>SIDESWIPE ACCIDENT - OPPOSITE DIRECTION</td>
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<td>31</td>
<td>ONE VEHICLE ENTERING OR LEAVING A PRIVATE DRIVeway</td>
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<td>32</td>
<td>ONE VEHICLE ENTERING OR LEAVING AN ALLEY OR PUBLIC ENTRANCE</td>
</tr>
<tr>
<td>33</td>
<td>ONE VEHICLE ENTERING PARKED POSITION (NOT IN A PARKING LOT)</td>
</tr>
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<td>34</td>
<td>ONE VEHICLE LEAVING PARKED POSITION (NOT IN A PARKING LOT)</td>
</tr>
<tr>
<td>35</td>
<td>ONE VEHICLE IN PARKED POSITION (NOT IN A PARKING LOT)</td>
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<td>36</td>
<td>MEDIAN CROSS-OVER ACCIDENT</td>
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<td>37</td>
<td>VEHICLE GOING IN WRONG DIRECTION</td>
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<td>38</td>
<td>COLLISION WITH A PEDESTRIAN</td>
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<td>COLLISION WITH A BICYCLE</td>
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<td>COLLISION WITH A NON-FIXED OBJECT (SINGLE VEHICLE)</td>
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<td>COLLISION WITH AN ANIMAL OR BIRD (SINGLE VEHICLE)</td>
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<td>RAN OFF ROADWAY (SINGLE VEHICLE)</td>
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<td>OVERTURNED IN ROADWAY (SINGLE VEHICLE)</td>
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<td>OCCUPANT FELL FROM MOVING VEHICLE</td>
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<td>46</td>
<td>OTHER ROADWAY OR MID-BLOCK ACCIDENT</td>
</tr>
</tbody>
</table>

BRIDGE RELATED ACCIDENTS

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>51</td>
<td>COLLISION WITH APPROACH GUARDRAIL</td>
</tr>
<tr>
<td>52</td>
<td>GAP BETWEEN BRIDGES</td>
</tr>
<tr>
<td>53</td>
<td>COLLISION WITH ABUTMENT</td>
</tr>
<tr>
<td>54</td>
<td>COLLISION WITH BRIDGE RAIL OR CURB</td>
</tr>
<tr>
<td>55</td>
<td>WENT THROUGH OR OVER BRIDGE RAIL</td>
</tr>
<tr>
<td>56</td>
<td>REAR END</td>
</tr>
<tr>
<td>57</td>
<td>HEAD-ON</td>
</tr>
<tr>
<td>58</td>
<td>SIDESWIPE - OPPOSITE DIRECTIONS</td>
</tr>
<tr>
<td>59</td>
<td>SIDESWIPE - SAME DIRECTION</td>
</tr>
<tr>
<td>60</td>
<td>RAN OFF ROAD AFTER LOSING CONTROL ON BRIDGE</td>
</tr>
<tr>
<td>61</td>
<td>OTHER BRIDGE RELATED ACCIDENTS</td>
</tr>
</tbody>
</table>
III. INTERCHANGE RAMP ACCIDENTS

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>COLLISION WITH A FIXED OBJECT IN GORE (SINGLE VEHICLE)</td>
</tr>
<tr>
<td>66</td>
<td>COLLISION WITH A FIXED OBJECT NOT IN GORE (SINGLE VEHICLE)</td>
</tr>
<tr>
<td>67</td>
<td>RAMP VEHICLE RAN OFF ROADWAY (SINGLE VEHICLE)</td>
</tr>
<tr>
<td>68</td>
<td>OVERTURNED ON RAMP (SINGLE VEHICLE)</td>
</tr>
<tr>
<td>69</td>
<td>OTHER SINGLE VEHICLE ACCIDENTS</td>
</tr>
<tr>
<td>70</td>
<td>REAR END - WHILE GETTING ON RAMP</td>
</tr>
<tr>
<td>71</td>
<td>REAR END - WHILE ON RAMP</td>
</tr>
<tr>
<td>72</td>
<td>REAR END - WHILE LEAVING RAMP</td>
</tr>
<tr>
<td>73</td>
<td>OTHER MULTIPLE VEHICLE ACCIDENTS - WHILE GETTING ON RAMP</td>
</tr>
<tr>
<td>74</td>
<td>OTHER MULTIPLE VEHICLE ACCIDENTS - WHILE ON RAMP</td>
</tr>
<tr>
<td>75</td>
<td>OTHER MULTIPLE VEHICLE ACCIDENTS - WHILE LEAVING RAMP</td>
</tr>
<tr>
<td>76</td>
<td>OTHER RAMP RELATED ACCIDENTS</td>
</tr>
</tbody>
</table>

IV. MISCELLANEOUS ACCIDENTS

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>ACCIDENTS IN PARKING LOTS</td>
</tr>
<tr>
<td>91</td>
<td>COLLISION WITH A TRAIN</td>
</tr>
<tr>
<td>92</td>
<td>OTHER RAILROAD CROSSING RELATED ACCIDENTS</td>
</tr>
<tr>
<td>93</td>
<td>COLLISION WITH A TOLL BOOTH</td>
</tr>
<tr>
<td>94</td>
<td>OTHER TOLL BOOTH RELATED ACCIDENTS</td>
</tr>
<tr>
<td>95</td>
<td>ALL OTHER ACCIDENTS</td>
</tr>
</tbody>
</table>

Accident Location Systems

The location of each accident must be referenced accurately to a known point or marker. Location descriptors generally in use are variations of three basic concepts:

1. route-mileage system (milepoint or reference point systems),
2. link-node system, and
3. coordinate system.

Route-mileage systems are based on milepoints or reference points. In both cases, the county and route numbers are usually given first, followed by the milepost or reference number. Mileposting begins and ends at a boundary such as county or state line, or the beginning or ending of a route. Mileposts are placed at regular intervals (such as every mile) along the highway so police officers record accidents by referencing them. Reference point systems consist of numbering landmarks along a road. Such features would include bridges, overpasses, creeks, and railroad crossings. Each system has certain advantages and disadvantages in terms of accuracy and clarity. Both are suited for use in rural areas.

Link-node or "nodal" systems involve assigning numbers to intersections and other points such as railroad crossings. An accident site is then located in terms of a distance from a node along a link. In some cases, numbers are assigned to each link, and an intersection is represented by the combination of two link numbers. Nodal systems are particularly applicable in urban areas where intersections are close together.

Coordinate systems describe a point along a road in terms of X and Y coordinates. Such systems are most applicable in states where rectangular boundary lines are common and where roads are generally in a rectangular configuration. Such a system may be applied best in rural areas where streets are not close together. Confusion may result in urban areas with closely spaced
An example of a coordinate system is the LORAN-C System, which uses radio signals to locate accidents. This system has been tested in Kentucky.

At the present time, the milepoint system is used in Kentucky to locate accidents in rural areas. The milepoints increase from the southern or western boundary (county or state lines) of a route or from the beginning point of the route if it does not cross such boundaries (1). The mileposts are generally spaced at 1-mile (1.601-km) intervals. In urban areas, mileposts are given for many accidents, but street names are also given. A large number of accidents, particularly in urban areas, occur on non-state-maintained streets where mileposts have not been placed. A link-node system is under study for implementation to improve reporting accuracy in urban areas. Jefferson and Shelby Counties were selected for trial implementation. Implementation of such a system would greatly enhance present accident location capabilities.

### Identifying Hazardous Locations

#### Norms and Criteria

To identify hazardous locations on a wide basis, accident data and traffic volumes must be available. The procedure should take into account the type of area (rural or urban), historical trends (a few months or years), length of the site, and the type of highway (two-lane, interstate, four-lane, etc.). Questions include: What size of accident data base should be used? How much weight should be given to fatal and injury accidents compared to property-damage-only (PDO) accidents? What form of priority listing should be used to select locations for future investigation? These and many other questions have been answered for Kentucky. A methodology has been developed to identify hazardous spots and sections in urban and rural areas, and to rank them in priority order for correction. Some background information and definitions are presented:

- **Spot** -- A specific, identifiable point on a highway. In rural areas of Kentucky, a spot is defined as a 0.3-mile (0.48-km) segment because the cause and result of an accident may encompass that distance. Also, a slight error in reporting accidents may result in variations of at least 0.1 mile (0.16 km) on either side of a stated point. Accidents occurring within about 200 feet (61 m) of an intersection on any approach are usually identified as an intersection spot (2, 3, 4).

- **Section** -- A length of highway or street with relatively homogeneous characteristics is considered a section. The length of a section may vary, but it is greater than 0.3 mile (0.48 km). Sections are often identified as 1.0-mile and 3.0-mile (1.6-km and 4.8-km) segments. However, uneven section lengths are also studied (2, 3, 4).

- **Intersection** -- The crossing of two major streets or highways defines an intersection for purposes of accident analysis. The intersection includes up to 200 feet (61 m) on all approaches. Intersections are identified by the two streets or route numbers.

- **Midblock** -- Midblock is considered to be a spot in an urban area. It is located by the street on which the accident occurs and the two adjacent cross-streets.

Criteria for identifying hazardous locations are based on frequency of accidents, rates, severities, or any combinations thereof. The five most commonly used methods are:

1. accident frequency,
2. accident-rate,
3. frequency-rate,
4. rate-quality control, and
5. accident severity.

The essential and basic types of data include the following:

- **Time Period** -- Time periods of one and two years have been used in Kentucky. The one-year period helps to select locations that become hazardous, and the two-year period provides the desired data stability.
However, a one-year period has been used most often in Kentucky because of ease in handling accident data.

**Accident Locations** — Accidents on posted routes in rural and urban areas are reported to the nearest 0.1-milepost. In urban or rural areas where mileposts are not available, intersection accidents are located in terms of the two intersecting streets or highways. Where a node system is used, the intersection node number would be used. Midblock accidents should be reported by the street where the accident occurred and the intersecting streets on both ends. Distance from the nearest intersection is also useful for better accuracy.

**Section Lengths** — Any section length may be used for routine searches through the accident tape. Section lengths of 1.0 and 2.0 miles (1.6 and 3.2 km) are commonly used. Spot lengths in rural areas are 0.3 mile (0.48 km).

**Traffic Volumes** — Average annual daily traffic (AADT) volumes must be available for calculation of accident rates.

**Highway Type** — In some identification methods, comparisons are made by type of highway. The highway categories used in Kentucky are:

**Urban Areas (Two Alternatives)**
- Two-lane
- Four-lane Divided
- Four-lane Undivided
- Interstate
- Parkway
- Local Streets
- Arterial.Collectors
- Freeways

**Rural Areas**
- One-lane
- Two-lane
- Four-lane Divided
- Four-lane Undivided
- Interstate
- Parkways

Data requirements for each method are given in Table 2 (2, 4). These data requirements include time period, accident

<table>
<thead>
<tr>
<th>DATA REQUIREMENTS</th>
<th>METHOD USED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TIME PERIOD</td>
</tr>
<tr>
<td>NUMBER OF ACCIDENTS</td>
<td>X</td>
</tr>
<tr>
<td>ACCIDENT RATE</td>
<td>X</td>
</tr>
<tr>
<td>NUMBER RATE</td>
<td>X</td>
</tr>
<tr>
<td>RATE-QUALITY CONTROL</td>
<td>X</td>
</tr>
<tr>
<td>SEVERITY</td>
<td>X</td>
</tr>
</tbody>
</table>
locations, section lengths, traffic volumes, average accident rates, and highway categories. All of the data are needed for the rate-quality control and frequency-rate methods. Highway categories are not necessary for the accident-rate method, and the frequency method requires only a time period and a listing of accident locations.

Criteria requirements for each method are shown in Table 3. For highway sections, the criteria are accidents per mile (1.6 km) and accidents per 100 million vehicle-miles (160 million vehicle-kilometers). For intersections and spots, number of accidents and accidents per million vehicles are used.

Following is a description of the basic methods used for identifying high-accident locations:

**Frequency of Accidents Method** -- The frequency method is the simplest and most direct. It considers only frequencies of accidents per spot or section of highway. Locations and sections with more than a predetermined number of accidents are classified as high-accident locations (5). This method is best used for street systems of small towns, local street systems of larger cities, and low-volume county roads.

The primary deficiency in using only this method is the lack of consideration for traffic volume and accident severity (2, 6). The frequency method is often used by states to select an initial set of locations, and then those locations are ranked in priority by some other method. Accident spot maps are often used to graphically plot accidents by location.

**Accident-Rate Method** -- This method involves calculation of accident rates for all spots and sections under consideration. Accident numbers are divided by vehicle exposure to give rates in terms of accidents per million vehicles (spots) or accidents per 100 million vehicle-miles (160 million vehicle-kilometers) (sections). Locations with rates exceeding predetermined levels are classified as high-accident locations (5).

To apply the rate method, traffic volumes must be known for all locations and sections under study. This method poses problems when locations with wide ranges of volumes are compared. For example, locations with an AADT of 100 or less will have a very high rate even when one accident occurred per year. A location with an AADT of 10,000 must have a very large number of accidents to have an equal accident rate.

The equation for accident rate for a

<table>
<thead>
<tr>
<th>CRITERIA MEASUREMENT UNITS</th>
<th>METHOD USED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NUMBER OF ACCIDENTS</td>
</tr>
<tr>
<td><strong>SECTIONS</strong></td>
<td>X</td>
</tr>
<tr>
<td><strong>ACCIDENTS PER MILE</strong></td>
<td>X</td>
</tr>
<tr>
<td><strong>ACCIDENTS PER 100 MVM</strong></td>
<td>X</td>
</tr>
<tr>
<td><strong>INTERSECTIONS &amp; SPOTS</strong></td>
<td>X</td>
</tr>
<tr>
<td><strong>NUMBER OF ACCIDENTS</strong></td>
<td>X</td>
</tr>
<tr>
<td><strong>ACCIDENTS PER MV</strong></td>
<td>X</td>
</tr>
<tr>
<td><strong>ACCIDENT SEVERITY</strong></td>
<td>X</td>
</tr>
</tbody>
</table>
spot location is as follows:

\[ R = \frac{(A)(1,000,000)}{365(T)(V)} \]  

in which \( R \) = accident rate at a spot in accidents per million vehicles, 
\( A \) = number of accidents for study period, 
\( T \) = period of study (years or fraction of years), and 
\( V \) = AADT during the study period (for intersections, the sum of the entering volumes on all approach legs).

For roadway sections, length becomes a consideration, and the equation becomes (2):

\[ R = \frac{(A)(1,000,000)}{365(T)(V)(L)} \]  

in which \( R \) = accident rate on the section in accidents per 100 million vehicle-miles (160 million vehicle-kilometers), and 
\( L \) = length of the roadway section (miles (1.6 kilometers)).

**Frequency-Rate Method** -- The frequency-rate method is normally applied by first selecting a large sample of high-accident locations. Accident rates are computed for those locations selected on the basis of accident frequency. This method eliminates the need to calculate accident rates for every location in the state. It also eliminates the low-volume locations with only one or two accidents per year.

This method provides greater reliability than either the frequency method or the rate method because locations must exceed criteria for both frequencies and rates. However, after the list of locations is selected using this method, there is still a problem with the ranking procedure. The low-volume locations will still tend to be ranked higher than the high-volume locations because accident rates are used for priority ranking.

**Rate-Quality Control Method** -- A variation of the rate method is the rate-quality control method. It utilizes a statistical test to determine whether the accident rate at a particular location is abnormally high compared to a predetermined average rate for locations having similar characteristics (3). The statistical tests are based on the commonly accepted assumption that accidents approximate the Poisson distribution. In this method, the accident rate at a location is compared to a critical rate, which is based on volume, average rate, and a statistical constant.

The equation for calculating the critical rate for a spot is as follows (3, 7, 8):

\[ R_c = R_a + (K)\sqrt{R_a/M} + 1/2M \]  

in which \( R_c \) = critical accident rate for a spot (accidents per million vehicles), 
\( R_a \) = average accident rate for all spots of similar characteristics or on similar road types (accidents per million vehicles), 
\( M \) = millions of vehicles passing over a spot in the study period, and 
\( K \) = a probability determined by the desired level of significance for the equation.

When highway sections are considered instead of spots, the values of \( R_c \), \( R_a \), and \( M \) are expressed in terms of 100 million vehicle-miles (160 million vehicle-kilometers). Any time period or section length (preferably 1.0 mile (1.6 km) or above) can be used in the equation. The \( K \) value is determined by the level of probability, \( P \), that an accident rate is sufficiently large that it cannot be reasonably attributed to random occurrences. The primary determinant of the constant, \( K \), is the number of hazardous locations that can be handled. Selected values of \( K \) are (3):

\[
\begin{array}{cccccc}
P & .995 & .975 & .950 & .925 & .900 \\
K & 2.576 & 1.960 & 1.645 & 1.440 & 1.232 \\
\end{array}
\]

The most commonly used \( K \) values are 2.576 (\( P = 0.995 \)) and 1.645 (\( P = 0.950 \)).

**Severity Method** -- There are numerous severity methods used in different states to identify and prioritize high-accident locations. Some states consider only injury and fatality accidents to identify locations and sections. Other states apply weighting factors to accidents based on severity and compute some form of severity index or severity number. Locations are then
ranked by the severity index or number.
Accident severities often are classified into five categories, depending on extent of injury, as follows (9):
- fatal accident - involves a fatality,
- A-type injury accident -- includes an injury that involves a bleeding wound, distorted member, or a person carried from scene,
- B-type injury accident -- includes an injury involving bruises, abrasions, swelling, or limping,
- C-type injury accident -- accident in which no visible injuries occur but in which there are complaints of pain, and
- PDO accident -- property-damage-only accident.

One of the more widely used severity indices is the equivalent-property-damage-only method (EPDO method). The formula used to calculate EPDO may vary among states and in Kentucky is as follows (9):

$$EPDO = 9.5F + 3.5A + C + PDO$$

in which EPDO = number of equivalent property-damage-only, PDO accidents,
F = number of fatal accidents,
A = number of A-type injury accidents,
B = number of B-type injury accidents,
C = number of C-type injury accidents, and
PDO = number of PDO accidents.

In this equation, each accident is classified as to the most severe injury, and an accident is counted only once. The highest possible EPDO value is 9.5. This would occur if all accidents were fatal or A-type injury accidents. The lowest possible EPDO at an accident location is 1.0. This would occur if all accidents were PDO accidents.

Procedure for Rural Highways
The basic procedure for identifying high-accident locations on Kentucky's rural highways was first developed in 1974 (3) and has remained the same; accident rates, however, have been updated. The frequency criterion is used to scan the accident tape and select spots and sections which exceed the norm. The norm for 0.3-mile (0.48-km) spots originally recommended was 5 accidents per year or 7 accidents in two years. For 1.0-mile (1.6-km) sections, this was 10 accidents per year or 15 accidents in two years. For 3.0-mile (4.8-km) sections, the criteria was 20 accidents per year or 30 accidents in two years (3). These norms were based on 1970-1972 data (10). Recently, average and critical frequencies of accidents were developed for 0.3-mile (0.48-km) spots and 1.0-mile (1.6-km) sections (for various types of highways) using 1978 accident data (11). The results for rural and urban highways are shown in Table 4. Curves giving the critical frequencies for section lengths.

Table 4. Statewide Average and Critical Number of Accidents by Highway Classification (1978 Data).

<table>
<thead>
<tr>
<th>AREA</th>
<th>HIGHWAY</th>
<th>ACCIDENTS PER 0.3-MILE SPOT</th>
<th>ACCIDENTS PER 1.0-MILE SECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(0.48 KM) AVERAGE</td>
<td>CRITICAL NUMBER</td>
</tr>
<tr>
<td>RURAL</td>
<td>ONE-LANE</td>
<td>.10</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>TWO-LANE</td>
<td>.42</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>FOUR-LANE, DIVIDED</td>
<td>1.90</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>(NO ACCESS CONTROL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FOUR-LANE, UNDIVIDED</td>
<td>3.76</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>INTERSTATE</td>
<td>1.32</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>PARKWAY</td>
<td>.33</td>
<td>3</td>
</tr>
<tr>
<td>URBAN</td>
<td>TWO-LANE</td>
<td>5.52</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>FOUR-LANE, DIVIDED</td>
<td>13.47</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>(NO ACCESS CONTROL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FOUR-LANE, UNDIVIDED</td>
<td>17.57</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>INTERSTATE</td>
<td>10.55</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>PARKWAY</td>
<td>.54</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 5. Accident Rates for Spots and Sections for Various Types of Rural Highway (1970-1972 Data).

<table>
<thead>
<tr>
<th>HIGHWAY</th>
<th>AVERAGE STATEWIDE ACCIDENT RATES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SPOTS (ACCIDENTS PER MILLION VEHICLES)</td>
</tr>
<tr>
<td>TWO- AND THREE- LANE</td>
<td>0.72</td>
</tr>
<tr>
<td>FOUR-LANE UNDIVIDED</td>
<td>0.94</td>
</tr>
<tr>
<td>FOUR-LANE DIVIDED</td>
<td>0.47</td>
</tr>
<tr>
<td>INTERSTATE AND PARKWAY</td>
<td>0.25</td>
</tr>
</tbody>
</table>

up to 20 miles (32 km) are given in APPENDIX C. The spots and sections qualifying (Table 4) are then tested by the rate-quality control method and the EPDD method. Locations must meet at least one of the criteria developed for these two methods to be eligible for field inspection (3).

The rate-quality control method first considers the type of highway on which each spot or section is located. The statewide average rates originally used in the analysis are given in Table 5 (10). Those rates were based on 1970 through 1972 data and have been updated using 1978 data (11). The rates were similar for some types of highways but increased among others. The differences in rates may be attributed to improved accident reporting rather than real increases in accident rates. These updated values are shown in Table 6 (Ra values used in Equation 3).

Interstates had the lowest rates for sections (69 accidents per 100 million vehicle-miles (160 million vehicle-kilometers); parkways had 84 accidents per 100 million vehicle-miles (160 million vehicle-kilometers). The highest rate was 357 for four-lane, undivided highways.

The critical rates for spots, as calculated using Equation 3, are shown in Figures 4 and 5. The curves are for spots

Table 6. Updated Accident Rates for Spots and Sections of Rural Highways (1978 Accident Data).

<table>
<thead>
<tr>
<th>AVERAGE STATEWIDE ACCIDENT RATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPOTS (ACCIDENTS PER MILLION VEHICLES)</td>
</tr>
<tr>
<td>ONE-LANE</td>
</tr>
<tr>
<td>TWO-LANE*</td>
</tr>
<tr>
<td>FOUR-LANE DIVIDED (NO ACCESS CONTROL)</td>
</tr>
<tr>
<td>FOUR-LANE UNDIVIDED</td>
</tr>
<tr>
<td>INTERSTATE</td>
</tr>
<tr>
<td>PARKWAY</td>
</tr>
</tbody>
</table>

* THREE-LANE ROADS HAD A VERY SMALL SAMPLE, SO THEY SHOULD BE INCLUDED IN THE TWO-LANE CATEGORY.
Figure 4. Critical accident rates for 0.3-mile (0.48-km) spots on rural, multilane highways (one-year data) ($P = 99.5$).

and are based on one year of data. A probability level of 0.995 was used.

The critical rate for sections was also computed using the rate-quality control formula (Equation 3). A graphical illustration of critical rates on two-lane highways using one year of accident data is shown in Figure 6 (3). A separate curve is given for section lengths of 1.0 mile (1.6 km) to 20 miles (32 km). As section length increases, the sample is larger, and scatter is reduced; thus, critical rates are lower. Curves are presented for AADT values of 100 to 10,000. Critical-rate curves for other types of highways are given in APPENDIX D (3).

After the critical rates are determined, rates are computed (Equations 1 and 2). To rank spots and sections, the critical rate factor of each location is found by the formula:

$$CRF = \frac{R}{Rc}$$

in which $CRF$ = critical rate factor, $R$ = accident rate, and $Rc$ = critical rate.

A location is critical when the rate factor is 1.0 or more. This means that the rate equals or exceeds the critical rate. Separate priority listings are normally made for spots and sections.

For locations that meet the frequency criteria but do not have critical rates, the EPDO value is also checked. The criteria recommended in the original report for spots were an EPDO of 12.5 for a one-year period or 21.5 for a two-year period. For 1.0-mile (1.6-km) sections, the EPDO criteria were 25 for one year or 40 for two years. For 3.0-mile (4.8-km) sections, the EPDO criteria were 50 for one year or 75 for two years. The updated (1978) values for rural and urban highways are shown in Table 7 (11). Curves giving the critical EPDO for section lengths up to 20 miles (32 km) are given in APPENDIX C.

The source deck for the computer program which determines high-accident locations is given in APPENDIX E. The procedure described here applies to highways posted with route markers and mileposts. A matching process is used to identify high-accident locations on other highways. A frequency cutoff is selected and roads with more accidents than the cutoff value are listed. The procedure does not consider length of the roadway.

Figure 5. Critical accident rates for 0.3-mile (0.48-km) spots on rural, one- and two-lane roads (one-year data) ($P = 99.5$).

Figure 6. Critical accident rates for rural, two-lane, highway sections (one-year data) ($P = 99.5$).
Table 7. Statewide Average and Critical Number of EPDO Accidents by Highway Classification (1978 Data).

<table>
<thead>
<tr>
<th>AREA</th>
<th>HIGHWAY</th>
<th>EPDO ACCIDENTS PER 0.3-MILE (0.48-KM) SPOT</th>
<th>EPDO ACCIDENTS PER 1.0-MILE (1.6-KM) SECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AVERAGE CRITICAL NUMBER</td>
<td>AVERAGE CRITICAL NUMBER</td>
</tr>
<tr>
<td>RURAL</td>
<td>ONE-LANE</td>
<td>.24</td>
<td>.81</td>
</tr>
<tr>
<td></td>
<td>TWO-LANE</td>
<td>1.02</td>
<td>3.39</td>
</tr>
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and it depends on road names being spelled correctly.

Procedures for City Streets

The original procedure for identifying hazardous locations on city streets was developed in 1975 (12). The procedure basically used the frequency criteria and the rate-quality control method for intersections and midblocks on arterial-collector streets. Freeway sections were also identified. Local streets were not included. However, it became evident this method of identifying urban locations by intersection or midblock and population group would not be the most efficient method under the current information storage format. Since a uniform accident reporting law has been implemented, both rural and urban accident data became available on computer tape. Therefore, when the rural accident rates were updated with 1978 data, rates were also calculated for urban locations (11). It was then possible to identify hazardous locations on urban streets using the same method as for rural highways. While this procedure is being used for urban areas, the original procedure provides an alternate method. A summary of that methodology follows.

Original Urban Procedure -- Cities with over 2,500 population were considered urban areas (12). The 1975 study identified 97 such cities. For cities in each population group, the average frequency of midblock and intersection accidents on arterial and collector streets were determined. Based on these averages, the critical frequency of accidents for each location was determined
based on a form of the rate-quality control formula. These critical frequencies were the criteria used initially to identify high-accident locations. For intersections, the criteria for a one-year period ranged from 19 (Group 1 cities; population over 200,000) to 4 accidents (Group 6 cities, population 2,500 to 5,000). After the midblocks and intersections were identified based on frequencies, the rate-quality control formula was applied. Average rates for midblocks and intersections on arterial-collector streets for each city size were determined. In a report identifying problem areas for Kentucky's Highway Safety Plan, rates by population category were calculated and cities with rates above critical were identified (13). The 1978 accident analysis also provided rates for several cities (11). For urban freeway sections, average and critical frequencies were determined. Critical frequency curves were determined for cities containing freeways in two population groups. All sections, midblocks, and intersections would then be ranked based on critical rate factor. Locations in various cities may also be compared based on critical rate factor.

A flow chart for the current procedure used to identify high-accident locations in urban areas based on accident rates is the same as for rural highways. The only difference is the values for frequencies, rates, and EPDO accidents used as criteria. Average and critical frequencies for 0.3-mile (0.48-km) spots and 1.0-mile (1.6-km) sections for urban highways were given in Table 4. Also, curves giving the critical frequencies for section lengths up to 20 miles (32 km) are given in APPENDIX C.

Spots and sections qualifying are then tested by the rate-quality control and EPDO methods. Statewide accident rates for urban spots and sections were calculated from 1978 data (Table 8) (11). Critical rates for spots were calculated as before using Equation 3. Curves giving these rates by AADT are given in Figure 7. Critical rates for sections were calculated as a function of section length and AADT. For example, the curves for four-lane, undivided streets are given in Figure 8. The curves for other urban highway sections are given in APPENDIX F.

Average and critical number of EPDO accidents for 0.3-mile (0.48-km) spots and 1.0-mile (1.6-km) sections for urban highways are given in Table 7. These can be used in the EPDO method. Also, curves giving the critical frequencies for section lengths up to 20 miles (32 km) are given in APPENDIX C.

As with rural highways, a matching procedure is used to identify high-accident locations on streets without route numbers and mileposts.

It should be noted that both rural and urban locations are identified on the

| Table 8. Accident Rates for Spots and Sections of Urban Highways (1978 Accident Data). |
|----------------------------------------|----------------------------------------|
| **HIGHWAY** | **AVERAGE STATEWIDE ACCIDENT RATES** | **SECTIONS** |
|             | **SPOTS** (ACCIDENTS PER MILLION VEHICLES) | **SECTIONS** (ACCIDENTS PER 100 MILLION VEHICLE MILES) |
| TWO-LANE    | 2.25 | 751 |
| FOUR-LANE DIVIDED (NO ACCESS CONTROL) | 1.97 | 656 |
| FOUR-LANE UNDIVIDED | 2.74 | 911 |
| INTERSTATE  | 0.63 | 227 |
| PARKWAY     | 0.31 | 101 |
investigating hazardous locations

after high-accident locations are identified and ranked, a detailed investigation of the sites ensues. the procedures involve the following (4):

1. preparing collision diagrams,
2. summarizing accident characteristics,
3. conducting field observations, and
4. selecting specific improvements.

collision diagrams

collision diagrams are used to analyze accident patterns. they include schematic drawings of accidents along with such information as (4):

1. location description,
2. general layout of location,
3. time and date of each accident,
4. severity of each accident,
5. pavement condition during each accident (wet, dry, or icy),
6. weather condition during accident,
7. paths of vehicles involved, and
8. traffic control devices present.

a sample diagram is shown in figure 9. the form was developed by the division of traffic.

figure 7. critical accident rates for 0.3-mile (0.48-km) spots on urban highways (one-year data) (p = 99.5).

rates have been determined. this program may be further expanded to identify locations which have had a critical frequency or rate of a certain type of accident.

figure 8. critical accident rates for urban, four-lane, undivided highway sections (one-year data) (p = 99.5).

investigating hazardous locations

after high-accident locations are identified and ranked, a detailed investigation of the sites ensues. the procedures involve the following (4):

1. preparing collision diagrams,
2. summarizing accident characteristics,
3. conducting field observations, and
4. selecting specific improvements.

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1. location description,
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3. time and date of each accident,
4. severity of each accident,
5. pavement condition during each accident (wet, dry, or icy),
6. weather condition during accident,
7. paths of vehicles involved, and
8. traffic control devices present.

a sample diagram is shown in figure 9. the form was developed by the division of traffic.

figure 9. intersection collision diagram.
The accident analysis is used to determine the type of safety improvement needed. Factors related to the driver, such as the type of driver error, and the vehicle, such as vehicle defects, may be studied in addition to the roadway factors. Road surface conditions, lighting, sight restrictions, and existing traffic control devices may be considered.

Condition Diagrams

A condition diagram is a scalar map showing many of the physical features of the location. Features such as roadway and shoulder widths, view obstructions, grades, traffic control, lighting, curbs, sidewalks, parking, and driveways may be shown. A condition diagram is sometimes used to assist in the selection of safety improvements whenever field inspection is not possible (8). It also can be used as a reference in the office to check dimensions, distances, etc., after the field inspection has been made. Photographs may be used as a permanent record of conditions. An example of a condition diagram is given in Figure 10. No specific form is used for drawing a condition diagram. Entries may describe conditions up to 200 feet (61 m) from major approaches.

Traffic Data Collection

To properly evaluate problems at intersections or other locations, traffic speeds, vehicle delays, volumes, and vehicle types may be helpful in selecting an appropriate safety improvement. Speed studies are particularly helpful in analyzing accidents at intersections and on sharp curves. Data are collected using a radar meter with digital readout. Speeds are recorded separately for cars and trucks on data forms shown in Figure 11. Size of the data set should be at least 100 vehicles, and may be determined more specifically based on statistical tests given by Pignataro (14).

Volume information is routinely collected by the Division of Highway Systems for most state-maintained roads and other selected roads. Such volume data are available on state AADT maps and in tabular form. A computerized, state-wide volume file is also available. For more specific volume counts by vehicle classification, a special form is used (Figure 12). For recording vehicle turning movements at intersections, another form is available (Figure 13).

Delay studies are useful in analyzing problems at urban intersections. One method of counting stopped-time delay is to time each vehicle from stopping to clearing the stop bar. However, at high-volume intersections, the procedure normally used involves counting the number of vehicles stopped on each intersection approach at periodic intervals (each 15 or 20 seconds). By multiplying the number of stopped vehicles by the time interval used, the approximate stopped-time delay can be found. The form shown in Figure 14 is used to collect the data.

Conflict Analysis

Traffic conflicts may be observed at a location to provide valuable information concerning driver confusion or error. A
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COMMENTS:

Figure 12. Vehicle classification volume count data sheet.
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Weather: ____________ Computer: ____________

Remarks: _______________________________________________________________________

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**TOTALS**

Figure 13. Intersection vehicular volume distribution summary.
conflict occurs when a driver commits a violation or makes an evasive action such as braking or weaving to avoid colliding with another vehicle or pedestrian. Types and frequencies of conflicts are measures of accident potential and operational problems. Many highway agencies are now using conflict data to complement accident data (15). Conflict counts enable a quick evaluation of changes in road design, signing, signalization, and other elements. The first formalized procedure for identifying and recording traffic conflicts at intersections was developed by Perkins and Harris of General Motors Corporation in 1967 (16). The use of conflict analysis techniques has been limited primarily to intersections.

However, procedures for analyzing other types of locations are under development (15).

Major types of conflicts at intersections include rear-end, left-turn, cross-traffic, red-light violation, and weave conflicts. Erratic maneuvers have also been used along with conflicts. An erratic maneuver is any sudden, unexpected movement by a vehicle that could result in an accident. An erratic maneuver differs from a conflict in that it usually involves only one vehicle committing an unsafe movement independent of any other vehicle. Whereas traffic conflict counts usually indicate the potential for accidents between two or more vehicles, erratic maneuver counts may provide information about the potential for single-vehicle accidents. A near-miss accident occurs when a collision between two or more vehicles is avoided due to a last-second evasive movement or stop. A near-miss accident is a very severe type of conflict or erratic maneuver; relatively few near-miss accidents may be observed at any location when compared to the number of conflicts or erratic maneuvers (15).

A procedure was developed for the systematic collection of traffic conflict data at intersections. The procedure is based on the General Motors Corporation procedure, but includes modifications in conflict types and data collection times (15, 16). A complete description of Kentucky's conflict procedure along with data forms and conflict definitions is given in Appendix G.

A current study involves relating accidents and conflicts at intersections. A revised intersection conflict data sheet was developed for that study and is also included in APPENDIX G (Figure G9).

The concept of a conflict diagram also has been introduced for use in a similar way as an accident diagram (15). Whereas an accident diagram shows only reported accidents (perhaps less than 50 percent of all accidents), a conflict diagram provides valuable information of near-accidents or potential accidents. An example of a conflict diagram is shown in Figure 15. The number of occurrences of each conflict type is given on each sketch. Moderate or severe conflicts are given in parenthesis.
Field Inspections

Locations found to be hazardous based on accident experience are inspected by a multidisciplinary team consisting of traffic engineers, maintenance engineers, police, and representatives of the appropriate highway district. Physical attributes of the location are studied along with other information such as collision diagrams, volume data, speed data, and delay information. Traffic flow is observed to detect any noticeable driver error or confusion. Recommendations for safety improvements are made by the investigative team.

Selecting Improvements

The selection of improvements must be made with the entire highway system in mind. For example, if changes in signal timing at an intersection are recommended, the effect of this change on adjacent signals must be known in terms of signal coordination and traffic flow. Care should be taken, for example, when reconstructing a section of road so no abrupt geometric changes will be introduced.

Based on eight specific types of accidents, a listing of suggested corrections at hazardous locations has been prepared (14). This listing is a guide for traffic engineers to select improvements for the reduction of specific accident types. This listing is given in APPENDIX H.

Several important points should be remembered when selecting highway improvements (4):

1. Identify all practical improvements -- everything from the do-nothing alternative to the ultimate improvement such as major reconstruction. Several alternatives can be considered in the economic analysis which will point to the best solution.
2. Identify all realistic combinations of improvements.
3. Identify the expected effect of all improvement combinations on all accidents (types and severities). This input is used for budgeting the safety improvements.

Figure 15. Conflict diagram at Euclid Avenue and Woodland Avenue intersection (Lexington).
Budgeting Safety Improvements

To budget safety improvements to yield the greatest benefit, an economic evaluation requires the input of construction and maintenance costs and benefits to be derived from accident reduction and other sources. The expected benefits and costs may then be compared by some method such as benefit-cost analysis, and project ranking and selection may be ordered by dynamic programming.

Estimates are to be made of benefits and costs for each improvement proposed. An economic analysis, of course, is only as reliable as the estimates of benefits and costs. Based on 447 improvements in Kentucky, average service lives, annual maintenance costs, and percentage reduction in accidents were determined and used as cited in Table 9 (17). Those improvements included 12 different types at intersections, 7 types for curves, and 19 general improvements. Annual maintenance costs varied from zero for renewable improvements such as pavement markings to $500 for highway lighting. Service lives of improvements ranged from 2 years for markings to 20 years for highway realignment projects. Accident reduction varied widely by improvement type and was highest (40 percent) for the installation of regulatory signs.

Dynamic programming (17) is an optimization technique that transforms a multistage decision problem into a series of one-stage decision problems. There are three main reasons why dynamic programming is used. First, it is designed to provide the best plan over a period of time. Second, it is possible to obtain the best combination of projects. Third, it yields an optimal investment plan when the usual benefit-cost, present worth, or maximum rate of return approaches are not practical. When the amount of money required for a single project is a large portion of the budget, the best set of projects does not necessarily consist of those which would be chosen by the conventional means of priority selection.

Detailed knowledge of the mechanics of dynamic programming is not required to implement a program. The input consists only of the costs and benefits anticipated for each project along with the time required for completion. Dynamic programming, by taking every possible combination of projects into account, avoids the possibility of missing much needed projects. The program currently used was developed in 1974 (17). It is based partly on Alabama’s CORRECT system (18, 19). Dynamic programming has also been used in the selection of projects for resurfacing (20).

To calculate benefits, an interest rate must be selected -- 10 percent has been commonly used. A traffic growth factor must be determined or assumed (about 5 percent is normally used). Costs of fatalities, injuries, and property damage must be inputted into the model. National Safety Council costs are used. Accident costs for 1979 are given below:
1. Fatality = $160,000
2. Injury = $6,200
3. Property-damage = $870

Table 9. Summary of Improvement Cost and Benefits.

<table>
<thead>
<tr>
<th>TYPE OF IMPROVEMENT</th>
<th>NUMBER OF PROJECTS</th>
<th>TOTAL ACCIDENT REDUCTION (PERCENT)</th>
<th>SERVICE LIFE (YEARS)</th>
<th>ANNUAL MAINTENANCE COST ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signs and Markings</td>
<td>9</td>
<td>36</td>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td>Warning Signs</td>
<td>23</td>
<td>35</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Regulatory Signs</td>
<td>16</td>
<td>22</td>
<td>3</td>
<td>35</td>
</tr>
<tr>
<td>Geometric Signs</td>
<td>10</td>
<td>14</td>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td>Sign Combinations</td>
<td>16</td>
<td>30</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Markings</td>
<td>8</td>
<td>16</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Sight Distance Imp.</td>
<td>9</td>
<td>28</td>
<td>3</td>
<td>50</td>
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<tr>
<td>Post Delinaments</td>
<td>3</td>
<td>25</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>Comb. Delinements, Markings</td>
<td>11</td>
<td>22</td>
<td>3</td>
<td>25</td>
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<tr>
<td>Signs, Maintenance</td>
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<tr>
<td>Shoulder Improvements</td>
<td>7</td>
<td>23</td>
<td>10</td>
<td>100</td>
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<tr>
<td>Comb. Resurf. Patching</td>
<td>22</td>
<td>15</td>
<td>10</td>
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<tr>
<td>Drainage, Guardrail</td>
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<tr>
<td>Rumble Stops</td>
<td>3</td>
<td>29</td>
<td>5</td>
<td>20</td>
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<tr>
<td>Remove Median Crossings</td>
<td>2</td>
<td>29</td>
<td>20</td>
<td>0</td>
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<tr>
<td>Lighting</td>
<td>1</td>
<td>28</td>
<td>10</td>
<td>500</td>
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<tr>
<td>Lighting &amp; Rumble Strips</td>
<td>1</td>
<td>17</td>
<td>7</td>
<td>100</td>
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<tr>
<td>Rumble Stops &amp; Beacon</td>
<td>2</td>
<td>32</td>
<td>7</td>
<td>50</td>
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<tr>
<td>Side Road Sign Only</td>
<td>31</td>
<td>19</td>
<td>5</td>
<td>25</td>
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<td>Prepare for Hidden Stop Sign Only</td>
<td>19</td>
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<td>Sign Group</td>
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<td>Comb. Delinements, Markings</td>
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<tr>
<td>Signs, Maintenance</td>
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<tr>
<td>Resurfacing, Patch, Drainage, Guardrail</td>
<td>32</td>
<td>33</td>
<td>10</td>
<td>100</td>
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<tr>
<td>Realignment (Relocate)</td>
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<td>12</td>
<td>10</td>
<td>100</td>
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<tr>
<td>Resurfacing, Patch, Drainage, Guardrail</td>
<td>32</td>
<td>33</td>
<td>10</td>
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<td>Sign Group</td>
<td>21</td>
<td>24</td>
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<tr>
<td>Warning Signs</td>
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<td>48</td>
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<td>Cerfication, Storage Lane</td>
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<tr>
<td>Channelization &amp; Signs</td>
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<tr>
<td>Install Beacons</td>
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<tr>
<td>Upgrade Beacons</td>
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<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Install Signals</td>
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<td>23</td>
<td>10</td>
<td>300</td>
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<tr>
<td>Upgrade Signals</td>
<td>2</td>
<td>18</td>
<td>10</td>
<td>250</td>
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Total Improvements: 447
The number of accidents in a chosen period of time at each location is multiplied by the expected percentage reduction of accidents for each improvement alternative. The annual benefits are then multiplied by an exponential growth, present-worth factor to obtain the present-worth benefits for the entire service life of the improvement.

The costs are the sum of the improvement cost and the maintenance cost for each project. A present-worth factor is used to adjust the maintenance costs at a future date to the present.

It is very difficult to estimate benefits and costs. Even with a large sample of before-and-after data for similar locations and improvements, accident reduction estimates may be inaccurate. This is attributable in part to differences in characteristics of seemingly similar highway locations. Spuriousness in accident occurrences contributes to the uncertainty in predicting future accidents. Predictions of reductions should be based on large data samples and be guided by engineering judgments. If benefit and cost inputs are carelessly or incorrectly estimated, results of dynamic programming will be equally in error.

One type of output from the dynamic programming model is presented in Table 10. This listing is by location number (1 to 61) and includes coded location information (county, route, and milepost), alternative number (1 to 7), project cost, dollar return (accident benefit), and benefit-cost ratio. After dynamic programming is constrained within a specified budget, projects are selected as shown in Table 11. This printout includes the projects selected and cites projects not selected due to insufficient funds (coded 0). The costs and returns are also cited there for each project along with totals (bottom of page) and accumulated returns. A copy of the computer program, a listing of variables, the input coding instructions, and other information necessary to implement the program have been provided in a previous report (17). The source deck for the dynamic programming program, however, is provided in APPENDIX I.
Evaluation of Improvements

After improvements are completed, an analysis may be made to evaluate the effectiveness of the improvements. This analysis involves a comparison of before and after data to determine what changes have occurred. Primarily, the evaluation involves an accident analysis; however, other evaluation criteria may also be applied.

Accident Studies

Comparison of before and after accidents shows the effectiveness of the...
improvements in reducing accidents. Also, the reductions may be used to improve predictions of the benefits to be derived from specific types of improvements. The basic data needed is a summary of accidents for at least a 1-year period before and after the improvement was completed. Two years of before data, of course, provide more reliable results than one year of data (9). A summary of accidents by location may be obtained using the Kentucky Accident Reporting System (KARS). However, it may be necessary to perform manual searches to ensure that all accident reports are being counted. Either a copy of each accident report may be obtained and used, or the accident information may be entered onto an accident report form developed by the Division of Traffic (Figure 16).

KENTUCKY DEPARTMENT OF TRANSPORTATION DIVISION OF TRAFFIC ACCIDENT REPORT FORM

<table>
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<th>Date</th>
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1. **DATE OF ACCIDENT** | **DAY OF WEEK** | **TIME OF DAY OF ACCIDENT**

2. **LOCATION OF ACCIDENT**

   Route/Street ____________________________ Mile Post ____________________________

   At Intersection with ____________________________ Route/Street ____________________________

3. **VEHICLE TYPE AND DIRECTION OF TRAVEL**

   Vehicle 1 ____________________________ headed N E S W on ____________________________

   Vehicle 2 ____________________________ headed N E S W on ____________________________

4. **TYPE OF ACCIDENT**

   - [ ] Head on
   - [ ] Sideswipe
   - [ ] Rear End
   - [ ] Right Angle
   - [ ] Left Turn
   - [ ] Fixed Object
   - [ ] Pedestrian
   - [ ] Other

5. **VISIBILITY**

   - [ ] Daylight
   - [ ] Night
   - [ ] Dusk
   - [ ] Fog
   - [ ] Rain
   - [ ] Other

6. **ROAD SURFACE**

   - [ ] Dry
   - [ ] Wet
   - [ ] Ice
   - [ ] Snow
   - [ ] Other

7. **CAUSE OF ACCIDENT**

   - [ ] Followed Too Closely
   - [ ] Inattentive
   - [ ] Excessive Speed
   - [ ] Ran Red Signal
   - [ ] Failed to Yield
   - [ ] Drove While Intoxicated
   - [ ] Ran Stop Sign
   - [ ] Passed Improperly
   - [ ] Turned Improperly
   - [ ] U Turn
   - [ ] Mechanical Failure
   - [ ] Failed to Signal
   - [ ] Jay Walked
   - [ ] Other

8. **REMARKS CONCERNING CAUSE OF ACCIDENT**

   CIRCLE ONE

   - [ ] POO
   - [ ] INJ
   - [ ] FATAL

---

Data Collected by ____________________________ Report Prepared by ____________________________

Figure 16. Accident report form, Division of Traffic, Kentucky Department of Transportation.
A "Location Improvement Worksheet" has been developed (Figure 17). Before and after data are summarized. Traffic volumes are entered so rates may be calculated and compared. The percentage reduction in accidents is also determined. Finally, an economic analysis is performed in terms of a benefit-cost ratio as shown in Figure 17. It is generally recognized that a ratio of one or greater means that the improvement was a worthy one.

A statistical evaluation may be made by application of the Chi-Square and Poisson distributions. Curves for determining the statistical significance of accident reduction are given in Figure 18 (21). The information needed is the number of accidents before improvement and the reduction after the improvement. The actual reduction may then be compared to the reduction required (Figure 18) to be significant. The curves are for a 95-percent level of confidence that the reduction was significant. This means there is only a five-percent probability the reduction occurred merely by chance. Depending on the reliability of the accident data, one of the two curves in Figure 18 may be selected for use. The Poisson distribution may be used when two or more years of accident data are available for the before period (22).

More detailed accident analyses may be performed. A common analysis is to compare the severity of the before and after accidents. The frequency or percentage of injury or fatal accidents may be compared. The severity index may also be used (9). A comparison between specific types of accidents may also be performed (a safety improvement could affect various types of accidents differently). Other analyses could include comparisons of various pavement surface conditions, light conditions, and other contributing factors.

Other Evaluations
In addition to detailed analyses and calculations of benefit-cost ratios, other criteria may be applied to the evaluation of safety improvements. Other criteria are given in Table 12. Accidents and benefit-cost ratios have been the primary criteria. An analysis of traffic speeds could include comparison of the average speed, 85th percentile speed, and 10-mph (4.5-m/s) pace. Conflicts and erratic maneuvers may be observed to find those conflicts and maneuvers that may be affected by the improvements. An analysis of delays and volumes may be useful after installation of a traffic signal. Brake applications have been used to evaluate improvements such as delineation of stop approaches. Encroachments and lateral

Figure 17. Location improvement worksheet.

![Figure 18. Curves for determining the statistical significance of accident reduction.](image-url)

<table>
<thead>
<tr>
<th>PRIMARY ACCIDENTS</th>
<th>BENEFIT-COST RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTHER SPEEDS</td>
<td>TRAFFIC CONFLICTS</td>
</tr>
<tr>
<td>CRITERIA</td>
<td>ERRATIC MANEUVERS</td>
</tr>
<tr>
<td></td>
<td>DELAYS</td>
</tr>
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<td></td>
<td>VOLUMES</td>
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<tr>
<td></td>
<td>CAPACITY</td>
</tr>
<tr>
<td></td>
<td>BRAKE APPLICATIONS</td>
</tr>
<tr>
<td></td>
<td>ENCROACHMENTS</td>
</tr>
<tr>
<td></td>
<td>LATERAL PLACEMENT</td>
</tr>
<tr>
<td>ENVIRONMENTAL</td>
<td>(NOISE LEVELS AND AIR QUALITY)</td>
</tr>
</tbody>
</table>

Placement have been used to evaluate improvements at curves. Also, evaluations of traffic signal systems have included an analysis of noise levels and air quality in addition to delays, volumes, capacity, and accidents.

Program Evaluation

In addition to an evaluation of individual safety improvements, an evaluation of the entire program may be useful. A previous report cited an evaluation of the high-accident spot-improvement program in Kentucky (9). Such an evaluation would determine the overall effectiveness of the program. A determination of the type of improvements made and a comparison of the benefits derived from the various safety improvements may be highly desirable.

References

Appendix A.

REPORTING FEATURES OF THE KENTUCKY ACCIDENT REPORTING SYSTEM
KARS Reporting Features

ON-LINE INQUIRIES -- Response given on CRT's
MASTER CASE NUMBER -- Allows access to any
specified accident report. Normally used in
conjunction with the Location Inquiry Report
(R-1346) to determine if additional in-depth
investigation is necessary.

LOCATION INQUIRY -- Provides inquiry by
roadway section or by intersection. This
report is identical to the first 80 print
positions of Report R-1346.

BATCH REPORTS -- Response provided by printout.
R-1340X -- DETAIL LISTING OF ALL ACCIDENTS BY
LOCATION -- Provides a detail listing of all
accidents by route number or street name.

R-1341X -- DETAIL LISTING OF ALL ACCIDENTS
WITH CONTRIBUTING ENVIRONMENTAL FACTORS --
This report identifies accident locations
where the roadway environment was a causitive
or contributing factor to the accident.

R-1342 and R-1343 -- ACCIDENT BUILDUP LISTING
-- These reports are used to aid in
identifying high-accident locations.

R-1344 -- AID SYSTEM ACCIDENT SUMMARY -- This
report summarizes accidents by AID Systems.
It is used to satisfy annual federal
reporting requirements.

R-1345X -- AGENCY ACCIDENT SUMMARY -- This
report is used to determine accident activity
by specific police agency.

R-1346 -- SELECTED LOCATION DETAIL LISTING --
This report identifies certain
characteristics of all accidents within a
specified time period at a particular
location or roadway section (route, street,
or intersection) to aid in surveillance of
high-accident locations.

R-1347 -- DETAIL ACCIDENTS BY AGENCY -- This
report is used to determine accident activity
by agency. It is sent to local police
departments for use in Selective Enforcement
Programs and is used by the Office of Highway
Safety in determining federal grant
approvals.

*Reports R-1340, R-1341, and R-1345 may be run by
any of the the following eleven political
jurisdictions or subsets of these jurisdictions.
The R-1341 may be run by "all" highway districts
or by an individual "highway" district. If it is
run by "all", the entire state would be provided,
collated by highway district. If it is run by a
particular district, only the counties associated
with that district would be provided.

1. County
2. Highway District
3. State Police Post
4. Area Development Districts
5. Emergency Medical Service (E.M.S.)
   Districts
6. Disaster Areas
7. Judicial Districts
8. State Senatorial Districts
9. State Legislative Districts
10. U. S. Congressional Districts
11. Sheriff's Districts
Appendix B.

LIST OF VARIABLES FOR THE "RECORDS ANALYSIS FOR PROBLEM IDENTIFICATION AND DEFINITION (RAPID)" SOFTWARE PACKAGE
<table>
<thead>
<tr>
<th>Number</th>
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<tbody>
<tr>
<td>1</td>
<td>County</td>
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<td>Disaster Emergency Service</td>
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<td>Incorporated City Name</td>
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<td>Accident Month-Day</td>
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<td>Accident Day of Week</td>
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<td>Accident Time of Day</td>
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<td>13</td>
<td>Occurrences by Number of Units Involved</td>
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<td>Occurrences by Number Killed</td>
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<td>Occurrences by Number Injured</td>
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<td>State, Local, Lot, etc.</td>
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<td>Lane Use-Locality</td>
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<td>Number of Traffic Lanes</td>
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<td>Roadway Surface Type</td>
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<td>Character of Roadway</td>
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<td>Weather Conditions</td>
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<td>Photos Taken at Scene</td>
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<td>Lapsed Time Notified to Arrival</td>
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<td>Unsafe Speed a Factor</td>
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<td>Fail to Yield Right of Way a Factor</td>
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<td>Following Too Close a Factor</td>
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<td>Improper Passing a Factor</td>
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<td>Disregard Traffic Controls a Factor</td>
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56 Improper Turn a Factor
57 Alcohol a Factor
58 Drugs a Factor
59 Sickness a Factor
60 Falling Asleep a Factor
61 Loss of Consciousness a Factor
62 Driver Inattention a Factor
63 Distractions a Factor
64 Physical Disability a Factor
65 Other Human Factors Involved
66 Vehicular Contributing Factors Involved
67 Defective Brakes a Factor
68 Defective Headlights a Factor
69 Other Lighting Defects a Factor
70 Defective Steering a Factor
71 Tire Failure-Inadequate Tires a Factor
72 Defective Tow Hitch a Factor
73 Overload-Improper Load a Factor
74 Oversized Load a Factor
75 Other Vehicular Factors Involved
76 Environmental Factors Involved
77 Animal Actions a Factor
78 Glare a Factor
79 Obstructed or Limited View a Factor
80 Debris in Roadway a Factor
81 Improper-Nonworking Traffic Control a Factor
82 Defective Shoulders a Factor
83 Holes, Deep Ruts, Bumps a Factor
84 Road Construction-Maintenance a Factor
85 Improper Parked Vehicle a Factor
86 Fixed Objects a Factor
87 Slippery Surface a Factor
88 Waterpooling a Factor
89 Other Environmental Factors Involved
90 Type of Vehicle Unit 1
91 Type of Vehicle Unit 2
92 Type of Vehicle Unit 3
93 Pre-Accident Vehicle Action Unit 1
94 Pre-Accident Vehicle Action Unit 2
95 Pre-Accident Vehicle Action Unit 3
96 Type of Accident-2nd Event Unit 1
97 Type of Accident-2nd Event Unit 2
98 Type of Accident-2nd Event Unit 3
99 Human Contributing Factor Unit 1
100 Human Contributing Factor Unit 2
101 Human Contributing Factor Unit 3
102 Vehicular Contributing Factor Unit 1
103 Vehicular Contributing Factor Unit 2
104 Vehicular Contributing Factor Unit 3
105 Environmental Contributing Factor Unit 1
106 Environmental Contributing Factor Unit 2
107 Environmental Contributing Factor Unit 3
108 Number of Occupants Unit 1
109 Number of Occupants Unit 2
110 Number of Occupants Unit 3
111 Vehicle Make Unit 1
112 Vehicle Make Unit 2
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Appendix C.

CRITICAL FREQUENCY OF TOTAL AND EPDO ACCIDENTS
Figure C1. Critical Frequency of Accidents on Rural Highways by Classification and Length of Highway.

Figure C2. Critical Frequency of Accidents on Urban Streets by Classification and Length of Street.
Figure C3. Critical Frequency of EPDO Accidents on Rural Highways by Classification and Length of Highway.

Figure C4. Critical Frequency of EPDO Accidents on Urban Streets by Classification and Length of Street.
Appendix D.

CRITICAL ACCIDENT RATES FOR RURAL HIGHWAY SECTIONS
Figure D1. Critical Accident Rates for Rural, One-Lane Highway Sections (One-Year Data) (P=99.5).

Figure D2. Critical Accident Rates for Rural, Two-Lane Highway Sections (One-Year Data) (P=99.5).
Figure D3. Critical Accident Rates for Rural, Interstate Highway Sections (One-Year Data) (P=99.5).

Figure D4. Critical Accident Rates for Rural, Four-Lane, Divided Highway Sections (One-Year Data) (P=99.5).
Figure D5. Critical Accident Rates for Rural, Four-Lane, Undivided Highway Sections (One-Year Data) (P=99.5).

Figure D6. Critical Accident Rates for Rural, Toll Road, Highway Sections (One-Year Data) (P=99.5).
Appendix E.

HIGH-ACCIDENT LOCATION PROGRAM SOURCE DECK
THE PURPOSE OF THIS PROGRAM IS TO LOCATE HIGH ACCIDENT AREAS IN KENTUCKY'S RURAL HIGHWAYS.

FILE: ACCIDENT SEVERITY.

THE NUMBER OF ACCIDENTS OCCURRING AT A LOCATION.

COUNTER FOR INCAPACITATING ACCIDENTS.

COUNTER FOR NONINCAPACITATING ACCIDENTS.

COUNTER FOR POSSIBLE INJURY ACCIDENTS.

THE SECTION LENGTH UP HIGHWAY TO BE INVESTIGATED, FOR DISPLAY PURPOSES.

COUNTER FOR FATAL ACCIDENTS.

J

USED AS A SUBSCRIPT.

THE SECTION LENGTH UP HIGHWAY TO BE INVESTIGATED, FOR USE BY THE PROGRAM.

COUNTER FOR PROPERTY DAMAGE ONLY ACCIDENTS, WHICH INCLUDES THOSE NOT NOTED.

THE HIGHEST VIE-WDIST LIMIT WHICH IS COMPUTED BY A TASKING A CONSTANT, IN THIS CASE 0.2 TO THE MILEPOST.

LEAST NUMBER OF LANES.

STORED COUNTY CODE.

STORED MILEPOST.

STORED ROUTE.

NUMBER OF ACCIDENTS NECESSARY TO IMPLEMENT A CRITICAL ACCIDENT.

ESTIMATED PROPERTY DAMAGE ONLY.

EJECT.

FILE DIVISION.

ENVIROMENT DIVISION.

CONFIGURATION SECTION.

FILE SEARCH COMPUTER, IBM-370.

INPUT-OUTPUT SECTION.

FILE-CONTROL.

SELECT CARDB FILE ASSIGN TO UT-SYSIN.

SELECT CARDB FILE ASSIGN TO UT-3SYSADD.

SELECT MACH FILE ASSIGN TO UT-3SYSADD.

DATA DIVISION.

FILE SECTION.

Skip.

This program checks the data prepared by the

RHS600J and searches it to find critical

locations. The selection of these locations is
determined by the ONE-CARD FILE card. This card
GIVES THE LENGTH OF A SECTION TO BE INVESTIGATED
AND THE NUMBER OF ACCIDENTS NECESSARY TO EXHIBIT
A CRITICAL LOCATION. (GOING INSTRUCTIONS FOR
THIS CARD IS GIVEN IN THE DATA ENTRY SECTION BE-
LOW.) WHEN A HIGH ACCIDENT LOCATION IS FOUND,
AN ESTIMATED PROPERTY DAMAGE ONLY REPORT Value
FALLS THAT LOCATION AS WELL AS THE COUNTY, ROUTE,
BEGINNING AND ENDING MILEPOSTS, NUMBER OF LANES
AND NUMBER OF ACCIDENTS FOR THAT LOCATION ARE
OUTPUT TO A TEMPORARY WORKSPACE. THIS WORKSPACE
IS THEN IN TURN UTILIZED BY THE SECOND STEP OF
THIS PROGRAM.

DATA ENTRY INSTRUCTIONS THE ONLY DATA ENTRIES
NECESSARY ARE FOR CREATING THE ONE-CARD FILE CARD.
CALL IN THE COUNTY CARD IN THE PROGRAM. THE LENGTH
UP HIGHWAY TO BE CHECKED CAN BE ANY NUMBER FROM
0.1 MILES TO 99.0 MILES. MILEPOST, THE MILEPOST
POINT IS IMPLIED AND SHOULD NOT BE PHYSICALLY
PLACE ON THE CARD. THEREFORE, A SECTION OF 0.1
MILE SHOULD BE USED AS 0.0 AND A SECTION UP
99.0 MILES CAN BE USED AS 99.0. THE NUMBER OF ACCID-
ENT ENTRIES NECESSARY IS INDICATED VALUE FROM
1 TO 99 AND SHOULD BE RIGHT SHIFTED WHEN CITED.

NAME CURR-COLUMN CURCOLUMN.

Section Length

Critical Number

Operations none.

VARIABLE LIST FOR TP-RECORD.

FILE LAYOUT FOR DATA SET TPSP, GENERATED BY PROGRAM

RMS600J USED AS INPUT TO THIS PROGRAM.

FILE RECORDS ARE OMITTED.

RECORD CONTAINS 30 CHARACTERS.

DATA RECORD IS LIMIT-CARD.

THIS IS THE FORMAT FOR THE INPUT DATA CARD FILE.

LIMIT-CARD.

LC-SECTION PIC 999.

FILLER PIC X.

LC-CONTRI PIC 999.

FILLER PIC X(1).

LC-REDEFINE LIMIT-CARD PIC 999.

SKIP.

FO ACCDT-FILE.

HILLC CHAINS 900 RECORDS.

RECORD CONTAINS 15 CHARACTERS.

LABEL RECORDS ARE STANDARD.

DATA RECORD IS TP-RECORD.

FILE RECORDS USED FOR DATA SET TPSP, GENERATED BY PROGRAM

RECORDS ARE OMITTED.

LABEL RECORDS ARE STANDARD.

DATA RECORD IS TP-RECORD.

FILE LAYOUT FOR DATA SET TPSP, GENERATED BY PROGRAM

RMS600J USED AS INPUT TO THIS PROGRAM.

TP-RECORD.

CC PIC 999.

RT PIC X.

MP PIC 999.

NL NUMBER OF LANES.

Hazardous Location File.
000219 FD MAIL-FILE
000220 DATA RECORDS ARE STANDARD.
000221 RECD CONTAINS 50 CHARACTERS
000222 BLOCK CONTAINS 100 RECDUCRS.
000224 01 LOCATION-RECORDS PIC X(50).
000226 02 SKIP.
000228 02 MOVE CC.
000229 02 READ-RT2.
000230 02 READ ACCI-FILE AT END GO TO EJN.
000232 02 PERFORM CLEAI-ARRAY-RT THRU EXIT-2 VARYING J FROM 1 BY 1
000234 02 UNTIL J > 0.
000236 02 MOVE HR TO SAVE-RT.
000238 02 MOVE CC TO SAVE-CC.
000240 02 PERFORM NLOC-LIMIT = SAVE-RT + NP-SECLTH.
000242 02 IF NL > 0 AND NL < 7, MOVE NL TO J.
000244 02 NL > 0 AND NL = 7, ACU I NL U J.
000246 02 IF AS = 1, AND 1 TO K-TR.
000248 02 IF AS = 2, AND 1 TO A-TR.
000250 02 IF AS = 3, AND 1 TO C-TR.
000252 02 IF AS = 4, AND 1 TO K-TR.
000254 02 IF AS = 0 RIP AS A, ACU 1 TiU P(N-TR.
000256 02 READ-RT2.
000258 02 IF RT NRT = SAVE-RT.
000260 02 IF MP < SAVE-MP OR MP > MP-LIMIT.
000262 02 EJECT.
000264 02 ELSE GUE AS IC-INC-RT.
000266 02 EJECT.
000268 02 IF MP-SECLTH IS < CS-CRITIC.
000270 02 MOVE SAVE-CC TO LR-CO.
000272 02 MOVE NL TO J,
000274 02 COMPUTE MP-SECTH TO LR-IP.
000276 02 MOVE NL TO J,
000278 02 COMPUTE NLOC.
000280 02 MOVVL SAVE-RT TO LR-IP.
000282 02 MOVVL MP-SECTH TO LR-IP.
000284 02 IF NL (J) < NLCCR OR NL (J) = J, GUE AS EXIT-1.
000286 02 COMPUTE NLCCR + NL (J).
000288 02 EJECT.
000290 02 IF JHJNE EXIT.
000292 02 IF JHJNE EXIT.
000294 02 IF JHJNE EXIT.
000296 02 IF JHJNE EXIT.
000298 02 IF JHJNE EXIT.
000300 02 IF JHJNE EXIT.
000302 02 IF JHJNE EXIT.
000304 02 IF JHJNE EXIT.
000306 02 IF JHJNE EXIT.
000308 02 IF JHJNE EXIT.
000310 02 IF JHJNE EXIT.
000312 02 IF JHJNE EXIT.
000314 02 IF JHJNE EXIT.
000316 02 IF JHJNE EXIT.
000318 02 IF JHJNE EXIT.
000320 02 IF JHJNE EXIT.
000322 02 IF JHJNE EXIT.
000324 02 IF JHJNE EXIT.
000326 02 IF JHJNE EXIT.
000328 02 IF JHJNE EXIT.
000330 02 IF JHJNE EXIT.
000332 02 IF JHJNE EXIT.
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000338 02 IF JHJNE EXIT.
000340 02 IF JHJNE EXIT.
000342 02 IF JHJNE EXIT.
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000346 02 IF JHJNE EXIT.
000348 02 IF JHJNE EXIT.
000350 02 IF JHJNE EXIT.
000352 02 IF JHJNE EXIT.
000354 02 IF JHJNE EXIT.
000356 02 IF JHJNE EXIT.
000358 02 IF JHJNE EXIT.
000360 02 IF JHJNE EXIT.
Appendix F.

CRITICAL ACCIDENT RATES FOR URBAN SECTIONS
Figure F1. Critical Accident Rates for Urban, Two-Lane Highway Sections (One-Year Data) (P=99.5).

Figure F2. Critical Accident Rates for Urban, Four-Lane, Divided (No Access Control) Highway Sections (One-Year Data) (P=99.5).
Figure F3. Critical Accident Rates for Urban, Four-Lane, Undivided Highway Sections (One-Year Data) (P=99.5).

Figure F4. Critical Accident Rates for Urban, Interstate Highway Sections (One-Year Data) (P=99.5).
Figure F5. Critical Accident Rates for Urban, Toll Road Highway Sections (One Year Data) (P=99.5).
Appendix G.

KENTUCKY'S TRAFFIC CONFLICT PROCEDURE
Kentucky's Traffic Conflict Procedure

DATA COLLECTION PROCEDURE

A traffic conflicts survey is the systematic surveillance of major intersection approach legs. An intersection approach leg is any one of the roadways converging and intersecting. At most intersections, conflict data should be collected on the two major approach legs. Where two major arterials intersect, data should be collected on all four legs. At T-intersections, the third leg is usually excluded from data collection.

The survey team consists of from one to three trained observers. Volume counts should be made with traffic counters for all movements of all approaches separately at a location near the intersection. It may sometimes be necessary to collect volume data for the same periods on another day. Conflict data should be collected by two observers, each positioned on a major approach about 100 to 300 feet (30 to 90 m) back from the intersection so vehicle brake lights can be seen. Observers may sit in state-owned vehicles parked on the road shoulder facing traffic or sit in chairs at urban intersections where sidewalks exist.

Data should normally be collected on a Tuesday, Wednesday, or Thursday for two or three hours when traffic is at or near peak volumes. For a two-hour count, data should normally be collected during the morning (7:30 to 8:30 a.m.) and the afternoon (4:30 to 5:30 p.m.) rush hours. If more data can be collected, other times may include noontime rush (11:30 a.m. to 12:30 p.m.) or other afternoon periods (3:30 to 4:30 p.m.). At intersections near shopping centers, data should be collected for periods near the closing time. In situations where weekend volumes are critical, data should be collected on those days. In some Kentucky cities, volume data is available for each hour of the day for major intersections. These data should be used to select peak volume times for collection of conflict data.

Conflict data should be collected in 15-minute periods and recorded on the data forms for signalized intersections (Figure G1) and nonsignalized intersections (Figure G2). Volume data should be recorded every 15 minutes on the volume data sheet. No breaks need to be taken; data are usually collected for only one or possibly two hours at a time. Conflict data should be collected on both approaches simultaneously, if possible. However, conflict counts on the major approach only may be made if another observer is not available.

The major weave and conflict types, which are listed on the data sheets for signalized intersections, are given below.

Weave

A weave vehicle is a situation in which a vehicle changes lanes as it approaches or passes through the intersection. A vehicle which momentarily leaves its lane -- that is, moves to another lane and returns immediately to its original lane -- should be counted as a weave if at least half of the vehicle penetrated the second lane. Count only one weave per vehicle. The cause for repeated weave patterns should be noted on the data sheet. A "weaved-for-left-turn" occurs when an approaching vehicle weaves into the right lane to avoid having to stop for a left-turning vehicle. A "weave-other" occurs when an approaching vehicle weaves for any other reason.

Weave Conflict

A weave-type conflict is defined as a situation in which a vehicle changes lanes into the path of another vehicle, causing the offended vehicle to brake or weave to avoid a collision. The fact that the weave conflict has occurred is evidenced by a brake-light indication or lane change by the offended vehicle.

In a weave conflict, Figure G3, Vehicle 1 weaves and changes lanes, causing Vehicle 2 to brake. As the conflict is viewed from the rear, a brake-light indication can be observed on Vehicle 2. The categories for left-turn result from a weave due to a left-turning vehicle as described previously.

Opposing Left-Turn Conflict

This occurs when a left-turning vehicle crosses directly in front of a through vehicle and causes it to brake or swerve. This conflict is viewed on the approach where the brake lights can be observed (Figure G4).

Run-Red-Light

This is a situation where a vehicle enters the intersection and crosses the curb-line or stop-bar on a red signal. Vehicles which entered the intersection legally and complete their movement after the signal changes are not considered violators. The left-turning vehicles which ran a red light have been separated from the others (through and right-turners).

Stopped Abruptly

This conflict type occurs when a vehicle makes an unusually quick deceleration during the yellow phase of the signal or cycle or shortly after the red phase appears. Usually, a noticeable dipping of the front end of the vehicle occurs and/or the screeching of tires is heard in severe cases.
Figure G1. Conflict Data Sheet: Signalized Intersections.
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>DIRECTION</th>
<th>DATE</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>STARTING TIME</th>
<th>AROUND LEFT TURNER</th>
<th>AROUND LEFT TURNER</th>
<th>OTHER</th>
<th>OTHER</th>
<th>OPPOSING LEFT TURN</th>
<th>RIGHT TURN</th>
<th>LEFT TURN</th>
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<th>LEFT TURN</th>
<th>THROUGH CROSS TRAFFIC</th>
<th>LEFT TURN</th>
<th>RIGHT TURN</th>
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<th>THROUGH CROSS TRAFFIC</th>
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</tbody>
</table>

1 = Routine; * = Moderate; O = Severe

Figure G2. Conflict Data Sheet: Unsignalized Intersections.
There are a number of special events which are not listed on the conflict data sheets. These include 6 weave types, 13 conflict types, and 26 types of erratic maneuvers; these are given in Table G1. Observers should be familiar with these categories of events and should carry a copy of this listing during all conflict surveys. Whenever one of these special events is observed, the letter corresponding to the event should be marked under one of the blank columns on the conflict data sheet. If one special event is observed with some regularity at a site, a column can be designated to count such events.

Table G1. Other Traffic Events.

<table>
<thead>
<tr>
<th>WEAVES</th>
<th>CONFLICTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Weave for stopped truck</td>
<td>G Conflict due to erratic maneuver</td>
</tr>
<tr>
<td>B Weave for stalled vehicle</td>
<td>H Slow for turn out of driveway or shopping entrance</td>
</tr>
<tr>
<td>C Weave for stopped bus</td>
<td>I Slow for turn into driveway or shopping entrance</td>
</tr>
<tr>
<td>D Weave for road maintenance or construction</td>
<td>J Driveway cross traffic from left</td>
</tr>
<tr>
<td>E Weave to avoid pedestrian</td>
<td>K Driveway cross traffic from right</td>
</tr>
<tr>
<td>F Weave into turn lane and back into major traffic flow</td>
<td>L Slow for stopped bus</td>
</tr>
<tr>
<td></td>
<td>M Slow for road maintenance or construction</td>
</tr>
<tr>
<td></td>
<td>N Slow for stopped truck</td>
</tr>
<tr>
<td></td>
<td>O Weave pedestrian conflict</td>
</tr>
<tr>
<td></td>
<td>P Previous conflict due to pedestrian (following car)</td>
</tr>
<tr>
<td></td>
<td>Q Right turn on red without stop</td>
</tr>
<tr>
<td></td>
<td>R Left-lane vehicle slow for right turn</td>
</tr>
<tr>
<td></td>
<td>S Slow or stop for stalled vehicle</td>
</tr>
<tr>
<td></td>
<td><strong>ERRATIC MANEUVERS</strong></td>
</tr>
<tr>
<td>T Left turn from wrong lane</td>
<td>A Turn into wrong lane (opposing lane)</td>
</tr>
<tr>
<td>U Right turn from wrong lane</td>
<td>BB Stop in median</td>
</tr>
<tr>
<td>V U-turn in road</td>
<td>CC Run off road</td>
</tr>
<tr>
<td>W Use of shoulder for turns</td>
<td>DD Right-turn-on-red without stopping</td>
</tr>
<tr>
<td>X Right-turner hitting curb</td>
<td>EE Late-entry right turn (or non-use of turn lane)</td>
</tr>
<tr>
<td>Y Vehicles overrunning stop bar and backing up</td>
<td>FF Late-entry left turn (or non-use of turn lane)</td>
</tr>
<tr>
<td>Z Vehicle backing from driveway across traffic lanes</td>
<td>GG Vehicle unexpectedly stopped in road</td>
</tr>
<tr>
<td>AA Turn into turn lane and back into traffic flow</td>
<td>HH Vehicle swerve across traffic lanes</td>
</tr>
<tr>
<td>BB Stop in median</td>
<td>II Vehicle backing in road</td>
</tr>
<tr>
<td>CC Run off road</td>
<td>JJ Turn into turn lane and back into traffic flow</td>
</tr>
<tr>
<td>DD Right-turn-on-red without stopping</td>
<td>KK Vehicle on wrong side of road</td>
</tr>
<tr>
<td>EE Late-entry right turn (or non-use of turn lane)</td>
<td>LL Wide turn (encroaching into adjacent lane)</td>
</tr>
<tr>
<td>FF Late-entry left turn (or non-use of turn lane)</td>
<td>MM Multiple vehicle erratic maneuver</td>
</tr>
<tr>
<td>GG Vehicle unexpectedly stopped in road</td>
<td>NN Multiple bicycle erratic maneuver</td>
</tr>
<tr>
<td>HH Vehicle swerve across traffic lanes</td>
<td>OO Bicycle on wrong side of road</td>
</tr>
<tr>
<td>II Vehicle backing in road</td>
<td>PP Bicycle riding in median</td>
</tr>
<tr>
<td>JJ Turn into turn lane and back into traffic flow</td>
<td>QQ Illegal pedestrian crossings</td>
</tr>
</tbody>
</table>
Slowed-for-Right-Turn
The slowed-for-right-turn conflict is a situation in which a vehicle slows and turns from a traffic lane used by through traffic while being followed by a through vehicle. As Vehicles 1 and 2 approach the intersection as a pair, Vehicle 1 slows to turn right from a lane used by through traffic; through Vehicle 2 brakes to avoid Vehicle 1 – the criterion of the conflict (Figure G5).

Slowed-for-Left-Turn
A slowed-for-left-turn conflict occurs when a leading vehicle, followed closely by a second vehicle, approach an intersection in a lane shared by through and left-turn vehicles. The first slows or stops to turn left; and the second, a through vehicle, brakes to avoid the slowing, turning vehicle.

Previous-Left-Turn Conflict
This type of conflict only occurs after a slowed-for-left-turn conflict. The first vehicle which slows or stops behind a left-turning vehicle is counted as a slowed-for-left-turn conflict, as stated above. If one or more other vehicles must also slow or stop for the same left-turner, then one previous-left-turn conflict is counted, regardless of the number of slowing vehicles. For any conflict count period, the number of slowed-for-left-turn conflicts must equal or exceed the number of previous-left-turn conflicts.

Other Previous Conflicts
Other previous conflicts occur when one or more vehicles break to avoid collision shortly after another conflict. An example of another previous conflict is shown in Figure G6 when Vehicle 2 slows to avoid Vehicle 1 which was involved in an opposing-left-turn conflict.

Traffic-Backup or Congestion Conflict
This occurs when a vehicle approaches an intersection on a green light and must slow or stop due to other vehicles backed up. Another cause of this conflict is where vehicles on the side street block the intersection, causing vehicles on the observed approach to brake. One conflict is counted per lane during the green phase for each event, regardless of the number of vehicles which brake. One exception is where two separate groups of vehicles (separated by a long gap) pass the intersection during the same green signal phase and when backup conflicts occur during each (independently of the other). No conflicts are counted for vehicles slowing or stopping during the yellow or red lights.

Slow-Moving-Vehicle Conflict
A slow-moving-vehicle conflict occurs when a vehicle slows or stops in a through lane on the green light and causes a following vehicle to brake (Figure G7).

Pedestrian Conflict
This occurs when a single vehicle slows to avoid a pedestrian crossing the street.

Of the weave and conflict categories defined for signalized intersections, most of them also apply to nonsignalized intersections. However, there are several categories which apply only to nonsignalized intersections.

Through-Cross-Traffic
The through-cross-traffic conflict occurs when a through, side-street vehicle crosses the path of a through,
right-of-way vehicle, causing the right-of-way vehicle to brake. Conflicts are initiated by cross-road vehicles approaching from the right (Figure G8) or left.

Left-Turn-Cross-Traffic
A left-turn-cross-traffic conflict occurs when a side street vehicle turns left across the path of the through, right-of-way vehicle, causing the right-of-way vehicle to brake. Conflicts are initiated by side-street vehicles turning left from the left or right.

Right-Turn-Cross-Traffic
A right-turn-cross-traffic conflict occurs when a side-street vehicle, approaching from the right, turns right into the path of a through, right-of-way vehicle and causes the right-of-way vehicle to brake. This type of conflict may also occur at signalized intersections, but it is not included as a major category on the signalized intersection data sheet because they occur so infrequently at such locations.

All conflicts should be designated by the observer as either routine, moderate, or severe. A routine conflict is usually characterized by normal brakelights where there is no real danger of collision. A large majority of conflicts at most intersections are routine. Moderate conflicts involve quick decelerations and situations where some urgency was noted in a driver's reaction (all abrupt stops are moderate conflicts). A severe conflict (near-miss accident) is where a collision is barely avoided due to a last-second movement or stop. Symbols used for recording routine, moderate, and severe conflicts are noted on the data sheets.
## INTERSECTION CONFLICT DATA SHEET

**LOCATION**

**APPROACH**

**OBSERVER**

**DATE**

<table>
<thead>
<tr>
<th>STARTING TIME</th>
<th>TRAFFIC BACKUP OR CONGESTION</th>
<th>OPPOSING LEFT TURN</th>
<th>SLOW FOR LEFT TURN</th>
<th>SLOW FOR RIGHT TURN</th>
<th>AROUND LEFT TURNER</th>
<th>OTHER</th>
<th>SLOW MOVING VEHICLE</th>
<th>CONFLICT TYPE</th>
<th>THROUGH LEFT TURN VOLUME</th>
<th>PEDESTRIAN CONFLICT</th>
</tr>
</thead>
<tbody>
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<td>C</td>
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<td>LT- ST- RT-</td>
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</tr>
</tbody>
</table>

### OTHER CONFLICT TYPES

- A - Right turn cross traffic, from left
- B - Bicycle
- C - Opposing right-turn-on-red
- D - Opposing LT-RT
- E - Rear end, vehicle backing
- F - Opposite both straight
- G - Left turn from wrong lane
- H - Right turn from wrong lane
- I - Other (Explain)

### SINGLE VEHICLE

- J - Ran red light (LT)
- K - Ran red light (ST-RT)
- L - RTOR-LTOR did not stop
- M - Abrupt stop

### C - Conflict

### SC - Secondary Conflict

### SEVERITY

- I - Routine
- **-** - Moderate
- ***-*** - Severe

### ADJACENT DRIVEWAY

- N - Entering
- O - Exiting

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**COMMENTS**

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Figure G9. Revised Intersection Conflict Data Sheet.
Appendix H.
SUGGESTED CORRECTIONS FOR HAZARDOUS LOCATIONS
Based on eight specific types of accidents, the following listing was developed for suggested corrections for hazardous locations (14). This listing is a guide for use by traffic engineers to help select improvements that will reduce specific accident types.

Right-Angle and Rear-End Collisions at Intersections
1. Removal of view obstructions, such as foliage, bushes, billboards, or parking at curb.
2. Installation of warning signs, if speeds are high and the element of surprise is present.
3. Installation of stop signs, if view is obstructed to such an extent that safe approach speed is 2 miles per hour (3.6 m/s) or less, if one street is an approach street, or if no other remedy reduces accident frequency.
4. Installation of traffic signals if minimum warrants are met.
5. Continuing operation of traffic signals during certain light-traffic hours when signals are normally off.
7. Relocation, repair, or other means of providing better visibility of signs or signals.
9. Provision of pedestrian crosswalk markings and/or pedestrian barriers.
10. Rerouting of through traffic onto specially designated and protected through streets.
11. Creation of one-way streets.
12. Provision of traffic signal system time for progressive movement.
13. Speed zoning to safe approach speed.

Head-On, Left-Turn Collisions at Intersections
1. Provision of turning guidelines.
2. Prohibition of left turns (provided such movement is of little importance).
3. Provision of channelizing islands.
4. Provision of protected turning interval, via traffic signal control.
5. Installation of STOP signs (provided no other remedy works).
6. Elimination of view obstructions.
7. Creation of one-way streets.
8. Routing of turning traffic via an alternate route (with proper signs) to eliminate left turns.

Pedestrian-Vehicular Collisions at Intersections
1. Installation of pedestrian crosswalk lines.
2. Erection of pedestrian barriers.
3. Installation of traffic signals.
4. Provision of pedestrian refuge islands.
5. Prohibition of curb parking.
6. Provision of adequate street lighting.
7. Creation of one-way streets.
8. Rerouting of through traffic to specially designated and protected through streets.
9. Addition of pedestrian indications and pedestrian actuation features to existing traffic signals.

Sideswipe Collisions
1. Installation of painted pavement lane lines.
2. Installation of channelizing islands at intersections.
3. Installation of advance warning signs to warn drivers of proper lane for certain destinations.
4. Speed zoning.
5. Provision of acceleration or deceleration lanes at intersections.
7. Creation of one-way streets.
8. Elimination of marginal obstructions caused by parked vehicles or other bottlenecks.

Head-On Collisions
1. Same remedies as for sideswipe collisions.
2. Installation of "no passing" zones at curves or other points with restricted view.
3. Installation of center dividing strip.

Vehicles Running Off Roadway
1. Installation of pavement centerline.
2. Installation of warning reflectors, guardrail, or white posts at curves.
3. Installation of advance warning signs.
4. Installation of roadside delineators.
5. Speed zoning.
6. Street lighting.
7. Skidproofing slippery pavements, improving shoulder maintenance, and prompt ice treatment and snow removal.

Collision with Fixed Objects
1. Application of paint and reflectors to fixed object.
2. Use of pavement guidelines to guide traffic around obstruction.
3. Street lighting.
4. Reduction of the number of fixed objects.
   a. Place necessary signs in the median, back-to-back wherever possible.
   b. Remove unnecessary sign posts (consolidate signs).
   c. Combine signs and light poles where possible.
   d. Utilize existing structures for posting signs.
   e. Use sign bridges where possible rather than gore signs.
5. Reduction of exposure to fixed objects.
   a. Place signs and light poles on the right side of pavements rather than in the median or gore areas, reducing exposure to total traffic.
b. Use sign bridges where possible rather than gore signs.

6. Minimizing hazards of fixed objects.
   a. Provide guardrail in front of fixed objects.
   b. Use prows and other methods wherever guardrail is not suitable.
   c. Use breakaway sign supports and light poles.

Collisions with Parked Cars
1. Parking prohibitions.
2. Change from angle to parallel parking.
3. Rerouting of through traffic to less congested, specially protected through streets.
4. Creation of one-way streets.
Appendix I.

DYNAMIC PROGRAMMING SOURCE DECK
PURPOSE

This program calculates costs and benefits for each alternative at each location then determines the optimal solution set of alternatives to be implemented for a given range of budgets.

INPUT AND OUTPUT

See Division of Research Report: "Optimal Highway Safety Improvements by Dynamic Programming".

DIMENSION TITLE(20),XLOC(90,10),NDE(90),C(90,11),B(90,11),LOC(90)

NINP = 501
NLOC = 90

NINP = NUMBER OF INCREMENTS—MAXIMUM BUDGET EQUALS NINP*INC
NLOC = MAXIMUM NUMBER OF LOCATIONS

READ< IN N, 1000 TITLE
1000 FORMAT(20A4)
WRITE< IOUTPR, 1010 TITLE
1010 FORMAT(20X,20A4/////)
READ< IIN N, 2000 NSTD,BUDGET,PR TSTR,PRTINC, IOUTCB
2000 FORMAT(14,11,F10.0,F11,15)
IF(IOUTC B.NE.Q1 IOUTCB=8
IF(IOUTC B.EQ .00) IOUTCB=IOUTPR
I=IN N-1
IX=BUDGET/I+.5
INC=IX
K1=PR TSTR/IX+.01+1
K2=PRTINC/IX+.01
CALL COSB EN(C,B, XLOC,LOC,NDE,NSTD,NLOC,XINC,IN N,IOUTCB,K1)

IF(K1.EQ.1) GO TO 10

CALL DYNM IC(C,B,LOC,XLOC,NDE,NSTD,XINC,K1,K2,NINP,NLOC,

+ ORET,NOO,IOUTPR)

10 CONTINUE
CALL EXIT

SUBROUTINE COSB EN(PWC,PRB, XLOC,LOC,NDE,NSTD,NLOC,XINC,IN N,IOUTPR,K1)

THIS SUBROUTINE CALCULATES PRESENT WORTH COSTS AND BENEFITS

ASSOCIATED WITH EACH ALTERNATIVE AT EACH LOCATION

DIMENSION XLO C(NLOC,5),SEV(8,4),CSEF(10,11),B(8),

+ NDE(NLOC),PWC(NLOC),PWB(NLOC),LOC(NLOC)

READ< IN N, 1000 CFAT,CINJ,CPDO, RATEIN,RATEGR
1000 FORMAT(BF10.0)
WRITE< IOUTPR, 1010 CFAT,CINJ,CPDO, RATEIN,RATEGR
1010 FORMAT(20X,20A4/////)
READ< IN N,NO100 TITLE
NO100 FORMAT(14,10A4,27X, F4.0,12,12,11)

THE ABOVE READS AND PRINTS THE BASIC PARAMETERS CONSTANT FOR THE ENTIRE PROGRAM.

SUBROUTINE

COSB0150 NUMBER = 1
COSB0160 KIK = 0
COSB0170 C BELOW IS THE INPUT WHICH IS EXECUTED FOR EACH ACCIDENT LOCATION.
COSB0180 10 READ< IN N,1020 N=I,$XLOC(NUMBER,I),I=1,10),TIME,NMO,NYR,NCAU
COSB0190 1020 FORMAT(14,10A4,27X, F4.0,12,12,11)
COSB0200 LOC(NUMBER) = NO1
COSB0210 IF(No1)20,180,20
COSB0220 20 CONTINUE
COSB0230 WRITE(OUTPR,1030)
COSB0240 1030 FORMAT(I111)
COSB0250 WRITE(OUTPR,1040)
COSB0260 1040 FORMAT(' REF NO*')
COSB0270 IF(NAU.EQ.0) GO To 30
COSB0280 WRITE(OUTPR,1050) No1,(XLOC(NUMBER,I),I=1,5),TIME,NMO,NYR,NAU
1050 FORMAT(3x,i4,3x,i4,5a,2x,'ACCIDENT HISTORY ',F5.2,
+ ' YEARS. MONTH ',I2,' YEAR ',I2,' CAUSE. ')
COSB0310 GO To 40
COSB0320 30 WRITE(OUTPR,1060) No1,(XLOC(NUMBER,I),I=1,5),TIME,NMO,NYR,NAU
COSB0330 1060 FORMAT(3x,i4,3x,i4,5a,2x,'ACCIDENT HISTORY ',F5.2,
+ ' YEARS. MONTH ',I2,' YEAR ',I2,' CAUSE. ')
COSB0340 CONTINUE
COSB0360 C SECOND CARD INPUT FOR EACH CRITICAL LOCATION (SEVERITIES).
COSB0370 READ(INN,100)NO2,(SEV(I,J),J=1,4),I=1,NAU,ALT
COSB0380 1070 FORMAT(14,1x,15f5.0)
COSB0400 NALT=ALT+.5
COSB0410 NDE(NUMBER) = NALT
COSB0420 C ROUTINE TO CHECK CARD SEQUENCE CODE.
COSB0430 IF(No1-No2).GE.60,50
COSB0440 50 WRITE(OUTPR,1080)No1,No2
COSB0450 1080 FORMAT(' SEQUENCE/ CODE NO. ERROR. CHECK *15, AND*,15,
+ EXECUTION TERMINATED')
COSB0460 KIK = 1
COSB0470 GO To 190
COSB0480 60 CONTINUE
COSB0490 C OUTPUT OF SEVERITIES AND TOTALS.
COSB0500 WRITE(OUTPR,1090)
COSB0510 1090 FORMAT(' ROADWAY NO. NO. NO*/,
+ CAUSE KILLED INJURED PDO/')
COSB0520 TOT1=0
COSB0530 TOT2=0
COSB0540 TOT3=0
COSB0550 TOT4=0
COSB0560 DO 80 I=1,NAU
COSB0570 WRITE(OUTPR,1100) I,(SEV(I,J),J=2,4)
COSB0580 1100 FORMAT (1x,17,12x,3f8.0)
COSB0590 70 CONTINUE
COSB0600 TOT1=TOT1+SEV(I,1)
COSB0610 TOT2=TOT2+SEV(I,2)
COSB0620 TOT3=TOT3+SEV(I,3)
COSB0630 TOT4=TOT4+SEV(I,4)
COSB0640 80 CONTINUE
COSB0650 WRITE(OUTPR,1110) TOT1,TOT2,TOT3,TOT4
COSB0660 1110 FORMAT(' TOTALS* ,12x,3f8.0)
COSB0670 C INPUT NEXT SET OF NALT CARDS, ONE FOR EACH ALTERNATIVE
COSB0680 NJ=3+NAU
COSB0690 DO 110 I=1,NALT
COSB0700 READ(INN,1120) NO3,(CSEF(I,J), J=1,NJ)
COSB0710 1120 FORMAT(I4,F8.0,F2.0,F0.0,F5.2)
COSB0720 IF(NO3-NO1).LT.90,100,90
COSB0730 90 WRITE(OUTPR,1080) No1, NO3
COSB0740 KIK = 1
COSB0750 GO To 190
COSB0760 100 CONTINUE
COSB0770 110 CONTINUE
COSB0780 C OUTPUT OF ALTERNATIVE INFORMATION.
COSB0790 WRITE(OUTPR,1130) I, I=1,NAU
COSB0800 1130 FORMAT(' ALTERNATIVE COST LIFE MAIN COST EFFECT ON...'
COSB0810 +815)
NUMBER COUNT CHECK OF SEVERITIES.

WRITE(0,1140) I,(CSEF(I,J),J=1,NJ)
FORMAT(17,F13.0,F8.0,F9.0,19X,8F6.2)
CONTINUE

COMPUTATION OF B(I), THE ITH ALTERNATIVE BENEFIT.

DO 140 I=1,NALT
B(I) = 0.
DO 130 J=1,NCAU
JEFT = J +3
B(I) = B(I) * (CFAT*SEV(J,2)+CINJ*SEV(J,3)+CPX*SEV(J,4))*
CSEF(I,JEFT)
CONTINUE

CALCULATION OF BENEFIT/COSTS AND OUTPUT.

DO 150 I=1,NALT
BNCS = B(I)/CSEF(I,1)
CONTINUE

WRITE(0,1170)
FORMAT(/// BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED///)
WRITE(0,1210)
FORMAT(160 I=1,NALT)
WRITE(0,1220)
XMAIN=CSEF(I,2)*CSEF(I,3)
BENM=B(I)-XMAIN
BNCM=BENM/CSEF(I,1)
WRITE(0,1220) I,XMAIN,CSEF(I,1),BENM,BNCM
CONTINUE

WRITE(0,1200)
FORMAT(/// BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED ***PRE)
WRITE(0,1210)
FORMAT(/// ALTERNATIVE MAINTENANCE COST BENEFIT

+ BENEFIT/COST*)
WRITE(0,1230)
FORMAT(/// ALTERNATIVE MAINTENANCE COST BENEFIT

NUMBER = NUMBER +1
GO TO 10
NUMBER = NUMBER -1
IF(NUMBER.EQ.NSTG) GOTO 190
WRITE(0,1240)
FORMAT(/// WARNING 

+NS EXPECTED = ',13)
RETURN
END
DYNA0010  SUBROUTINE DYNAM(C,B,LOC,XLOC,NDE,NSTG,XINC,K1,K2,NINP,NLOC,
DYNA0020 + ORET,NOD,NOUTPR)
DYNA0030 C THIS SUBROUTINE USES "DYNAMIC PROGRAMMING" TO FIND THE OPTIMAL
DYNA0040 C SOLUTION SET ALTERNATIVES (ONE AT EACH LOCATION) GIVEN COSTS,
DYNA0050 C BENEFITS AND A RANGE OF BUDGETS. THE ALGORITHM IS BASED ON WORK BY
DYNA0060 C RICHARD BELLMAN (DYNAMIC PROGRAMMING, 1957)
DYNA0070 DIMENSION ORET(NLOC,NINP),NOD(NLOC,NINP),NDE(NLOC),
DYNA0080 + (NLOC,11),B(NLOC,11),R(11),XLOC(NLOC,5),LOC(NLOC)
DYNA0090 C THESE DIMENSIONS MUST BE AT LEAST AS BIG AS THE NUMBER OF LOCATIONS
DYNA0090 C DIMENSION CC(200),BB(200),AA(200),BC(200),LL(200),KKK(200)
DYNA0090 IST=0
DYNA0100  VRET=0.0
DYNA0110  WRITE(IOUTPR,1130)
DYNA0120  WRITE(IOUTPR,1000)
DYNA0130  1000 FORMAT(' ','40(',*)', 'PARAMETER VALUES',40('*/'))
DYNA0140  WRITE(IOUTPR,1010)
DYNA0150  1010 FORMAT(' ',27X,18('=',5X,'OUTPUT',18(''))
DYNA0160  WRITE(IOUTPR,1020) NSTG,XINC,K1,K2
DYNA0170  1020 FORMAT(5X, 'LOCATIONS--INCREMENT--LOWER LIMIT--INCREMENTS PER ST
DYNA0180 + EP--3X,19,3X,F12.2,19,10X,19,0X,'--LOCATION--ALTERNATIVES')
DYNA0190  DO 10 I=1,NSTG
DYNA0200  WRITE(IOUTPR,1030) LOC(I),NDE(I)
DYNA0210  1030 FORMAT(7X,15,110)
DYNA0220  10 CONTINUE
DYNA0230  WRITE(IOUTPR,1040)
DYNA0240  1040 FORMAT(' ?',30('=',5X,'LOCATIONS,ALTERNATIVES,COSTS AND BENEFITS',
DYNA0250 + +30('*/'))
DYNA0260  WRITE(IOUTPR,1050)
DYNA0270  1050 FORMAT(1H, '--LOCATION--LOCATION NAME',28('=',5X,'ALT-NUM------C
DYNA0280 +UST------RETURN-------B/C RATIO')
DYNA0290 C FIND THE OPTIMAL ALTERNATIVE AT THE I-TH LOCATION WITH J INCREMENTS
DYNA0300 C AVAILABLE
DYNA0310  DO 140 I=1,NSTG...
DYNA0320  NDEC=NDEC(I)+1
DYNA0330  R(I)=0.
DYNA0340  DO 20 IC=2,NDEC
DYNA0350   20 R(IC) = R(I),IC)
DYNA0360  DO 30 IC=2,NDEC
DYNA0370   30 ICM = IC-1
DYNA0380  BCRAT = R(IC)/CM(I,IC)
DYNA0390  IF(IC.EQ.2) AA(I)=BCRAT
DYNA0400  WRITE(IOUTPR,1060) LOC(I),(XLOC(I,J),J=1,10),ICM,C(I,IC),R(IC),
DYNA0410  + BCRAT
DYNA0420  1060 FORMAT(19,5X,10A4,16,3X,F11.0,F11.0,4X,F10.2,F15.0,F15.0)
DYNA0430  30 CONTINUE
DYNA0440  WRITE(IOUTPR,1070) (8F10.0)
DYNA0450 C INCREMENT BUDGET
DYNA0460  XIN=(J-1)*XINC
DYNA0470  DUM=-100000000000.
DYNA0480  NDEC=NDEC(I)+1
DYNA0490 C DETERMINE THE BEST ALTERNATIVE--NOD(I,J)--AT I-TH LOCATION GIVEN
DYNA0500 C J-1 INCREMENTS TO SPEND ON LOCATION I THRU LOCATION I-++++YIELDING
DYNA0510 C A RETURN OF--ORET(I,J)--
DYNA0520  DO 120 K=1,NDEC
DYNA0530  CALL XOUT(I,IST,XIN,K,KICK,XINC,C,NLOC)
DYNA0540  IF(KICK.EQ.0,50,40
DYNA0550  40 GI TO 120
DYNA0560  50 CONTINUE
DYNA0570  IF(I.EQ.1) 60,70
DYNA0580  60 TEST=R(K)
DYNA0590  GI TO 80
70 TEST=TEST(I)*0.9+RET(I-1,IST)
DYN06010 GO TO 80
DYN0620 IF((DUM-TEST))90,100,100
DYN0630 DUM=TEST
DYN0640 RET(I,J)=DUM
DYN0650 NOD(I,J)=K
DYN0660 GO TO 110
DYN0670 110 CONTINUE
DYN0680 120 CONTINUE
DYN0690 130 CONTINUE
DYN0700 140 CONTINUE
DYN0710 CALL DATAHDD(AA,LL,NSTG)
DYN0720 WRITE(IOUTPR,1049)
DYN0730 FORMAT(•1*,25(•*)•,'LOCATIONS,ALTERNATIVES,COSTS, AND BENEFITS••',
DYN0740 + 'ORDERED BY BENEFIT/COST RATIO••',
DYN0750 + 25(•*)///)
DYN0760 WRITE(IOUTPR,1051)
DYN0770 1051 FORMAT (1H,'•LOCATION---LOCATION NAME•',28('•'), 'ALT-NUM-------C
DYN0780 + 'OST------RETURN-----B/C RATIO-------ACCUM COST--ACCUM RETURN••')
DYN0790 TOITRN=0
DYN0800 TOTCST=0
DYN0810 DO 149 II=1,NSTG
DYN0820 I=LL(II)
DYN0830 IC=2
DYN0840 ICM1=IC-1
DYN0850 R(IC)=B(I,IC)
DYN0860 TOITRN=TOITRN+R(IC)
DYN0870 TOTCST=TOTCST+C(I,IC)
DYN0880 WRITE(IOUTPR,1060) LOC(I),(XL0C(I,J),J=1,10),ICM1,C(I,IC),R(IC),
DYN0890 + AA(II),TOTCST,TOITRN
DYN0900 149 CONTINUE
DYN0910 1061 FORMAT('••')
DYN0920 WRITE(IOUTPR,1061)
DYN0930 IPAGE = 0
DYN0940 DYN0720 C WRITE MAIN BUDGET OUTPUT HEADING
DYN0950 WRITE(IOUTPR,1080)
DYN0960 DYN0740 1080 FORMAT('••',90(*')///',37(*')///', 'BUDGET OUTPUT•',37(*')///',
DYN0970 + 90(*')//////)
DYN0980 DYN0760 DO 160 M=K1,NINP,K2
DYN0990 J=M
DYN1000 XIN=(J-1)*XINC
DYN1010 BUDG=XIN
DYN1020 DYN0790 IPAGE = IPAGE + 1
DYN1030 DYN0800 IF(IPAGE NE.1) WRITE(IOUTPR,1130)
DYN1040 DYN0810 C WRITE INDIVIDUAL BUDGET OUTPUT HEADING
DYN1050 WRITE(IOUTPR,1290) BUDG
DYN1060 1290 FORMAT('••',15X,'BUDGET =',F12.0,/)  
DYN1070 WRITE(IOUTPR,1090)
DYN1080 DYN0830 1090 FORMAT('••',15X,'BUDGET LOCATION =',4X,'LOCATION NAME
DYN1090 +',4X,'ALT-NUM',5X,'COST',6X,'RETURN',4X,'ACCUM RETURN••')
DYN1100 DYN0860 1100 FORMAT('••',6X,F15.2)
DYN1110 DYN0870 TOTCST = 0
DYN1120 DYN0880 TOTITRN = 0
DYN1130 DYN0890 DO 150 L=1,NSTG
DYN1140 I=NSTG+1-L
DYN1150 K=NOD(I,J)
DYN1160 KKK(I)=K
DYN1170 CC(I)=C(I,K)
DYN1180 BB(I)=B(I,K)
DYN1190 DYN0990 CALL XOUTD(I,IST,XIN,K,KICK,XINC,C,NLOC)
DYN1200 DYN1000 J=IST
DYN1210 DYN1010 XIN = XIN-C(I,K)
SUBROUTINE XOUTC(I,ST,XX,M,NLOC,C)
XOUT0010  RETURN
XOUT0020  C
XOUT0030  C  THIS SUBROUTINE CALCULATES THE OUTPUT STATE NUMBER
XOUT0040  C  RESULTING FROM THE INPUT XX AND SAFETY MEASURE K. IT
XOUT0050  C  ALSO DETERMINES THE COST OF A PARTICULAR SAFETY MEASURE
XOUT0060  C  CORRESPONDING TO STAGE I.
XOUT0070  C
XOUT0080  DIMENSION C(NLOC,11)
XOUT0090  OUT=XX-C(I,K)
XOUT0100  IF(OUT) 10,20,20
XOUT0110  10 KICK=1
XOUT0120  20 KICK=0
XOUT0130  30 KICK=0
XOUT0140  40 KICK=0
XOUT0150  50 KICK=0
XOUT0160  60 KICK=0
XOUT0170  70 KICK=0
XOUT0180  80 KICK=0
XOUT0190  90 KICK=0
XOUT0200  100 KICK=0
XOUT0210  110 KICK=0
XOUT0220  120 KICK=0
XOUT0230  130 KICK=0
XOUT0240  140 KICK=0
XOUT0250  150 KICK=0
XOUT0260  160 KICK=0
XOUT0270  170 KICK=0
XOUT0280  180 KICK=0
XOUT0290  190 KICK=0
XOUT0300  200 KICK=0
XOUT0310  210 KICK=0
XOUT0320  220 KICK=0
XOUT0330  230 KICK=0
XOUT0340  240 KICK=0
XOUT0350  250 KICK=0
XOUT0360  260 KICK=0
XOUT0370  270 KICK=0
XOUT0380  280 KICK=0
XOUT0390  290 KICK=0
XOUT0400  300 KICK=0
XOUT0410  310 KICK=0
XOUT0420  320 KICK=0
XOUT0430  330 KICK=0
XOUT0440  340 KICK=0
XOUT0450  350 KICK=0
XOUT0460  360 KICK=0
XOUT0470  370 KICK=0
XOUT0480  380 KICK=0
XOUT0490  390 KICK=0
XOUT0500  400 KICK=0
XOUT0510  410 KICK=0
XOUT0520  420 KICK=0
XOUT0530  430 KICK=0
XOUT0540  440 KICK=0
XOUT0550  450 KICK=0
XOUT0560  460 KICK=0
XOUT0570  470 KICK=0
XOUT0580  480 KICK=0
XOUT0590  490 KICK=0
XOUT0600  500 KICK=0
XOUT0610  510 KICK=0
XOUT0620  520 KICK=0
XOUT0630  530 KICK=0
XOUT0640  540 KICK=0
XOUT0650  550 KICK=0
XOUT0660  560 KICK=0
XOUT0670  570 KICK=0
XOUT0680  580 KICK=0
XOUT0690  590 KICK=0
XOUT0700  600 KICK=0
XOUT0710  610 KICK=0
XOUT0720  620 KICK=0
XOUT0730  630 KICK=0
XOUT0740  640 KICK=0
XOUT0750  650 KICK=0
XOUT0760  660 KICK=0
XOUT0770  670 KICK=0
XOUT0780  680 KICK=0
XOUT0790  690 KICK=0
XOUT0800  700 KICK=0
XOUT0810  710 KICK=0
XOUT0820  720 KICK=0
XOUT0830  730 KICK=0
XOUT0840  740 KICK=0
XOUT0850  750 KICK=0
XOUT0860  760 KICK=0
XOUT0870  770 KICK=0
XOUT0880  780 KICK=0
XOUT0890  790 KICK=0
XOUT0900  800 KICK=0
XOUT0910  810 KICK=0
XOUT0920  820 KICK=0
XOUT0930  830 KICK=0
XOUT0940  840 KICK=0
XOUT0950  850 KICK=0
XOUT0960  860 KICK=0
XOUT0970  870 KICK=0
XOUT0980  880 KICK=0
XOUT0990  890 KICK=0
XOUT1000  900 KICK=0
XOUT1010  910 KICK=0
XOUT1020  920 KICK=0
XOUT1030  930 KICK=0
XOUT1040  940 KICK=0
XOUT1050  950 KICK=0
XOUT1060  960 KICK=0
XOUT1070  970 KICK=0
XOUT1080  980 KICK=0
XOUT1090  990 KICK=0
XOUT1100  RETURN
XOUT1110  END
IST = (OUT/XINC) + 1.5

IST = (OUT/XINC) + 1.5

RETURN

END

SUBROUTINE DATAORD (D,L,M)
DIMENSION D(M),L(M)
DO 10 I=1,M
10 L(I) = I
DO 20 I=1,M
IF(1.EQ.M) GO TO 20
K = L(I)
S = D(I)
J1 = I
20 CONTINUE
DO 30 J=1,M
IF(S.GE.D(J)) GO TO 30
S = D(J)
K = L(J)
J1 = J
30 CONTINUE
D(J1) = D(I)
D(I) = S
L(J1) = L(I)
L(I) = K
RETURN
END