Deliverable 4 – Vol. II
Road Work Zone Safety
Practical Handbook
Background Report

PUBLIC

ARROWS
Advanced Research on Road Work Zone Safety Standards in Europe

Contract No. RO-96-SC.401

Project Coordinator: NTUA - National Technical University of Athens (GR)

Partners:
SWOV - Institute for Road Safety Research (NL)
BAST - Federal Highway Research Institute (DE)
VTI - Swedish National Road and Transport Research Institute (SE)
3M - 3M Hellas Limited (GR)
CRR - Belgian Road Research Centre (BE)
CROW - Information and Technology Centre for Transport and Infrastructure (NL)
CDV - Transport Research Centre (CZ)
ZAG - Slovenian National Building and Civil Engineering Institute (SI)

Date: 16 November 1998

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NTUA	
SWOV	*BAST*
VTI	*3M*
CRR	*CROW*
CDV	*ZAG*

EUROPEAN COMMISSION
Directorate-General for Transport
DG VII - E3
Transport RTD Programme

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The **ARROWS project** was originally developed to help meet (some of) the goals of the Road Transport theme of the Fourth Framework Transport Work programme. ARROWS is an acronym for the European research project: Advanced Research on Road Work zone Safety Standards in Europe. Its objectives are multiple:

- to inventorize work zone safety measures;
- the assess the nature and extent of the (traffic) safety problem at work zones, in terms of traffic accidents and road user behavior;
- to assess the effectiveness of existing safety measures;
- to review methods for assessing said effectiveness, and propose a standard evaluation test bench;
- to propose and evaluate improved sets of safety measures;
- to recommend a framework for European standards;

and

- to provide a practical handbook for improving the safety of road workers and users.

The present Deliverable 4 - Volume II reports on the work carried out within ARROWS Workpackage 4 (Practical Handbook). It constitutes a Background Report to the ARROWS Practical Handbook, which is produced as Deliverable 4 - Volume I. The Workpackage consisted of the following Tasks:

- **Task 4.1 - Safety Principles**. The initial objective of this Task was to propose a set of safety principles for the proper planning, design, implementation, operation and follow-up/assessment of road work zones across Europe. This is reported in *Chapter 1* of the present volume. During the course of the project, the subtask of *Accident Scenario Construction* was added to this Task, with the objective to complement the conclusions from behavioural and accident studies through analysis of expert-generated data on “virtual work zone accidents”. The procedure and results are reported in *Chapter 2* of the present volume. Furthermore, *Appendices* 1 through 9 present detailed information about the accident scenario pilot study’s inputs and outputs.
- **Task 4.2 - Recommendations and Compatibility**. The objective of this Task was to formulate recommendations of sets of measures (layout, traffic control devices, other road equipment, and other measures) for all types of road work zone, as well as to determine possibilities for harmonisation of national guidelines and compatibility with relevant European agreements (such as TERN, CEN, and TEM). The work carried out for this Task is reported in *Chapter 3* of the present volume.
- **Task 4.3 - Practical Handbook**. The practical handbook is the key output of ARROWS and constitutes Volume I of this Deliverable. Itemisation of the cases selected as layout examples, as well as identification of safety issues - including “tips” and “checklists” - was largely based on the material of Tasks 4.1 and 4.2. Moreover, recommendations for the road worker are presented in *Annex I* to this volume, and a discussion of issues related to the management of road work zones appears in *Annex II* to this volume.

Chapter 1 is a compilation of safety principles, derived from the work which has been conducted in the ARROWS project, which can be used for the planning, design, implementation and operation European road work zones.

This compilation is primarily based on the compiled and original findings of previous phases of the ARROWS project. To this end, each of the involved partners was asked to prepare a contribution, based on a specific ARROWS Task report. Those sub-task assignments were:

- Typology (CROW)

- Measures (3M)
- Standards and Practices (BAST)
- Behaviour (BAST)
- Accidents (3M)
- Methods (3M)
- Synthesis of Improved Sets of Countermeasures (3M).

All partners were also encouraged to freely contribute as they saw fit. The possibility of incorporating existing guidelines from each partner's country was also stimulated.

The idea was that, to the extent that previous ARROWS work was systematic, complete, and unambiguous, then (some) principles should be extractable in a structured way. To the extent that these conditions did not obtain, then less structured contributions could also be useful.

Even though there are (some) gaps, ambiguities and overlap between principles, every principle and/or argument mentioned in this paper can be profitably considered.
Chapter 2 deals with accident scenario construction. The ARROWS consortium is interested in gathering and organising scientific knowledge concerning work zone traffic accidents, in order to produce suggestions for pan-European guidelines for implementing work zones. One effort to that end was not as illuminating as originally hoped, due to limitations in the scientific literature. In addition, there were no funds available for gathering data from actual work zone accidents, nor for analysing the data that already exists in (inter-)national data-bases.

To cover this lack, it was suggested that if we had no access to actual accidents then it might be useful to extract the intuitions of the ARROWS consortium about work zone traffic accidents. To this end, we asked these experts to consider virtual accidents, which we further treated as if they were real.

It was also the intention to include experts form outside the consortium, who represented other groups of stakeholders in the area of work zone safety: policy makers, police officials, contractors, etc.

This could have allowed a broader view of the problem area, contributed to the overall acceptance of the consortium's efforts, provided a common forum for a pan-European discussion of the subject, and allowed for comparisons of differences and similarities between viewpoints.

Due to a number of limitations, a more modest pilot study was conceived, which would make use of a session of the ARROWS Workshop in Athens in 1997 as the kickoff. This author prepared six discussion papers, which were to presented to six parallel working groups of 5 workshop participants each . Each group attempted (by means of a brain-storming procedure) to consider possible answers to central questions poised in the discussion papers.

The results of these working groups were then combined with existing accident forms, information found in previous ARROWS deliverables, and other relevant sources of information, to produce a "virtual" work zone traffic accident registration form. Eight copies of said form were sent to all participants of the Athens Workshop with the request to consider a concrete work zone traffic accident (either real or imagined) and to fill in an accident form in order to describe that accident. This was done for a total of eight times. 5 times subjects were given a road type of which the said accident had to occur, 3 times the subjects could freely determine the road type themselves.

About 2/3 of the subjects responded, and their returned accident registration forms were entered into the computer and analysed by means of non-linear Principal Component Analysis.

This process has resulted in very simple and clear results. Namely, the variability in the characteristics of work zone traffic accidents, as studied in the present report, can be reduced to three underlying, basic dimensions:

- the type of road on which the work zone is located, with motorways being contrasted with urban local roads;
- the duration of the work zone, varying from short-term and ad hoc to long-term and more-extensively organised.
- the time-of-day cycle. It is only this last dimension which is clearly associated with different types of accidents.

These results may then be used as starting points for developing checklists and guidelines, which may then be incorporated in a practical handbook.

Chapter 3 deals with recommendations and compatibility. Before planning of work zone and before decision of the technique of ensuring the concrete work zone the designer should collect as much as possible information about planning activities on roads (e.g. detailed description of appropriate road segment, range of planned work zone, current traffic signs and devices on this road segment, possibly supposed diversion and its length and direction and contingently order of phases of traffic lights).

The design of work zone measures should follow possible stages of activities, its possible combinations, types and duration.

It is evident that the different level of work zone ensuring (measures) will be designed for appropriate type of work zone. Therefore during the planning phase is necessary respect the location of work zone i.e. on urban roads (main, local), on rural roads (primary, secondary) and on motorways or expressways, farther its duration - long-term or short-term (stationary and mobile) - only during day light, and also take heed to possible concurrence of works.

If the ensuring of work zone with short term duration shows as insufficient from the point of view of road safety (i.e. gross fog or rain, snow etc.), it is necessary to use the same purpose of measures as on work zone with long term duration.

The purpose of ensuring of concrete work zone should come out from the appropriate model traffic scheme mentioned in practical handbook.

The form of work zone ensuring is necessary to decide on the base of local conditions (partial or complete road enclosure, diversion). The basic principle is to keep as far as possible the same number of lines on road or to find the traffic solution, which makes possible to keep traffic in both directions.

In case there is only one line in the work place area for both traffic directions it is necessary to decide on the basis of a local situation and traffic intensity whether it is possible to lead traffic on the basis of the intermittent traffic, with help of traffic signal or to set up a diversion. It is also possible to use the both way combination (for instance to set up diversion for particular vehicles, particular time or for one traffic direction only).

If the traffic intensity is too high and there is no possibility to set up diversion it is necessary to think of making provisional diversion road in the work area.

In the case of partial or complete road enclosure is necessary to consider the ensuring of cyclist and pedestrians, too. In the case of works on foot-paths or on cycle tracks is necessary to provide alternate and safe way of transportation for this vulnerable traffic participants.

Complete road enclosure for all kinds or same kinds of traffic is a big interference with organisation of traffic, because it means to set up a diversion.

In case a diversion road is used for longer time it is good to sign it up as a main road particularly if the traffic on important and busy road is turn away. Except interference into a giving way rule changes there may be also an importance of temporally speed decrease limit in area, which is unsuitable for temporally increase traffic. A diversion must be signed by traffic signs in advance for all drivers to make possible to get use to those traffic changes. It is useful to inform about a diversion in media.

Some main aspects for installing work zones are:

- Choose time and duration of work zones in correspondence to traffic requirements and volume.
- Adhere the number of lanes as far as possible.
- Govern the design of the work zone (alignment, lane width and length).
- Determine uniform layouts with signs as few as possible but as many as necessary.
- Make work zones consistent during working and cancel them after the work is finished.
- Use high quality materials for signing and marking.
- Maintain traffic signs, markings and safety devices in a proper form all the time.
- Train personnel in regard to their responsibility and their own safety aspects.

0. INTRODUCTION

The **ARROWS** Project (**A**dvanced **R**esearch on **RO**ad **W**ork Zone **S**afety Standards in Europe) is funded by the European Commission under the Transport RTD Programme of the 4th Framework Programme. It began on 18 September 1996 under the provisions of Contract No. RO-96-SC.401.

ARROWS is being carried out by a consortium of the following nine partners:

NTUA - National Technical University of Athens (Project Coordinator - GR)
SWOV - Institute for Road Safety Research (NL)
BAST - Federal Highway Research Institute (DE)
VTI - Swedish National Road and Transport Research Institute (SE)
3M - 3M Hellas Limited (GR)
CRR - Belgian Road Research Centre (BE)
CROW - Information and Technology Centre for Transport and Infrastructure (NL)
CDV - Transport Research Centre (CZ)
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The main objectives of ARROWS include:
- Development of a unified range of applicable road work zone safety measures and principles that should govern the planning, design, implementation and operation of road work zones so as to mitigate their adverse effects on the safety of workers and road users.
- Production of a practical handbook for practical guidance to network managers at all levels.

In order to achieve the above objectives, the work content of ARROWS has been organized into five Workpackages, subdivided into a total of twelve Tasks.

The present Deliverable 4 - Volume II reports on the work carried out within ARROWS Workpackage 4 (Practical Handbook). It constitutes a Background Report to the ARROWS Practical Handbook, which is produced as Deliverable 4 - Volume I. The Workpackage consisted of the following Tasks:
- **Task 4.1 - Safety Principles**. The initial objective of this Task was to propose a set of safety principles for the proper planning, design, implementation, operation and follow-up/assessment of road work zones across Europe. This is reported in *Chapter 1* of the present volume. During the course of the project, the subtask of *Accident Scenario Construction* was added to this Task, with the objective to complement the conclusions from behavioural and accident studies through analysis of expert-generated data on “virtual work zone accidents”. The procedure and results are reported in *Chapter 2* of the present volume. Furthermore, *Appendices* 1 through 9 present detailed information about the accident scenario pilot study’s inputs and outputs.
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- **Task 4.3 - Practical Handbook**. The practical handbook is the key output of ARROWS and constitutes Volume I of this Deliverable. Itemisation of the cases selected as layout examples, as well as identification of safety issues - including “tips” and “checklists” - was largely based on the material of Tasks 4.1 and 4.2. Moreover, recommendations for the

road worker are presented in *Annex I* to this volume, and a discussion of issues related to the management of road work zones appears in *Annex II* to this volume.

Deliverable 4 was compiled by the National Technical University of Athens, under the supervision of Prof. George Kanellaidis (project co-ordinator). The following individuals participated in the production of Volumes I and II:

- Mr. Ioannis Dimitropoulos, Ms. Sophia Vardaki, , Mr Ioannis Petropoulos, Ms. Anastasia Flouda (NTUA): Co-authors of Volume I; editing, compilation and production of Volumes I and II.
- Mr. Chad Gundy (SWOV): Author of Chapter 1 and Chapter 2 of Volume II, as well as Appendices 1 through 9 to Volume II.
- Dr. Wolfgang Schulte (BAST): Author of Chapter 3 of Volume II; design of layouts / examples for Volume I.
- Mr. John Boender (CROW): Co-author of Volume I.
- Mrs. Sophie Jehaes (CRR): Preparation of Glossary and participation in editing of Volume I;
- Mr. John Boender (CROW): author of Annex I to Volume II.
- Mr. Pavel Tucka (CDV): Author of Annex II to Volume II.
- Other members of the ARROWS Consortium and participants in the ARROWS Workshop assisted by providing comments and suggestions on the handbook.

1. ROAD WORK ZONE SAFETY PRINCIPLES: A Compilation

1.1. Introduction

The present Chapter is a compilation of safety principles, derived from the work which has been conducted in the ARROWS project, which can be used for the planning, design, implementation and operation European road work zones.

This compilation is primarily based on the compiled and original findings of previous phases of the ARROWS project. To this end, each of the involved partners was asked to prepare a contribution, based on a specific ARROWS Task. Those task assignments were:

- 1.1: Typology (CROW)
- 1.2: Measures (3M)
- 1.3: Standards and Practices (BAST)
- 2.1: Behaviour (BAST)
- 2.2: Accidents (3M)
- 2.3: Methods (3M)
- 3.1 / 3.2: Synthesis of Improved Sets of Countermeasures (3M)

All partners were also encouraged to freely contribute as they saw fit. The possibility of incorporating existing guidelines from each partner’s country was also stimulated.

The idea was that, to the extent that previous ARROWS work was systematic, complete, and unambiguous, then (some) principles should be extractable in a structured way. To the extent that these conditions did not obtain, then less structured contributions could also be useful.

Even though there are (some) gaps, ambiguities and overlap between principles, every principle and/or argument mentioned in this paper can be profitably considered.

1.1.1. Compiling Safety Principles

The objective of the present Chapter is to produce a compilation, and attempting a synthesis, of safety principles, which can be used for the proper planning, design, implementation and operation of European road work zones. These principles can then be used as input for the production of the above mentioned practical handbook.

While a “safety principle” could be viewed as some kind of abstract generalization concerning safety, we felt that the actual definition of a safety principle better be left over to each of the partners responsible for the individual contributions. Namely, in this “pre-normative” phase of ARROWS it was not the intention to press definitions that were too constricting.

This compilation presented here is based on two sources of input.

First of all, all partners were encouraged to contribute as they saw fit, and were encouraged to make use of their own national **guidelines** or other sources. This approach is primarily free-form, and allows one to utilize knowledge not directly incorporated in previous ARROWS undertakings.

Secondly, and more importantly, the compiled and original findings of previous phases of the ARROWS project were utilized. To this end, each of the involved partners was asked to prepare a contribution, based on a specific ARROWS Task. These were:

1) **Task 1.1 / Typology:** refers to a three dimensional work zone typology. The three dimensions of the typology are: road type, work zone operation (duration), and work zone-road interaction (layout and location). The ARROWS typology is a major product of the project. The ARROWS typology is meant as guideline for the classification of road work zones. A clear classification is necessary for a concise yet comprehensive presentation of the ARROWS output. For the proper formulation of safety principles, listening of recommendations, and especially for the effective illustration of cases in the practical handbook, a soundly-based classification and terminology is a basic prerequisite.

2) **Task 1.2 / Measures:** refers to currently used and innovative work zone safety measures. The task aims at creating a full inventory of safety measures, accompanied by identification of the main objectives and features associated with each measure. The following categories of items were included: road layout adjustment, traffic control devices (e.g. signs and markings), other road equipment (e.g. barriers), and miscellaneous. Emphasis is given on what exists, and not on how it should be used.

3) **Task 1.3 / Standards and Practices:** refers to presently existing European standards and practices on work zone traffic guidance and design. Regulations, guidelines, standards and recommendations can be found in practically all countries for the preparation and operation of work zones on roads and motorways. These give fundamental or detailed information for the designing and setting up of such work zones in accordance with traffic flow principles.

4) **Task 2.1 / Behaviour:** refers to a literature study concerning driver behaviour and attitudes at work zones insofar as they are safety related. In order to improve road work zone safety, one must formulate guidelines and standards intended to achieve this aim. A prerequisite for this is knowledge about road user behaviour and conflicts when passing road works of varying designs under different conditions.

5) **Task 2.2 / Accidents:** refers to a literature study concerning work zone traffic accidents. A logical prerequisite for preventing road work zone traffic accidents is insight into their nature and extent, and the risk factors involved.

6) **Task 2.3 / Methods:** refers to a literature study of experimental and other research methods for the evaluation of work zone safety measures. Experimental and other research methods were examined in Task 2.3. with the aim to present a concise overview of existing and proposed experimental methods for the evaluation of safety measures and to select and define an appropriate set of experimental evaluation methods.

7) **Workpackage 3 / Improvements:** refers to the synthesis of improved sets of work zone safety measures. This synthesis of improved sets was performed by the project leader, NTUA, following an ARROWS Workshop in Athens during November, 1997. It aimed in creating a complete set of summary tables of improvements to the existing state of practice, mainly as proposed in the ARROWS Workshop and, consequently, based on all the analysis work performed during this project. This work was a useful recapitulation of all the synthesis work performed in ARROWS, to which were embodied the opinions, expertise and propositions of all experts participating in the Workshop.

The idea for this additional approach was that to the extent that previous ARROWS work was systematic, complete and unambiguous, then safety principles could be extracted in a systematic manner.

Partners wrote their contributions using a common format, containing various topics that will be described in later sections of this Chapter. It was thought that while not all sections would be directly applicable to all sub-task reports (in which case, that section could be left blank), it was felt that a common format could provide a common frame of reference.

1.1.2. Structure of this Chapter

This Chapter is structured in the following manner.

First of all, after this introductory section, attention is paid to what 'safety principles' are, which definitions can be named and can or should be used?.

Then, safety principles as derived from previous workpackages of the ARROWS project are presented under the following headings (corresponding to the contents of the ARROWS Tasks):

- Typology of road work zones
- 'Hardware' safety measures (equipment, markings, signs, protective devices, and other hardware)
- Behavioural factors
- Accidents
- Research methods
- Future directions and other aspects (e.g., procedures, regulations, checklists, auditing, enforcement, training, and other software; standardization and harmonization issues).

Discussion, conclusions, and recommendations are made in section 1.9. This section also contains a list of general safety principles, based on the principles as were described in the previous sections. Finally, in section 1.10, the topic of safety principles is considered from a practical point of view.

The contents of the following sections are based on contributions by BAST (Germany), CROW (the Netherlands), CDV (Czech Republic), 3M (Greece), and VTI (Sweden).

1.2. Safety principles

Contributing partners were asked to provide a definition of what they meant by the term “Safety Principles”, the possibilities for ambiguity being enormous. In addition, it was also suggested that the reasons (scientific or other) for accepting a specific safety principle should be made explicit, so that one might have some idea of how much belief could be attached to a specific idea.

Regulations, guidelines, standards and recommendations can be found in practically all countries for the preparation and operation of work zones on roads and motorways. These give fundamental or detailed information for the designing and setting up of such work zones in accordance with traffic flow principles. In most countries these sets of regulations are based on several decades of development and experience. In so far there are principles, but very seldom it is said which are the basic ideas. So, safety principles can be derived only indirectly.

Generally the aims of regulations, guidelines, etc. give the minimum needed signalisation on a road work zone to inform, give the way and guide road users through the work zone. The German guidelines (source: BAST), for example, state that this should be done with severity, coherence and clearness:

- *severity*: selection of measures should be so that the safety of road users and road workers is best served.
- *coherence*: signalisation can not always be the same for each work zone; then, it must be adapted before the road work beginning to the local situation. A planning of the conception, execution and adaptation has to be prepared systematically and coherently before the road work.
- *clearness*: guiding road users and helping them to modify and adapt progressively their behaviour to the situation require some easy-reading and trusting signs. Signalisation could never give wrong or non-adapted information.

Severity, coherence, and clearness could be called safety principles: ‘high level’ stand points, statements and ideas (valuations) that *govern* the concrete and operational design and use of measures, devices and procedures in relation to road works with the purpose to increase safety. In this sense, principles do *not* set specific/fixed speed limits or suggest specific devices, e.g. for guiding road users. Decisions of that type are conditional, and such concrete questions, setting the detailed procedure and design guidelines, are operated at lower levels of the process.

The safety principles should be able to cover all phases of a road work, i.e. planning and preparation, responsibility assignment, implementation, carrying out, evaluation and follow up.

Other examples of general safety principles that can be named are:

- visibility of work zones for road users,
- uniformity of work zone form and layout,
- optimal sequence of measures (traffic signs and devices) in work zones
- comprehensibility of work zone (measures) for road users.

In the following sections it will be attempted to derive more of this type of general, as well as more specific safety principles from the results of previous ARROWS work packages. In the final section those safety principles will be presented that are thought to be of importance to guide the planning, design and implementation of work zones.

1.3. Typology of road work zones

1.3.1. Objective of typology

The ARROWS typology is meant as a guideline for the classification of road work zones. A clear classification is necessary for a concise yet comprehensive presentation of the ARROWS output. For the proper formulation of safety principles, listening of recommendations, and especially for the effective illustration of cases in the practical handbook, a soundly-based classification and terminology is a basic prerequisite. In this sense, such a classification itself can be named as an example of a general safety principle.

Because the typology will be meaningful regarding the practical handbook, it is most essential that the typology is primarily "output-oriented". Seen in this light, the typology aids in the harmonised approach of designing safe road work zones all over Europe. Therefore the typology is a guide to the selection of the proper type of road work zones and associated safety measures.

1.3.2. Road Work Zone

A road work zone is defined as the part of a road facility influenced by works occurring on, near or above it. Besides the immediate 'work area' actually occupied by the road works, a road work zone is a more widespread area. A road work zone consists also of the area that is used for control measures - such as signs, markings and protective devices - and of a buffer, an area between the work area and the oncoming traffic.

For each stream of traffic affected by the road works, the following additional distinct areas, or components, can be defined along a road Work zone: (i) the advanced warning area, (ii) the transition area, (iii) the termination area. In addition, the work area proper is surrounded by a 'buffer'.

For the purposes of ARROWS, road work zones are examined in terms of the safety of traffic and road workers. Therefore types of works will be defined with regard to their relevance to the interaction between road work zones and traffic. Besides knowing 'What' work is carried out and 'How', the classification of road work zones will be based on the answers to the questions of 'Where' and 'When'.

1.3.3. Principles

The classification typology is, as stated, an output-oriented system. In order to fulfil this goal, the following four *principles* have been regarded as basic requirements. These principles have been incorporated in the classification system.

Compatibility: The typology connects to established practice in most countries. Compatibility applies to both classification and terminology

Comprehensiveness: All main classification factors and their categories are included. This ensures accurate of the output and also takes care of achieving future harmonisation in comparable classification situations.

Clarity: The typology is adequately clear and plain so that smooth implementation at all levels is guaranteed. Over-specification, special cases and vagueness of concepts, have been avoided.

Flexibility: The classification system offers the ability to merge or further subdivide classification categories. This flexibility offers adaptation to local practices.

1.3.4. The classification factors of the typology

Within the scope of ARROWS a table-oriented structure is used as typology. Two main classification factors are considered: road type and (duration of) operation. The resulting cross-classifications have been further subdivided, using characteristic types of interaction between the Work zone and the roadway.

Road type
Five categories are considered:
(A) Motorway and dual carriageway
(B) Rural primary
(C) Rural secondary
(D) Urban main
(E) Urban local
In general, varying national definitions of road classes can be adequately accommodated under this broad classification of road types.

Classification is chosen so to incorporate the type (area), cross-section and functional classification of road. Dual- and single-carriageway roads feature basic differences in traffic operation so that separate consideration is involved.

Motorways are the most clearly-defined type of road that both is included in the Trans European Road Network as well as in most of the national road work zone guidelines. In contrast with the other four categories the distinction between rural and urban motorways has no supplementary advantages. Where as normally on urban roads the traffic mix is more varied than on rural roads, this difference does not apply to motorways.

Rural and urban roads, other than motorways or 'near-motorways', are further subdivided on the basis of their function. Rural roads are distinguished into primary roads, with a clear (inter)national relevance, and secondary roads, which have a less important functionality. Similarly, urban roads are categorised into main and local ones.

Operation
Three categories regarding work zone operation are considered:
(1) Long-term
(2) Short-term stationary
(3) Mobile-term mobile

The division between long-term, short term stationary and short-term mobile is considered as a meaningful one, common in most countries. The threshold between long- and short-term should be based on the requirement for the work zone to stay in place at least overnight. The definition for mobile is fairly straightforward.

Road/work zone interaction
The following categories regarding the types of interaction between the Work zone and the road way are considered:

(a) Lane narrowing
(b) Lane closure
(c) Diversion (transferring all or part of the traffic from one road - 'diverted road' - to another - 'diversion route')
(d) Contraflow/crossover (transferring all or part of the traffic to the other carriageway or lanes from the opposite direction)
(e) Alternate one-way traffic
(f) Work zone on intersection / interchange
(g) Shoulder/roadside
(h) Central reserve
(i) Footway/bikeway
(j) Tramway

This classification factor refers mainly to spatial characteristics of a roadwork zone, in terms of anticipated effects on the cross-section and on the traffic streams involved. It refers also to the relative (lateral) location of the work zone in relation to the road.

A work zone may be located either (partly) on or (completely) off the roadway. The main effects usually considered for on-roadway road work zones are the first six categories ((a) - (f)). These categories are applicable to most road work zones. Off-roadway locations commonly include last four categories ((g)-(j)).

1.3.5. Structure of the typology

As mentioned before, a table-oriented structure is used as typology within the scope of ARROWS. Two main classification factors are considered: road type and operation. The resulting cross-classifications have been further subdivided, using characteristic types of interaction between the work zone and the roadway.

This typology results in 99 layout possibilities. Each layout is a description which contain the type, amount and the position of elements of road work safety for the involved road work zone.

1.4. 'Hardware' Safety Measures

Task 1.2 of the ARROWS project included an inventory of what can be called 'hardware' safety measures (equipment, markings, signs, protective devices, and other hardware), accompanied by the identification of the main objectives and features associated with each one. The aim of the review was primarily to identify which measures exist and are used, and not how these should or must be used. It is therefore not easy to deduce a set of safety principles from such an inventory of existing measures. However, some safety principles may be identified to underlie the use of specific measures or devices. These will be described in the following sections. It should be noted that these 'principles' should be viewed as 'descriptive', rather than 'normative'.

Hardware analysis was the main issue of the safety measures review that has been performed (i.e., principles related to the design and use of hardware safety measures). However, as already sited, only in a few of the specific items, safety principles may be formulated. These items and the corresponding safety principles are the following:

1.4.1. Traffic signs and markings

Good visibility of the work zone area can be considered an important safety principle. With regard to traffic signs and markings this implies that higher quality materials should be used for traffic signs used in road work zones than in normal signing. Furthermore, the correct identification and recognition of the area as being a work zone is important (drivers should not only be aware that 'something' is happening, but also 'what' is happening in order for them to behave appropriately). In this context, a specific colour identifying 'work zones' can be helpful. For example, a pan-European colour could be designed to differentiate work zones from permanent signing and markings. Yellow was proposed to be this colour, which is also compatible to the TEM standards.

Yellow fluorescent material with high retro reflectivity (types II and, mainly, III) for the construction of traffic signs was agreed to be the optimal solution for signing. The form to be used was not agreed, since no research exists on the most effective type to driver's perception. Three types have been proposed and was decided to be evaluated in a later stage of ARROWS (if it is going to be assigned to the consortium):

- Rectangular external yellow background
- External yellow background of the same shape with the sign enclosed in it
- Internal yellow background to signs with white background in normal signing (i.e. danger warnings, speed limits, mainly)
- When the evaluation is completed the most effective form of work zone signing will be selected and proposed in a full pre-normative way.

Markings should, also, be of yellow colour in road work zones. It should be noted, however, that a separation must be made at this point between short and long term work zones. This is due to the fact that in most cases of short term work zones no horizontal signing (marking) is used.

In long term work zones, where yellow markings should be used, the most important issue, related to road users safety, is the appropriate selection of materials for them. Plain yellow markings paint may be used in most cases. However, in an important number of cases (e.g. differentiation of the work zone alignment during works, need for quick placement and removal, important traffic volumes, etc.) an important safety principle is the compulsory use of upgraded materials. Self - adhesive retro reflective tapes is the basic upgraded material to be used in such cases. Furthermore, in cases of unfavourable climatic conditions, the need for use of additional measures, i.e., mainly, wet pavement tapes and/or pavement reflectors ("cats eyes") is suggested.

Additionally the important role in safety, in some cases, of Variable Message Signs, Roll Up Traffic Signs and Wet Reflective Pavement Tapes has been decided to be highlighted and a more specific pre-normative selection of them to be performed in a later stage of ARROWS (if any).

1.4.2. Closure and warning equipment

Traffic cones used in road work zones should be of standard types, both in size and constructional characteristics. This is due to the fact that some of the cones actually used are either not easily perceivable from important distances (mainly in high speed roads with important traffic volumes) or do not have adequate stability and are removed from passing vehicles' wind pressure becoming, thus, useless in their role and, additionally, potential danger to oncoming traffic when rolling in the main traffic stream. For this reason *standardisation* of traffic cones is an important safety principle to road work zone equipment.

In work zones settled in urban areas, a most important issue related to safety is the appropriate *protection of pedestrians* in cases of obstruction of sidewalks from the road work zone. The basic safety principle in this case is the designation of the appropriate *necessary space* for the safe pedestrian movement and the correct use of the necessary equipment for it (fences, traffic closures with warning lights, safety barriers, etc.), depending on the general infrastructure of each specific area.

1.4.3. Miscellaneous items

Among the miscellaneous items examined in safety measures, the only safety principle that may be formulated is the compulsory use of retro reflective fluorescent jackets, following EN 471 standard, from all persons working in work zones nearby the main traffic stream of the road. This aids passing car drivers to recognize them as road workers.

1.4.4. Conclusion

A large number of items related to safety aspects concerning work zone equipment, already exists. However, in practically none of these items a real effort of pan-European standardisation has been undertaken, both in form and usage.

For this reason, it may be concluded that it is essential that effort is made in the (near) future, in the safety measures field, to achieve common European standards in the form and usage of, as many as possible, of them, in relation to each specific parameter of the road work zone structure. Of course, since ARROWS is only a pre-normative project, these ‘standards’ may be regarded as general directions in this field and not as the creation of final standards, including constructional aspects. A first attempt could be made within the two remaining tasks of the ARROWS project (4.2. "Recommendations and Compatibility" and 4.3. "Practical handbook").

In a later phase of ARROWS (if any) this point may be faced by creating selection tables out of which may be chosen the appropriate type of item in each case, according to road infrastructure and traffic characteristics (e.g. the size of traffic cones, the material to be used in road markings, the use of road reflectors, the class of retro reflective material to be used in signs, etc.).

1.5. Behavioural Factors

In task 2.1 of the ARROWS project, the existing literature dealing with aspects of driver behaviour at road work zones was reviewed. Although it appeared difficult to generalize findings of individual studies, some conclusions derived from those studies are relevant for the topic of safety principles. Although many people are involved in an active or passive manner in work zones, the available studies deal with drivers. The behaviour of workers, pedestrians, cyclists, or inhabitants near work zones have hardly been studied.

A cause for real concern in relation to work zone safety, is that drivers believe that they take enough caution and slow down enough when passing, while experimental studies and observations clearly show that they behave not as they claim but in an even more problematic manner than they apparently think.

Speeding - driving too fast, relative to the conditions and to the signed speed limit - is a general finding of various behavioural studies. The majority of drivers approach road work zones driving much too fast. They do not decelerate until just before an abrupt change in the conditions, and then they decelerate extremely hard.

From these results, it may be derived that safety principles with regard to behavioural factors involve the setting of right ‘expectations’ of drivers who approach road work zones: it must be clear that they approach a work zone, and what behaviour - of which speed is of major concern - is appropriate there. It is also important to communicate to drivers why the desired behaviour is requested from them, and where and when the works will take place. The information provided should be reliable and up to date. One of the reasons why drivers do not obey the speed limit near work zones is probably that they often experience that there is no work going on at the time they are passing a work zone.

The actual start and end of the work site must be identified by specific elements so that motorists are aware that they are in a special zone in which the utmost care is called for and can adjust their speed and driving behaviour accordingly.

Dynamic speed signal control taking account of the hazardous situation is more likely to be accepted than a static speed limit signal. However, it is necessary to awaken the motorists sense of personal responsibility by, for example, adapting speed signal control to suit the situation.

The aim should be a moderate and even decrease in speed. If driver awareness is increased by road equipment elements, more stable behaviour can be expected in consequence due to the assumed reduction in reaction time which results.

When it comes to measures intended to reduce speeds at road works, not only the actual development and design of measures and devices are of importance; it is also necessary to consider in which phase of passing a road work drivers should be influenced, i.e. the location of a device should be carefully decided. Thus, speed limit signs, feedback variable message signs, lane narrowing devices and other measures used to make drivers slow down should preferably be positioned before they enter the transition area.

1.5.1. Conclusion

With regard to road user behaviour, speeding is a major concern at or near road work zones. The setting of correct ‘expectations’ of drivers who approach road work zones, effective communication to drivers, and providing reliable and flexible information can be named as ‘safety principles’ which are considered relevant in attempting to make drivers behave in a desired manner.

Standardisation of work zone areas regarding traffic guidance, alignment, and width of temporary lanes, as well as of individual signposts and guiding devices, is often proposed (see Deliverable 2: Behavioural studies) and is assumed to strongly contribute to the solution of the safety problem at road works. Even though previous experience and expectations play an essential role in drivers’ behaviour, it is worth considering that a uniform appearance of work sites may give drivers a feeling of familiarity and false safety - meaning that they no longer possess an adequate sensitivity for unexpected hazardous situations that may occur (Pomerada and Zacharias,1991; cited in Deliverable 2: Behavioural studies). However, care should be taken that such a remark is not translated to mean that ‘random’ measures and unique solutions would be better than a functional and logical standardisation of work zone safety measures.

1.6. Accidents

Accidents being the result of lack of safety, safety principles proposed should focus in reducing them in work zones. To achieve this, the primary concern was to perform the appropriate analysis to detect the typology of work zone accidents actually occurring. In task 2.2., accident studies performed worldwide were analysed. The results of this analysis were far from satisfactory, being in many cases contradictory (others giving, in work zones, results of very important accident increase, others of minor increase and, even some, of decrease in comparison to normal traffic situation) and/or insufficient to reach concrete conclusions.

Safety principles in the accidents field mainly concern the adoption of a common (at least, minimum) basis in accident elements to be registered Europe wide. This will greatly ease further analysis in accident studies and, consequently, it will offer more reliable results on the accident creation mechanism that will help in better confronting accidents and improving safety in road work zones. Safety principles appearing further in this section focus in this specific aspect.

Safety principles, in the work zone accidents field, concern the description and presentation of a complete and reliable set of input elements that should appear in all European accident records. These elements must be designed so as to be the basis for reliable accident studies that may offer comparable results.

Actually, accident studies concerning work zones, have very few comparable elements. For this reason, results in them greatly differ, depending on the methodology used by each research group. Reliable conclusions are impossible to be extracted from them and only expert guesses may be used to reach some work hypothesis, more or less close to reality.

1.6.1. General safety principles

General safety principles in this field concern the minimum set of elements to be used in safety records related to work zone accidents and in analysis aspects that should appear so that results may be comparable, both between different types of work zones and between work zone and normal traffic conditions. These elements should include external factors, road users / workers behaviour and work zone typology aspects. They should be presented in the form of multiple choice cases to be more comprehensive and easier, for the persons in charge, to register the accidents.

1.6.1.1. External factors

Traffic volumes, speed before the work zone and in the work zone, weather conditions, time and day of accident, lighting and road surface conditions and general road infrastructure (number of lanes before work zone, type of road) are the external factors that should be included in accident records to give the general idea of the conditions that an accident has occurred.

1.6.1.2. Road users / workers behaviour

Compliance with speed limits, headways among vehicles in the specific work zone, type of accident, vehicles involved in it and estimated speed of vehicles participating in the accident are the basic elements that should appear in accident records concerning road users behaviour. Additionally, if possible, actions preceding the accident may be included in the accident records.

The distance from the main traffic stream that workers are working in the specific work zone and the kind of work, they are involved at, are the basic elements that should appear in workers behaviour in the accident record.

1.6.1.3. ARROWS typology

The work zone typology is an important element that should appear to the accidents record. Compliance with the ARROWS typology is strongly recommended in it.

Road type, duration, and road/work zone interaction

The area in which the work zone exists (urban, suburban, rural), the existence of pedestrian movements and the number of lanes before and in the work zone are the main elements that should appear concerning the road type.

Long term, short term stationary and short term mobile are the main duration aspects of the road work zone that should appear concerning the work zone duration.

The area of the work zone (advance warning area, narrowing area, buffer zone, work area, termination area, run off area) in which the accident occurred are the main aspects that should appear concerning road/work zone interaction.

1.6.2. Conclusions

Actual accident records are, in most cases, insufficient to perform a comprehensive and complete accident analysis in work zones. Safety principles in this field, as they appeared both from the analysis performed in task 2.2. and in the work performed by the ARROWS consortium afterwards, pinpointed the need for a more complete and standardised way in recording and analysing accidents occurring in work zones.

The work performed in this section explicitly gives the necessary methodology to be followed in order to achieve this goal.

1.7. Research Methods

Experimental and other research methods were examined in task 2.3. with the aim to present a concise overview of existing and proposed experimental methods for the evaluation of safety measures and to select and define an appropriate set of experimental evaluation methods.

In relation to safety principles, few guidelines can be determined from this review. Safety principles in this field concern the appropriate selection of experimental and other evaluation methods to be used in each specific work zone design, depending on its characteristics, in order to guarantee the optimum safety aspects in it together with a satisfactory level of operation of the road axis and of the work zone itself. This action was undertaken in the conclusions of task 2.3. in the form of a selection table, which will be the basis of the safety principles that will be proposed further in this section.

1.7.1. General safety principles

Following the methodology issues elaborated, when dealing with road work zones, given that practically all items used for both their design and equipment are inherited from normal road design and equipment, no testing concerning physical properties nor model testing may be needed. It is, thus, concluded that the experimental and research testing performed in work zone design should be the following:

a) At first an office design, concerning both the work zone master plan and the equipment details should be performed.
b) Based on this, a simulation design and testing of the work zone performance should be conducted.
c) In cases of innovative design and/or use of innovative items in it or in cases of extremely complicated road work zones (e.g. in highways or in rural networks with heavy traffic), a test track testing should be performed to evaluate the human behaviour and behavioural modification aspects related to this design or to some critical aspects of it.
d) Finally, a road/real time testing should be performed, in cases that the proposed design is meant to become a standard to many similar road work zone layouts. In this case, the first of these layouts should be studied in detail before reaching the standardisation phase.

1.7.2. Conclusions

Safety principles in experimental and other evaluation methods refer to the appropriate selection of experimental and other evaluation methods to be used in each specific work zone design, depending on its characteristics, in order to guarantee the optimum safety aspects in it together with a satisfactory level of operation of the road axis and of the work zone itself.

From the work performed in this field within the ARROWS project, it was concluded that, referring to the ARROWS typology, the optimal choice of experimental and other research methods to be performed in each specific work zone, may be standardised in order to offer a comprehensive tool to all actors involved in work zone design. This selection is related to:

- The importance of the road work zone

- The innovations used in it
- Its role in a standardisation aspect

Depending on the above, only a design as described under (a) earlier in this section may be sufficient to a work zone of small importance, with standardised aspects and no innovative items used in it. For more important work zones and/or including some innovation aspects in them procedures in (a) should be followed by the ones in (b), for even more important and/or using more innovative aspects, procedures described in (c) should, also, be used so as in extremely important work zones and/or including many innovative items that are, additionally meant to become the basis for standardisation issues, procedures described in (d) should, also, be part of the research/experimental evaluation.

1.8. Future Directions and Other Aspects

1.8.1. General

Future directions in safety measures should, mainly, focus in pan-European standardisation issues, since this is the most "weak" point in this field.

Even if the guidelines are laid down in the most perfect manner, the large number of possible work zone types and traffic guidance systems means that the person responsible for the safety of a work zone must be prepared to think about the individual problem and be prepared to make available what is optimally required for the drivers and other travellers. Obviously the promoting of measures to ensure that the relevant contractors understand the safety aspects and feel responsible for these is an important task in connection with work zones on motorways and other roads.

Although the sets of regulations in most countries not only provide the opportunity for but also require the intensive checking of work zones that have been set up, there are great shortcomings in this area in practice. It is therefore not uncommon for work zones that have been designed, set up and/or equipped in an inadequate manner to cause accidents.

1.8.2. Procedures, regulations and other software safety measures

Procedures, regulations, checklists, auditing, enforcement and training being the main issues of safety measures used, it can be said that, on each specific item reviewed, these issues cannot be defined following a general rule but should be regarded separately.

Additionally, concerning traffic information on radio, an important safety principle is the pan-European adoption of a common frequency and a common technology for the transmission of urgent messages related to traffic items (e.g. road closure due to accident, danger of ice on road surface, etc.).

In order that as many as possible of these aspects can be observed, it is laid down in most countries that a plan with the traffic signs as well as the marking and safeguarding systems is prepared before work is commenced. Depending on the particular legal requirements, such plans must be checked, corrected if necessary and then prescribed for the work by in each case the responsible, official authority.

It can unfortunately be seen in a number of plans for the safeguarding of work zones that the principle "the more the better" has been followed. To be particularly mentioned in this connection is excessive use of blinking and flashing lights. Nevertheless priority should be given to the fundamental principle that a traffic situation, which will be unexpected and unusual for the majority of drivers, should be designed in a quiet and easily over viewed manner, instead of in a manner that - through the introduction of additional distractions - will impair drivers' abilities to master the particular situation.

The activities performed in the context of the ARROWS-project will (a.o.) lead to the production of a practical handbook (task 4.3). Some ‘principles’ can be formulated with regard to this handbook (see task 3.2: Workshop in Athens, November 1997).

In order to promote safety, the Practical Handbook should be brief, illustrated, portable, user-friendly, comprehensive, accessible and modular, allowing for checklist or "ask yourself" control. It should include all basic safety principles already described in a complete and comprehensive way.

Specific safety principles in the thematic unit of improvements concerns the adoption of some key ideas discussed during the Workshop in the final formulation of the principles and ideas to be included in the Practical Handbook.

The most important among them are:

- The "self-explaining road work zones"
- Application of the "interoperability" principle for reducing the number of different layouts and using the same type of material for different work zones
- Future use of pan-European studies, meta-studies and accident scenario construction for road work zones
- Proper signing helps enforce or induce desired behaviour regarding speed choice and/or merging
- Compatibility of principles and ideas included in the Handbook to already existing important European Standards (e.g. TEM standards)

Principles as can be derived from task 3.2 may be resumed as a final "fine tuning" of the principles, propositions and pre-normative ideas included in the Practical Handbook before finalising both contents and the way to present each and every one of them. It is evident that the important work performed within the ARROWS project will be more effective if presented in a well-developed format.

Additionally, some improvements should be undertaken in items already analysed and presented, in a way to embody in them the most important key ideas expressed during the Workshop, before presenting them in their final form in the Practical Handbook.

1.9. Discussion, Conclusions and Recommendations

1.9.1. Background and results

The objective of the present Chapter is to produce a compilation, and attempting a synthesis, of safety principles, which can be used for the planning, design, implementation and operation of European road work zones.

In the previous sections, the ARROWS partners compiled what they felt to be important safety principles, with respect to road work zones.

All partners were encouraged to freely contribute as they saw fit. The possibility of incorporating existing guidelines from each partner's country was also stimulated.

In addition, a number of partners systematically summarized the safety principles which could be extracted from each of the previous ARROWS internal reports.

The idea was that, to the extent that previous ARROWS work was systematic, complete, and unambiguous, then (some) principles should be extractable in a structured way. To the extent that these conditions did not obtain, then less structured contributions could also be useful.

One could be reasonably pleased with the results. Even though there are (some) ambiguities and overlap between principles, every principle and/or argument mentioned in this paper can be profitably considered.

A general description of the types of principles found in the previous sections may be seen in Table 1. In that table, we find the ARROWS Task (i.e., the source of information) crossed with content.

Rather than a recapitulation of specific principles, it can be noted in each cell of the table:
- how extensive (or succinct) the found principles are;
- whether the principles are explicitly scientifically supported or seem to represent more practical sources of knowledge;
- how specific (or general) the principles are.

That some or many cells are empty is inevitable: the ARROWS sub-tasks are already partially content-driven, so the columns and rows of this table are not 100% independent.

In any case, a number of structural aspects appear:
- few of the principles mentioned here seems to be based upon explicit scientific arguments, relying more on practical insights;
- there are no principles related to the internal structure of the work zone,
- and relatively few related to standardization and "other" issues;
- a great deal is found concerning general principles, much less information is found concerning other matters.

Table 1
General overview of type of principles, with respect to extensiveness, support and specificity.

Subject Matter (content)	**ARROWS Tasks (source)**						
	Task 1.1	Task 1.2	Task 1.3	Task 2.1	Task 2.2	Task 2.3	WP 3
General Principles	none	none	extensive practical specific	short practical specific	short practical general	extensive practical specific	short practical general
External (risk) Factors	none	none	short practical specific	none	short practical specific	none	none
Road User/Worker Behaviour	none	none	short practical specific	short practical general	short practical specific	none	none
“Hardware” Safety Measures	none	extensive practical specific	none	short practical general	none	none	none
“Software” Safety Measures	none	short practical general	short practical general	none	none	none	none
Internal Work Zone Structure	none	none	none	none	none	none	none
ARROWS Work Zone Typology	short practical specific	none	short practical specific	none	short practical specific	none	none
Standardization Issues	none	none	none	short practical specific	none	none	none
Future Directions	none	short practical general	short practical general	none	none	none	none

Other Aspects	none	none	none	none	none	none	short practical general

1.9.2. Room for improvement

There are also a number of aspects that lend themselves for improvement.

A very important consideration concerns the amount of empirical and/or theoretical evidence supporting specific principles. All partners were asked to explicitly underpin their principles with reasons why we should be willing to accept them. One has the impression that this aspect has not been sufficiently carried out, often for very good reasons. (E.g., the empirical or scientific support for a specific generalization may be non-existent.)
Nevertheless, one is left with a collection of principles, without a clear idea of how much belief should be attached to each individual principle.

A second point has to do with the relative utility of principles. Suppose that there are two equally well supported principles, only one principle is much more effective in reducing accidents. For example, even if one could perfectly protect road workers (by replacing them with robots, for example), this would address only a small fraction of the road accidents that one e might be able to prevent by, for example, implementing better driver guidance. Should both principles be given equal value and priority?

Related to these two points, but perhaps more fundamental, is the problem of explicating what is meant by “principles”, and how they should be structured. The first months of the present sub-task was characterized by an exchange of divergent views concerning this matter. The present text serves to underscore the range of possibilities.
There are safety “principles” ranging from generalities encouraging “self-explaining roads” to highly specific suggestions of what road workers should do before they start setting-up a work zone.

There may exist an “essential tension” between the idea of “principles” (higher order generalities) and the requirements for a practical handbook (e.g., recommendations for specific behaviours). Such a psychological tension isn’t necessarily harmful, nor uncommon. Similar problems exists in descriptions of naturally occurring taxonomies of objects, such as the members of the animal kingdom. (Lay-)people generally compromise between the generality of phyla and the specificity of genus and species, by working with an intermediate level of abstraction, called the “basic level”. Of course, people with different backgrounds (and needs) can use different basic levels.

The situation here is that the consortium has not clearly developed either a common scientific nor practical “basic level” of safety principles.

This is last point is hardly surprising, noting that:
- scientific knowledge of work zone accidents and driver work zone behaviour is hardly extensive;
- practical knowledge concerning the day-to-day problems and practices of designing and implementing work zones has not been systematically tapped in the ARROWS project;
- checklists, procedures, regulations, etc. are only sporadically available;
- motorway (and highway) work zones has received a great deal of attention, perhaps to the detriment to work zones on other road types;
- different (sorts of) safety principles are applicable to different groups of stakeholders: road workers need other principles than policy makers. There may still exist some uncertainty in the choice of the primary target group(s).

1.9.3. Conclusion

One conclusion is rather straightforward. Namely, almost any systematic grouping and explication of safety principles leading to further pan-European standardization would be beneficial for road safety. The compilation found in the present Chapter provides such a starting point.

Even so, the scientific underpinning of the principles presented here (or any other principles) deserves a more elaborate consideration, if only to maximize their potential.

1.9.4. Recommendations

The following aspects could be profitably considered.

- A vigorous program of pan-European work zone accident research should be started. One needs to better understand the problem that we wish to solve.
- Work zone implementational schemes should be subject to systematic investigation and evaluation. One needs to know what works well and what doesn't.
- Safety principles, in general, could be profitably ordered by target group and task..
- A pan-European forum or procedure for **developing** standardized guidelines, checklists, audits, and procedures should be considered.
- More attention should be paid to "low-grade" work zones, such as work zones of short duration on urban roads with limited space.
- Road administrators should explicitly require a safety plan as a component in contract tenders, and be willing to pay for the consequences.

1.9.5. A tentative list of safety principles

Based on the available results of the ARROWS project, and despite the fact that at present no firm conclusions can be drawn, it was nevertheless attempted to derive a tentative list of what can be called safety principles that should govern the planning, design, implementation and operation of road work zones.

From the previous sections the following rather abstract terms can be extracted on which 'governing' safety principles should be based when planning, designing, and implementing road work zones:

- classification
- uniformity
- compatibility
- comprehensiveness
- clarity
- flexibility

coherence
visibility
standardisation
communication

Based on, or 'inspired' by, these terms, the following safety principles can tentatively be formulated:

1.9.4.1. Work-zones vs. other works

The road as a working place should be ranked equal with other (ordinary) working places concerning the safety for *all actors* involved, and the working environment for all worker categories.

Road works are special working places from the point of view that they affect a third party, the road users. The road users should have the right to be considered, and requiring the same level of safety as in undisturbed traffic as well as a certain level of passability.

1.9.4.2. Planning and procedures

For all road works, a traffic control plan *must* always be prepared and *approved before* the work begins. The traffic control plan should show the type and location of signs, closures, vehicles and other devices at each work site, and be done according to the regulations in force.

Unannounced audits at work sites should be performed, "checking up" signing, layout procedures undertaken etc.

The road works may begin only after the installation of all traffic signs and facilities.

1.9.4.3. Traffic conditions and disturbance

Unless there are special reasons traffic should be diverted to other roads, or the work carried out under low traffic conditions.

The duration of road works should be minimised (including optimum construction phase planning and shift work, e.g., work from daybreak to nightfall as well as on Saturdays and if needed at nights)

If different types of work are necessary at the same site (e.g. laying of water, gas, electricity, telephone and waste-water lines in urban areas), they should be co-ordinated so that the number of traffic disturbances and road closures as well as the amount of traffic exposure to the workers can be minimised.

Road works should be planned and performed to minimise disturbances (for example noise during the night) and disruptions to other functions of the community (for example trade and public transport).

The road works should preferably be executed at the time of low traffic intensity, i.e. outside traffic peaks and recreational traffic.

1.9.4.4. Work zone layout

The layout of road works and the feedback given when passing should assure low speed levels.

The layout of road works should make it obvious how to interact with workers and other road users.

It is important to establish buffer zones (in which there should be no equipment and in which no one should work) especially in the case of work zones on roads with more than three lanes.

The total closing of traffic lanes as well as of entries and exits to/from motorways is to be avoided where possible.

Ensuring the least possible influencing of the flow of traffic, e.g. by keeping the same number of traffic lanes in particular on roads with high traffic volume.

In case it is needed to close lane(s) on motorways or dual carriage ways, it is necessary to close lane(s) from the left side (‘quick lane(s)’) and conduct traffic through the right line(s).

Speed reduction should be achieved only in steps (e.g., of 20 km/h within a suitable distance).

Fundamentally with motorways the holding ready of alternative routes for use in case of severe disruptions in the region of a work zone, e.g. as a result of an accident.

Access to and opening up of work zones wherever possible from the outside and not via the road affected itself.

No empty, unmanned or abandoned work zones. As soon as the construction work has been concluded or halted, the systems disrupting traffic should be removed immediately or rapidly or at least reduced. Speed limits and in particular those imposed for the safety of those working in the work zone should be removed by covering over the relevant signs or providing indication that these do not apply outside working hours.

1.9.4.5. Road workers

Safety clothing *should always* be worn by all personnel categories working at road works. These clothes are the workers life insurance.

Relevant education and training *must* be provided for all personnel categories involved in road works.

The education and training of the different personnel categories should *not* be given *once* and then never more. It has to be repeated and up-dated.

The responsibility of signing and layout according to set traffic control plan (including flexibility and modifications, see below) should be assigned to one or a couple of workers.

1.9.4.6. Road users

Correct and actual (up-dated) information to road users should be given a prominent role.

As driving to a large extent is an automatised behaviour (at least concerning experienced drivers), it is important to design the entrance of the road work area in a way that notifies the driver that s/he is entering a road section requiring more "active" driving.

Road works should be designed to prevent divided attention, distraction and overload of the road users. Therefore, the sequence of information, warnings, closures and other devices presented to the road users (drivers) at a work site should be positioned with *enough separation* to enable their processing of the messages, deciding what to do and doing it.

Pre-information should be given well in advance of the road work, telling the road users what to expect, and for how long (in time and distance), enable him/her to be mentally prepared.

The best way to make road users act according to the intentions of the road work designer and comply to given information, warnings, guidance etc. when passing road works is to use "correct" traffic control devices. Thus, the signs, layout, devices and procedures used should be easily understood and experienced as motivated. Therefore, as responsible for a road work, it is important to ask oneself 'Will a driver understand how I want him/her to drive through the work zone?' The easiest way to answer the question is to take on the role of the driver and actually drive through the zone, in both directions.

Traffic guidance in the work zone area has to be unambiguous, clear and easily recognizable for road users. All traffic signs and devices have to be easily visible and understood.

The driver's directional guidance through the work zone deserves special attention (by means of, e.g., guiding equipment, road studs, foils, suitable and uniform angles of standing of transverse closures).

The needs and safety of unprotected road users e.g. pedestrians, (motor)cyclists and mopedists must be considered, with special attention given to the needs of the disabled (e.g., routes can be diverted from those of motor vehicles, or special facilities for these road users can be made in the work zone area). This is especially important at work sites with a large proportion of vulnerable road users.

1.9.4.7. Contractors

Efforts must be made to create possibilities for the training of contractors. More guidelines and less checks will only be effective when an appropriate level of understanding and co-operation can also be expected from the side of the contractors.

1.9.4.8. Signing

As few signs as possible should be used, but as many as necessary.

The signing and layout of road works should be flexible, following changes and different phases of the work.

Traffic signs and traffic devices should only be used when road works are actually conducted (for example, modifications due to no operational work taking place during night time but starting up again every morning; clearly inform whether workers or only the "work" are present).

Traffic signs and devices used have to be updated according to the stage of works in work zone.

Colour coding. A specific colour should be assigned for information panels, signs, guidance devices etc. at road works.

The general design (e.g. shape) of different types of road signs like warning, prohibition and information signs should be kept also at road works. Road users are traditionally very well familiarised with what type of messages the different sign shapes convey. Therefore, from the shape they can understand the basic aim of a message also if the sign is covered by for example snow or dust (at least the latter is not uncommon at road works).

Road work signs, markings, and devices should be of good quality (e.g. kept clean), which should be secured by procedures and protocols for maintenance and operation. The road users' confidence and respect of road work devices are dependent on their standard, management and attendance.

Traffic signs and devices have to be functional (clean, correctly located and fixed).

Installation of traffic signs and traffic devices has to be provided in the direction of traffic flow and uninstallation (removing) has to be provided against the direction of traffic flow.

In the area of the work zone no irrelevant or distracting information should be present (e.g., advertising).

The work zone traffic signing should be provided in the same way in similar situations.

1.9.4.9. Evaluation

Systematic evaluation of the effect of safety measures as well as systematic work zone accident registration using a common format, should be included in the process of planning and executing road works. This will help to better understand (behavioural) mechanisms leading to accidents, which will then contribute greatly to improving the safety at road work zones.

1.10. Safety Principles from a Practical Point of View

1.10.1. Introduction

Safety principles reflect the high level stand points, statements and ideas that govern the concrete and operational design and the use of measures, devices and procedures in relation to road works with the purpose to increase safety. These principles cover all phases of a road work, i.e. planning and preparation, responsibility assignment, implementation, carrying out, evaluation and follow up.

The formulation of safety principles contributes to the usability of the developed safety measures. For several reasons safety principles have been incorporated in guidelines.

At first, the applied safety principles give a good background to the safety measures. Having knowledge of the prevailing safety principles adds to better understanding and acceptation of the prescribed safety measures.

At second, the safety principles give direction to the customisation of prescribed safety measures to local circumstances. Many road work zones will not fit exactly in the typology that is used to determine the necessary safety measures. By using the safety principles the safety planner is able to adapt the safety measures from the handbook to the local situation.

In such a case the adaptation takes place in a way according to the intentions of the measures in the handbook.

In the third place, safety principles help the developers of new safety measures. Developers may want to introduce new technologies. Safety principles will support them to decide how these new technologies have to be introduced. Safety principles are independent of available technologies and therefor useful for an unprejudiced consideration of different safety technologies.

Finally, clear safety principles may act as assessment tool for planned and installed safety measures. A perfect planned and installed site will seldom be met. Nevertheless, sites that have been set up according to good safety principles give more safety. The layout of a road work zone must besides their correspondence with the prescribed safety measures, also be judged on their correspondence with the safety principles. This is an important perception not only for the safety planner, but also for the other involved parties as road directorates, building contractors and safety inspectorates.

The paragraphs of this section focus on safety principles from a practical point of view. The next paragraph considers the different interests that underlie the formulation of prevailing safety principles. Paragraphs 1.10.3 and further will go into detail on safety principles which have proven to be useful in European circumstances.

1.10.2. Safety principles, balance of interests

The perfect safety measure does not exist; accidents will always occur. Important criterion for the application of a safety measure is therefore not only his safety increasing effect but also his effects on other aspects. A safety measure does not only affect safety but also aspects as traffic circulation, environment and workability of the road work. Established safety principles reflect the ideas and opinions about the balance between safety and these other aspects, related to road works.

This paragraph gives insight in the balance between aspects of a road work zone. This insight is useful for the adequate understanding of safety principles.

During road works, traffic flow and safety can be adversely affected by:
- Increased traffic congestion as a result of reduced route and/or network capacity;
- Increased dangers to drivers encountering unfamiliar traffic and road situations as well as construction works and equipment;
- Increased risk potential for workers.

The adverse effects of road works on the safety of road users and the need to minimise the possible disruption of traffic should be taken into account when determining the timing, form and type of road works. The main objective is to obtain a compromise between, on the one hand, safe and efficient (in time and cost) performance of the works and, on the other hand, safe flow (with minimum accident risk) with the minimum inconvenience (disruption, undue delay). A balance must therefore be achieved between the following:
- Traffic flow and road user inconvenience;
- Safety of motorists and workers;
- Efficient road work scheduling and economic traffic operation;
- Environmental impact and other quality requirements.

Preconditions for minimising the effects of road works on safety, traffic flow and the environment are the following:
- Integration of safety and traffic control aspects at all stages, from project design to completion of works;
- Work zones must be planned to take account of the traffic requirements; it is important to keep the original number of lanes as long as possible;
- Measures taken for the traffic management system and the organisation of construction work are interactive: they can be optimised by means of an iteration procedure;
- Each measure used must assure safety of workers and high quality of work; it must be justifiable when compared to the costs involved and should have acceptable negative effects.

The next paragraphs give an overview of safety principles. General safety principles which give direction to all safety measures are subject of paragraph 1.10.3.

Paragraphs 1.10.4 to 1.10.7 go into detail of safety principles that govern the four main stages of a road work process. These stages are:
- planning and designing a road work zone;
- setting up a road work zone;
- carrying out a road work;
- dismantling a road work zone.

1.10.3. General safety principles

The general safety principles in this paragraph reflect the idea that a good safety measure contributes to the safety of road workers and road users, minimises traffic disruption and does not lead to excessive nuisance of the work processes of all parties involved.

1.10.3.1. Safety plan

Traffic safety measures at a road work zone should be an integral and high-priority element of every project from planning through design and construction. Maintenance and utility work should be planned and conducted with the safety of motorists, pedestrians and workers kept in mind at all times. To ensure an integral approach, safety plans should be developed for every project. Good plans arise when all parties involved cooperate in the making of the plans.

1.10.3.2. Trained personnel

Besides a good safety plan, the employment of well-trained personnel on all levels is essential to achieve high safety levels. Although safety measures can raise the safety level at a road work zone, much safety can be gained by well-considered behaviour of road workers and other personnel. Training of personnel therefore should aim in the first place at making people aware of all potential risks near a road work zone. At second, attention should be given to defined procedures and guidelines.

1.10.3.3. Public relations

Planning and training have little impact on the behaviour of traffic participants. Still one tries to influence the traffic behaviour around a work zone. Higher attention levels prevent from severe incidents. Maintaining good public relations is therefore necessary. Publicising the existence and reasons for work zones can be of great assistance in influencing traffic participants, both in adapting their behaviour near a work zone as well as in choosing an other travel pattern (e.g. route diversion or mode change).

1.10.4. Planning and designing a road work zone

Planning of road works helps to safeguard safety, to minimise traffic nuisance and to control the costs concerned with managing a road work zone.

A traffic control plan must always be prepared and approved before the work begins. This plan should show the type and location of signs, closures, vehicles and other devices at each work site, and be done according to the regulations in force. Part of the plan is also a script for the setting up, the maintaining and the dismantling of the work zone. The plan establishes the responsibilities of road workers, road directors and safety inspectors. A trained official must approve the plan and should monitor the implementation of the plan.

1.10.4.1. Safety

The incident risk at a work zone can be minimised with several principles. Combining different road works at the same location, e.g. maintenance of equipment, must take place at the same time and with a minimum delay of time. If possible road works must be performed during off-peak periods, eventually during the night.

The actual work zone has to be separated from traffic space. A buffer zone between the oncoming traffic and the actual work zone has to protect road workers from a collision with a stray vehicle. The in- and outgoing work traffic should have good sight on the bypassing traffic. Their slip roads must prevent from dangerous situations.

1.10.4.2. Traffic nuisance

The basic principles governing the design of road work zones are the same as the safety principles which govern the design of permanent roadways and roadsides. The goal of the layout is to route traffic through the work zone using geometrics and traffic control devices comparable to those for normal highway situations. If this is not possible the use of clear and visible signs to get the attention of traffic participants is necessary.

1.10.4.3. Maintaining a work zone

The design of the work zone has to enable all parties to process their work without severe nuisance. Therefore enough space has to be incorporated for the storage of materials and equipment and for the safe parking of maintenance vehicles. To enable the police, emergency services and inspectorates to do their work, space has to be reserved for them.

1.10.5. Setting up a road work zone

Setting up a road work zone must be done according to the current plan. Main safety principles concern the safety of the road workers and the way traffic is controlled.

1.10.5.1. Road workers

Installation of the traffic signs and devices should be provided in the direction of the traffic flow. Removing has to be provided against the direction of traffic flow. The installing and removal of safety measures at work zones are the two most dangerous phases in the entire period of a road work. While working the eyes have to be kept as much as possible to the oncoming traffic.

1.10.5.2. Traffic control

When it is necessary to close a lane on a motorway or a dual carriageway, it is preferable to close lane(s) from the left side - quick lane(s) - and conduct traffic through the right lane(s).
Prevent that temporary measures are in conflict with permanent traffic signs. Cover permanent signs if they lead to misunderstanding.

1.10.6. Carrying out a road work

While carrying out a road work much attention has to be given to the inspection and the adaptation of installed safety measures.

1.10.6.1. Inspection

Individual persons should be assigned responsible for the safety of the work zone. These trained persons have to watch over the safety measures and the behaviour of the people which stay in the work zone. The assigned persons must have the opportunity to modify conditions or halt work until applicable or remedial safety measures are taken. Planned and unannounced inspections by official organisations must guarantee permanent safety at work zones.

It is advised to monitor occurring incidents. The analyses of the accidents may lead to better safety measures in the future.

1.10.6.2. Adaptation of safety measures

During road works, circumstances change: works progress in time and place, the weather varies and traffic volumes are subject to changes. The installed safety measures have to be adapted to varying circumstances. It is important to keep safety measures not unnecessary long in use and to avoid empty, unmanned or abandoned road work zones as much as possible. This prevents irritations by road users.
Road work zone speed limits have to be removed by covering over the relevant signs or providing indication that these do not apply outside working hours.

1.10.7. Dismantling a road work zone

After finishing a road work the dismantling of the road work zone can start. Just as with the setting up of a road work zone the main safety principles concern the safety of the road workers and the way traffic is controlled.

1.10.7.1. Road workers

Removal of safety equipment has to be provided against the direction of traffic flow. The installing and removal of safety measures at work zones are the most dangerous phases in the entire period of a road work. While working the eyes have to be kept as much as possible to the oncoming traffic. Escape routes should be prepared in such way that crossing a traffic lane is not necessary. Finally, the removal of equipment has to be done in as little stages as possible.

1.10.7.2. Traffic control

The permanent traffic situation is recovered after all equipment and all waste material is removed.

2. ACCIDENT SCENARIO CONSTRUCTION: A Pilot Study

2.1. Introduction

2.1.1 Lack of evidence

A review of accident studies, implemented as *Sub-Task 2.2: Accidents Studies,* of the ARROWS project, has been conducted by the SWOV, NTUA, ZAG, and the BAST, four of the ARROWS partners (Gundy, 1998). Unfortunately, that review found relatively few clear-cut results which would directly lead to practical guidelines in a practical handbook. It was felt that there was relatively little hard empirical evidence concerning the effectiveness of Work zone safety measures.

Noting that the original ARROWS plan envisioned empirical accident- and safety-measure-evaluation studies, which were subsequently scrapped, one can only conclude that the lack of hard, empirical knowledge is troubling. The consequences for the practical handbook are non-negligible.

2.1.2 An Alternative source of information

Nevertheless, Gundy (1998) suggested that the consortium consider developing multiple work zone *accident scenario*s (i.e., coherent patterns of virtual accident characteristics), assuming that there are distinctly different types of work zone traffic accidents. Generally speaking, scenarios are often developed when the phenomenon of interest is too expensive or impossible to investigate directly. In the present case, we do not have the possibility to investigate work zone accidents directly. Scenarios, extracted from the opinion of experts participating in the ARROWS consortium, is an implementable (albeit somewhat unusual) method for obtaining and summarizing knowledge that we would like to have, and would otherwise have to do without.

If such accident types could be roughly determined, then we could use them to:

- design devices and layouts to take those different possibilities into account;
- establish checklists to ensure that Work zone designers and workers are aware of the different kinds of problems;
- direct future research.

These results (devices, checklists, layouts) could then be used for developing a practical handbook, the primary goal of the consortium.

If, in addition, a scenario construction procedure were to involve the combined efforts and knowledge of all stakeholders (e.g., policy makers, scientists, contractors, etc.), then a number of other benefits may be reaped:

- the accident typology derived would be as broadly applicable as possible;
- participants would become “co-owners” of the end product, the practical handbook, promoting the acceptability of the results;
- explicit and vivid (accident) images could encourage communication among participants of diverse backgrounds; and
- multivariate thinking (as opposed to only multiply-univariate) could be encouraged, a boon for future research.

All in all, there seems to be a number of excellent reasons for pursuing this suggestion.

The approach does involve a number of basic questions. *First of all*, we would like to know if a scenario construction methodology, or any other methodology, is a useful technique for extracting knowledge from the minds of traffic safety experts. *Secondly*, assuming that our methodology is useful, then we would like to know whether the knowledge extracted from the members of the present ARROWS consortium is actually valuable. *Thirdly*, how is the knowledge extracted from the members of this consortium related to the knowledge available in other groups of stakeholders, such as contractors or policy makers? And*, finally*, what is the relation between the scenarios generated in the present study related to actual work zone traffic accidents?

Insofar as these questions address legitimate scientific concerns in the present situation, such as the nature and value of the knowledge of work zone safety experts, or the reliability, generalisability and validity of knowledge extraction techniques, we can be short. We do not know, for it has never been applied before in this manner, to our knowledge, to traffic safety research. In addition, scenario construction methodology is rarely ever validated, because it almost always concerns objects which don't (yet) exist or are otherwise too expensive to collect.

We do suspect, however, that involving a broad group of stakeholders would produce a much richer and multi-facetted typology, and we would highly recommend it in further investigations.

To clear up any possible misunderstanding, we would prefer to investigate actual work zone accidents. Lacking that possibility in the present situation, we feel that scenarios (or patterns of accidents), extracted from experts, are a viable alternative. We feel that it is perfectly justifiable to systematically extract the opinions and intuitions of experts, using the methodology presented in this report, which could then be used by those same experts to develop a practical handbook.

Even so, the relation between real accidents and the opinions of experts , even if vividly formulated, is unclear at best, and we should never confuse the two.

2.1.3. Background and limitations of scenario construction

Scenario construction is, as found in the literature, an amorphous collection of procedures applied to e.g., war gaming, ecology, business strategies, human computer interfaces, and a European project for knowledge management. Q-sorts, structured interviews, brainstorms, Object oriented techniques, list generations, repertory grids, observational techniques, are only a few of the methods used in scenario development. It would seem that the entire scala of psychological (and other) methods could and are employed in such an undertaking. It would seem that "scenario construction" is rather flexible in nature.

Even so, all authors agree that, ideally, scenario construction is a labour intensive project involving a duration of many months, and requiring intensive (face-to-face) interaction between team members. Flexible temporal and monetary constraints are a pre-requisite. Furthermore, almost all authors emphasise that the construction process requires about 8-12 sequential steps, each step being (partially) dependent upon the preceding ones (see, e.g., Reibnitz, 1988, Godet, 1987).

It would seem that none of these conditions obtain in the present case.

Happily, some authors, familiar with similar practical constraints, emphasise the use of "discount" methods (see Carroll, 1995) for generating a great deal of information in an inexpensive manner. Other authors also suggest only implementing out one or two (of the 12) most important (?) steps. How one goes about doing this is mostly left to the readers' imagination.

Altogether this implies that scenario construction, under the present constraints, can only result in a very rough and incomplete pilot study, albeit with a great deal of freedom in choosing the exact procedure that we wish to follow. Hopefully, in addition to possibly providing highly specific and immediately useful information, the findings and conclusions of the present work may also be used in preparing a more definitive study.

2.1.4. Objectives

Subject to the constraints imposed by the present situation, we wish to provide two new sources of information for the ARROWS consortium, in two steps:

1) to obtain as much relevant expert opinion, as is possible within a short amount of time, about road work zone accidents, their causes, and prevention (including, among other things, lists of accident characteristics), based on the opinions of the ARROWS consortium.

2) to develop an empirical typology (derived from patterns of those same characteristics) of virtual work zone accidents based on consensual opinion of the members of the ARROWS consortium.

Information from the first step **may** be used for the second step. However, it may also be independently useful for describing general background conditions relevant for predicting work zone accidents, or for orienting future research.

The second step is intended to develop explicit accident types, which may be used in developing a practical handbook and for which specific countermeasures may be thought useful.

2.2. General Overview

The following two sections describe the two steps taken in the present application, their rationale, and their findings.

In general, the **first** step mentioned concerns the generation of ideas (by experts) concerning work zone accidents.

This idea generation phase was conducted during 6 parallel working groups in one 1.5 hour sitting during the ARROWS workshop in Athens in November, 1997. The members of the ARROWS consortium, and other invited experts, participated in this workshop. Those participants are our experts.

The method for generating these ideas roughly involved four steps:
1) presenting 6 different specific questions to 6 small groups of experts (stakeholders) and explaining the procedure for answering that question
2) brainstorming by that group of experts and
3) culling and organising those ideas by the same group of experts
4) optionally indicating the degree of relatedness between each of the surviving ideas, and
5) preparing a presentation of those results.

Each of the six groups was presented with a different question. Some of these questions were only intended to generate background information not directly relevant to the analysis of individual accidents. For example, which factors influence the exposure of traffic to work zones? The answer to this questions could, for example, be used to predict temporal or regional trends.

Other questions were used to test procedures. Concretely, one group was asked to imagine several (virtual) work zone accidents. This group was free to use any procedure or information that they deemed helpful (i.e., real accident experiences, near misses, anecdotes, fantasy, etc.) as long as the group found the results to be credible. We were curious as to whether the virtual accidents collection procedure envisioned in the second phase was at all viable.

A third, and perhaps most directly useful groups of questions, had to do with generating accident characteristics, causes, and cures which could be used as input for the second phase of data collection.

Thus, the workshop was used for multiple purposes, of which personally involving the participants (c.q., stakeholders) was not a negligible factor. A strict, logical, linkage between the first and second steps was not viewed as being of primary importance.

The **second** step was intended to combine individual accident characteristics into unified accident patterns. This step consisted, first of all, of generating a virtual accident registration form. Input for this form was threefold:
- the ideas gathered at the workshop,
- general knowledge about accident registration,
- any extra ideas found in the ARROWS task reports.

The accident registration forms thus assembled would then be sent to the workshop participants, who would then be asked to imagine a road work zone accident, and fill in the corresponding form.

The procedure for generating virtual accidents was first used, to our knowledge, by Rumelahrt et al. (1988) in their study of the schemata of household rooms.

This process would be repeated for each of several standard road types.

(This last stratification is to prevent too little variation in accident types: most research and knowledge concerns motorway work zone accidents, while there are many other varieties.)

These virtual accidents would then be collected and analysed by means of non-linear Principal Component Analysis. (See Gundy, 1990, for the application of a comparable procedure to more than 25000 real accidents.)

The resulting accident dimensionality (with their corresponding characteristics) may be viewed as an accident typology, underlying (individual) accident scenarios.

2.3. Step One: Generating Accident Characteristics at the Workshop

As mentioned in the previous sections, an ARROWS Workshop was held in Athens in November, 1997. It was thought that implementing a first phase in the scenario construction process during this workshop, would achieve a number of goals.

First of all it would do much to support the "interactive" nature of the workshop intended by the consortium. Secondly, it could help serve to bind other, non-consortium, stakeholders to the ARROWS project[1].

Finally, and most importantly for this report, it would serve as a first step of data collection for the scenario construction process. As we have previously mentioned, it seems important that scenario construction teams work in a face-to-face intensive manner, and this workshop would be the only opportunity for doing this on a broad scale during the course of the ARROWS project. Unfortunately, most scenario construction projects tend to address one (set of) question(s) at a time, learning from errors and using the output of one session as input for the next one. Given that only a total of about 1-2 hours were available, and that it didn't seem useful to work with one large group (there were more than 30 participants), it was felt that splitting the workshop into 6 parallel sessions, with 6 different questions, would be the most productive approach.

2.3.1. Method

The 33 workshop participants[2] were split up into 6 groups of 5 or 6 members each. Care was taken beforehand to ensure that neither professional backgrounds nor nationalities were overly concentrated in any one of the six groups. (This is not to say that the workshop participants were a representative sample of anything: Greeks and Slovenians were greatly over-represented; officials, contractors, road worker unions, and police officials were grossly under-represented.)

After the participants had gathered into their respective, pre-assigned groups, the author - presented an introduction of the procedure to be followed. Each member of each group was given a document designed to explain the question asked of each group as well as the procedure for answering it. (See appendices 1a, 2a, 3a, 4a, 5a and 6a for a copy of each groups' document.)

This procedure consisted generally (there were exceptions) of the following steps:

1) reading the document,
2) generating answers to the central question(s) posed to the group, by means of a brain-storming procedure,
3) organising and culling the answers generated,
4) optionally noting the degree of relatedness between the culled answers,
and

[1] This goal was only partially achieved, due to the fact that there were only a small number of non-consortium participants at the workshop.

[2] See Appendix 7 for a list of the participants and their affiliations: this is our database of experts.

5) preparing a short (i.e., 5 minute) presentation of those results for the following morning.

One member of each group was briefed the previous evening in order to ensure that the goals and corresponding procedures were clear. This member then proceeded to act as facilitator for their corresponding group.

2.3.2. The questions

Of course, the questions chosen to be answered by this procedure are of paramount importance. This author, together with other ARROWS project group participants (VTI and ZAG), attempted to identify an overall, unifying, theoretical background for determining which questions to ask. This grandiose plan was not successful. Rather, this author finally chose an eclectic approach, asking 6 questions which he felt would provide a broad background for future work. (It should be noted that a great deal of raw material had already been produced by previous ARROWS tasks.)

These questions were:

Question 1

- *What are the most important unsafe acts leading to work zone traffic accidents?*
- *What are the most effective defences against unsafe acts?*
- *What are the most important (psychological) precursors leading to those unsafe acts?*

These questions should be applied to road users as well as workers.

This group of questions was derived from the work of Wagenaar et al. (1994), as described in their generic TRIPOD model of accident causation.

Question 2

- *Which background (or exogenous) factors influence the nature and extent of traffic exposure to road work zones?*
- *Which factors can be used to describe the nature and extent of traffic exposure to road work zones*?

These questions were asked to determine the basic components of the exposure of traffic to work zones, a conditio sine qua non for work zone traffic accidents. Such questions have to be answered in order to describe the "augmented" null hypothesis (see Gundy, 1997), or simply provide measures for quantifying work zone accident risk. Of course, the search for temporal an geographical differences in accident risk would also be founded upon these variables.

Question 3

- *What are the root causes (i.e., latent failure types) of work zone traffic accidents? What are the most effective countermeasures for remedying these root causes?*

These two questions are also derived from the Tripod model (Wagenaar et al., 1994), and are linked with the questions asked in Group 1. Namely, " root causes" are viewed (in the Tripod model) as being the cause of (psychological) precursors of unsafe driving acts. We also thought it to be interesting to see if there were differences in the countermeasures suggested, when we consider "root causes" as opposed to the behaviour of road users as being the focal event in describing accidents.

Question 4

- *Which factors, internal or external to work zones, influence (work zone) traffic accident risks?*

Of course, the identification of risk factors is the key aspect of this investigation. We felt that we could ask people this directly.

Question 5

- *Who are the group(s) of actors whose behaviour is relevant for safety in work zones?*
- *What are their goals, and their problems?*
- *Which strategies/resources can they deploy to achieve their goals? And who is the target/ or is effected by these strategies?*

These three questions were inspired by Godet (1987). We also felt that they were quite compatible with the Tripod framework. In a nutshell, people do things for a reason; the choices made determines the system, which then determines the sorts of errors made, and the accidents that occur. It would be interesting to compare the outcome of this Group with the outcome of the "root causes" Group.

In any case, we would hope that the description of the various actors, their (possibly conflicting) goals, and their techniques, could provide a rationale for the problems that we encounter.

Question 6

- *What are the characteristics of the most important and distinguishable types of work zone traffic accidents? Which countermeasures may be the most effective for each type?*

The countermeasure questions is a standard one for this "output oriented" project. Even so, the Group answering this question was something of a guinea pig: we wanted them to construct accident "images" in a manner similar to that envisioned for the following Step of the project: the generation of virtual (i.e., imaginary) accidents. We were not directly interested in the answers generated by this group, but rather in testing the feasibility of the following step. If, for example, the members of the Group had great difficulty in generating virtual accidents, then we would have to reconsider our procedures.

2.3.3. Results

The complete lists of results, as retrieved from the groups' notes, are found in Appendices 1 through 5, the number of the Appendix corresponding to the Question number. We do not feel that it is especially fruitful to present tall lists and tables here. However, as an example, we will present the results of the third work group (latent failures types) in Table 2. (See also Appendix 3.)

Table 2: Contents of Appendix 3: Latent Failure Types and Remedies

- Poor car maintenance: *procedures and enforcement*
- Private car culture: *changing priorities in the political agenda*
- Physical environment around work zones: o*rganisation and standardisation issues*
- Enforcement: *structured schemes for officer education, penalty structure and policy resources*
- Training and education
- Inexistence of checklists of necessary actions
- Maintenance of devices: p*rocedures, responsibilities*
- Lack of time
- Inconsistency of road work zone layout: *guidance*
- Absence of auditing procedures
- Conflicting goals and interests of actors
- Unrealistic restrictions
- Pre-trip information: *appropriate media and usability*
- Degree of usability
- Young drivers education on road work zone crossing
- Absence of dedicated, specialised workforces for road work zones
- Adverse climatic effects on the behaviour of drivers and workers: *awareness of problem through e.g. appropriate campaigns*
- Traffic composition: *in road work zone with more than 2 lanes, restriction of some vehicles categories in one lane*
- Procedures: *public acceptance testing reactions ahead*
- Unclear decision making: r*ight time and level*
- Structure of the urban environment
- Poor quality of construction material
- Legislation
- Institutional framework
- Cultural environment

We would emphasise that all lists and tables were explicitly considered when devising the accident registration form mentioned in the next chapter.

2.3.4. Discussion and conclusion

Without going into detail, we'd like to divide our comments into three groups.

First of all, many of the items generated in these sessions are well known, and hardly a revelation. For example, the importance of enforcement is mentioned in at least three of the six groups. We might even say that it would be surprising if such items weren't mentioned.

While these kind of result are hardly shocking, it is useful to have explicitly gathered them.

Secondly, we are somewhat disappointed by the apparent vacuity of some of the answers. For example, differences in traffic exposure is explained by "regional" factors. Or, that the root causes of work zone traffic accidents are the "structure of the urban environment, institutional frameworks, and cultural environments".

This criticism is not meant to be a criticism of the workshop participants, but a criticism of the procedure that was applied, which was of course limited by temporal and budgetary factors.
With more time, a second workshop session for example, a task force could have singled out a number of central questions and asked participants to delve more deeply into that

problem area. This would be the normal procedure in an extensive scenario construction project, as opposed to the present pilot study. In addition, more time could be spent on estimating the degree of relatedness between the lists of answers given. Of course, the available time was much too short to do so in the present situation.
In any case, the raw material is available in our appendices, and other researchers are invited to make use of it.

Third of all, we do have a number of interesting results.

In the first place, there is a number of highly specific hypotheses, generated primarily in Group 4 which concerned itself with Risk Factors. There we see, for example, that low traffic volumes lead to high speeds (and more severe accidents), and high volumes lead to queuing collisions.

In addition, there is also (especially in Group 3 : Latent Failure Types) a very strong emphasis on procedures and communication: organization and standardisation, auditing procedures, checklists, the availability of pre-trip information, etc. It would seem that arguments could be made that behavioural research is clearly becoming a necessary companion to the more engineering oriented disciplines in the improvement of work zone safety.

Furthermore, we are also pleased by the explication of the relations between the relevant actors and their (possibly conflicting) goals (Group 5). There we see that not only do contractors play a very central role in influencing and being influenced in the network of relations between actors, but they are also a participant in a very fundamental conflict. Namely, they have to bid low in order to obtain a contract, and they have to maximise profits, as does every commercial organization. One way of doing this is to use low(er) grade products, and avoid unnecessarily complicated and expensive (safety?) procedures.

Of course, no organization would completely ignore safety aspects, but in the absence of standardised
-checklists,
-procedures, and
-auditing programs (see the remarks of Group 3), etc. , who really knows what is “safe” and what is only a costly extravagance?

It would therefore seem that the goals of the ARROWS consortium are quite legitimate (i.e., in the eyes of its members): the standardised procedures and checklists have to be posited before they can be (universally) adopted!

Unfortunately, this necessary condition is not sufficient. Road authorities have to not only adopt a (common?) list of safety requirements that contractors will be held to, but they also have to have more funds to pay for the accompanying extra costs.

How much these extra costs would be, and what has to be done in order to get governments to dig more deeply into their pockets, has not been adequately explored in present case. (It was only slightly touched upon in Group 3, when they considered the political agenda, and legislation.)

It may be quite illuminating to further consider this central problem.

2.4. Step Two: Combining Accident Characteristics in the Virtual Accident Survey

2.4.1. Introduction

In this second phase, it was our intention to develop (partially on the of the results of the Workshop) a virtual work zone traffic accident form, to distribute it to the participants of the Workshop. The participants would then be asked to consider a (virtual) accident by any means that they deemed useful, a procedure first applied by Rumelhart et al. (1988).
They could refer to accidents that they had personal knowledge of, near accidents, anecdotes, or fantasised accidents. Our only requirement was that the accident considered be realistic and specific in the opinion of the participant.
The participants would then asked to fill in their accident form accordingly. We would then collect these forms and analyse them, attempting to draw some tentative conclusions about the structure of work zone traffic accidents.

This process, and the corresponding products are described in this chapter.

2.4.2. The accident form

An accident form was produced on the basis of several inputs. *First of all,* we used the information gleaned during the workshop session, which was described in the previous chapter., and summarised in the Appendices. Secondly, we made extensive use of ARROWS Deliverables 1 and 2. *Third of all*, we considered descriptions of variables, derived from diverse authors and databases. (e.g., Gundy (1990); Kars (1997); Immers, Prak, & Reijs (1995); Noordzij (1995); Poppe (1995); Coe (1997).)

This *work zone traffic accident form* resulting from this process is found in Appendix 8.

Each respondent was sent 8 accident forms to fill in. Five of these forms had a pre-determined road-type (derived from the ARROWS typology), and three of these forms were open. The idea was that we wanted to collect a number of different accident forms from each subject, otherwise multivariate analysis would be meaningless. Additionally, we wanted subjects to consider less salient, yet possibly important, types of work zone traffic accidents.

We would like to remark that the time allowed for pre-testing of this form was negligible, and that we would recommend more effort in this direction. We would also like to emphasise that European safety research would be greatly facilitated by common data collection techniques. More specifically, an universally accepted, common (work zone) accident registration form would be enormously useful.

2.4.3. Subjects

All of the 32 ARROWS Workshops participants (with the exception of SWOV participants) were sent a package of accident forms in March of 1998. Two weeks later a follow-up request was sent to the non-respondents. Furthermore, the need for filling in the accident forms was accented at an ARROWS co-ordination meeting in Germany, two weeks after the follow-up request. Finally, the NTUA co-ordination office was asked to approach non-responding participants.

22 (groups of eight) accident forms were returned to the SWOV. A number of minor irregularities were detected, but these were deemed inconsequential, especially noting the pilot character of this study. One (group of) form(s) was largely left blank, so we did not analyse it.

While (21/32=) 65% would seem to be a rather impressive response rate, we would like to note that there are a number of problems with the present sample of accident forms.

First of all, the total number of forms (21*8= 168) is rather small for a multivariate analysis of 50 odd variables. We would have felt more comfortable had all of the participants responded (approx. 250 forms.) Even so, 500 forms is clearly desirable. *Secondly*, the virtual accidents are hardly independent from each other: each subject generated eight accidents. (Most multivariate methods assume independence of observational units.) *Third of all*, the workshop participants were primarily members of the ARROWS consortium, with only limited representation of other interested parties. Also, non-response was especially high for subjects outside of the consortium. To give some idea, the vast majority of respondents were affiliated with a research institute or university, and fully 1/3 of the respondents were from a Slovenian background. The generalisability of the results found here to other contexts could therefore be viewed with some suspicion.

All of this implies that the statistical properties of this sample of virtual accidents, and the generalisation of the results to a population, are highly suspect. (Of course, we have already mentioned that the generalisation of a sample of virtual accidents to the population of accidents is problematical.)

2.4.4. Analysis and discussion

The data from these 168 accidents forms were entered into the computer, labelled in a fashion corresponding to the registration form, and some categories were collapsed.

This data set was then analysed by means of non-linear Principal Component Analysis (PCA), i.e., the PRINCALS analyse program developed by the University of Leiden. (Gifi,1990). The purpose of the analysis was to reduce a complex description of work zone accidents to its underlying, basic dimensions.

The PRINCALS computer program[3] does two things. First of all, it implements PCA, which is a rather standard technique to reduce a large matrix of variables to a smaller set of compound variables. Therefore, instead of considering 50+ variables, we can look at a smaller set of, perhaps two or three, underlying variables which *summarise* the 50+ original variables. The degree to which each variable is described by the underlying component variables is reflected in the “component loadings”.
Secondly, this program *optimally re-scales* the original variables (subject to certain constraints) so that the PCA analysis is as comprehensive as possible. This is a question of measurement level: PCA normally presumes metric variables, such as weight or length, while almost all of the variables in the present situation are only ordinal or nominal, such as road-type or day of the week. After optimal re-scaling, the variables may then be treated as numerical. The values of the re-scaled categories for each variable are found in the “category co-ordinates”.

[3]Versions of the Princals algorithm may be found in the SAS and SPSS statistical packages.

The marginal frequencies for each variable , their labels, their measurement levels[4], the corresponding optimal scaling results, and the PCA analysis are extensively reported in Appendix 9. The gist of those results are reported in the following text.

We extracted three principal components, with corresponding eigenvalues of 0.144, 0.117, and 0.078. (Other analyses indicated that extracting more components was not very fruitful.) Given that we have about 50 variables in the analysis, it would appear that a multivariate data-reduction is highly profitable in the present situation. (That is, we've explained about 1/3 of the total variance with only three compound variables, instead of the seventeen variables that would otherwise be needed.)

In order to interpret this analysis we, first of all, have to consider the distribution of the component loadings: that is we have to see which variables load heavily on the various principle components. Secondly, we have to consider the category co-ordinates so that we can interpret the meaning of the (rescaled) variables.

In Table 3, we see the component loadings for each variable on three principal components (dimensions).

[4]We constrained the solution to force category scores to lie on a single vector: this is the so-called "single" option. We feel that, in the present case, this constraint makes the interpretation easier without sacrificing generality.

Table 3 Component Loadings

Variable	Dimension 1	2	3	Description
E.1ROADT	-.842	-.072	-.024	Road Type
E.2DAY	-.239	.402	.130	Day of Week
E.3TIM	.137	-.710	-.087	Time of Day
E.4MONTH	-.225	-.442	.278	Month of Year
E.5ROAD	-.463	.076	.294	Road Sitation
E.6WEATH	-.286	-.199	.344	Weather Conditions
E.7SURFA	-.197	-.211	.374	Road Surface Conditions
E.8LIGHT	.104	-.641	.115	Light Conditions
E.9STREE	.308	-.410	-.093	Street lighting
E.10ROAD	-.405	-.147	.147	Type Road Surface
E.11SPEE	.678	-.205	-.241	Speed Limit
E.12UNUS	.554	-.010	-.042	Unusual Sitation
E.13ADMI	.743	.029	.002	Road Administrator
E.14TEMP	-.045	.160	-.435	Temporary Conditions
E.15INTE	-.430	-.590	-.069	Traffic Intensity
E.16N_CA	.681	.185	.041	Number of Carriageways
E.17LANE	.675	.101	-.024	Total Number of Lanes
D.10MAN	.103	.658	.261	Manoeuvre Collision Partner
D.11ORIE	.110	.613	.261	Orientation
D.1ACC	-.445	.115	.224	Accident Severity
D.2LOC	-.396	.018	.093	Location in Work zone
D.3AGE	-.356	-.131	.217	Driver Age
D.4GENDE	-.122	.121	.300	Driver Gender
D.5DRIVI	.231	-.002	-.186	Driver Experience
D.6AIMP	-.230	.592	.168	Driver Impairment I
D.6BIMP	-.186	.594	.230	Driver Impairment II
D.6CIMP	-.226	.476	.174	Driver Impairment III
D.7UNSAF	-.328	-.346	-.086	Unsafe Driving Acts
D.8MAN	-.383	-.245	-.008	Maneouvre Driver
D.9COLL	-.217	-.655	-.236	Collision Partner
T.10TYPE	-.192	.334	-.497	Type of Work Zone
T.1DURAT	-.299	.426	-.505	Duration of Works
T.2SIZE	-.456	.160	-.280	Size of Works
T.3LAYOU	-.208	-.229	.566	Layout of Works
T.4LOCA	.302	-.156	-.377	Location of Works
T.5ACON	-.535	.008	-.283	Control Devices I
T.5BCON	-.395	.250	-.537	Control Devices II
T.5CCON	-.407	.214	-.250	Control Devices III
T.6AEQU	-.346	.022	-.232	Road Equipment I
T.6BEQU	-.464	.113	-.357	Road Equipment II
T.7AMIS	-.189	-.347	.171	Miscellaneous Equipment I
T.7BMIS	-.152	-.176	.184	Miscellaneous Equipment II
T.8AENF	-.269	-.065	-.521	Enforcement/Publicity I
T.8BENF	-.260	-.161	-.331	Enforcement/Publicity II
T.9WORK	.049	-.631	.109	Zone Operation
V.1ACOU	-.402	-.224	.207	Countermeasures I
V.1BCOU	-.445	.143	.377	Countermeasures II
V.1CCOU	.234	.215	.412	Countermeasures III

E refers to variables grouped in "General Accident Background"
D refers to variables grouped in "Accident Characteristics"
T refers to variables grouped in "Work Zone Characteristics"
V refers to variables grouped in "Countermeasures"

The number immediately after the period refers to the order of the variable in the accident registration form (see Appendix 8). The letters thereafter are a mnemonic referring to specific variable in the registration form.

Considering Figure 1 (or Table 3) for the component loadings above 0.50[5] , we see that the **first principal component** is heavily determined by road type (e.1.roadt), the number of carriageways and lanes (e.16n_ca and e.17lane) , the speed limit (e.11spee), by an "unusual situation" (e.12unus), the road administrator (e.13admi), and the type of traffic control device (t.5acon).

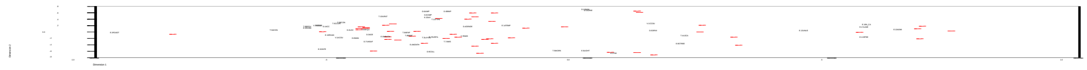

Figure 1 Component Loadings of Virtual Work Zone Traffic Accident Data on first Two Principal Components

We could delve into the category quantifications and co-ordinates, (see Appendix 9), but the main implication should be already clear. Namely, the first principle component is determined by the Road Class, contrasting motorways, on the one hand, with urban local roads, on the other hand. (The other road types intermediate to these two extremes, with rural primary roads being more similar to motorways, and rural secondary roads being more similar to urban local roads.) The road type has an evident and causal relation with the number of carriageways and lanes, the speed limit, and the road administrator. (E.g., motorways have more lanes, more carriageways, higher speed limits, etc. than urban local roads.)

We will examine the structure of this first principal component in more detail (by looking at the variables with weaker loadings, with correspondingly weaker contributions), but the main point is clear. Our first dimension primarily reflects a rather fixed and dominant infra structural aspect: road type.

We find this to be rather comforting. It not only underscores the assumptions of the ARROWS work zone typology, but it would be disturbing to find that infrastructure didn't play an important role[6].

Less obvious, but also logical, is the role of "unusual situations" and traffic "control devices". Accidents on urban local roads are more likely to be near a bicycle or pedestrian crossing, a bus or tram lane, or a parking place. Motorway accidents, on the other hand, are more likely to have an exit/entrance ramp in the vicinity, or something from the "other" category.

[5]This cut-off is rather arbitrary. However, this cutoff ensures that the variables mentioned are rather heavily involved in a given principale component.

[6]An interested reader asked whether it whether it would not be wise to investigate each road type separately, and if we only got out what we put into the data collection (i.e. "road type" as important variable.) W.r.t. the first question, separate analyses on an already miniscule database is hardly wise. In addition, our question was not "what are the similarities (and differences) between workzone accidents on different road types?" but "what are the most important similarities among work zone accidents in general?" W.r.t. the second question, we asked subjects to consider different road types, for fear that they would consider only minor variations of a salient type (e.g., motorways). There was no requirement that this distinction would dominate all others.

Quality traffic signs and traffic markings are more likely to be found on motorways[7], while accidents on urban, local streets are most likely to have no special traffic control devices involved.

If we consider variables with weaker component loadings on the first dimension, i.e., loadings greater than or equal to 0.40, but less than 0.50, then the pattern mentioned above is fleshed in. Variables involved include: the road situation (e.5road), the type of road surface (e.10road), traffic intensity (e.15inte), accident severity (d.1acc), work zone size (t.2size), control devices III (t.5ccon, perhaps also t.5bcon), road equipment II (t.6bequ), and countermeasures I and II (v.1acou and v.1bcou). (See Table 1.) We can interpret these variables by considering the (single) category co-ordinates in Appendix 9.

We find that road work zone accidents on motorways are relatively likely to be on a straight or curved road section as opposed to junctions on urban roads; that bitumen/asphalt and concrete are more likely to used on motorways as opposed to "other" substances on urban roads; that intensities are likely to be (very) high on motorways; that accident severities on motorways are likely to high, involving fatalities or severe personal injury as opposed to less severe accidents on urban roads; road work size on motorways is relatively likely to be large or moderate as opposed to small on urban roads; motorways have a variety of control devices in use, while urban streets may have traffic lights or (limited use of) standard signs; motorway work zones may have a variety of road equipment available, while urban street work zones may have none at all. (Due to the unique nature of the "countermeasures"variables, we'll consider them integrally after all three dimensions have been handled.)

This "work zone hardware and infra-structure" dimension says, disappointingly, relatively little about behaviour- or accident-related variables, unless perhaps one is willing to consider the variables with even weaker loadings.

The **second dimension** (see Figure 1 and Table 2) is also interesting. (We maintain our arbitrary cut-off of 0.50.) Variables such as time of day (e.3.tim), lighting conditions (e.8light), traffic intensity (e.15.inte), driver impairment (d.6aimp and d.6bimp), the collision partner (d.9colli), the manoeuvre and orientation of the collision partner (d.10man and d11.orie), and the operational status of the work zone (t.9work).

Considering category co-ordinates (see Appendix 9), we find that day-time versus night-time accidents are contrasted. It's more likely to be dark during the night-time, traffic intensities are generally lower, and generally there is no other collision partner other than an inanimate object. The driver is more likely to be impaired by alcohol or fatigue during the night, and the work zone is more likely to be shut down. (The opposite is generally true for daytime accidents.)

One could go into more detail by looking at variables with lower loadings on this dimension (i.e. >=0.40): day of the week (e.2day), month of the year (e.4month), street lighting (e.9stree), driver impairment III (d.6cimp), and work zone duration (t.1durat). Considering the category co-ordinates found Appendix 9, we find that: night time accidents are generally associated with the weekends and daytime accidents with the mid-weekdays; night time accidents are associated with the spring and summer, and day-time accidents with fall and winter (?); night-time accidents tend to occur where there is no street lighting, day-time

[7]Interestingly enough, our subjects are most likely to consider motorway work zones, when left to their own devices. (See marginal frequencies in Appendix 9.) Whether this is a form of bias, and what it's consequences may be, is not known to us.

accidents where there are (non-operating) street lights; and again, drivers are less likely to be impaired during the daytime.

This second dimension, representing the day-night cycle, is surprisingly clear. This would also seem to be a rather fundamental aspects of any transportation system. We find it interesting that driver-behavioural and dynamic-accident-characteristics load on this dimension (and do not load on the other dimensions).

The **third dimension** (not shown here, but see Table 2) is clearly weaker, even though we can envision something rather concrete. Only four variables load heavily on it: work zone duration, layout, control devices, and enforcement/publicity (t.1durat, t.3layou, t.5bcon and t.8aenf). Short-term works, with no enforcement or publicity, with lane narrowing or closures, and with no extra control devices are contrasted with the opposite situation. This dimension seem to represent short-term, more ad hoc, work zones as opposed to the more substantial variety. Interestingly, accident and background characteristics don't load very well on this dimension.

Considering variables with weaker loadings on this already relatively weak dimension, we find temporary conditions (e.14temp), type of work zone (t.10type), and counter-measures (v.1ccou and possibly v.1.bcou). Long-term work zones are more likely to involve temporary detours as opposed to short-term work zones; short-term works are primarily maintenance oriented as opposed (re-)construction on long term work zones.

This dimension therefore seem to underscore the other central dimension of the ARROWS typology, yet is not clearly related to a specific type of accident.

We should mention that accident countermeasures are hardly dominant in this analysis: they only load on the first and third dimension to a limited extent (i.e., loadings are great than 0.40, but less than 0.50). This is somewhat disappointing, noting that the development of effective countermeasures is a major aspect of the present ARROWS project. This limited effect could be a reflection of a number of causes. Perhaps there is little unanimity among our respondents, perhaps they are less than enthusiastic about the possibilities of specific counter-measures, or perhaps they feel that effective countermeasures are not limited to specific situations.

We note, in any case, that our subjects have a tendency to feel that driver-oriented countermeasures (better general info, enforcement, education/ training) are somewhat more effective on motorways. Countermeasures aimed at the operation and layout work zone itself (quality assurance & checklists, better worker supervision, better signs and symbols) as well as lower speeds may have more impact on urban streets.
In addition, increasing work zone visibility, better education and training , lower speeds, and better signs and symbols are thought to be relatively more effective for short-term work zones. Variable message signs or traffic lights are thought to be more effective for longer-term works.

2.5. Discussion and Conclusions

2.5.1. Background and summary

The ARROWS consortium is interested in gathering and organising scientific knowledge concerning work zone traffic accidents, in order to produce suggestions for pan-European guidelines for implementing work zones. One effort to that end (c.q. Gundy (1997)) was not as illuminating as originally hoped, due to limitations in the scientific literature. In addition, there were no funds available for gathering data from actual work zone accidents, nor for analysing the data that already exists in (inter-)national databases.

To cover this lack, it was suggested that if we had no access to actual accidents then it might be useful to consider virtual accidents, and treat them as if they were real. In order to ensure some modicum of validity, it was proposed that we approach an international panel of experts on the subject matter (i.e., the ARROWS consortium), in an attempt to extract their intuitions about work zone traffic accidents.

It was also the intention to include experts form outside the consortium, who represented other groups of stakeholders in the area of work zone safety: policy makers, police officials, contractors, etc.

This could have allowed a broader view of the problem area, contributed to the overall acceptance of the consortium’s efforts, provided a common forum for a pan-European discussion of the subject, and allowed for comparisons of differences and similarities between viewpoints.

Unfortunately, attempts for a systematic approach to scenario building (in an attempt to pursue these goals) were not possible due to financial and temporal restrictions. A more modest pilot study was then conceived, which would make use of a session of the ARROWS Workshop in Athens in 1997 as the kickoff. This author prepared six discussion papers, which were to presented to six parallel working groups of 5 workshop participants each. Each group attempted (by means of a brain-storming procedure) to consider possible answers to central questions poised in the discussion papers.

The results of these working groups were then combined with existing accident forms, information found in previous ARROWS deliverables, and other relevant sources of information, to produce a “virtual” work zone traffic accident registration form. Eight copies of said form were sent to all participants of the Athens Workshop with the request to consider a concrete work zone traffic accident (either real or imagined) and to fill in an accident form in order to describe that accident. This was done for a total of eight times. 5 times subjects were given a road type of which the said accident had to occur, 3 times the subjects could freely determine the road type themselves.

About 2/3 of the subjects responded, and their returned accident registration forms were entered into the computer and analysed by means of non-linear Principal Component Analysis.

2.5.2. Primary findings

This process has resulted in very simple and clear results. Namely, the variability in the characteristics of work zone traffic accidents, as studied in the present report, can be reduced to three independent, underlying, basic dimensions[8]:

- the type of road on which the work zone is located, with primarily motorways being contrasted with urban local roads;
- the duration of the work zone, varying from short-term and ad hoc to long-term and more-extensively organised;
- the time-of-day cycle. It is only this last dimension which is clearly associated with different types of accidents, and behaviour.

2.5.3. Discussion

While this author did not predict this outcome, it is (after the fact) a substantial and easily understood one. Road type and work zone duration are the two basic dimensions of the ARROWS work zone typology as previously determined in ARROWS' Deliverable 1. It should be pointed out that the ARROWS typology was of work zones, while the presently derived dimensions refers to work zone accidents. These are not the same thing, since accidents have characteristics not directly related to work zones, and vice versa.

General accident studies, as well as psychological studies of recognition, classification, and inference of road scenes in other contexts, (e.g,. Gundy (1990), Gundy et al. (1997), Gundy (in preparation)) indicate that infra-structural aspects are fundamental building blocks ("enablers") for road safety and driver behaviour.

One, however, could too easily over-emphasise the importance of the structure of the environment on behaviour and safety. It is, for example, the case that the respondents to this study already knew about the ARROWS work zone typology. It is also the case that environmental variables are often easier to establish when investigating accidents, thus their co-variation is also easier to detect. In addition, we asked our experts to explicitly consider different road types (i.e., infra-structures) , in an effort to preclude concentration exclusively on the motorway situation. (While we introduced some additional variability along these lines, we did not require that its' covariance with other variables would dominate other non-road-type-related aspects.)

Therefore, we would hesitate to conclude that the (primarily) environmental aspects found here are sufficient or complete for describing work zone traffic accidents. They are, however, most certainly essential.

The second aspect concerns the day-night cycle. Such a distinction was already hinted at in the work zone accident literature (Gundy, 1998), and is apparently important in the minds of our experts. It reflects not only covariations in environmental factors, but also societal, behavioural, and physiological aspects of road use. As such, it would be appear that it is justifiably a prime candidate for a general (work zone) accident typology.

We do, however, find two things somewhat surprising.

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[8]Each of these dimensions are characterized in the previous chapter by a larger number of variables: here we present only a compact and simple description.

First of all, we are somewhat disappointed by not finding a clearer relation between accident and road user characteristics, on the one hand, and the two dimensions describing the road environment and the work zone, on the other. We also failed to find such a relation in the work zone accident literature (Gundy, 1998), and we had hoped to gain some insights by means of the present study. It could be the case that there is no clear relation, or perhaps that our experts have no common and clear idea of what that relation is. Our experts feel, for example, that "driving too fast" is a problem (e.g., in 25% of the cases it is cited as an "unsafe driving act"), but it is apparently not a problem uniquely related to a specific road type, work zone duration, or time of day.

They also may feel that, to the limited extent that driver age plays a role, younger drivers (<45 years) have more problems on motorways, while older drivers may have more problems on urban roads. However, this relation is so weak that it leaves a lot of room for doubt as to its existence, to say nothing about its cause.
Perhaps we could have profitably asked another question, namely: "Which patterns of accident and behavioural characteristics distinguish between work-zone-accidents and non-work-zone-accidents on the same road?" This could be considered for a future study.

A *second* (somewhat) surprising result concerns the effectiveness of countermeasures. Countermeasures have an unimpressive correlation[9] with road type and work zone duration, and no relation with time of day. This is disappointing, noting that the development of effective countermeasures is a major aspect of the present ARROWS project. This limited effect could be a reflection of a number of causes. Perhaps there is little unanimity among our respondents, perhaps they are less than enthusiastic about the possibilities of specific counter-measures, or perhaps they feel that effective countermeasures are not limited to specific situations.

We note, in any case, that our experts tend to feel that driver-oriented countermeasures (better general info, enforcement, education/ training) are somewhat more effective on motorways. Countermeasures aimed at the operation and layout work zone itself (quality assurance & checklists, better worker supervision, better signs and symbols) as well as lower speeds may have more impact on urban streets.

In addition, increasing work zone visibility, better education and training , lower speeds, and better signs and symbols are thought to be relatively more effective for short-term work zones. Variable message signs or traffic lights are thought to be more effective for longer-term works.

Perhaps our experts feel that on one hand substantial safety improvements on major work zones (e.g. on motorways) are unlikely: efforts should be directed to improving driver behaviour. On the other hand, work zones of short duration or on urban roads, both situations involving a great deal of temporal and spatial constraints, may offer more possibilities for improvement by paying more attention to procedures for implementing work zones.

It would be useful to explicitly test the extent to which these findings are veridical reflections of our experts' opinions.

[9] We could have explicitly tried to maximize the differences between accident patterns and their relation with countermeasures, but this would have required a supplemental analysis.

2.5.4. Improvements

A number of improvements or follow-up studies could be profitably undertaken.

First and foremost, we should not confuse virtual with real accident studies. A vibrant and concrete mental image can sometimes be more attractive than a more gray and mundane, yet accurate, description of reality. Furthermore, the relation between the two kinds of accidents is hardly clear or substantiated.

(However, we would be surprised if the findings as mentioned till now in this study would be fundamentally contradicted in an actual accident study.) The present study could be profitably replicated, but then with real accidents, so that they validity of the present method could be established.

Secondly, the statistical properties of the analysis done here are suspect. Small numbers and dependencies between observations are clear problems. The use of this analysis technique as a means of "data reduction" is justified. However, when we would want to generalise to a population of objects (of virtual accidents?, of experts?, of real accidents?) then great care must be exercised. Monte Carlo studies or larger samples could be implemented in order to establish the stability and generality of these findings.

Thirdly, the breadth of the background of respondents and the completeness of the accident registration form are a subject of concern. If we had interviewed road workers and emergency personnel, then perhaps a different picture could emerge. Future work could attempt to systematically sample other groups of stakeholders and/or experts.

Fourth of all, it should be clear to everyone that factors relevant for accident causation can not always be easily studied at the level of individual accidents. For example, we determined in chapter 3.4 that the conflicting role of contractors (i.e., maintain safety yet with minimal costs) is something that should be attended to. This aspect was not adequately represented in the multivariate analysis of individual accidents. A more complete investigation of the problems surrounding this area would require different levels of analysis.

Fifthly, budgetary constraints precluded spending more than a few days with this multivariate data set. We feel that other, more sophisticated questions[10] can be profitably posed, and investigated.

Sixthly, we cannot say very much about relative frequencies of different types of accidents, nor about relative risk factors. In ensuring that our subjects considered non-motorway accidents, we biased our data collection procedures. We did not attempt to measure relative risks. Future work, with real accidents, should attempt to supplement this.

Seventhly, as previously pointed out, the present study had facilities to only implement 2 data collection steps, while "standard" scenario studies utilise 8-12. This implies that not all of the potential products of a scenario construction process are available. For example, this process is often felt to be conducive for stimulating communication between groups with different backgrounds, e.g., between contractors, safety researchers, and road administrators. A complete implementation of a scenario constructions project, perhaps expanding upon the rudiments of the present pilot, could be useful.

[10]E.g., we would have liked to have spent some time with investigating "accident causes", a free form question included in the survey. We suspect that behavioural aspects might predominate, which could then be related to the infra-structural ones described above.

"K-sets" analyses of the various groups of variables could also be done.

2.5.5. Conclusions

This study's primary objective was to extract the expert opinions of the ARROWS consortium concerning the patterns of work zone road accidents, and to derive a typology of these accidents. This typology may then be used for inclusion in a practical handbook, also to be developed by the ARROWS consortium.

The procedure used in the present study has resulted in a typology reflecting three underlying dimensions: road type (motorways versus urban roads), time of day (day versus night), and work zone duration (short-term versus long-term).

These three aspects can be combined to generate 8 basic accident situations for inclusions in a practical handbook. Checklists and procedures may then be developed for each situation, or at least the need for such specific checklists could be made clear.

2.5.6. Recommendations

- We feel that much more should be done to develop a general international traffic accident registration form. This would be essential for promoting and co-ordinating pan-European accident studies.
- The work zone accident form developed here could form the basis for future pan-European work zone accident research. Of course, it should be extensively tested, expanded, and improved before any large-scale use.
- A more complete (and extensive) scenario construction methodology should be applied to the present problem area, as well as to other possible areas. In addition, since we feel that the methodology is potentially quite valuable, it should be further developed as a research tool, and its process-facilitation and measurement- characteristics determined (e.g., reliability and validity).
- Future studies of this kind could profitably employ experts with a broader spectrum of backgrounds and viewpoints.
- Future work zone accident studies should attempt to apply multivariate techniques as a research tool.
- Most importantly, further ARROWS work can make profitable and explicit use of the three typological dimensions found in the present pilot study: road-type, work-zone duration, and day-night cycle. The first two dimensions reflect the two most important dimension mentioned in the ARROWS work zone typology, and the present study substantiates (albeit not independently) that finding. The third dimension is a useful addition, which also finds some empirical support (see Gundy, 1998.)

3. RECOMMENDATIONS AND COMPATIBILITY

3.1. Introduction

Road works have to be carefully planned and well organised in order to harmonise with requirements of Road User and Road Working Agency operating on the same media - Road at the same time. Environmental requirements have to be respected especially in the urbanized areas. Some of these requirements are listed in the next table:

ASPECTS TO BE CONSIDERED	**REQUIREMENTS**
road user	***traffic requirements:*** -minimal travel time delay, -safe traffic, -unimpeded traffic, etc..
road working agency	***road work requirements:*** -spatial (work zone area must enable safe organized and efficient continuous work), -temporal (the nature of road works implies time and duration of road works),
Road	***traffic service levels (road type):*** - design (width, number of lanes, slopes, curves, etc.)
Environment	***negative road work impact:*** - pollution (noise, waste materials, etc.)

The following aspects of planning are examined:
1. Appraisal; objectives associated with road work zones and means for achieving them
2. Operational aspects: time, space and information
3. Planning principles for specific layouts and types of road work zone
4. Signing principles: Quality, location and visibility
5. Safety equipment and measures for drivers and workers

3.2. Appraisal, Objectives and Means

3.2.1. The balance between safety and other considerations

Time and duration of road works are two elements where all these requirements eventually meet. It is a question of balancing the economic loss due to traffic travel time delays versus economic gains of traffic service level improvement accomplished by road works.

Though it is in the planning process necessary to take in account every detailed element affecting road works and traffic as well, understanding the characteristics of the main actors substantially enables complex road work planning design.

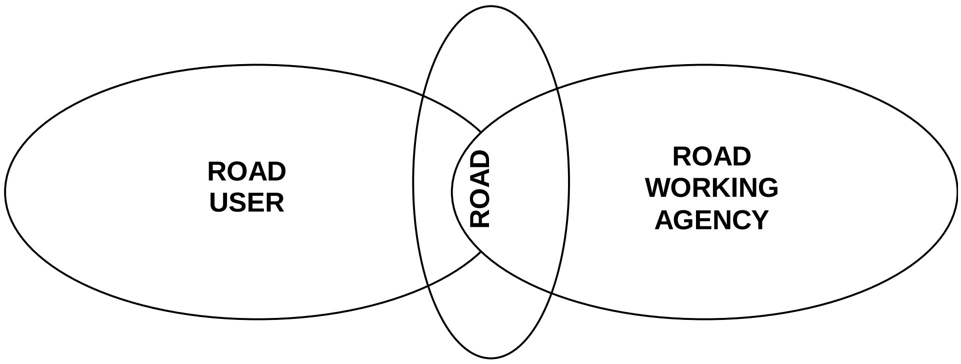


Figure 2: Principle overlapping of different requests

Requirements of Traffic and Road Works generally do not match but they have eventually to be coordinated to the optimum in the time variable.

Coordination must be established in the framework of temporal and spatial feasibilities (road type, road design etc.) including possible environmental considerations. As presented in figure 3, high demands of the traffic, require temporally short road works, while complex road works need more time and should therefore carried out during low volume traffic times, mainly.

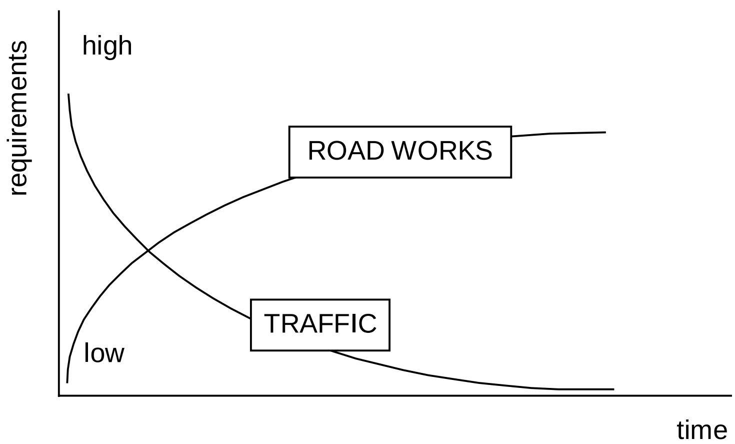


Figure 3: Interdependencies of traffic and road works

For the development of optimum traffic engineering solutions the following criteria should be taken into account:

- Safety for workers and motorists
- Quality requirements, e.g. efficient management systems
- Economic efficiency
- Time frame

- Environmental impact
- Road traffic and motorway construction authorities as well as contractor have to harmonize their activities, required for securing work zones, before the beginning of the road work.

Given the continuing and increasing requirement for major maintenance coupled with limited public resources, use should be made of costing / evaluation procedures at work zones to determine more comprehensively the cost of construction / maintenance and to permit the effect of alternative maintenance programmes to be investigated at the planning stage. When planning maintenance programmes, network information regarding details of the level and composition of traffic flow supplemented by local data is necessary.

Preconditions for the above are:

- The development of national databases (traffic, accidents) supplemented by local information in order to define the levels of risk (incidents / accidents), levels of inconvenience (delays or congestion), levels of dissatisfaction (opinions of inconvenience suffered), effectiveness of techniques and devices (at a particular location or with particular equipment).
- The development of methods and models for traffic simulation and forecasting (short- and long-term), modelling road capacities and lane restrictions; evaluating indirect user costs (accidents, delays, inconvenience); selecting maintenance and repair programmes. To ensure compatibility between national costing procedures, harmonisation and updating of basic values and criteria, as well as adaptation to particular sites, is necessary.

Motorway authorities, when inviting tenders for road works or approving road works, must consider the traffic control requirements and specify the minimum acceptable restrictions to traffic flow during the course of the works. Authorities should notify or consult with the police regarding the traffic management techniques chosen. Any form of traffic control that is introduced must be approved by the road authority and operated in accordance with best traffic engineering techniques.

When determining the form and timing of road works, full account must be taken of their effects on the safety of road users and of the need to minimize the possible disruption of traffic. The main objective is to obtain a balance between safe, economical and speedy performance of the works while also allowing traffic to flow safely and with the minimum disruption and without undue delay.

In order to minimize the effects of road works on safety and traffic flow the following should be taken into account:

- Integration of safety and traffic control aspects at all stages from project design to completion of works
- Work zones must be planned to take account of the traffic requirements; it is important to keeping the original number of lanes as long as possible
- Measures taken for the traffic management system and the organisation of construction work are interactive: they can be optimised by means of an iteration procedure
- Each measure used must assure safety of workers and high quality of work; it must be justifiable when compared to the costs involved and to have acceptable negative effects

3.2.2. Some safety considerations

The safest and more efficient traffic operation should be chosen. Some relevant principles include the following:

- maintaining the number of lanes, with altered layout and/or narrow lanes, contra-flow or added lanes
- closing lanes as little as possible, leaving at least one lane in each direction. Narrow lanes or altered layout should be used as far as possible to avoid flow restrictions and one-way or diversion shortcomings
- using one-way operations with fixed priority, agents or signals if short work zone length and low traffic volumes allow it
- finding some limited extra-capacity with diversions to alternative routes if they can support it and if they are carefully controlled
- workers' education and drivers' information are necessary

For each work zone a well-qualified person must be put in charge of safety aspects concerning road works and of monitoring and directing the traffic passing the work zone.

When works are likely to cause congestion, accidents or breakdowns can result in stationary traffic which may create a hazardous situation. It may therefore be appropriate to have recovery vehicles permanently on site or available on immediate call out. Provisions should be made for the safe operation of work or incident management vehicles, particularly on high speed, high volume roadways.

The whole management system (signs, marking, traffic equipment, etc) must be designed to meet the motorists' limitations and minimize the demands of the driving task. Therefore the system should help drivers to make proper choices rapidly, reinforce critical information without being excessive, appear credible and not provide conflicting information, follow the evolution of the works in time and in space, and be removed as soon as it becomes particularly or totally unnecessary.

The separation of decision points for the driver is important. Measures should be uniform and taken one at a time.

It is essential to ensure that any unavoidable reduction of forward visibility available to drivers is kept to a minimum at all times. In case that works are situated near a bend , it is essential that adequate advance warning sign (because of the reduced visibility) is given to the approaching drivers.

Signing, markings and safety devices used should be consistent with intended travel paths. In case of long term work zones the inconsistent signs, markings and devices should be replaced, covered or altered to suit the circumstances ensuring that all times the signing represents the prevailing conditions accurately. In case of short term work zones attention should be given to devices that emphasis the appropriate path.

One particular safety consideration is speed control. It is recommended to make realistic estimates of the approach speeds. The speed limits should appear reasonable and not be unrealistic and hard-to-justify (e.g. physical conditions, works requiring protection are taking place on the central reserve or on the carriageway). The speed limits should be supported by appropriate accompanying measures and not only relying on signing (e.g. reduced carriageway width, police presence). Low speed limits should not be prolonged through long stretches. Normal speed should be resumed as soon as possible. The advance warning signs must be positioned well in advance of the works site and repeated, permitting traffic to reduce speed comfortably to the desired level, but not so far as to risk being judged premature by drivers and thus ignored at the part of the layout where compliance is required.

Maintenance of roadside safety should not be overlooked. For emergency situations, disabled vehicles, accommodation of the run-off-road incidents, provision of a roadside recovery area should be assured. Equipment workers' vehicles, material and debris should be stored in such a manner that are not vulnerable to run-off-the-road vehicle impact. Any obstruction on the central reserve should be kept as far as possible from the edges of the carriageways and in such a position that sight lines are not obstructed and that there is no interference with the proper function of the safety fence.

For the safety of works personnel:
- The establishment of well-defined minimum-width safety zones, into which workers and plant should not enter in the normal course of work and in which materials should not be deposited, is an essential prerequisite to ensuring safety during road works.
- Whenever possible the work should be carried out from vehicles. Appropriate means should be adopted of allowing workers to enter and leave the site safely at the beginning and end of each shift or working day and in an emergency.
- For their own safety it is important that all personnel working on or near the carriageway are readily visible to all drivers. To this end high visibility garments must be worn (EN 471).
- Employers should not allow excessive hours to be worked, since fatigue reduces awareness and thus increases the potential for accidents in the dangerous environment of road works.
- Flagging should be employed only when all other traffic control methods are inadequate to warn and direct the drivers.

From the view of traffic safety it is also very important how to begin putting the signalisation, since this short time can come to critical situations which lead to the traffic accident. This is very important also by short-term work where the first sign or announcement is moving with regard to traffic demands.

3.3. Operational Aspects

3.3.1. Time scheduling

The planning of work zones in the network is closely connected to their timing. Road works should be carefully planned and carried out at times when traffic volumes are lower, and the durations should be as limited as possible. Coordinating the planning and organisation of major projects over the network (and by taking advantage of the seasonally differing traffic volumes), the execution of such works can be arranged and timed in such a way that traffic disturbances are minimized. Coordination with works on the same road or in the same area is very important.

Road works should not be carried out during those times of the year when traffic peaks are expected. On the basis of an analysis and evaluation of data recorded by traffic counters, it is possible to determine critical traffic volumes and provide graphic displays that can help to determine the best time for setting up a work zone.

The objective is to ensure as much as possible the function and the capacity of longer road sections despite the work activity. Road works should not be carried out at the same time on parallel alternative routes.

Among the measures that must be taken in order to minimize the impairment of traffic flow and safety, which may occur during maintenance and rehabilitation on roads for long distance traffic, are the following:

- Shortening of construction times, especially on motorways with high traffic volumes;
- A better balanced arrangement and timing of work zones, thus avoiding a concentration of work zones;
- Reduction of the number of work zones during holiday periods.

Where practical sufficient resources should be made available to keep sites occupied and operating during normal working hours, since long stretches of coning with no sign of activity aggravate road users and bring legitimate coning into disrepute.

When a length of road is closed the opportunity should be taken to carry out all other maintenance required on that length of road.

3.3.2. Physical planning

The basic safety principles governing the design of permanent roads should also govern the design of the road work zone areas. Geometrics and traffic control devices should be comparable to those for normal situations.

Points of special consideration that should be examined are the following:

- The alignment, profile and length of the work zone
- The location of the work zone; the number of lanes and their widths in the work zone (reduction in the number of lanes, geometry of crossover section, etc.)
- When using a crossover section: the length and design of the crossover zone; the length of the contra-flow section; the quality of signing and road marking

The length of work zones with narrowed lanes, i.e. with limited capacity, should be generally restricted so as to be acceptable by motorists.

The minimum distances between consecutive work zones should be such that the flow of traffic can return to normal between them. The separation should permit fast-moving traffic to overtake slow-moving vehicles so that platoons can be dissipated and traffic normalized.
The required number of lanes in the work zone must be provided in order to maintain smooth flow of traffic. If the shifting of lanes, narrowing of lanes (temporary lanes) and special construction measures are not sufficient, alternative routes should be provided. As a last resort, the number of lanes is to be reduced.

To minimize the extent of the disruption to traffic and maximise safety, the work zone should be kept as small as possible.

Frequent and abrupt changes in geometrics, such as lane narrowing, dropped lanes or main roadway transitions requiring rapid maneuvers- should be avoided.

Where lane layout is altered it should provide radii that conform to the same criteria used for normal design.

Attention should be paid not only to the conspicuity and location of the devices but also to their design and material to reduce the risk of serious damage in a collision.

Buffer zones should be provided whenever possible. Also, accesses to works vehicles should be located and designed with care to ensure that vehicles can enter and leave the site in safety.

Traffic signs should be placed in sequence moving downstream and removed moving upstream. In case that the traffic will be directed into the opposite lane, devices for the opposite traffic should be placed first.

Traffic signs and devices in work zones should be made contemporary during working in a work zone and cancelled them after the work is finished. Additionally, signs and devices, which are necessary only during the working time should be removal afterwards.

3.3.3. Information management

Information management refers not only to the information to be provided to road users during operation of a road work zone but also to that required for the very planning of the road works.

As a precondition for efficient and safe work planning and work site traffic regulations, precise knowledge of the following conditions is necessary:

- Traffic expected over the year, on weekdays, during 24 hours, during peak hours, proportion of heavy vehicle traffic, special traffic volumes, speeds, holiday traffic
- Work to be carried out, the subdivision into contract sections, possible methods of construction
- Locality (work zone accessibility; road area adjacent to the work zone: geometry, structural design, traffic guidance devices, existing crossings of central reservation, etc.)
- Work planned on the same road section or on the alternative route
- Environmental protection

Important information for traffic management procedures also includes: traffic volume and speed both upstream and at the work area, with and without work in progress; mobility of work zone, when not stationary; transversal encroachment of work zone compared with normal platform (external or median, shoulders, carriageway kept open to traffic, total closure of one or both carriageways); danger involved in case of intrusion into work zone.

Traffic flows at all sites should be regularly monitored so that if problems develop appropriate action could be taken.

A plan (in detail appropriate to the complexity of the works project) should be prepared and understood by all responsible parties before the site is occupied. That information should be distributed widely (e. g. by mass media) and specifically (e. g. to those especially affected).

Training of upper-level personnel through field personnel is important.

Regarding information for road users, cooperation with mass media in publicizing the existence of work sites is important, as is consultation of residents and users. Public transport operators should also be informed.

3.4. Specific Layouts / Types of Work Zone

3.4.1. Contraflow

Crossovers should be placed far enough from the activity area to protect it from errant vehicles and should be designed for expected operating speeds. The length of contra-flow lanes is normally related to the distance between available median crossings.

Separation from the opposing lanes in the same carriageways should be emphasized. It is recommended to create a buffer zone when space allows it.

Refuges could be provided in the median to accommodate vehicle breakdowns and a fast intervention system should be set up. Provision for incident detection should be made.

3.4.2. Detour

Diversions / detours should be planned taking into account of the suitability of the diversionary route for the expected traffic flows, comprehensive directional signing, priority at junctions, the presence of low bridges, and the effect of diverted traffic on the environment.

Some negative aspects of detours are: longer driving time; more delays and higher operating costs; lower level of service; deterioration and/or congestion of alternative route; user confusion, especially with partial diversion. Diversions from motorways to roads of other type should only be put into effect when absolutely necessary, since it will normally be safer to keep traffic on the motorway.

Traffic diversions require:
- that the alternative route be compatible with the additional traffic
- that driver information be very efficient
- that the alternative route be marked throughout in a very clear way
- especially in the case of constructing a temporary diversion, that it will be maintained in a satisfactory condition throughout the period of the diversion.

3.4.3. Lane closure

Any alternative strategy would in principle be preferable to a reduction in the number of lanes.

Critical information should be provided in time about which lane is blocked. In long term work zones it is preferable to close first the fastest lane and not the slowest, even if the work zone occupies the latter. If the work zone occupies a center lane in a multilane road, it is recommended to also close the adjacent lane to avoid an “island” situation.

If two or more lanes are to be closed, a common but not universal practice is to do it one at a time, starting with the fastest lane.

3.4.4. Other

One-way operation: Its effect (delays) on traffic flow should be analysed to see whether another policy permitting two-way operation, such as a temporary diversion or altered lanes could be more convenient.

Short-term road works: require special attention. Their signing should be particularly careful as local road users may be surprised and respond abruptly or in an unexpected manner.

Stationary road works: The perception of the work zone from a distance and user guidance through the work zone, should be as good at night as during the day. Signing, marking and the devices must be effective under varying conditions of light and weather.

3.5. Signing Principles

3.5.1. Introduction

Work zone signing is one of the most critical parameters of safety in these areas. Actual situation in work zone traffic signing is not satisfactory in the point of view of compatibility among signing standards and principles existing in the different European countries. ARROWS will recommend the most appropriate signing principles to reach a higher degree of European standardisation aiming, however, to cause as few changes as possible to existing national standards.

3.5.2. General signing principles

- Higher quality materials should be used for traffic signs and markings in road work zones than in normal signing due to more critical traffic conditions in them.
- A specific pan-European colour should be designed to differentiate work zone from permanent signing and markings. Yellow was proposed to be this colour, which is also compatible to the TEM standards.
- Special safety audits concerning the general layout of each work zone, with special focus to appropriate signing, should be compulsory before and during work zone operation.

3.5.3. Traffic signs

From the point of view of quality of materials to be used in traffic signs, yellow fluorescent material with high retroreflectivity (types II and, mainly, III) for the construction of traffic signs was agreed to be the optimal solution. Fluorescent high reflectivity (type III) material offers the best overall performance in all conditions. It has a considerable advantage in signing, in cases of difficult traffic situations (unfavourable weather characteristics, pedestrian crossings, school area, etc.), which become even more crucial in work zone signing in the point of view of traffic safety but, also, of road operation.

The form to be used was not agreed, since no research exists on the most effective type to driver's perception. Three types have been proposed and was decided to be evaluated in a later stage of ARROWS:

- Rectangular external yellow background.
- External yellow background of the same shape with the sign enclosed in it.
- Internal yellow background to signs with white background in normal signing (i.e. danger warnings, speed limits, mainly).

When the evaluation is completed the most effective form of work zone signing will be selected and proposed in a full pre-normative way.

From the point of view of location and typology of traffic signs, the main principles are the following:

- In cases of divided directions of traffic, when the road has three or more lanes per direction, traffic signs should be placed both on the right and on the left side of its road, at least in long term work zones.
- The first sign, announcing the road work zone, should be at least 800 m ahead of the beginning, in long term work zones and 600 m in short term ones.
- The traffic signs that should be used in a compulsory way in all work zones are the ones that warn on the existence of the work zone (workman with shovel), the ones fixing the

diminished speed limits and the ones showing the type of deviation (right, left, contraflow, lane closure, etc.) caused to the normal traffic flow by the work zone.

- In work zones with a length exceeding 2.000 m, reminder signs (on speed limits, other restrictions or special conditions) should be placed at least every 1.000 m.
- Signs should be placed at normal signing height in cases of long-term work zones. In cases of short term work zones they may be placed at a lower height, since it is sometimes ineffective to be held at normal height with foundation plates. However, they must be placed at sufficient height to give appropriate visibility to oncoming drivers, depending on the road special characteristics (urban or rural, traffic volumes, speed, alignment, percentage of heavy vehicles, etc.). In urban work zones, when pedestrians paths may cross the area of the work zone that the signs are placed, minimum height of the lowest edge of signs should not be less than 2.25 m.
- The size of signs depends on the road special characteristics (mainly traffic speed) in the same way as in normal signing.
- Special attention should be given in the compatibility of signs and markings.
- When a work zone does not influence traffic flow when not in operation, special work zone signing should be duly covered during these periods.

3.5.4. Markings

Markings used actually do not differ from the ones of permanent signing with the only distinction of colour in work zone markings, only in some countries and with different colours predicted by national legislations. Due to that, an important improvement that should be proposed through ARROWS, in this item, is the adoption of special specifications in road work zone markings.

Following that, yellow is suggested, if also adopted as the work zone signing background colour, as the special colour for work zone markings. This will result in making yellow colour immediately recognisable by drivers as a unique and exclusive work zone signing colour, both for signs and for markings.

It should be noted, however, that a separation must be made at this point between short and long term work zones. This is due to the fact that in most cases of short term zones no horizontal signing (marking) is used.

In long term work zones, where yellow markings should be used, the most important issue, related to road users safety, is the appropriate selection of materials for them. Plain yellow markings paint may be used in most cases. However, in an important number of cases (e.g. differentiation of the work zone alignment during works, need for quick placement and removal, important traffic volumes, etc.) compulsory use of upgraded materials should be predicted. The selection of materials to be used in each case may be performed from a specially conceived selection table which may be created, as pre-normative tool, in a later stage of the ARROWS project (if any).

Additionally, in night driving, there is no specification of higher reflectancy of markings, although work zones should be more clearly distinguished since danger in driving through them is, in general, higher than in normal road sections. Self-adhesive retroreflective tapes is the basic upgraded material to be used in such cases. These tapes should, also, offer to work zone markings a high reflectancy value (to be determined by the specific CEN work group).

Moreover, in cases of unfavourable climatic conditions, the need for use of additional measures, i.e., mainly, wet pavement tapes and/or pavement reflectors (“cats eyes”) is suggested.

3.6. Safety Equipment and Measures for Drivers and Working People

The safest way to perform road works is to do this work free of traffic so by a complete road closure.

However, in many cases there are no alternative routes available or the traffic flows need to be maintained on the road at hand.

3.6.1. Drivers

On locations where the roadwork is performed on a lane when traffic is still passing the work zone this creates a disturbance in the free flow of traffic due to the diminishing of the number of lanes and the use of smaller traffic lanes.

In work zones objects are standing like trucks, materials and construction machines. It is also possible that the road surface in the work zone is removed or holes are made for renewal of cables. The work zone is therefore a dangerous location to enter for drivers passing this work zone.

The passing of a work zone is in many cases quite narrow and it is not impossible for a driver to accidentally enter this work zone. Therefore guiding equipment and safety equipment is necessary.

Guiding equipment can guide traffic along the work zone. For the purpose alternatively beacons, cones, plastic barriers and fences can be used.

Safety equipment can protect traffic from entering the work zone. Most effective safety equipment is a concrete or steel barrier. Barriers have to be tested under EN 1317-2 and qualified by a relevant containment level T1 to T3. The use has to be decided under safety and economic aspects. The installing and removing of barriers takes a lot of time and is very dangerous (there is no protection). When the work to be done is taking more time (a few days or longer) it is in most cases efficient to use the barriers.

3.6.2. Road workers

Road works not only create safety problems for traffic passing the work zone but the safety of road workers themselves is at least as important than the safety of drivers. Road workers simply don’t have a choice. They have to work in the work zone.

Road workers are faced with different safety problems in the work zone. First of all the protection against traffic passing the work zone. Safety equipment like concrete and steel barriers placed between the work zone and the traffic lanes can effectively provide this protection.

In the work zone there are also safety problems. Near construction machines there should be a safety zone of about 60 centimetres to give road workers the opportunity to step aside safely when a machine is passing them without them having to step into the traffic lane on locations with only guiding equipment.

When a car hits the mobile trailer at the beginning of the work zone this mobile trailer or parts of it can enter the work zone. Therefore it is not allowed to work in an area of about 100 meters behind the action vehicle.

Also the workers are faced with vehicles driving backwards in the work zone. These vehicles should be equipped with a device that gives a vocal signal when the vehicle is driving backwards. A rear-view camera can also be installed to give the driver information on what is going on behind his vehicle.

The visibility of road workers can be improved by good safety clothing. This clothing is retroreflecting fluorescent with stripes of a higher quality retroreflection give optimal recognition also during nighttime conditions (EN 471).

3.7. Harmonised Layouts

3.7.1. Basic principles

The previous sections of this chapter were concerned with principles which relate mainly to the planning of work on roads and the contractors accepting the orders for such work. The following will describe in what way the road user can effectively be supplied with necessary information regarding the kind, extent and layout of work zones. It would appear a meaningful starting point to refer for comparison to the corresponding procedures and designs already in practice today.

However, analysis of the rules and regulations of 20 European countries regarding the layout of work zones on roads shows that there are considerable differences in some cases in the signing and closing off of work zones (Task 1.3). This can be put down mainly to the developments and traditions over the years, differences shown by experience in the behaviour of road users or simply less strict safety requirements. This means that current practices are only of limited relevance for the development of a harmonised proposal for the layout of all European work zones.

To show what is meant in detail, Fig. 4 displays by way of an example all the different signing systems contained in the regulations of the countries referred to for the two situations of lane closure [”lane reduction to the left” and ”lane reduction to the right”] for the advance warning area of a work zone on motorways for all countries in alphabetic manner. The positions of the following traffic signs have been indicated with black bars:

- last speed limit before the lane reduction
- last traffic routing panel before the lane reduction
- first identification through the traffic sign ”work zone” in the area directly in front of the work zone (the „2000 m sign“ in CZ and DE as well as the „2300 m sign“ in GB are only valued as additional announcement).

This is shown once again in Fig. 5 which list the positions of the speed limits, traffic routing panels and the work zone sign as stipulated in the various countries` regulations for the same work zone situation.

Furthermore Fig. 6 shows the corresponding situation with regard to an advance warning area into the work zone on motorways without lane reduction (closure).

First of all, it can be seen that there are considerable differences for the same traffic routing situation. If a comparison is made of basically similar situations, the chances of harmonisation are further reduced. Unfortunately, no approaches or indications for determining whether one of the ways of signing or closing off work zones or of routing traffic is particularly favourable can be derived from the investigations into accident occurrence and driver behaviour.

Additionally, it is not understandable, if work zones are not announced (DK, EE, LT and NO) or only shortly in front of the work area (BE, CH). Also it seems not be helpful, if this announcement is only given more than 1.600 m before the work zone; the driver may have forgotten that information meantime.

It was therefore decided to initially develop a proposal independently of the existing regulations but taking basic principles into consideration to a large extent. In the interest of the road users, it was planned that, through the harmonisation, only the decisive characteristics of the work zone ahead would be shown, if possible within a standard signing system:

- as few elements for the various traffic routing situations as possible.
- schematised adaptation to traffic routing situations through the exchange of only a few traffic signs.

Using a new approach the attempt was therefore made to facilitate the elaboration of a standardised proposal by elaborating certain principles for the current layouts. The underlying thought was to convey to the road user through signing systems which were as harmonised as possible the subsequent traffic routing, if possible in all situations. Obviously, differentiation should be made in this regard between the different road types: roads inside built-up areas (urban roads), roads outside built-up areas (rural roads) and motorways. Compromises of various kinds cannot be avoided in this regard. Despite this the aim should be, through giving due regard to existing regulations, to achieve the greatest possible approximation.

The following principles were elaborated:

- a small number of basic elements only which can be varied according to traffic routing;
- first notification of a work zone at a suitable distance before the start of a restriction of traffic space due to a work zone;
- a reduction of speeds in the approach area to the work zone carried out in regular steps e.g. by 20 km/h at the same longitudinal distance (”speed funnel”);
- signalling of the subsequent traffic routing using one or more traffic routing panels according to the type of road;

3.7.2. Long-term work zones on motorways

In an initial step the systemology of situations assigned to particular signing schemes was compiled for all conceivable traffic routing on motorways. Analysis of all the countries` regulations showed that only 5 basic elements for the different work zone areas were necessary to create full scale layouts:

- Fig. 7 shows all the traffic routing situations which occur in the advanced warning areas without a lane reduction (designation ”adv”) and fig 8 with lane reduction (designation ”nar”].
- Usually the traffic is directed after routing situations according to fig. 7 and 8 onto temporary lanes or onto the contraflow lane(s) through a transition area. In the case of no lane closure these routing elements are described as simple transition areas (designation ”tra”) in fig. 9. But it is another situation if the transition follows a lane closure. In this case after the narrowing area, a stabilizing area is necessary before the transition. The possible variations are shown in fig. 10 (designation ””tra” for ”transition area” with the additional sign „-“ for closed lanes).
- Fig. 11 shows the variations in the area of the activity area of work zones (designation ”act”) and
- Fig. 12 the diagrams for the termination area (designation ”ter”).

If one want to create the full layout for a work zone with this system only the combination of the layout parts is necessary (Fig. 13).

This system and the analysis of the different regulations demonstrate the possibility to present only principle layouts for every situations in fig 7 to 12. The basis for this decision are some principles and the endeavour to incorporate a minimum of the rules of the different regulation of the European countries. But having in mind the analysis in Task 1.3 and the former fig 4 to 6 one will accept that the result will cause chances for every country, if the system will be accepted at least.

So the element for the situation in fig. 7 and 8 was designed taking into account the above principles (see 3.7.1) and following analysis results and considerations:

- only the longitudinal positions of the signs are laid down in the basic element. The contents of the traffic routing panels are adapted to the respective requirements. The speed limits can be selected according to the regulations in the respective country;
- the traffic routing is shown via corresponding traffic routing panels;
- in some countries it is usual in transitions onto the counterflow lane to indicate to the road user on a traffic routing panel that their will be oncoming traffic. This alternative can also be shown

The analysis of the situations e.g. in fig. 4 and 6 shows that on average in each case 2 signs „speed limit" and 2 routing panels are assigned. Further one will find the distances of following signs in front of the work zones on average:

- Last sign „speed limit" 170 m
- Last „routing panel" 250 m
- Last but one sign „speed limit" 430 m
- Last but one „routing panel" 580 m
- First sign „work zone" 680 m

These values are used as orientating points but harmonized[11].

This and similar examinations were the basis for the proposals of principle layouts:

- Fig. 14 shows the basic elements for the situations in accordance with fig. 7 **and** 8 (advance warning areas without and with lane closure respectively). As listed in at the bottom of the tables in fig 4 and 6 the countries use 2 speed limits and 2 lane panels in average.
- Fig. 15 shows the basic elements for the situations in accordance with fig. 9 (simple transition areas). This system should be used between advance warning area (fig 14) and activity area, if there is no further lateral transfer of lanes.
- Fig. 16 shows the basic elements for the situations in accordance with fig. 10 (combined narrowing, stabilizing and transition areas). In this case the traffic flow should become stable before an additional lateral transfer will follow.
- Fig. 17 shows the basic elements for the situations in accordance with fig. 11 (activity areas).
- Fig. 18 shows the basic elements for the situations in accordance with fig. 12 (termination areas).

To demonstrate the possible combinations in regard to fig 13 by use of the above developed parts of layouts fig 19 and 20 give the necessary impression, in fig 20 together with the situation for the contraflow traffic area.

To support often existing situation on four lane motorways a couple of layouts are created on these basic elements, which will be presented in the following practical handbook. In this connection an example for exits and entrances within the area of a work zone on motorways is presented with basic layout principles for these intersections. One should have in mind that this proposal is based only on examples from CZ, DE, FR and NL.

3.7.3. Short-term work zones on motorways

11 Remark: An average value may not be an excellent basis, but due to lack of other means and information such a value reflects a general experience be included in the countries' layouts.

In most of the analysed country regulations layouts are existing for the situation of short-term work zones (Task 1.3). The main principles are identical but the devices differ from country to county. Additionally only few differences are existing between short-term stationary work zone layouts (information available from 12 countries) and mobile work zone layouts (information available from 10 countries). In so far it was easy to develop some basic layouts for these situations (see practical handbook).

3.7.4. Long-term work zones on rural roads

A similar analysis of the existing layouts on rural roads leads to comparable results than for motorways, but it can be stated that more uniformity exits (fig. 21). It is conspicuous that in some countries no speed limit is specified (GB, GR, NO, SE) which will cause a more serious situation for the workers.

In so far a correspondingly small number of layouts can also be proposed for the in principle far easier situations on roads outside rural areas (fig. 22). In this case it would be possible to make an additional division according to the traffic volume and reduce the signs local.

3.7.5. Long-term work zones on urban roads

Examples for the situation with work zone regulations for urban roads without and with lane reduction are presented in fig. 23 and 24. As expected the differences are not smaller than for the other analysed road regulations in the European countries.

Therefore, a simple harmonised signing system would also be suggested for traffic situations inside built-up areas (fig. 25).

The idea to create layouts for work zones at intersections can not be realized due examples in the regulation of only two countries in Europe.

3.7.6. Long-term work zones on foot- and bikeways

Examples for layouts regarding footways are available in 12 of the 20 European countries; for bikeways only in two countries. The principles are nearly the same and very simple. Often the work zone has influence on the vehicle traffic due to narrowing the lanes. Based on these information some layouts are created for work zones in these traffic areas (see practical handbook and example in fig. 26).

3.8. Summary

Before planning of work zone and before decision of the technique of ensuring the concrete work zone the designer should collect as much as possible information about planning activities on roads (e.g. detailed description of appropriate road segment, range of planned work zone, current traffic signs and devices on this road segment, possibly supposed diversion and its length and direction and contingently order of phases of traffic lights).

The design of work zone measures should follow possible stages of activities, its possible combinations, types and duration.

It is evident that the different level of work zone ensuring (measures) will be designed for appropriate type of work zone. Therefore during the planning phase is necessary respect the location of work zone i.e. on urban roads (main, local), on rural roads (primary, secondary) and on motorways or expressways, farther its duration - long-term or short-term (stationary and mobile) - only during day light, and also take heed to possible concurrence of works.

If the ensuring of work zone with short term duration shows as insufficient from the point of view of road safety (i.e. gross fog or rain, snow etc.), it is necessary to use the same purpose of measures as on work zone with long term duration.

The purpose of ensuring of concrete work zone should come out from the appropriate model traffic scheme mentioned in practical handbook.

The form of work zone ensuring is necessary to decide on the base of local conditions (partial or complete road enclosure, diversion). The basic principle is to keep as far as possible the same number of lines on road or to find the traffic solution, which makes possible to keep traffic in both directions.

In case there is only one line in the work place area for both traffic directions it is necessary to decide on the basis of a local situation and traffic intensity whether it is possible to lead traffic on the basis of the intermittent traffic, with help of traffic signal or to set up a diversion. It is also possible to use the both way combination (for instance to set up diversion for particular vehicles, particular time or for one traffic direction only).

If the traffic intensity is too high and there is no possibility to set up diversion it is necessary to think of making provisional diversion road in the work area.

In the case of partial or complete road enclosure is necessary to consider the ensuring of cyclist and pedestrians, too. In the case of works on foot-paths or on cycle tracks is necessary to provide alternate and safe way of transportation for this vulnerable traffic participants.

Complete road enclosure for all kinds or same kinds of traffic is a big interference with organisation of traffic, because it means to set up a diversion.

In case a diversion road is used for longer time it is good to sign it up as a main road particularly if the traffic on important and busy road is turn away. Except interference into a giving way rule changes there may be also an importance of temporally speed decrease limit in area, which is unsuitable for temporally increase traffic. A diversion must be signed by traffic signs in advance for all drivers to make possible to get use to those traffic changes. It is useful to inform about a diversion in media.

Some main aspects for installing work zones are:

- Choose time and duration of work zones in correspondence to traffic requirements and volume.
- Adhere the number of lanes as far as possible.
- Govern the design of the work zone (alignment, lane width and length).
- Determine uniform layouts with signs as few as possible but as many as necessary.
- Make work zones consistent during working and cancel them after the work is finished.
- Use high quality materials for signing and marking.
- Maintain traffic signs, markings and safety devices in a proper form all the time.
- Train personnel in regard to their responsibility and their own safety aspects.

ANNEX I: Recommendations for the road worker

Sources:
- 'Road work zone safety: a compilation', Arrows Task 4.1 internal report
- 'Road Work Zone Safety Practical Handbook', Draft Arrows Deliverable No. 4 - Vol. 1
- 'Veilig werken aan wegen', Dutch guidelines for Road Works

1. Introduction

Three main approaches can be distinguished for increasing safety at a road work zone. The first is influencing the behaviour of road users. Examples of measures that support this target are speed reductions and warning signs. A second approach is to shield the work area from passing traffic. The use of buffer areas and contraflow are good examples of such an approach. The last approach that contributes to the safety at road work zones is redirection of the behaviour of road workers towards a safer way of working.
This last approach is considered in this chapter, whereas in other parts of the ARROWS deliverables measures for improving the behaviour of road users and for protecting traffic from unwanted entering of work areas are described.

Pointing out the risks of road works may encourage a safer behaviour of road workers. Most road workers and other involved staff are not conscious of the high risks while working at a road work. Several elements may reduce this lack: good education of the personnel, listing and analysing the revealed risks and specific preparation for every work. This chapter deals with the last element: a good preparation of the road workers.

A proper preparation may contribute to the awareness of the dangers involved with traffic and road works. Therefore it is recommended to instruct all employees at the start of each road work. Such an instruction should incorporate adequate information about road works in general and the concerned project in specific.

The sections 1.2 to 1.6 give detailed instructions and recommendations for road workers. These instructions are related to the relation between traffic and safer road works. Other risks that are not directly related to traffic, for example working with equipment, fall outside the scope of this chapter. Starting point is that the risk for collision is recognised and that nor the road worker nor the road user is unnecessary involved in dangerous situations. Five main stages of a road work process are distinguished. Each section handles with one of these stages:
- setting up a road work zone;
- approaching and entering a road work zone;
- carrying out a road work;
- leaving a road work zone;
- dismantling a road work zone.

For every stage the involved risks are described and important points of attention are mentioned.

In every stage the required instructions which road workers should get before the beginning of the stage are the same. The aspects that have to be part of this instruction are:

- The desired behaviour of the road worker towards the traffic.
- The requirements that have to be fulfilled during the work.
- Action to be taken before the activities can start: where should the involved persons put their attention on, which personal safety equipment is needed and how and when should this equipment be used.
- In which way the activities are concluded.
- Procedures to be followed in case of incidents.

The checklist for the road worker in section 1.7 concludes this chapter.

2. Setting up a road work zone

Risks

The risks for a collision are high compared with other stages because the road work zones have to be build in the flow of through traffic. Especially putting up the required signs and beacons is a hazardous job: the road users are still unaware of the measures and do not adapt their speed.

Points of attention

- Traffic: take care of the traffic and work faced towards the through traffic.
- Work: operate from a safe position e.g. the shoulder lane, soft shoulder or footpath.
- Escape: take continuously care of an escape route that does not require to cross a traffic lane.
- Visibility: use good and clean safety clothes and appropriate lighting equipment.
- Traffic amount: wait until quiet moments, take time to estimate the traffic amount before acting.
- Guidelines: put up signs from the outside to the inside: start at the safe shoulder part. Position signs and beacons in a good visible and readable way. In case of lane closure on motorways or dual carriageways, it is preferable to close lane(s) from the left side - quick lane(s) - and conduct traffic through the right lane(s). Work also from the front to the back of the work area.
- Work area: take care that you precisely know where to be, use an actual drawing or map. Know which signs and beacons where have to be raised.
- Temporary measures: if these measures, e.g. safety measures, conflict with current traffic signs, you should cover these signs.
- Preparation: prepare yourself good so that as little time as possible is required to implement the activities.
- Set-up of work zone: look to the work zone through the eyes of the road users. Are the signs well positioned and is clear which behaviour is expected (speed adaptation, lane narrowing)?
- Parking facilities: take care of safe car parks;
- Setting up of the work area: create enough space for rest and sanitary facilities, for material storing and take care of adequate lighting especially in case of night work;

- Equipment: use only equipment that is in good condition. Take care that the equipment can not fall over or blown away by wind. Check the signs, equipment and batteries regularly.

3. Approaching and entering a road work zone

Risks
Approaching and entering a road work zone give less danger if a (soft) shoulder lane or a special implemented lane is available.

Points of attention
- Traffic: be clear towards the road users in your actions, do not hesitate and stay correct. Be careful while leaving your vehicle.
- Visibility: use good and clean safety clothes. Do not use optical signs on vehicles (e.g. flashing lights) within the work area.
- Weather: be extra alert during times of fog or bad weather circumstances. Have in mind that both you and the road users have to deal with less sight.
- Control: check that all work areas and activities as parking are within the enclosure.
- Parking facilities: park on a safe spot, as far as possible on the soft shoulder or at the edge of the work zone. Do not park on bicycle or foot paths. Take care that in case of a collision your vehicle is not ‘launched’ into the work area. Park at least 100 meters away from the work area, put on your hand brake and turn the front wheels in a direction that is safe for you and the road user. Think that in case of a collision from the back the direction of the front wheels is the direction in which your vehicle will move;
- Work traffic: provide all trucks and vans with yellow signs with the text ‘work traffic’ in black;
- Control of enclosure: check the enclosure regularly, at least at the beginning of a new day or shift. If the enclosure is not in the original state, restore it or inform the person ion charge of the road work zone.

4. Carrying out a road work

Risks
Collisions appear because of bad driving behaviour of through traffic, inferior or confusing enclosures or works that are carried out outside of the enclosure, e.g. in case of mobile works or works on the soft shoulder.

Points of attention
- Traffic: take good care and look whether the traffic behaves as is meant with the safety measures and signs. Are the ‘no overtaking’ and speed limit signs observed? If not inform the person in charge of the road work zone.
- Work area: stay within the work area. If work outside the work area is required, discuss with the person in charge of the road work zone to come to a safe solution.
- Driving: drive carefully in the work zone. Within the work area drive at a foot pace.
- Night works: take care of adequate lighting.

- Visibility: Take care that your work area and your material is well visible. Use good and clean safety clothes. Do not use optical signs within the work area.

5. Leaving a road work zone

Risks

Leaving the work zone gives extra risks for collisions. Especially when the only opportunity to leave the zone is by traffic lanes with through traffic. Loaded trucks have to deal with long acceleration times, thus having difficulties while joining the through traffic.

Points of attention

- Lane for work traffic: at long-lasting and large road works and at major roads a separate lane is usually made. This lane is meant explicit for work traffic. Use this lane as much as possible.
- Traffic: wait until a quiet moment before leaving the work area, take time to estimate the traffic amount before acting.
- Traffic behaviour: take care that all other traffic understand your intention to leave the work area.
- Optical signs: if allowed use flashing or warning lights.
- Moving the enclosure: if it is necessary to move the enclosure to leave the work area, take care that the enclosure is restored in the original state. Prevent that the driver of the vehicle leaving the work area should do this himself.
- Exit of work area: the exit and slip roads of a work area should be well visible and marked all the time.

6. Dismantling a road work zone

Risks

The risk for collisions are huge compared with other stages because the activities have to be done in the flow of through traffic. Especially removing the signs and beacons is a hazardous job: the behaviour of the road users is uncertain.

Points of attention

- Duration of enclosure: to prevent irritations of the road user, do not maintain the enclosure unnecessary.
- Begin of dismantling activities: wait with the dismantling until the person in charge has given order and act according to the instructions and guidelines.
- Escape: take continuously care of an escape route that does not require to cross a traffic lane.
- Clearing up: work from the back to the front and from the outside to the inside of the work zone. This means that work is done opposite traffic direction and from the traffic lane towards the work area.
- Traffic: take care of the traffic and use the protection of the remaining enclosure.
- Temporary measures: if these measures, e.g. temporary lane closures, conflict with current traffic signs, you should cover these signs.

- Loading of equipment: take care that unnecessary equipment directly is loaded in a truck and not temporarily is stored on the soft shoulder.
- Signs: do not forget to re-establish covered signs in their old state.
- Last action: remove the signs at the begin of the work zone that warn the passing traffic for road works.

Checklist for the road worker

Everyone who has a work area on or along a road - especially when traffic uses that road - should be aware of the major safety points. It is out of question whether this is a principal, a road director or a contractor, all should have a certain knowledge of the involved risks and safety measures.

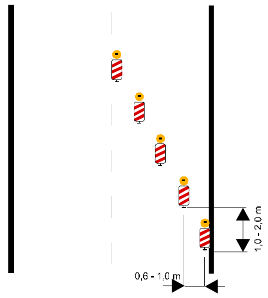
Advice:
- Be extra careful during fog and other bad weather circumstances.
- Park your car in a way that your sight is not hindered, use the hand brake and turn the front wheels in a, for you and the road users, safe position.
- Stay within the enclosure. Discuss with the person in charge of the work zone for a safe solution if you have to work outside the work area.
- Take your time while joining the traffic, estimate the speed and wait for a quiet moment. Use where necessary and allowed your flashing or warning lights.
- To prevent irritations of the road user, do not maintain the enclosure unnecessary.
- Make yourself known with the revealed risks and incidents.
- Contact the person responsible for safety issues in case of any questions. He is your first person to approach.
- Inform the person responsible for safety issues or the person in charge of the work zone about every unsafe situation.

If you consider the risks to large, you can interrupt your activities anytime.

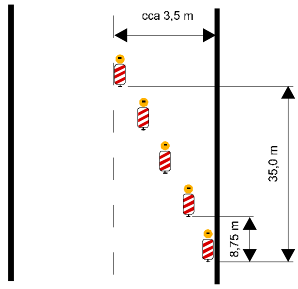
Questions
You should always be able to answer **YES** to the following questions:
- Do you know who is responsible for safety issues at your work zone?
- Are you well visible and does that also apply to your material and signs? Think also about your clothes and lighting.
- Is there an indication that road works are performed?
- Do you know the allowed speeds in the surroundings of the work zone?
- Have you been instructed on:
    - setting up the road work zone in a safe manner;
    - approaching and entering the road work zone in a safe manner;
    - carrying out the road work in a safe manner;
    - leaving the road work zone in a safe manner;
    - dismantling the road work zone in a safe manner.
- Do you have enough overview over the lay-out of the work zone?
- Is there enough space between the traffic lanes and the work area?
- Are there adequate emergency plans? Do you know what to do in case of incidents?
- Are there other contractors at work at the work zone? If so, do you know the safety appointments and are they well tuned?
- Are the rest and sanitary facilities well accessible?
- Are the routes to the work zone and its slip roads well visible and marked?
- Is there a daily check of the safety measures?

ANNEX II: Aspects of Managing a Road Work Zone

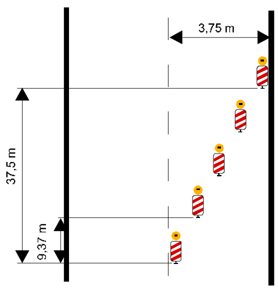
example of transverse closure in urban area



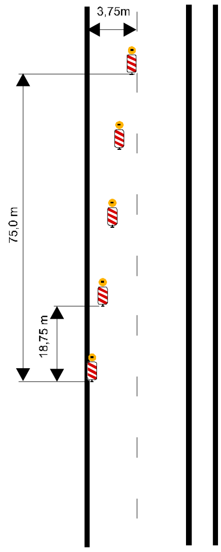
example of transverse closure in rural area



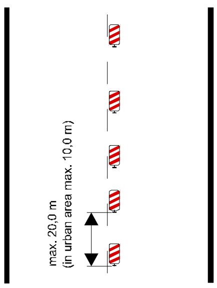
example of transverse closure on motorway or expressway
(min. angle of standing 1:10)



example of transverse closure on motorway or expressway
(recommended angle of standing 1:20)



example of longitudinal closure



- The speed limit on work zone

  There is a need to select the speed limit value with respect to the road type and real conditions on concrete work zone. In order to achieve continuous traffic it is effective the work zone design by that way to be able use minimum speed limit value 60km.h^{-1} or higher on motorways or expressways and minimum speed limit value 40 km.h^{-1} or higher on the other roads.

When work zones trench with the pedestrian or cycling traffic zones directly on the road, there is a need to make safe solution for this traffic participants.

- The traffic lanes width

For the minimum width of the traffic lane on work zone 2,75 m is recommended. Traffic in both directions is possible with a road width of 5,5 m.

- The transverse closure

It is recommended to practise with guiding beacons mostly, which are located in the sharp angle to the roads axe and to complete with the yellow or orange warning lights set. To practise of the single cross lock is different in accordance with the work zone location (in urban areas, in rural area and on the motorway or expressways) - see next pictures:

When two traffic lanes or more in the same driving direction must be closed, in addition there is a need to built transverse closure of every traffic lane separately and among them to create the longer short-lived (passing) sectors which are determined by the longitudinal closure (transverse closure are longitudinal indented and a number of the traffic lanes is reduced gradually).

On Work zones with short term duration the most often mobile trailer as the transverse closure are used.

- The longitudinal closure

It is recommended to practise with the guiding beacons or traffic cones (in the case of work zone with short term duration) which are located in the longitudinal distances max. 20 m (in urban areas max. 10 m) is recommended:

- The separation of the same direction traffic lanes

The same direction traffic lanes are separated by the shot term road marking which are made from the temporary road studs the most often, alternative from the yellow foil. In the area of the traffic transfer and in the adequate distance ahead of it and behind it the traffic lanes are segregated by the continual lengthways line.

- The separation of the contra-flow traffic lanes

The separation of the contra-flow traffic lanes is practised with guiding equipment (emphasising beacon, small guiding beacon, guiding sill, safety barrier). At the selecting of the applicable type of guiding equipment there is a need to consider the traffic intensity on the work zone.

- The entrance or exit from the work zone on the directional divided roads

In the case entrance or exit to work zone in the area of leading traffic with the auxiliary traffic lanes is need to endeavour about the fabrication of the linking (respectively striking) lane or even in the shorted temporary form.

- It is important to pay attention to ensuring of building operations, securing of workers and vulnerable traffic participants (adequate working clothing, education of workers, their separation from traffic, etc.) and provide public information about work zone through media.

APPENDICES to Chapter 2

Appendix 1:
Unsafe Driving Acts, their Psychological Precursors, and their Defences

Unsafe Driving Acts

•Disturbance/ distraction
•Unsafe speed
•Improper manoeuvres
•Improper behaviour in work zone

-mobile phone
-inadequate speed
-road worker taking risks
-unwarranted lane changes
-not giving way
-following too close
-sudden movement by workers
-sudden braking
-show intentions too late
-passing to close to works
-distraction of driver by children/passengers/animals
-workers not following guideliness
-lane changing at wrong location or in an improper manner

Psychological pre-cursors

- Bad health
- Absentmindedness
- Aggressivenesss
- Lack of skill
- Familiarity with the local situation
- Conflicts

-people think that they are good and safe drivers
-haste
-irresponsibility
-uncertainty
-conflicts
-ignorance
-lack of experience
-unfamiliarity
-auto-pilot
-sleepiness
-absentmindedness
-drugs/ill/stress
-alcohol
-bad eyesight
-young drivers; showoff
-bad trip planning (start late)
-unable to understand signs

Defences

- Campaigns/information
- Enforcement
- Local information on the spot
- Separation of traffic and work zones
- Readability of road

-campaigns/information via mass media
-feed back
-instructing road users and workers
-inspections
-sirens and cables
-enforcement
-guidelines
-video control
-telematics
-radio data systems
-prohibition of use of mobile phones and smoking in cars
-hands free phone mandatory
-ensure visibility of workers
-lower speeds
-reduce disturbing information
-reduce visibility of work
-increase visibility of work zones
-smooth transitions (alignment)
-quality procedures
-adjust signing before/during/after
-clear information about changes in geometry
-symbols in signs
-buffer space/ zones
-detouring traffic
-work outside traffic/ complete closures
-barriers
-supervision of workers
-traffic lights
-complete traffic plan
-variable message signs

Inter-relations

For the most part, the matrix of inter-relations was only filled in very sparsely, presumably due to a lack of time. There were about 200 possible (asymmetric) relations, of which only about 70 were actually filled in. For this reason, a systematic analysis is not possible.

Some general trends do emerge.

In general, bad health may have a strong (causal) relation with other psychological pre-cursors, but other pre-cursors are more or less independent of each other.

Most pre-cursors have a moderate to large effect on most unsafe acts, as would be expected. They have little or no (causal) relation to the defence that may be implemented. This is also as expected.

In addition, defences have a differential effect on unsafe acts. That is some defences are better suited for some unsafe acts, and less well suited for other ones. This, of course, is as expected.

Appendix 1a: Unsafe Acts, Causes, and Defences

Background

Accidents are almost always preceded by someone's *unsafe action(s)*. (Which is not to say that the actor actually foresaw the possible consequences of such behaviour.) Fortunately, not all unsafe acts lead to accidents: good luck plays quite often an important role. Leaving luck aside, good planning and design can erect *defences* against these unsafe acts, preventing accidents. These defences can anticipate a wide range of unsafe acts, but they can never anticipate every contingency. For this reason, it may be more efficient to consider the possible psychological *causes* (or precursors) of these unsafe acts, enabling one to nip the unsafe acts in the bud.

Example

An (fictitious) example of the possible insights gained by elucidating the chain of psychological precursors as a cause of an unsafe act, which may then be defended against.

More and more people have to work at the office during the evening. When they finally get to drive home, they are probably quite tired, and are anxious to get back to their family. Perhaps there is even some increased chance of alcohol use. These factors may encourage higher speeds, and lower attention levels. Work zone warning signs may not be noticed until too late.

This problem may be defended against by means of modern electronic navigation and communication systems (e.g., RDS-TMC), warning drivers about work zones (tens of) minutes before they are actually encountered.

The Question(s)

-What are the most important unsafe acts leading to work zone traffic accidents?
-What are the most effective defences against unsafe acts?
-What are the most important (psychological) precursors leading to those unsafe acts?

These questions should be applied to road users as well as workers.

The Procedure

Phase One

We want lists of factors (variables, characteristics) which are relevant for answering the question(s) asked. We will generate these lists by the procedure of "brainstorming".

Brainstorming is the name given to the process of interactively generating ideas in small groups. The purpose is to generate as many ideas as possible. In order to stimulate this process, one should not criticise other ideas, only build upon them, or add completely new ideas.

These ideas are written down as quickly and as clearly as possible (on a flip-over or a blackboard). Hopefully this growing list of ideas stimulates participants to add more and more ideas to it.

In order to structure the process somewhat, it could be useful to categorise ideas into lists and sub-lists. For example, "average number of members of a household" is a demographic factor, and could be placed on that sub-list along with other demographic factors.

Therefore, in this first phase, we primarily want suggestions and ideas for naming factors which answer the question(s) that we posed.

In addition, suggestions and ideas for structuring the lists (and sub-lists) of factors may also be entertained, even though it can be left to the following phase.

Again, suggestions and ideas should not be criticised. The quantity, not the quality of the ideas, is important. The order in which the questions mentioned above are answered may be left up to the participants. The various questions may also be answered one at a time, or simultaneously.

Phase Two

In this phase, the quality and organization of the factors we just generated is our major concern.

First of all, if the factors have not already been organised into lists and sub-lists, then this is the time to do it. Any argument that the participants deem relevant to grouping the factors is a valid argument. At the very least, the distinction should be made between unsafe acts, defences, and precursors. One could also make the distinction between road users and road workers.

Secondly, half-baked or frivolous factors have to be weeded out, leaving only the "important" ones. Perhaps two labels are simply different descriptions of the same underlying factor, so that one factor can be removed from the list.
The group should decide itself which factors are important and which are not.

100 factors, however, are much too many, and 2 factors are far too few.
10-20 factors would seem to be an reasonable number.

Phase 3

Time permitting, we would also like to address an additional problem. Namely, we would like to organise our thoughts about how the factors selected in the previous step(s) are related to one another.

We can make a matrix with the same number of rows and columns as the number of factors that we selected. We then organise the factors in the same way as we did in the previous phase, and place a (label) for each factor in the corresponding rows and columns of the matrix.

For example, if we were describing the matrix of factors, acts, and defences we might create the following matrix:

	ON:	1.	2.	3.	4.	5.
INFLUENCE OF:						
Precursors						
1. aggression		x				
2. sleepiness			x			
Unsafe Acts						
3. high speed				x		
4. ignoring signals					x	
Defences						
5. police enforcement						x

For every cell a_{id} in this matrix, we then have to determine (by means of group discussion), the extent to which row factor i influences (or causes) column factor j.

++ means “has a very large positive influence”
+ means “has a positive influence”
0 means “has no appreciable influence”
- means “has a negative influence”
-- means “has a large negative influence”
? or blank means “no idea/ no time to reach an agreement”
x means “not applicable”

By filling this matrix in, we can obtain an idea of which precursors are likely to lead to which unsafe behaviours, and which defences are most effective against which unsafe behaviours.

It should be clear that the more factors we have, the larger the matrix and the more work there is.
The available time will not permit an extended discussion for each cell of the matrix. The most important cells, on which there is broad agreement, should be filled in first. Many cells may have to be left blank.

Phase 4

One of group's participants should also be elected to present the results the following morning. He or she can use the (legible and organised) output of the previous steps as a visual aid. A short (informal) 3-5 minute presentation should then be prepared.

C. Gundy
21/11/97

Appendix 2: External Factors

•Traffic Characteristics
- ·volume
- ·vehicle type
- ·day of the week
- ·motives of drivers

•Work zone Characteristics
- ·length
- ·position: longitudinal and lateral
- ·duration
- ·number of workers
- ·type of work
- ·equipment

•Safety Measures
- ·signing (speed limits and road markings)
- ·protection

•Type of Road
- ·motorways
- ·rural/urban

•Time
- ·hour of the day
- ·day of the week
- ·season (weather)

•Maintenance management
- ·investment
- ·use of maintenance program

•Enforcement

•Compliance to existing standards/regulations

•Regional factors (location)

•Existing quality of road surface

•Use of detour (yes/no)

Note: Participants were unable to clearly distinguish between “causes” and “descriptions” of traffic exposure to work zones. We find this to be somewhat surprising.

Inter-relations
The upper diagonal of the matrix of relations between factors was almost completely filled in, and the lower diagonal matrix was left completely blank. (Participants possibly felt that these causal relations were symmetrical.)
However, only binary codes were used (instead of the 5 point scale that we suggested). In any case, this matrix was not analysable by means of MDS or PCA.

Appendix 2a: External Factors

Background

Work zone traffic accidents have two crucial pre-requisites: work zones and traffic. Understanding how, when, where, etc. traffic encounters work zones is essential for comparing accident rates between countries or over time. It can also provide insight into the nature and extent of the work zone traffic accidents that occur, and possibly even enable us to predict futures changes in accident rates.

Economic, political, demographic, geographic, and climatological factors can all play a role.

Example(s)

An (fictitious) example of the possible importance of predicting (changes in) traffic volumes and work zone activities:

Recent, enormous growth spurts in the economic development of country X has lead to unprecedented growth in traffic volume. This, in turn, has lead to demands for new roads. Also, years of poor economic performance has limited governmental revenues. This, in turn, has lead to low levels of road maintenance, whose neglect is only now being remedied
Result: more traffic, more work zones, and a predicted increase in the number of work zone accidents.

Another example:

High traffic volumes in the densely populated country Y have placed heavy (maintenance) demands on the traffic system there. However, daytime maintenance schedules only increase the burden on the traffic system by introducing extra delays and congestion. Officials therefore decided to shift a significant portion of the maintenance operations to less demanding periods of the day, i.e., evening and night.
This shift can have large consequences for the nature and severity of the resulting work zone traffic accidents.

The Question(s)

-Which background (or exogenous) factors influence the nature and extent of traffic exposure to road work zones?
-Which factors can be used to describe the nature and extent of traffic exposure to road work zones?

The Procedure

Phase One

We want lists of factors (variables) which are relevant for answering the question(s) asked. We will generate these lists by the procedure of "brainstorming".

Brainstorming is the name given to the process of interactively generating ideas in small groups. The purpose is to generate as many ideas as possible. In order to stimulate this process, one should not criticise other ideas, only build upon them, or add completely new ideas.
These ideas are written down as quickly and as clearly as possible (on a flip-over or a blackboard). Hopefully this growing list of ideas stimulates participants to add more and more ideas to it.

In order to structure the process somewhat, it could be useful to categorise ideas into lists and sub-lists. For example, "average number of members of a household" is a demographic factor, and could be placed on that sub-list along with other demographic factors.

Therefore, in this first phase, we primarily want suggestions and ideas for naming factors which answer the question(s) that we posed.
In addition, suggestions and ideas for structuring the lists (and sub-lists) of factors may also be entertained, even though it can be left to the following phase.

Again, suggestions and ideas should not be criticised. The quantity, not the quality of the ideas, is important. The order in which the questions mentioned above are answered may be left up to the participants. The various questions may also be answered one at a time, or simultaneously.

Phase Two

In this phase, the quality and organization of the factors we just generated is our major concern.

First of all, if the factors have not already been organised into lists and sub-lists, then this is the time to do it. Any argument that the participants deem relevant to grouping the factors is a valid argument.
At the very least, the distinction should be made between factors used to **describe** traffic exposure to work zones (internal variables), and the factors which **influence** traffic exposure to work zones (external variables).

Secondly, half-baked or frivolous factors have to be weeded out, leaving only the "important" ones. Perhaps two labels are simply different descriptions of the same underlying factor, so that one factor can be removed from the list.
The group should decide itself which factors are important and which are not.

100 factors, however, are too many, and 2 factors are far too few.
10-20 factors would seem to be an reasonable number.

Phase 3

Time permitting, we would also like to address an additional problem. Namely, we would like to organise our thoughts about how the factors selected in the previous step(s) are related to one another.

We can make a matrix with the same number of rows and columns as the number of factors that we selected. We then organise the factors in the same way as we did in the previous phase, and place a (label) for each factor in the corresponding rows and columns of the matrix.

For example, if we were describing the causes and effects of unemployment, we might create the following matrix:

	ON:	1.	2.		3.	4.	5.	6.	7.
INFLUENCE OF:									
1. unemployment rate		x							
2. unemployment benefits paid			x						
3. consumer confidence					x				
4. inflation						x			
5. price of oil							x		
6. crime rate								x	
7. prime interest rate									x

For every cell a_{id} in this matrix, we then have to determine (by means of group discussion), the extent to which row factor i influences (or causes) column factor j.

++ means “has a very large positive influence”
\+ means “has a positive influence”
0 means “has no appreciable influence”
\- means “has a negative influence”
-- means “has a large negative influence”
? or blank means “no idea/ no time to reach an agreement”
x means “not applicable”

By filling this matrix in, we can get some idea of to which extent variables are related, as well as which variable may cause the other ones.

It should be clear that the more factors we have, the larger the matrix and the more the work. The available time will not permit an extended discussion for each cell of the matrix. The most important cells, on which there is broad agreement, should be filled in first. Many cells may have to be left blank.

15-20 factors would be the most that could be filled in using this procedure.

Phase 4

One of group's participants should also be elected to present the results the following morning. He or she can use the (legible and organised) output of the previous steps as a visual aid. A short (informal) 3-5 minute presentation should then be prepared.

C.Gundy
21 November, 1997

Appendix 3: Latent Failure Types and Remedies

- Poor car maintenance : *procedures and enforcement*
- Private car culture: *changing priorities in the political agenda*
- Physical environment around work zones: o*rganization and standardisation issues*
- Enforcement: *structured schemes for officer education, penalty structure and policy resources*
- Training and Education:
- Inexistence of checklists of necessary actions
- Maintenance of devices: p*rocedures, responsibilities*
- Lack of time:
- Inconsistency of road work zone layout: *guidance*
- Absence of auditing procedures:
- Conflicting goals and interests of actors:
- Unrealistic restrictions:
- Pre-trip information: *appropriate media and usability*
- Degree of usability:
- Young drivers education on road work zone crossing:
- Absence of dedicated, specialised workforces for road work zones:
- Adverse climatic effects on the behaviour of drivers and workers: *awareness of problem through e.g. appropriate campaigns*
- Traffic composition: *in road work zone with more than 2 lanes, restriction of some vehicles categories in one lane*
- Procedures: *public acceptance testing reactions ahead*
- Unclear decision making: r*ight time and level*
- Structure of the urban environment:
- Poor quality of construction material:
- Legislation:
- Institutional framework:
- Cultural environment:

Appendix 3a : Latent Failure Types

Background

When discussing the causes of accidents, one is often inclined to point to events close in time or space to the actual accident. Deeper analysis, however, often reveals that the root causes of accidents are often direct or indirect consequences of the choices that an organization (or society) makes. These so-called "latent-failure types" are often ignored until their error-generating capacity results in unacceptable accident losses.

Research has found 11 classes of General Failures Types[12]:
-hardware
-design
-maintenance management
-operating procedures
-error-enforcing condition
-housekeeping
-incompatible goals
-communication
-organization
-training
-defence planning.

For example, "*procedures* covers the absence of procedures, presence of incorrect, unnecessary, or clumsy procedures, unfamiliarity with procedures or lack of understanding of complex procedures, and the habitual, and not corrected violation of procedures." "*Defence planning* refers to absence of a structured analysis of system defences and the lack of implementing those defences, once their need is identified."

One can argue that attacking the root causes of accidents make be more efficient than trying to remedy their many consequences. I.e., the design and organization of the work zone workplace, and adequate planning, training, and procedures may be the most efficient means for tackling the accident problem.

The Question(s)

What are the root causes (i.e., latent failure types) of work zone traffic accidents? What are the most effective countermeasures for remedying these root causes?

[12] See Wagenaar et al. (1994).

The Procedure

Phase 1

We want lists of factors or characteristics, which are relevant for answering the question(s) asked. We will generate these lists by the procedure of "brainstorming".

Brainstorming is the name given to the process of interactively generating ideas in small groups. The purpose is to generate as many ideas as possible. In order to stimulate this process, one should not criticise other ideas, only build upon them, or add completely new ideas.

These ideas are written down as quickly and as clearly as possible (on a flip-over or a blackboard). Hopefully this growing list of ideas stimulates participants to add more and more ideas to it.

These lists of characteristics may contain anything that the participants deem useful.

In order to structure the process somewhat, it could be useful to categorise ideas into lists and sub-lists. For example, " poor visibility due to mist" is an external factor, and could be placed on that sub-list along with other external factors.

We would suggest that use is made of the list of 11 General Failure Types mentioned on the previous page.

Therefore, in this first phase, we primarily want (lists of) specific characteristics for answering the question that we posed.

In addition, suggestions and ideas for structuring the lists (and sub-lists) of characteristics may also be entertained, even though it can be left to the following phase.

Again, suggestions and ideas should not be criticised. The quantity, not the quality of the ideas, is important. The order in which the two questions mentioned above (i.e., the root causes and proposed remedies) are answered may be left up to the participants. They may be answered one at a time, or simultaneously.

Phase 2

In this phase, the quality and organization of the factors we just generated is our major concern.

First of all, if the factors have not already been organised into lists and sub-lists, then this is the time to do it. Any argument that the participants deem relevant to grouping the factors is a valid argument.

At the very least, the distinction should be made between characteristics used to **describe** the latent failure types, and their corresponding countermeasures. (The use of the General Failure Types may be useful.)

Secondly, half-baked or frivolous factors/characteristics have to be weeded out, leaving only the “important” ones. Perhaps two labels are simply different descriptions of the same underlying factor, so that one factor can be removed from the list.
The group should decide itself which characteristics are important and which are not.

100 failure types and countermeasures, however, are too many, and 2 factors are far too few.

Phase 3

One of the group's participants should also be elected to present the results the following morning. He or she can use the (legible and organised) output of the previous steps as a visual aid. A short (informal) 3-5 minute presentation should then be prepared.

C.Gundy
21/11/97

Appendix 4: Risk Factors

External

+•Weather: reduced visibility and/or slippery surface with
- ·rain
- ·fog
- ·snow

+•Time of Day: reduced visibility in darkness
-•Environment:
- ·distractions (urban vs. rural)
- ·pedestrian cyclists,
- ·festivals and other activities

+•Alignment:
- ·slope
- ·hills/curves leads to increased driver workload
- ·downhill leads to higher speeds
- ·uphill leads to lessened manoeuvrability of lorries, etc.

+•Traffic Volume:
- ·low volume leads to high speeds
- ·high volume leads to queuing collisions

o•Traffic Composition:
- ·high %age lorries leads to poor manoeuvrability and reduced visibility

-•Driver Familiarity:
- ·familiar drivers are safer
- ·tourists, etc. are less safe

-•Lanes: original number and width
-•Surface condition or original road (?)
o•Junctions within work zone
- ·special/ extra signing

Internal

++•Quality of traffic management
- ·lane reduction ++
- ·lane width -
- ·technical elements (e.g. crossover length) +
- ·advance warning o
- ·signalisation and equipment +
- ·quality of equipment (e.g., reflective materials) ++

o•Length of work zone
o•Duration of works
- ·long periods traffic diversions leads to accidents elsewhere -
- ·short periods- high risk to workers when setting out or taking in signs +

++•Access/egress from work zone by works vehicles
+•Dust
+•”Interesting” (i.e., distracting) works machinery
++•Division of contra-flow traffic
++•Division of work area from traffic
-•Dazzling of oncoming traffic
o•Workers setting out/taking in signs
++•Maintenance of temporary signals and signs

Countermeasures for ++ Risk Factors

•Quality of traffic management:
- ·Re: lane reduction:
  - *try to keep same number of lanes by narrowing lanes or using shoulder*
- ·Re: quality of equipment:
  - *good reflectivity and good road markings*

•Maintenance of Equipment
- ·regular surveillance of site
- ·spare signs/ equipment available
- ·cleaning reflective materials

Appendix 4a: Risk Factors

Background

Work zones generally have higher accident rates than the same road sections without a work zone. However, it doesn't seem likely that this higher risk is evenly distributed over all aspects or components of work zones. If we could identify those aspects with the highest accident risk, then we could more efficiently concentrate our safety efforts.

Example

For example, there are different work zone functions (e.g., maintenance and construction), internal structure (in- and out-transitions, the work zone proper), temporal aspects (long-term versus very short-term), work zone forms (e.g., lane closures, counterflow), various moments in the work zone life cycle (from setting up to breaking down a work zone). There are also factors external to the work zone, such as weather and time of day, which may influence accident risk.

The Question

-Which factors, internal or external to work zones, influence traffic accident risks?

The Procedure

Phase One

We want lists of factors (variables) which are relevant for answering the question(s) asked. We will generate these lists by the procedure of "brainstorming".

Brainstorming is the name given to the process of interactively generating ideas in small groups. The purpose is to generate as many ideas as possible. In order to stimulate this process, one should not criticise other ideas, only build upon them, or add completely new ideas.
These ideas are written down as quickly and as clearly as possible (on a flip-over or a blackboard). Hopefully this growing list of ideas stimulates participants to add more and more ideas to it.

In order to structure the process somewhat, it could be useful to categorise ideas into lists and sub-lists. For example, "average number of members of a household" is a demographic factor, and could be placed on that sub-list along with other demographic factors.

Therefore, in this first phase, we primarily want suggestions and ideas for naming factors which answer the question that we posed.
In addition, suggestions and ideas for structuring the lists (and sub-lists) of factors may also be entertained, even though it can be left to the following phase.

Again, suggestions and ideas should not be criticised. The quantity, not the quality of the ideas, is important.

Phase Two

In this phase, the quality and organization of the factors we just generated is our major concern.

First of all, if the factors have not already been organised into lists and sub-lists, then this is the time to do it. Any argument that the participants deem relevant to grouping the factors is a valid argument.

Secondly, half-baked or frivolous factors have to be weeded out, leaving only the "important" ones. Perhaps two labels are simply different descriptions of the same underlying factor, so that one factor can be removed from the list.
The group should decide itself which factors are important and which are not.

100 factors, however, are much too many, and 2 factors are far too few.
10-20 factors would seem to be an reasonable number.

Phase 3

Supposing that we have 10-20 risk factors, we have to define the relevant values (characteristics) that those factors can have. For example, if we have chosen the risk factor "weather conditions", then one could indicate that sunshine, partly cloudy, rainy, snow or sleet, and mist were the values that "weather conditions" could assume.

Any method that the group finds useful (e.g., brainstorming, group consensus, etc.) in filling in these risk factors is acceptable.

Phase 4

In this phase, we would also like to address an additional problem. Namely, we would like to have estimates of the relative risk of all of the characteristics found in the previous step.

One could make a list with a label for each characteristic (e.g., partly cloudy, rainy, etc.), and for each label, choose one of the following evaluations:

++ means "has a very large relative accident risk"
\+ means "has a somewhat larger relative accident risk"
0 means "has an average relative accident risk "
\- means "has a rather small relative accident risk"
-- means "has a very small relative accident risk"
? or blank means "no idea/ no time to reach an agreement"
x means "not applicable"

By "relative risk", we refer to refer to the average risk of work zones as a whole.

It would also be preferable if the reasons for each evaluation could be mentioned. Of course, this may not be possible, given the time limits. And sometimes "gut" feelings are difficult to explain.

Phase 5

For each list item with the ++ evaluation (i.e., very large accident risk), list at least two countermeasures which could conceivably reduce that accident risk.

Please be as explicit as possible.

Phase 6

One of group's participants should also be elected to present the results the following morning. He or she can use the (legible and organised) output of the previous steps as a visual aid. A short (informal) 3-5 minute presentation should then be prepared.

C. Gundy
21/11/97

Appendix 5: Actors, Goals, and Strategies

Summary of Important Actors

•Politicians
•Authorities
•Road Users
•Contractors
•Traffic/Road Engineers
•Emergency Services
•Road Workers
•Industry

Actors	Goals
·commuters	quick/reliable travel
·prof. delivery drivers	quick/reliable travel
·pedestrians	comfortable/quick travel
·tourist	comfortable/slow travel
·road-workers	doing job; keep boss happy; safety; being efficient
·contractors	stay within budget & time target; maximise profits; use lowest grades/products
·road engineers	design best case; meet standards
·politicians	re-election;quick fixes;make impression
·supervisor	work completion under contract conditions
·police	law and order; enforcement
·traffic engineer	traffic safety and flow
·broadcaster	provide info
·road operators	traffic flow and safety
·HLV drivers	getting through sporty and fast
·special convoys	being safe; not creating unsafe situations
·dangerous goods transport	being safe; not creating unsafe situations
·long distance driver	clear guidance, credibility, uniform info
·elderly drivers	safety
·motor- and bi-cyclists/pedestrians	high speed or comfortable travel
·industry	reliable profit
·transport operators	reliable profit
·equipment manufacturers (machinery/safety)	market share;machinery ??
·military convoys	smooth travel; no damage; speed
·public transport (buses)	quick and reliable travel
·sports people	speed
·trauma team	speed

There seemed to be some difficulties in finding a common terminology: there are many international differences.

-Authorities influence each other as well as contractors.
-Road users can only influence other by means of their behaviour and public opinion.
-Contractors have major influence.
-Engineers have influence due to their "good knowledge and reliable advice".
-Emergency services have little influence, except on road users.
-Road workers have little influence, except via their unions.

Influence Chart

	Influence Strategies of:							
upon:	**politi-cians**	**author-ities**	**road user**	**con-tract.**	**engin-eers**	**emr. serv.**	**road work-er**	**indus-try**
politi-cians	-	power, support recomme nd	public opinion actual behav-iour	lobbying	recom-mend/ publ.	safety	unions	lobby**
author-ities	direct inter-vention	-	law suits	lobby/ pricing	recom-mend/ publ.	pressur e	unions	lobby**
road users	cam-paigns	pr/ rules/ sign/ demos.	-	sticker /publicity	demos	eneme nt	0	advertis e
contract-or	0	hand-books/ tender/ budget alloc.	Complain ts	-	publ.	sign-off works*	union	lobby/ demos
engin-eers	advise	guide-lines/ rules	petition	lobby/ trade fairs	-	sign-off works*		lobby/ demos
emer-gency services	legislati on	rules/ cooperati on	0	spon-soring	design recom-mend-ations	-	0	0
workers	0	employme nt legis.	driving too fast	work cond./ wages	info	0	-	0
indust-ries	impose standar ds	direct comm./ standards	0	machine ry	direct commu ni-cation	0	0	-

*there are international differences
**different arguments are used for politicians and authorities

N.B. Diagonal cells can influence each other on the international level.

Appendix 5a: Actors, their Goals, Resources, and Strategies

Background

Work zone traffic accidents don't just happen: people are always doing something for a reason, when things don't turn out right.
If we want to understand the what and why of behaviour in work zones, we have to know WHOSE behaviour is relevant. In addition, it would be helpful to understand what those *actors* want, why they want it, and how they go about getting it.
In addition, their strategies for obtaining their goals may impact upon, or even clash with, strategies of other actors. How these interacting strategies are resolved, is possibly the fundamental cause of (observable) behaviour in work zones.

Example

An (fictitious) example of the possible importance of the interacting of multiple strategies in causing the way in which protective measures in work zones are implemented.:

Workers Unions demand more protection traffic accident for their members, after a series of fatal accidents. Contractors and manufacturers agree, and mention the fantastic results achieved when using Truck Mounted Attenuators (TMAs), in reducing accident likelihood and severity. Local road authorities also want to protect road workers, but their funds are very limited, and they can purchase only one TMA. All parties agree to try this one TMA on a trial basis. Unfortunately, one TMA cannot protect much of the road network, and other countermeasures are tabled due to lack of funds.

The Question(s)

-Who are the group(s) of actors whose behaviour is relevant for safety in work zones?
-What are their goals, and their problems?
-Which strategies/resources can they deploy to achieve their goals? And who is the target/ or is effected by these strategies?

The Procedure

Phase One

We want a list of (groups of) actors whose behaviour is relevant for work zone safety. We will generate this list by the procedure of "brainstorming".

Brainstorming is the name given to the process of interactively generating ideas in small groups. The purpose is to generate as many ideas as possible. In order to stimulate this process, one should not criticise other ideas, only build upon them, or add completely new ideas.
These ideas are written down as quickly and as clearly as possible (on a flip-over or a blackboard). Hopefully this growing list of ideas stimulates participants to add more and more ideas to it.

Again, suggestions and ideas should not be criticised. The quantity, not the quality of the ideas, is important.

Phase Two

In this phase, the quality of the list of groups of actors that we just generated is our major concern.

Frivolous or 'far-fetched" groups of actors have to be weeded out, leaving only the most "important" ones. Perhaps two labels are simply different descriptions of the same underlying group of actors, so that one label can be removed from the list.
The group should decide itself which actors are important and which are not.

We would expect that 5, and certainly not more than 10, "important" groups of actors can be identified.

Phase Three

As a following step, we need to organise our thoughts about what each groups' goals and resources are. I.e., what does each group want to achieve?, and what are the resources that they can apply towards their goals?

We can ask these two questions of each of the previously mentioned identified groups in turn.
The method of brain-storming, followed by selection of the most "important" findings, is the method that should be used.

We could then make a list of each important group of actors, with their corresponding objectives, and means. This should be written down, of course.

Phase 4

Time permitting, we can make a matrix with the same number of rows and columns as the number of groups of actors. We can then place a label for each groups of actors in the corresponding rows and columns of the matrix.

For example, if we were describing the problems surrounding air transportation in populated areas, we might create the following matrix:

	ON:	1.	2.	3.	4.	5.	6.
ACTION OF:							
1. unions		-					
2. airlines			-				
3. manufacturers							
4. consumers					-		
5. governments						-	
6. environmentalists							-

For every cell a_{id} in this matrix, we then have to determine (by means of group discussion), the strategies that row actor i can or does deploy to impact upon column actor j.

Even in the example mentioned here, there are a lot of cells that can be filled in. Due to time limitations, we suggest that the group begins with the most important cells, and proceeds to the lesser important ones if time is available. Even so, it is often is the “lesser” cells that many surprising conclusions may be found.

We suspect that there may be many blank cells left.
We would also like to mention that “not applicable” or “unknown” is a valid conclusion.

Phase 5

One of group’s participants should also be elected to present the results the following morning. He or she can use the (legible and organised) output of the previous steps as a visual aid. A short (informal) 3-5 minute presentation should then be prepared.

C.Gundy
21/11/97

Appendix 6a: Accident Types (Images)

Background

If we could consider different types of work zone traffic accidents, then perhaps we could more efficiently tailor our safety measures to address their different specific problems.
Of course, some safety measures could be useful for all types of accidents, but practical reasons may limit their application.

Example(s)

An (fictitious) example of the possible importance of differentiating between different types of work zone accidents:

The street lights in some stretches of two-lane rural roads often have to be replaced. These roads happen to have low volumes and the road users usually drive at high speeds. Furthermore, only one maintenance team is employed to undertake this maintenance. This team only works during the daytime in good weather, but they do have to park their maintenance vehicle very close to the edge of the road.
A Truck Mounted Attenuator may be a suitable, albeit expensive, safety measure for protecting this team.

Another (fictitious) example:

A dual carriageway urban artery has to temporarily close one of its lanes for emergency repairs. These repairs have to be implemented shortly after rush hour, during good weather. High speeds and rather dense traffic is expected. Previous experience indicates that there can be problems at the point whether the two lanes have to merge. So, in addition to warning signs and signals, it may be decided to prominently place a police cruiser near the transitional area in order to encourage motorists to moderate their speed.

The Question(s)

What are the characteristics of the most important and distinguishable types of work zone traffic accidents? Which countermeasures may be the most effective for each type?

The Procedure

We want to implement the complete procedure mentioned below at least 4 times, once for each of the following situations.

First of all, we want to generate an salient image of an traffic accident during long-term re-construction on a major inter-urban, dual carriage-way motorway. Participants can consider what they think (on the basis of their professional experience) to be the prototypical work zone motorway accident, or they may consider a single salient work zone motorway accident that they have personally experienced. Or they may want to generate ideas (or suspicions) on the spot.

Secondly, we want to generate a second work zone accident on the same type of road, but with as radically different characteristics as possible. This is intended to contrast with the first accident generated.

Thirdly, we would like to generate an image of an accident on a short-term maintenance work zone on a two-lane urban artery.

Fourthly, generate an accident image on the previous two-lane road, but with as radically different characteristics as possible. This accident is intended to contrast with the previous one.

Phase 1

We want lists of characteristics which are relevant for answering the question(s) asked, for each of the four situations sketched above. (We will consider only one situation at a time.) We will generate these lists by the procedure of "brainstorming".

Brainstorming is the name given to the process of interactively generating ideas in small groups. The purpose is to generate as many ideas as possible. In order to stimulate this process, one should not criticise other ideas, only build upon them, or add completely new ideas.
These ideas are written down as quickly and as clearly as possible (on a flip-over or a blackboard). Hopefully this growing list of ideas stimulates participants to add more and more ideas to it.

These lists of characteristics may contain anything that the participants deem useful:
personal characteristics, road type, weather, work zone layout, vehicle manoeuvres, ...

In order to structure the process somewhat, it could be useful to categorise ideas into lists and sub-lists. For example, " poor visibility due to mist" is an external factor, and could be placed on that sub-list along with other external factors.

Therefore, in this first phase, we primarily want (lists of) specific characteristics for answering the question that we posed.

In addition, suggestions and ideas for structuring the lists (and sub-lists) of characteristics may also be entertained, even though it can be left to the following phase.

Again, suggestions and ideas should not be criticised. The quantity, not the quality of the ideas, is important.

Phase 2

In this phase, the quality and organization of the factors we just generated is our major concern.

First of all, if the factors have not already been organised into lists and sub-lists, then this is the time to do it. Any argument that the participants deem relevant to grouping the factors is a valid argument.
At the very least, the distinction should be made between characteristics used to **describe** the accident types, and the countermeasures.

Secondly, half-baked or frivolous factors/characteristics have to be weeded out, leaving only the “important” ones. Perhaps two labels are simply different descriptions of the same underlying factor, so that one factor can be removed from the list.
The group should decide itself which characteristics are important and which are not.

100 characteristics however, are too many, and 2 factors are far too few.
10-25 characteristics per accident type would seem to be an reasonable number.

Repeat the previous two steps for each of the four types of accident mentioned at the beginning of the Procedure section.

Phase 3

One of the group’s participants should also be elected to present the results the following morning. He or she can use the (legible and organised) output of the previous steps as a visual aid. A short (informal) 3-5 minute presentation should then be prepared.

C.Gundy
21/11/97

Appendix 7: List of Participants and their Affiliations

Names	Institute/Organization
Mr. Rene BASTIAANS	DGVII - Commission of European Communities
Dr. George KANELLAIDIS *Associate Professor* Mr. Ioannis DIMITROPOULOS Mr. Ioannis PETROPOULOS Ms. Sophia VARDAKI Ms. Anastasia FLOUDA	NTUA - National Technical University of Athens - **(GR)**
Ms. Marjan HAGENZIEKER Mr. Chad GUNDY	SWOV - Institute for Road Safety Research - **(NL)**
Dr. Wolfgang SCHULTE	BAST - Federal Highway Research Institute - **(DE)**
Ms. Lena NILSSON	VTI - Swedish Road and Transport Research Institute - **(SE)**
Mr. Frank HANIOTIS Mr. Nicolas PORIOTIS Mr. Peter DIBBERN	3M Hellas - **(GR)** 3M Europe - **(DE)**
Ms. Sophie JEHAES	CRR - Belgian Road Research Centre - **(BE)**
Mr. John BOENDER Mr. Jan MULDER	CROW - Information and Technology Centre for Transport and Infrastructure - **(NL)**
Mr. Pavel TUCKA	CDV - Transport Research Centre - **(CZ)**
Mr. Bojan LEBEN Mr. Vladimir DEMSAR Prof. Marko POLIC Dr. Niko CERTANC Mr. Jan SAJOVIC Mr. Miro MLADENOVIC	ZAG - Slovenian National Building and Civil Engineering Institute - **(SI)**
Ms. Maria SAKKI	CEN/TC 226 - COST 331 Representative for Greece - **(GR)**
Mr. Graham COE *Senior Researcher*	TRL - Transport Research Laboratory - **(UK)**
Mr. Rene DE GROENE *Manager of Commercial Affairs*	Traffic Service Van Strien BV - **(NL)**
Mr. Jan M. BOONE *Senior Project Manager*	Traffic and Transportation Department of the Dutch Ministry of Transport and Public Works [Rijkswaterstaat] - **(NL)**
Ms. Josephine SCHOELLER	RD - Danish Road Directorate - **(DK)**
Mr. Peter BEHRMAN Mr. Sten FOUGMAN	SNRA - Swedish National Road Administration - **(SE)**
Prof. Manuel G. ROMANA	E.T.S. de Ingenieros de Caminos, Canales y Puertos Universidad Politecnica de Madrid **(ES)**
Dr. Anthony STATHOPOULOS *Associate Professor*	NTUA - National Technical University of Athens - **(GR)**
Dr. Pierangelo SARDI *President of S.I.P.Si.Vi.*	Societa Italiana di Psicologia della Sicurezza Viaria - **(IT)**
Dr. Aggelos NIKIFORIADIS	Greek Ministry of Environment, Planning and Public Works - **(GR)**

Appendix 8: Virtual Accident Form

27 February, 1998
C.M. Gundy
Leidschendam, The Netherlands

nr._________
form 8

(VIRTUAL) WORK ZONE TRAFFIC ACCIDENT FORM

Before you begin filling in this form, please first read it through in its entirety.

We ask to you to think of a specific work zone traffic accident. This accident may have actually occurred, be entirely imaginary, or perhaps derived from your professional experience. It must, however, be realistic, and specific.

We want you to fill in **all** of the following questions in this form. If you don't know which box is most appropriate, then fill in the your best guess.

We'll ask you do this, in total, 8 times on 8 different copies of this form: once for each of the 5 major road types, and 3 times you can choose the road type yourself.

If a box in the following question is ticked, then you must think of a work zone accident occurring on that road type.

If no box is ticked, then you are free to choose any road type that you feel is appropriate: in which case, please fill in the corresponding box.

-Road Type

- o motorway or dual carriageway expressway
- o rural primary road
- o rural secondary road
- o urban main road
- o urban local road

GENERAL ACCIDENT BACKGROUND

-Day of the week:

- o Sunday
- o Monday
- o Tuesday
- o Wednesday
- o Thursday
- o Friday
- o Saturday

-Time of Day: __:00 hours (24 hour system)

-Month

- o January
- o February
- o March
- o April
- o May
- o June
- o July
- o August
- o September
- o October
- o November
- o December

-Road Situation

- o straight road section
- o curve
- o junction
- o T-junction
- o entrance/exit ramp
- o other: ________________________

-Weather Conditions

- o dry
- o rain
- o mist
- o snow,hail
- o windy

-Road Surface Condition

- o dry
- o wet
- o snow,ice
- o road surface in poor repair (potholes, etc.)
- o other substance (e.g., spilled oil)

-Light Conditions

- o daylight
- o dark
- o dawn/dusk

-Street Lighting
- o on
- o not on
- o not present

-Type Road Surface
- o bitumen/asphalt
- o concrete
- o cobblestones/bricks
- o other: ____________________

-Speed Limit: ____ km/hour

-Unusual Road Characteristics
- o on or nearby pedestrian/bicycle crossing
- o nearby bridge
- o on or nearby tunnel/viaduct
- o on or nearby exit/entrance
- o on or nearby bus/tram stop
- o on or nearby parking space
- o nearby petrol station
- o steep hill
- o narrow road
- o other: _____________________

-Road Administrator
- o local authorities
- o regional authorities
- o national authorities
- o other: _____________

-Temporary Conditions
- o other accident
- o detour
- o other: ____________

-Traffic Intensity
- o very high
- o high
- o moderate
- o low
- o very low

-Number of carriageways
- o one
- o two

-Total number of lanes: ____

WORK ZONE CHARACTERISTICS

-Duration
- o long-term
- o short-term stationary
- o short-term mobile

-Size: how large was work zone area?
- o quite large
- o moderate size
- o relatively small

-Road/ Work Zone Interaction: Layout
- o lane narrowing
- o lane closure
- o diversion/detour
- o contraflow/crossover
- o alternate one-way traffic

-Road/ Work Zone Interaction: Location
- o intersection/interchange
- o shoulder/roadside
- o central reserve/ median
- o footway/bikeway
- o tramway

-Traffic Control Devices Employed (more than one item may be ticked)
- o standard type traffic signs
- o traffic signs with higher quality materials
- o traffic signs jointly used with blinkers
- o traffic marking
- o traffic lights
- o fluorescent retro reflective traffic signs
- o roll-up traffic signs
- o wet reflective pavement tapes
- o variable message signs (VMSs)
- o none of the above

-Other Road Equipment Used (more than one item may be ticked)
- o closure equipment (cones, guiding beacons, etc.)
- o warning equipment (warning light, flashing arrow, etc.)
- o guiding equipment
- o protective equipment (fence, safety barrier)
- o bearing equipment (foundation plate, post, stand)
- o road reflectors
- o crash-cushion- truck tyres
- o speed reducer in rubber-bumps
- o none of the above

-Miscellaneous Items Used (more than one item may be ticked)
- o flags and hand signalling devices
- o moving sign bridge and portable mould bridge
- o crash cushion of Truck Mounted Attenuator (TMA)
- o emergency car
- o retro reflective fluorescent clothing
- o none of the above
- o other__________________

-Enforcement/Publicity (more than one item may be ticked)
- o police presence
- o electronic devices, cameras
- o information in mass media
- o traffic information on radio
- o none of the above
- o other: __________

-Work zone Operation
- o in operation
- o not in operation
- o in process of being assembled/disassembled
- o abandoned

-Type of Work
- o construction
- o reconstruction
- o maintenance

Do you have any remarks about special features or characteristics of the work zone in question, which have not been included in the preceding description?
Perhaps there is an aspect that you feel substantially contributed to the accident that occurred there..

____

____

____

____

ACCIDENT CHARACTERISTICS

-Accident Severity
- o fatalities
- o severe personal injuries
- o slight personal injuries
- o property damage only

-Location in Work zone
- o announcement area
- o advance warning area
- o narrowing area
- o stabilizing area
- o transition area
- o buffer zone
- o activity area
- o termination area
- o run-off area

There are an enormous number of possible combinations of road users and object involved in a (work zone) traffic accident. This makes the registration complex and the analyses unwieldy. For that reason we will assume that all accidents to be considered involve at least one (automobile) driver. If (many) more drivers are involved, then assume that the one mentioned here is the one primarily at fault. If none of the (many possible) driver(s) is at fault, then just mention the driver that you find the most salient.

-Driver Age:
- o < 25 years
- o 25-34 years
- o 35-44 years
- o 45-54 years
- o 55-64 years
- o >64 years

-Driver Gender
- o Male
- o Female

-Amount of Driving Experience

- o more than ten years experience
- o two-ten years experience
- o less that two years experience
- o just got his/her license

-Driver Impairment/Mental State (more than one box may be ticked)

- o drugs
- o alcohol
- o fatigue
- o illness
- o absentmindedness
- o aggressiveness
- o lack of skill
- o unfamiliar with local situation
- o distracted
- o none of the above

-Unsafe Driving Acts

- o driving too fast
- o unwarranted lane changes
- o **not** yielding/stopping/obeying traffic signals
- o following too closely
- o sudden braking
- o showing intentions too late/failure to signal/misleading signal
- o passing too close to road-works
- o improper lane changes
- o loss of control of vehicle
- o other: ___________________
- o none of the above

-Manoeuvre 1: what was the driver doing just before the collision?

- o just driving straight ahead
- o overtaking
- o merging (at entrance/exit ramp)
- o merging (at lane narrowing/closure)
- o lane changing
- o turning/driving through intersection
- o braking
- o swerving
- o entering/leaving parking space
- o entered the wrong lane
- o other: ___________________

-Collision Partner: with whom or what did the driver collide with?

- o collided with another traffic vehicle (car, bus, lorry, van)
- o multiple vehicle accident
- o collided with pedestrian or bicyclist
- o no other object involved: just ran off road
- o collided with a stationary road-side object not involved in the work zone
- o collided with work zone debris
- o collided with work-zone hardware/equipment
- o collided with road worker or moving work zone vehicle

-Manoeuvre 2: what was the collision partner doing just before the collision?

- o not applicable
- o just driving/riding straight ahead
- o crossing the road
- o lying/waiting/standing/working on side of road
- o lying/waiting/standing/working on the road itself
- o overtaking
- o merging (at entrance/exit ramp)
- o merging (at lane narrowing/closure)
- o lane changing
- o turning/driving through intersection
- o braking
- o swerving
- o entering/leaving parking space
- o entered the wrong lane
- o other: ________________

-Orientation: at which angle was the collision partner oriented with respect to the driver?

- o not applicable
- o 0°, same direction
- o 90°, second collision partner came from right
- o 180°, opposite directions
- o 270°, second collision partner came from left

-CAUSE: What would you say was the single, most important, direct **cause** of the accident considered here? Please be brief.

____

Countermeasures

Which of the following countermeasure(s) would possibly have been most effective in preventing the accident that you just described? You must tick at least one box, but not more than three boxes.

- o general information/publicity campaigns/telematics/radio information systems
- o better and more enforcement/surveillance/video control/ higher fines
- o better education and training of road users and/or workers
- o quality assurance schemes/guidelines/checklists/comprehensive planning/inspections
- o better supervision of workers
- o lower speeds
- o restrictions on smoking and mobile phones in cars
- o better information about changes in geometry and smooth transitions in alignment
- o keeping same number of lanes by narrowing or using shoulder
- o better/clearer/more understandable signing/guidance/symbols
- o barriers/buffer zones/TMA/complete separation of work and traffic
- o variable message signs/traffic lights
- o better worker visibility
- o better work zone visibility
- o reduce distractions and visibility of work
- o better maintenance of equipment e.g., regular cleaning, site inspection, spare available, etc.
- o using good road markings with good reflectivity
- o other: ________________________

PERSONAL CHARACTERISTICS

Would you please fill in the following questions about yourself?

-Age: ______ years

-Country in which you work:

o	NL	o	GR
o	D	o	SI
o	GB	o	BE
o	SE	o	CZ
o	other		

-Employer

- o research institute/university
- o government
- o private sector
- o other ______________________

Finally, do you have any general thoughts or comments concerning this registration form, this specific project, or ARROWS in general?

____

Thank you for your time!

Appendix 9: Princals Analysis of Accident Forms

P R I N C A L S - VERSION 0.6
BY
DEPARTMENT OF DATA THEORY
UNIVERSITY OF LEIDEN, THE NETHERLANDS

Dimension	Eigenvalue
1	.1438
2	.1171
3	.0782

Variable: E.1ROADT

Type: Single Nominal   Missing: 0

Category:		Marginal Frequency	Quantification
1	motorway	55	-1.19
2	rur primary	28	-.29
3	rur second	29	.75
4	urban main	31	.36
5	urban local	25	1.63

Single Category Coordinates

Category	Dimension 1	2	3
1	1.01	.09	.03
2	.24	.02	.01
3	-.63	-.05	-.02
4	-.31	-.03	-.01
5	-1.38	-.12	-.04

Variable: E.2DAY

Type: Single Nominal   Missing: 0

Category:		Marginal Frequency	Quantification
1	sunday	25	-1.55
2	monday	19	.86
3	tuesday	25	1.12
4	wednesday	21	.74
5	thursday	21	.74
6	friday	26	-.04
7	saterday	31	-1.13

Single Category Coordinates

Category	Dimension 1	2	3
1	.37	-.62	-.20
2	-.21	.35	.11
3	-.27	.45	.15
4	-.18	.30	.10
5	-.18	.30	.10
6	.01	-.01	.00
7	.27	-.46	-.15

Variable: E.3TIM Time of Day

Type: Single Nominal Missing: 9

Category:		Marginal Frequency	Quantification
1	1:00-6:59	15	2.48
2	7:00-11:59	48	-.73
3	12:00-16:59	45	-.78
4	17:00-19:59	24	.52
5	20:00-24:59	27	.78

Single Category Coordinates

Category	Dimension 1	2	3
1	.34	-1.76	-.22
2	-.10	.52	.06
3	-.11	.55	.07
4	.07	-.37	-.05
5	.11	-.56	-.07

Variable: E.4MONTH Month

Type: Single Nominal Missing: 1

Category:		Marginal Frequency	Quantification
1	winter	23	1.00
2	spring	62	-.97
3	summer	36	-.56
4	fall	46	1.28

Single Category Coordinates

Category	Dimension 1	2	3
1	-.22	-.44	.28
2	.22	.43	-.27
3	.13	.25	-.16
4	-.29	-.57	.36

Variable: E.5ROAD

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1	straight section	93	-.47
2	curve	39	-.56
3	junction	14	1.62
4	T-junction	15	2.50
5	exit/entrance ramp	4	.38
6	other	3	1.24

Single Category Coordinates

Category	Dimension 1	2	3
1	.22	-.04	-.14
2	.26	-.04	-.16
3	-.75	.12	.48
4	-1.16	.19	.73
5	-.18	.03	.11
6	-.57	.09	.36

Variable: E.6WEATH

Type: Single Nominal Missing: 1

Category:		Marginal Frequency	Quantification
1	dry	104	-.75
2	rain	32	.70
3	mist	13	1.54
4	snow,hail	11	2.30
5	windy	7	.88

Single Category Coordinates

Category	Dimension 1	2	3
1	.21	.15	-.26
2	-.20	-.14	.24
3	-.44	-.31	.53
4	-.66	-.46	.79
5	-.25	-.18	.30

Variable: E.7SURFA Road Surface

Type: Single Nominal Missing: 1

Category:		Marginal Frequency	Quantification
1	dry	105	-.74
2	wet	47	1.05
3	snow,ice	12	2.20
4	other	3	-.44

Single Category Coordinates

Category	Dimension 1	2	3
1	.15	.16	-.28
2	-.21	-.22	.39
3	-.43	-.46	.82
4	.09	.09	-.16

Variable: E.8LIGHT Light Conditions

Type: Single Nominal Missing: 2

Category:		Marginal Frequency	Quantification
1	daylight	100	-.82
2	dark	43	1.45
3	dawn/dusk	23	.71

Single Category Coordinates

Category	Dimension 1	2	3
1	-.08	.52	-.09
2	.15	-.93	.17
3	.07	-.46	.08

Variable: E.9STREE Street Lighting

Type: Single Nominal Missing: 1

Category:		Marginal Frequency	Quantification
1	on	26	-.08
2	not on	61	-1.24
3	not present	80	.97

Single Category Coordinates

Category	Dimension 1	2	3
1	-.03	.03	.01
2	-.38	.51	.12
3	.30	-.40	-.09

Variable: E.10ROAD Type Road Surface

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1	bitumen/asphalt	142	-.24
2	concrete	11	-1.08
3	cobblestones/bricks	12	3.21
4	other	3	2.79

Single Category Coordinates

Category	Dimension 1	2	3
1	.10	.04	-.04
2	.44	.16	-.16
3	-1.30	-.47	.47
4	-1.13	-.41	.41

Variable: E.11SPEE Speed Limit

Type: Ordinal Missing: 0

Category:		Marginal Frequency	Quantification
1	<50 km/hr	27	-1.33
2	50 km/hr	27	-1.08
3	60-70 km/hr	35	-.35
4	80 km/hr	38	.62
5	>80 km/hr	41	1.30

Single Category Coordinates

Category	Dimension 1	2	3
1	-.90	.27	.32
2	-.73	.22	.26
3	-.24	.07	.09
4	.42	-.13	-.15
5	.88	-.27	-.31

Variable: E.12UNUS Unusual Situation

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1	ped/bicycle	16	-1.90
2	bridge	15	.72
3	tunnel	9	.28
4	exit/entrance	20	.99
5	bus/tram	3	-1.13
6	parking	5	-2.60
7	petrol station	5	.54
8	hill	11	-.50
9	narrow road	26	-.73
10	other	15	1.13
11	n.a.	43	.42

Single Category Coordinates

Category	Dimension 1	2	3
1	-1.05	.02	.08
2	.40	-.01	-.03
3	.16	.00	-.01
4	.55	-.01	-.04
5	-.62	.01	.05
6	-1.44	.03	.11
7	.30	-.01	-.02
8	-.28	.01	.02
9	-.40	.01	.03
10	.62	-.01	-.05
11	.23	.00	-.02

Variable: E.13ADMI Road Authorities

Type: Single Nominal Missing: 1

Category:		Marginal Frequency	Quantification
1	local	63	-1.18
2	regional	35	-.01
3	national	69	1.08

Single Category Coordinates

Category	Dimension 1	2	3
1	-.88	-.03	.00
2	-.01	.00	.00
3	.80	.03	.00

Variable: E.14TEMP Temporary Conditions

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1	other accident	4	.43
2	detour	21	-2.64
3	other	53	.33
4	n.a.	90	.40

Single Category Coordinates

Category	Dimension 1	2	3
1	-.02	.07	-.19
2	.12	-.42	1.15
3	-.01	.05	-.14
4	-.02	.06	-.18

Variable: E.15INTE Traffic Intensity

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1	very high	21	-.81
2	high	41	-1.03
3	moderate	47	-.22
4	low	32	.56
5	very low	27	1.91

Single Category Coordinates

Category	Dimension 1	2	3
1	.35	.48	.06
2	.44	.61	.07
3	.09	.13	.01
4	-.24	-.33	-.04
5	-.82	-1.13	-.13

Variable: E.16N_CA   Number of Carriageways

Type: Single Nominal   Missing: 0

Category:		Marginal Frequency	Quantification
1	1	84	-1.00
2	>= 2	84	1.00

Single Category Coordinates

Category	Dimension 1	2	3
1	-.68	-.19	-.04
2	.68	.18	.04

Variable: E.17LANE   Total number of Lanes

Type: Ordinal   Missing: 0

Category:	Marginal Frequency	Quantification
1	7	-2.18
2	93	-.68
3	3	.85
4	49	1.08
5	0	.00
6	16	1.43

Single Category Coordinates

Category	Dimension 1	2	3
1	-1.47	-.22	.05
2	-.46	-.07	.02
3	.57	.09	-.02
4	.73	.11	-.03
5	.00	.00	.00
6	.96	.14	-.03

Variable: D.10MAN Manoeuvre partner

Type: Single Nominal Missing: 3

Category:		Marginal Frequency	Quantification
1	n.a.	46	-1.30
2	driving straight ahe	48	.58
3	crossing road	7	-.46
4	at side of road	5	.04
5	on road itself	17	.64
6	overtaking	4	1.16
7	merging at ramp	4	1.77
8	merging at lane narr	4	.73
9	lane changing	0	.00
10	turning/driving at i	7	.69
11	braking	13	.86
12	swerving	1	1.63
13	parking space	1	.55
14	wrong lane	1	2.66
15	other	7	-1.79

Single Category Coordinates

Category	Dimension 1	2	3
1	-.13	-.86	-.34
2	.06	.38	.15
3	-.05	-.30	-.12
4	.00	.03	.01
5	.07	.42	.17
6	.12	.76	.30
7	.18	1.16	.46
8	.08	.48	.19
9	.00	.00	.00
10	.07	.45	.18
11	.09	.56	.22
12	.17	1.07	.43
13	.06	.36	.14
14	.27	1.75	.69
15	-.18	-1.18	-.47

Variable: D.11ORIE   Orientation

Type: Single Nominal   Missing: 2

Category:		Marginal Frequency	Quantification
1	n.a.	48	-1.55
2	same direction	70	.75
3	came from right	23	.12
4	opposite direction	19	.71
5	came from left	6	.77

Single Category Coordinates

Category	Dimension 1	2	3
1	-.17	-.95	-.40
2	.08	.46	.20
3	.01	.07	.03
4	.08	.44	.19
5	.08	.47	.20

Variable: D.1ACC   Accident Severity

Type: Single Nominal   Missing: 0

Category:		Marginal Frequency	Quantification
1	fatalities	19	-.97
2	severe personal inju	48	-1.30
3	slight personal inju	43	.63
4	property damage	58	.94

Single Category Coordinates

Category	Dimension 1	2	3
1	.43	-.11	-.22
2	.58	-.15	-.29
3	-.28	.07	.14
4	-.42	.11	.21

Variable: D.2LOC Location in Zone

Type: Single Nominal Missing: 2

Category:		Marginal Frequency	Quantification
1	announcement area	7	.28
2	advance warning area	12	.28
3	narrowing area	52	-1.07
4	stabilizing area	5	-1.53
5	transition area	22	-.01
6	buffer zone	7	-.70
7	activity area	51	.64
8	termination area	4	.48
9	run-off area	6	3.40

Single Category Coordinates

Category	Dimension 1	2	3
1	-.11	.01	.03
2	-.11	.01	.03
3	.43	-.02	-.10
4	.61	-.03	-.14
5	.00	.00	.00
6	.28	-.01	-.07
7	-.25	.01	.06
8	-.19	.01	.04
9	-1.35	.06	.32

Variable: D.3AGE Driver Age

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1	< 25	40	-.85
2	25-34	40	-.29
3	35-44	31	-.87
4	45-54	31	.73
5	55-64	18	1.94
6	> 64	8	1.88

Single Category Coordinates

Category	Dimension 1	2	3
1	.30	.11	-.18
2	.10	.04	-.06
3	.31	.11	-.19
4	-.26	-.09	.16
5	-.69	-.25	.42
6	-.67	-.25	.41

Variable: D.4GENDE Driver Gender

Type: Single Nominal Missing: 2

Category:		Marginal Frequency	Quantification
1	male	129	-.55
2	female	37	1.87

Single Category Coordinates

Category	Dimension 1	2	3
1	.07	-.07	-.17
2	-.23	.23	.56

Variable: D.5DRIVI Driver Experience

Type: Ordinal Missing: 1

Category:		Marginal Frequency	Quantification
1	>10 years	76	-1.10
2	2-10 years	63	.87
3	<2 years	24	.87
4	just got license	4	1.60

Single Category Coordinates

Category	Dimension 1	2	3
1	-.25	.00	.20
2	.20	.00	-.16
3	.20	.00	-.16
4	.37	.00	-.30

Variable: D.6AIMP Driver Impairment

Type: Single Nominal Missing: 1

Category:		Marginal Frequency	Quantification
1	drugs	1	-7.04
2	alcohol	15	-2.33
3	fatigue	17	-.35
4	illness	3	1.26
5	absentmindedness	22	-.09
6	agressiveness	28	.03
7	lack of skill	15	.09
8	unfamiliar with situ	32	.52
9	distracted	4	.67
10	none of the above	30	.80

Single Category Coordinates

Category	Dimension 1	2	3
1	1.62	-4.17	-1.18
2	.54	-1.38	-.39
3	.08	-.21	-.06
4	-.29	.75	.21
5	.02	-.05	-.02
6	-.01	.02	.00
7	-.02	.06	.02
8	-.12	.31	.09
9	-.15	.40	.11
10	-.18	.47	.13

Variable: D.6BIMP Drive Impairment II

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1		0	.00
2		1	-7.03
3		5	-4.21
4		0	.00
5		7	-.77
6		3	-1.12
7		10	-.45
8		19	-.20
9		16	.03
10		1	1.07
11	n.a.	106	.42

Single Category Coordinates

Category	Dimension 1	2	3
1	.00	.00	.00
2	1.31	-4.17	-1.62
3	.78	-2.50	-.97
4	.00	.00	.00
5	.14	-.46	-.18
6	.21	-.66	-.26
7	.08	-.27	-.10
8	.04	-.12	-.05
9	-.01	.02	.01
10	-.20	.64	.25
11	-.08	.25	.10

Variable: D.6CIMP Driver Impairment III

Type: Single Nominal Missing: 0

Category:	Marginal Frequency	Quantification
1	0	.00
2	0	.00
3	0	.00
4	0	.00
5	2	-7.48
6	1	-5.55
7	1	-.94
8	7	-1.31
9	7	-.73
10	0	.00
11 n.a.	150	.24

Single Category Coordinates

Category	Dimension 1	2	3
1	.00	.00	.00
2	.00	.00	.00
3	.00	.00	.00
4	.00	.00	.00
5	1.69	-3.56	-1.30
6	1.26	-2.64	-.96
7	.21	-.45	-.16
8	.30	-.62	-.23
9	.17	-.35	-.13
10	.00	.00	.00
11	-.05	.12	.04

Variable: D.7UNSAF   Unsafe Driving Acts

Type: Single Nominal   Missing: 0

Category:		Marginal Frequency	Quantification
1	driving too fast	43	.04
2	unwarranted lane cha	7	-1.81
3	not yielding, etc.	24	.28
4	following too closel	13	-1.08
5	sudden braking	12	.44
6	incorrect signalling	13	-.89
7	passing too close	19	.92
8	improper lane change	11	-2.00
9	loss of control	11	1.41
10	other	6	-.52
11	none of the above	9	1.87

Single Category Coordinates

Category	Dimension 1	2	3
1	-.01	-.01	.00
2	.59	.63	.16
3	-.09	-.10	-.02
4	.36	.38	.09
5	-.15	-.15	-.04
6	.29	.31	.08
7	-.30	-.32	-.08
8	.65	.69	.17
9	-.46	-.49	-.12
10	.17	.18	.05
11	-.61	-.65	-.16

Variable: D.8MAN   Manoevre Driver

Type: Single Nominal   Missing: 0

Category:		Marginal Frequency	Quantification
1	driving straight ahe	75	.20
2	overtaking	14	-1.77
3	merging at ramp	3	-3.32
4	mergin at lane narro	14	-1.26
5	lane changing	17	-.02
6	turning/driving at i	7	2.48
7	braking	23	.27
8	swerving	7	1.25
9	at parking space	0	.00
10	wrong lane	6	.18
11	other	2	2.21

Single Category Coordinates

Category	Dimension 1	2	3
1	-.08	-.05	.00
2	.68	.44	.01
3	1.27	.82	.03
4	.48	.31	.01
5	.01	.00	.00
6	-.95	-.61	-.02
7	-.10	-.07	.00
8	-.48	-.31	-.01
9	.00	.00	.00
10	-.07	-.04	.00
11	-.85	-.54	-.02

Variable: D.9COLL Collision Partner

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1	other motorized vehi	68	-.77
2	multiple vehicles	10	-1.35
3	pedestrian/bicyclist	9	.84
4	ran off road	10	1.69
5	stationary non-wz-re	13	1.52
6	workzone debris	5	2.32
7	workzone hardware	30	.66
8	road worker or vehic	23	-.44

Single Category Coordinates

Category	Dimension 1	2	3
1	.17	.50	.18
2	.29	.89	.32
3	-.18	-.55	-.20
4	-.37	-1.11	-.40
5	-.33	-1.00	-.36
6	-.50	-1.52	-.55
7	-.14	-.43	-.16
8	.10	.29	.10

Variable: T.10TYPE   Type of Work

Type: Single Nominal   Missing: 2

Category:		Marginal Frequency	Quantification
1	construction	20	-1.09
2	re-construction	74	-.81
3	maintenance	72	1.15

Single Category Coordinates

Category	Dimension 1	2	3
1	.21	-.36	.54
2	.16	-.27	.40
3	-.22	.38	-.57

Variable: T.1DURAT   Duration of Works

Type: Single Nominal   Missing: 1

Category:		Marginal Frequency	Quantification
1	long-term	74	-1.06
2	short term stationar	57	.52
3	short term mobile	36	1.39

Single Category Coordinates

Category	Dimension 1	2	3
1	.32	-.45	.54
2	-.15	.22	-.26
3	-.42	.59	-.70

Variable: T.2SIZE   Size of Works

Type: Single Nominal   Missing: 0

Category:		Marginal Frequency	Quantification
1	quite large	35	-1.40
2	moderate size	44	-.74
3	relatively small	89	.92

Single Category Coordinates

Category	Dimension 1	2	3
1	.64	-.22	.39
2	.34	-.12	.21
3	-.42	.15	-.26

Variable: T.3LAYOU Layout

Type: Single Nominal Missing: 4

Category:		Marginal Frequency	Quantification
1	lane narrowing	57	-.30
2	lane closure	62	-.77
3	diversion/detour	18	2.32
4	contraflow/crossover	14	.84
5	alternate one-way tr	13	1.23

Single Category Coordinates

Category	Dimension 1	2	3
1	.06	.07	-.17
2	.16	.18	-.43
3	-.48	-.53	1.31
4	-.17	-.19	.47
5	-.26	-.28	.70

Variable: T.4LOCA Location of Works

Type: Single Nominal Missing: 9

Category:		Marginal Frequency	Quantification
1	intersection/interch	47	-1.43
2	shoulder/roadside	88	.83
3	central reserve/medi	18	-.06
4	footway/bikeway/tram	6	-1.41

Single Category Coordinates

Category	Dimension 1	2	3
1	-.43	.22	.54
2	.25	-.13	-.31
3	-.02	.01	.02
4	-.43	.22	.53

Variable: T.5ACON   Control Devices I

Type: Single Nominal   Missing: 0

Category:		Marginal Frequency	Quantification
1	standard traffic sig	117	.26
2	quality traffic sign	19	-2.20
3	traffic signs with b	12	-.93
4	traffic markings	2	-2.13
5	traffic lights	1	3.74
6	fl. retro-reflective	2	.23
7	roll-up traffic sign	0	.00
8	pavement tapes	0	.00
9	variable message sig	0	.00
10	none of the above	15	1.50

Single Category Coordinates

Category	Dimension 1	2	3
1	-.14	.00	-.07
2	1.18	-.02	.62
3	.50	-.01	.26
4	1.14	-.02	.60
5	-2.00	.03	-1.06
6	-.12	.00	-.07
7	.00	.00	.00
8	.00	.00	.00
9	.00	.00	.00
10	-.80	.01	-.43

Variable: T.5BCON   Control Devices II

Type: Single Nominal   Missing: 1

Category:		Marginal Frequency	Quantification
1		0	.00
2		2	-2.04
3		36	-1.17
4		16	-1.77
5		10	.86
6		8	-.07
7		1	-.95
8		0	.00
9		1	.66
10		0	.00
11	n.a.	93	.74

Single Category Coordinates

Category	Dimension 1	2	3
1	.00	.00	.00
2	.81	-.51	1.10
3	.46	-.29	.63
4	.70	-.44	.95
5	-.34	.22	-.46
6	.03	-.02	.04
7	.38	-.24	.51
8	.00	.00	.00
9	-.26	.17	-.36
10	.00	.00	.00
11	-.29	.18	-.40

Variable: T.5CCON Control Devices III

Type: Single Nominal Missing: 0

Category:	Marginal Frequency	Quantification
1	0	.00
2	0	.00
3	1	-3.50
4	1	-3.44
5	5	-2.79
6	9	-2.69
7	0	.00
8	1	-1.95
9	3	-2.29
10	0	.00
11 n.a.	148	.37

Single Category Coordinates

Category	Dimension 1	2	3
1	.00	.00	.00
2	.00	.00	.00
3	1.43	-.75	.87
4	1.40	-.74	.86
5	1.14	-.60	.70
6	1.10	-.58	.67
7	.00	.00	.00
8	.79	-.42	.49
9	.93	-.49	.57
10	.00	.00	.00
11	-.15	.08	-.09

Variable: T.6AEQU Road Equipment I

Type: Single Nominal Missing: 3

Category:		Marginal Frequency	Quantification
1	closure equip.	89	-.38
2	warning equip.	30	-.88
3	guiding equip.	2	-.50
4	protective equip.	13	-.09
5	bearing equip.	0	.00
6	road reflecters	1	-3.59
7	crash cushions	1	1.46
8	speed reducer	0	.00
9	none of the above	29	2.01

Single Category Coordinates

Category	Dimension 1	2	3
1	.13	-.01	.09
2	.30	-.02	.20
3	.17	-.01	.12
4	.03	.00	.02
5	.00	.00	.00
6	1.24	-.08	.83
7	-.50	.03	-.34
8	.00	.00	.00
9	-.69	.04	-.47

Variable: T.6BEQU Road Equipment II

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1		0	.00
2		24	-1.31
3		21	-.78
4		12	-1.82
5		3	-.78
6		0	.00
7		3	-2.10
8		0	.00
9		1	1.47
10		0	.00
11	n.a.	104	.74

Single Category Coordinates

Category	Dimension 1	2	3
1	.00	.00	.00
2	.61	-.15	.47
3	.36	-.09	.28
4	.85	-.21	.65
5	.36	-.09	.28
6	.00	.00	.00
7	.97	-.24	.75
8	.00	.00	.00
9	-.68	.17	-.52
10	.00	.00	.00
11	-.34	.08	-.27

Variable: T.7AMIS Miscellaneous Equipment

Type: Single Nominal Missing: 5

Category:		Marginal Frequency	Quantification
1	flags and hand devic	10	-1.32
2	moving sign bridge	1	-3.47
3	Truck Mounted Attenu	5	-3.05
4	emergency car	2	-3.10
5	retro-refl. clothing	38	-.75
6	none of the above	105	.69
7	other	2	1.07

Single Category Coordinates

Category	Dimension 1	2	3
1	.25	.46	-.22
2	.65	1.20	-.59
3	.57	1.06	-.52
4	.59	1.08	-.53
5	.14	.26	-.13
6	-.13	-.24	.12
7	-.20	-.37	.18

Variable: T.7BMIS Miscellaneous Equipment II

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1		0	.00
2		0	.00
3		0	.00
4		1	-5.80
5		2	-6.85
6		0	.00
7		1	-6.04
8		0	.00
9		0	.00
10		0	.00
11	n.a.	164	.16

Single Category Coordinates

Category	Dimension 1	2	3
1	.00	.00	.00
2	.00	.00	.00
3	.00	.00	.00
4	.88	1.02	-1.07
5	1.04	1.21	-1.26
6	.00	.00	.00
7	.92	1.07	-1.11
8	.00	.00	.00
9	.00	.00	.00
10	.00	.00	.00
11	-.02	-.03	.03

Variable: T.8AENF Enforcement and Publicity I

Type: Single Nominal Missing: 1

Category:		Marginal Frequency	Quantification
1	police presence	5	-.81
2	electronic devices,	0	.00
3	mass media	39	-1.31
4	radio traffic info	23	-.81
5	none of the above	97	.83
6	other	3	-2.34

Single Category Coordinates

Category	Dimension 1	2	3
1	.22	.05	.42
2	.00	.00	.00
3	.35	.09	.68
4	.22	.05	.42
5	-.22	-.05	-.43
6	.63	.15	1.22

Variable: T.8BENF Enforcement and Publicity II

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1		0	.00
2		0	.00
3		0	.00
4		22	-2.57
5		0	.00
6		1	1.36
7		0	.00
8		0	.00
9		0	.00
10		0	.00
11	n.a.	145	.38

Single Category Coordinates

Category	Dimension 1	2	3
1	.00	.00	.00
2	.00	.00	.00
3	.00	.00	.00
4	.67	.41	.85
5	.00	.00	.00
6	-.35	-.22	-.45
7	.00	.00	.00
8	.00	.00	.00
9	.00	.00	.00
10	.00	.00	.00
11	-.10	-.06	-.13

Variable: T.9WORK Zone Operation

Type: Single Nominal Missing: 0

Category:		Marginal Frequency	Quantification
1	in operation	104	-.65
2	not in operation	48	1.56
3	assmbled/disassemble	8	-.93
4	abandoned	8	.04

Single Category Coordinates

Category	Dimension 1	2	3
1	-.03	.41	-.07
2	.08	-.98	.17
3	-.05	.59	-.10
4	.00	-.02	.00

Variable: V.1ACOU Countermeasures I

Type: Single Nominal Missing: 3

Category:		Marginal Frequency	Quantification
1	better general info	14	-1.59
2	enforcement	42	-.51
3	education/training	34	-.49
4	quality assurance/ch	15	1.20
5	worker supervision	5	.57
6	lower speeds	11	.64
7	less smoking/mobile	2	-.55
8	specfic geometry inf	13	.09
9	keep same # lanes	4	-.26
10	better signs/symbols	10	1.21
11	buffer/barriers	4	-.37
12	VMS/traffic lights	1	3.27
13	worker visibility	1	1.19
14	workzone visibility	4	1.78
15	less distractions	0	.00
16	workzone maintenance	1	6.67
17	good road markings	0	.00
18	other	4	-.24
19		0	.00
20		0	.00

Single Category Coordinates

Category	Dimension 1	2	3
1	.64	.36	-.33
2	.20	.11	-.11
3	.20	.11	-.10
4	-.48	-.27	.25
5	-.23	-.13	.12
6	-.26	-.14	.13
7	.22	.12	-.11
8	-.04	-.02	.02
9	.10	.06	-.05
10	-.49	-.27	.25
11	.15	.08	-.08
12	-1.31	-.73	.68
13	-.48	-.27	.25
14	-.72	-.40	.37
15	.00	.00	.00
16	-2.69	-1.50	1.38
17	.00	.00	.00
18	.10	.05	-.05
19	.00	.00	.00
20	.00	.00	.00

Variable: V.1BCOU   Countermeasures II

Type: Single Nominal   Missing: 0

Category:	Marginal Frequency	Quantification
1	0	.00
2	6	-.64
3	15	-2.03
4	7	.76
5	7	.69
6	21	-.52
7	1	-2.08
8	7	.33
9	4	.16
10	13	-.69
11	6	-.54
12	12	.26
13	1	2.34
14	18	-.36
15	2	2.53
16	4	2.28
17	2	-.42
18	3	-.62
19	0	.00
20 n.a.	39	.93

Single Category Coordinates

Category	Dimension 1	2	3
1	.00	.00	.00
2	.29	-.09	-.24
3	.90	-.29	-.77
4	-.34	.11	.29
5	-.31	.10	.26
6	.23	-.07	-.20
7	.92	-.30	-.78
8	-.15	.05	.13
9	-.07	.02	.06
10	.31	-.10	-.26
11	.24	-.08	-.20
12	-.12	.04	.10
13	-1.04	.33	.88
14	.16	-.05	-.13
15	-1.12	.36	.95
16	-1.01	.33	.86
17	.19	-.06	-.16
18	.27	-.09	-.23
19	.00	.00	.00
20	-.41	.13	.35

Variable: V.1CCOU Countermeasures III

Type: Single Nominal Missing: 0

Category:	Marginal Frequency	Quantification
1	0	.00
2	0	.00
3	2	-.13
4	2	1.43
5	3	-.54
6	7	-.77
7	1	3.32
8	1	4.81
9	1	.93
10	6	.04
11	6	.50
12	7	-.60
13	0	.00
14	19	-2.01
15	5	1.99
16	1	-2.77
17	4	-.98
18	5	.91
19	0	.00
20 n.a.	98	.27

Single Category Coordinates

Category	Dimension 1	2	3
1	.00	.00	.00
2	.00	.00	.00
3	-.03	-.03	-.05
4	.33	.31	.59
5	-.13	-.12	-.22
6	-.18	-.17	-.32
7	.78	.71	1.37
8	1.13	1.03	1.98
9	.22	.20	.38
10	.01	.01	.02
11	.12	.11	.21
12	-.14	-.13	-.25
13	.00	.00	.00
14	-.47	-.43	-.83
15	.47	.43	.82
16	-.65	-.60	-1.14
17	-.23	-.21	-.40
18	.21	.19	.37
19	.00	.00	.00
20	.06	.06	.11

Summary of Analysis

Multiple Fit

Variable	Row Sums	Dimension 1	2	3
E.1ROADT	.802	.710	.070	.023
E.2DAY	.282	.075	.163	.044
E.3TIM	.556	.025	.504	.026
E.4MONTH	.407	.120	.205	.082
E.5ROAD	.463	.235	.113	.115
E.6WEATH	.262	.092	.050	.121
E.7SURFA	.256	.062	.052	.142
E.8LIGHT	.436	.011	.411	.013
E.9STREE	.322	.103	.179	.040
E.10ROAD	.225	.164	.032	.028
E.11SPEE	.586	.464	.048	.074
E.12UNUS	.401	.307	.036	.058
E.13ADMI	.570	.552	.002	.016
E.14TEMP	.273	.045	.036	.192
E.15INTE	.620	.214	.369	.037
E.16N_CA	.500	.464	.034	.002
E.17LANE	.518	.456	.034	.027
D.10MAN	.684	.111	.445	.129
D.11ORIE	.488	.032	.376	.081
D.1ACC	.294	.199	.030	.065
D.2LOC	.267	.159	.061	.047
D.3AGE	.259	.134	.042	.083
D.4GENDE	.120	.015	.015	.090
D.5DRIVI	.129	.077	.009	.044
D.6AIMP	.671	.166	.378	.127
D.6BIMP	.551	.119	.365	.067
D.6CIMP	.359	.083	.234	.042
D.7UNSAF	.399	.150	.157	.091
D.8MAN	.314	.169	.114	.030
D.9COLL	.688	.135	.444	.109
T.10TYPE	.397	.037	.112	.248
T.1DURAT	.529	.092	.182	.255
T.2SIZE	.326	.212	.026	.089
T.3LAYOU	.525	.137	.056	.332
T.4LOCA	.290	.106	.040	.145
T.5ACON	.431	.293	.036	.102
T.5BCON	.582	.195	.076	.312
T.5CCON	.374	.174	.110	.089
T.6AEQU	.269	.139	.039	.092
T.6BEQU	.427	.236	.029	.161
T.7AMIS	.272	.067	.130	.075
T.7BMIS	.091	.024	.032	.035
T.8AENF	.467	.152	.022	.293
T.8BENF	.207	.068	.029	.110
T.9WORK	.459	.040	.399	.021
V.1ACOU	.403	.187	.115	.102
V.1BCOU	.562	.260	.087	.215
V.1CCOU	.443	.129	.123	.191
Mean:	.412	.171	.139	.102

Single Fit

Variable	Row Sums	Dimension 1	2	3
E.1ROADT	.715	.709	.005	.001
E.2DAY	.235	.057	.161	.017
E.3TIM	.531	.019	.504	.008
E.4MONTH	.323	.050	.195	.077
E.5ROAD	.307	.215	.006	.086
E.6WEATH	.239	.082	.040	.118
E.7SURFA	.223	.039	.044	.140
E.8LIGHT	.435	.011	.411	.013
E.9STREE	.272	.095	.168	.009
E.10ROAD	.207	.164	.022	.021
E.11SPEE	.560	.460	.042	.058
E.12UNUS	.309	.307	.000	.002
E.13ADMI	.553	.552	.001	.000
E.14TEMP	.217	.002	.026	.189
E.15INTE	.538	.185	.348	.005
E.16N_CA	.500	.464	.034	.002
E.17LANE	.467	.456	.010	.001
D.10MAN	.511	.011	.433	.068
D.11ORIE	.456	.012	.375	.068
D.1ACC	.261	.198	.013	.050
D.2LOC	.166	.157	.000	.009
D.3AGE	.191	.127	.017	.047
D.4GENDE	.120	.015	.015	.090
D.5DRIVI	.088	.053	.000	.035
D.6AIMP	.431	.053	.350	.028
D.6BIMP	.440	.035	.353	.053
D.6CIMP	.308	.051	.227	.030
D.7UNSAF	.235	.107	.120	.007
D.8MAN	.207	.147	.060	.000
D.9COLL	.532	.047	.429	.056
T.10TYPE	.395	.037	.111	.247
T.1DURAT	.525	.089	.181	.255
T.2SIZE	.312	.208	.026	.078
T.3LAYOU	.416	.043	.053	.320
T.4LOCA	.258	.091	.024	.142
T.5ACON	.366	.286	.000	.080
T.5BCON	.507	.156	.063	.289
T.5CCON	.274	.166	.046	.062
T.6AEQU	.174	.120	.000	.054
T.6BEQU	.356	.215	.013	.128
T.7AMIS	.185	.036	.120	.029
T.7BMIS	.088	.023	.031	.034
T.8AENF	.348	.072	.004	.271
T.8BENF	.203	.068	.026	.110
T.9WORK	.412	.002	.398	.012
V.1ACOU	.255	.162	.050	.043
V.1BCOU	.360	.198	.021	.142
V.1CCOU	.271	.055	.046	.170
Mean:	.339	.144	.117	.078

Component Loadings

Variable	Dimension 1	2	3
E.1ROADT	-.842	-.072	-.024
E.2DAY	-.239	.402	.130
E.3TIM	.137	-.710	-.087
E.4MONTH	-.225	-.442	.278
E.5ROAD	-.463	.076	.294
E.6WEATH	-.286	-.199	.344
E.7SURFA	-.197	-.211	.374
E.8LIGHT	.104	-.641	.115
E.9STREE	.308	-.410	-.093
E.10ROAD	-.405	-.147	.147
E.11SPEE	.678	-.205	-.241
E.12UNUS	.554	-.010	-.042
E.13ADMI	.743	.029	.002
E.14TEMP	-.045	.160	-.435
E.15INTE	-.430	-.590	-.069
E.16N_CA	.681	.185	.041
E.17LANE	.675	.101	-.024
D.10MAN	.103	.658	.261
D.11ORIE	.110	.613	.261
D.1ACC	-.445	.115	.224
D.2LOC	-.396	.018	.093
D.3AGE	-.356	-.131	.217
D.4GENDE	-.122	.121	.300
D.5DRIVI	.231	-.002	-.186
D.6AIMP	-.230	.592	.168
D.6BIMP	-.186	.594	.230
D.6CIMP	-.226	.476	.174
D.7UNSAF	-.328	-.346	-.086
D.8MAN	-.383	-.245	-.008
D.9COLL	-.217	-.655	-.236
T.10TYPE	-.192	.334	-.497
T.1DURAT	-.299	.426	-.505
T.2SIZE	-.456	.160	-.280
T.3LAYOU	-.208	-.229	.566
T.4LOCA	.302	-.156	-.377
T.5ACON	-.535	.008	-.283
T.5BCON	-.395	.250	-.537
T.5CCON	-.407	.214	-.250
T.6AEQU	-.346	.022	-.232
T.6BEQU	-.464	.113	-.357
T.7AMIS	-.189	-.347	.171
T.7BMIS	-.152	-.176	.184
T.8AENF	-.269	-.065	-.521
T.8BENF	-.260	-.161	-.331
T.9WORK	.049	-.631	.109
V.1ACOU	-.402	-.224	.207
V.1BCOU	-.445	.143	.377
V.1CCOU	.234	.215	.412

Iteration Number	Total Fit	Total Loss	Multiple Loss	Single Loss
18	.3392	2.6608	2.5884	.0724

No correlations were calculated due to the missing items in the data matrix.

REFERENCES

i. Chapter 1

ARROWS Deliverable 1 (May 1997). Road work zone typology, safety measures, standards and practices. National Technical University of Athens, Department of Transportation Planning and Engineering, Greece.

ARROWS Deliverable 2 (October 1997). Road work zone behavioural studies, accident studies and research methods. National Technical University of Athens, Department of Transportation Planning and Engineering, Greece.

ARROWS Deliverable 3 (February 1998). ARROWS workshop / Synthesis of improved sets of safety measures for road work zones. National Technical University of Athens, Department of Transportation Planning and Engineering, Greece.

Part VI of the Manual on Uniform Traffic Control Devices (MUTCD), U.S. Department of Transportation Federal Highway Administration, 1995.

'Veilig werken aan de Weg', Dutch guidelines for Road Works, 1998.

ii. Chapter 2

Barney, G.O., 1982, *The Global 2000 Report to the President. A report prepared by the Council on Environmental Quality and the Department of State*. New York: Penguin.

Caluwe, L.de, Geurts, J., Buis, D., & Stoppelenburg, A., 1996. *Gaming: organisatieverandering met spelsimulaties*. The Hague: Delwel/ Twijnstra Gudde Amersfoort.

Carroll, J.M. (ed.), (1995), *Scenario-based design: Envisioning work and technology in system development*. New York: Wiley.

Coe, G., 1997, *Accident Causation Coding Pilot*, handout at ARROWS Workshop, Athens, Greece, November, 1997.

Gifi, A. *Non-linear multivariate analysis*. Wiley, New York, 1990.

Godet, M., 1987, *Scenarios and Strategic Management*, London: Butterworths.

Gundy, C.M., 1990, *A traffic accident typology*, Institute for Road Safety Research SWOV, Leidschendam, report R-90-48.

Gundy, C.M., 1998, *Road Work Zone Accident Studies: ARROWS task 2.2 internal report.* Leidschendam, The Netherlands: Institute for Road Safety Research SWOV R-98-17.

Gundy, C.M., Verkaik, R., & Groot, I.M. de (1997). *Cognitive organisation of roadway scenes III*. Institute for Road Safety Research SWOV, Leidschendam, report R-97-27.

Gundy, C.M. (in preparation) *The Application of Psychological Models to the Recognition and Classification of Road Categories by Road Users*. Institute for Road Safety Research SWOV, Leidschendam.

Heijden, K. van der, 1996, *Scenarios: the art of strategic conversation*. New York: John Wiley& Sons.

Immers, L.H., Prak, P., & Reijs, Th.A.M., 1995, *Behoeftebepaling verkeersongevallengegevens*. TNO Beleidstudies en Advies, TNO-report P95-012.sam.

Kars, V. 1997, *Take good CARE: de bruikbaarheid van de CARE-database voor beleid en onderzoek,* Institute for Road Safety Research SWOV, Leidschendam, unpublished internal report.

Noordzij, P.C., 1995, *Behoefte aan gegevens over verkeersongevallen*, Institute for Road Safety Research SWOV, Leidschendam, report R-95-71.

Poppe, F., 1995, *Nederlandse ongevallengegevens in international perspectief*. Institute for Road Safety Research SWOV, Leidschendam, report A-95-28.

Rumelhart, D.E., Smolensky, P., McClelland, J.L., and Hintron, G.E., (1988), Chapter 14: Schemata and Sequential Thought Processes in PDP Models, *Parallel Distributed Processing: Explorations in the microstructure of cognition. Volume 2: Psychological and Biological Models*. London: MIT Press.

Schwartz, P., 1991, *The art of the long view*. New York: Doubleday.

iii. Chapter 3

ARROWS Deliverable 1 (May 1997). Road work zone typology, safety measures, standards and practices. National Technical University of Athens, Department of Transportation Planning and Engineering, Greece.

ARROWS Deliverable 3 (February 1998). ARROWS workshop / Synthesis of improved sets of safety measures for road work zones. National Technical University of Athens, Department of Transportation Planning and Engineering, Greece.

Traffic Signs Manual Chapter 8, Traffic Safety measures and Signs for Road Works and Temporary Situations, Department of Transport, 1991 (UK)

Part VI of the Manual on Uniform Traffic Control Devices (MUTCD), U.S. Department of Transportation Federal Highway Administration, 1995.

Traffic Management and Safety at Highway work zones, OECD, 1989.

FIGURES 4 to 26