

# **TOWARDS SAFER ROADS AND STREETS USING AI AND ENGINEERING**

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## **ABSTRACT**

This paper briefly outlines *expert systems* and in particular the development of a software package, utilising artificial intelligence technology, that will determine street junction treatment and control. The paper then discusses New Zealand's road safety statistics over recent years and compares them with similarly motorised countries. A significant proportion of accidents in New Zealand occur at junctions, consequently any initiatives that can be taken to reduce accidents at junctions has major social and economic benefits and incentives.

This *expert system* will determine the appropriate form of treatment and control from the four main junction categories, taking into account safety, capacity and other important factors. It then attempts to determine the most appropriate form within these category options - this requires a higher and less well defined level of evaluation. In some cases, the recommendations given for the junction treatment and control will be dependent upon further input.

The *expert system* has the potential to save considerable professional time and effort. More importantly, it is expected to contribute towards consistent and more appropriate decision making. Determining the appropriate form of junction control and design treatment, is often the work of relatively inexperienced personnel. Hence, considerable benefits were envisaged from developing an *expert systems* software package for producing safer roads and streets.

## 1.0 INTRODUCTION

### 1.1 Decision Making in the Design of Street Junctions

The safety and efficiency characteristics of the road network depend largely on the operation of the junctions (or intersections, as they are usually referred to in New Zealand). This applies particularly in the urban and urban fringe areas. It is at junctions that the majority of vehicle and pedestrian conflicts occur, manifesting in delays and accidents. Therefore, it is imperative that the most appropriate decisions of junction type, design and control are made when junction improvements or new construction are being programmed.

Determining the appropriate form of junction control and therefore the safest design treatment, is often the work of relatively inexperienced personnel. Hence, considerable benefits were envisaged from developing an *expert systems* software package to this area of professional expertise.

## 2.0 AI AND EXPERT SYSTEMS

### 2.1 Historical Background

*Expert systems* technology is a means by which knowledge can be effectively stored and retrieved and therefore managed. *Expert systems* originated from scientific research coined "*Artificial Intelligence*" (*AI*) borne in the early 1960's.

In the late 1970's with the development of relatively cheap microelectronics technology and the emergence of a new generation of faster and more powerful computers, researchers and businesses began to see the potential applications of *AI*. From the initial all encompassing field of *AI* three relatively independent research areas emerged being :

- **Natural Language Processing** : computer programs that can read, speak, or understand language as people use it in everyday conversation.
- **Smart Robotics** : especially concerned with how to develop visual and tactile programs that will allow robots to observe the ongoing changes that take place as they move around the environment.
- **Expert Systems** (Knowledge Based Systems) : developing programs that use symbolic knowledge to simulate the behaviour of human experts.

The first twenty five years of *AI* had a quiet life as the "*exotic subspecialty of computer science studying intelligence and performing experiments on how to make computers intelligent*", Feigenbaum et al [1]. During this time *AI* was mainly researched in America and was supported by the United States Defense Department. However, in 1981, "*the quiet obscurity of AI was transformed into highly visible frenzy by the dramatic announcement by Japan's Ministry of International Trade and Industry (MITI) of the establishment of a program of advanced research and development in AI, a project the Ministry named Fifth Generation Computer Systems (FGCS)*", Feigenbaum et al [1]. This FGCS project was initiated to develop computer hardware and software for systems the Japanese

generically called, Knowledge Information Processing Systems (KIPS), the equivalent of the American term Knowledge Processing.

## 2.2 What are Expert Systems?

*Expert systems* or often called *Knowledge based systems (KBS)* are a relatively new generation of computer programs that are used to solve specific problems in a similar fashion to human specialists. Compared to conventional programs they are very modular, can process information which may be incomplete or subject to uncertainty, and they apply heuristic reasoning or "rules of thumb" in order to develop conclusions.

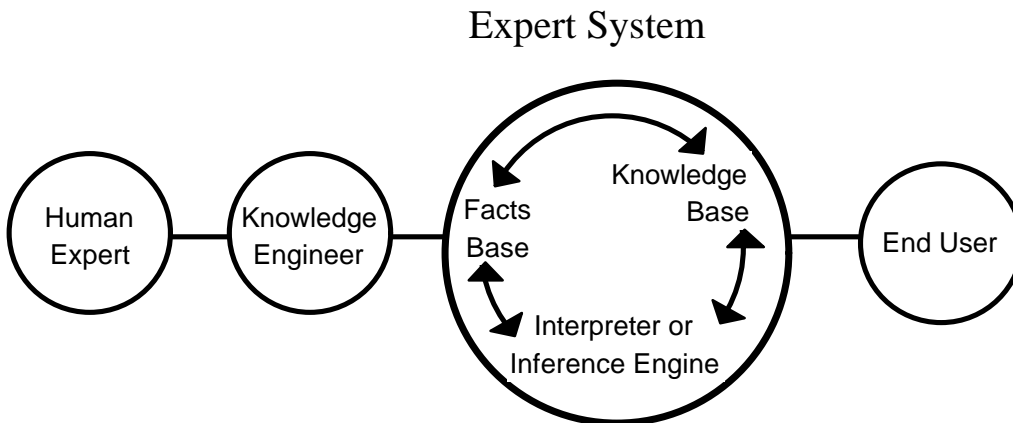
Edward A. Feigenbaum of Stanford University states "*an Expert System is a computer program that uses knowledge and reasoning techniques to solve problems normally requiring the abilities of human experts*", Feigenbaum [2]. However, Ignizio [3] provides a better definition of an *expert system* as a "*computer program that exhibits, within a specific domain, a degree of expertise in problem solving that is comparable to that of a human expert*" (emphasis added).

## 2.3 Expert Systems Architecture, Shells and Knowledge Engineers

Knowledge in the form of numerous facts is not regarded as intelligence but the ability to use relationships between these facts to infer further knowledge can be considered as intelligence. *Expert systems* is therefore an attempt to develop a software program to be able to infer further knowledge and conclusions from facts that are supplied by the user, and consequently the computer program can act "*like a human expert*" and be able to solve specific problems in a particular domain.

It is at this point where *expert systems* programs depart from the traditional *procedural or algorithmic methods*. *Expert systems* use *declarative or symbolic knowledge programming* which is less concerned with algorithms that exploit the knowledge by specifying WHAT is known and HOW it is to be manipulated and rather only specify WHAT is known. The knowledge is therefore separated from inference and control and is much easier to understand and to subsequently modify.

**Figure 1** shows what has become the standard architecture and the corresponding definitions for *expert systems* Bonnet et al [4].



### Figure 1 : Basic Architecture of an expert system.

**The Facts Base** : This comprises the permanent facts of the field to which the problem belongs, together with the special facts concerning the particular problem that has to be solved (can be known as the database).

**The Knowledge Base** : This consists of rules, which usually enable deductions to be made from the given facts, therefore adding new facts to the base.

**The Inference Engine (or Interpreter)** : This uses the knowledge base to reason through the problem, given the contents of the facts base.

**Knowledge Engineer** : The person responsible for placing the knowledge into the *expert system's* knowledge base by means of an *expert system shell* \* (see below). The knowledge engineer is also the interface between the *human expert* and the *expert system*.

**The User** : This is the person for whom the *expert system* is designed for as a decision-making tool as a consultant.

\* **Expert System Shells (or interface)** : Rule based computer software that can be used to build *expert system* applications. They are designed specifically to enable *expert system* developers to build applications rapidly and deliver them as finished systems.

## 2.4 Specific Benefits in Developing an Expert System

Due to the fact that computers can store vast amounts of information both easily and now very cheaply, *expert systems* can be developed to store more knowledge and facts than any single human expert. Retrieval can be guaranteed and the knowledge is always accessible thus relieving the dependency on the human expert.

Many additional benefits flow from the use of *expert systems* such as:

### Accessibility

- makes knowledge easily and permanently available
- allows knowledge to be easily changed or added to.

### Consistency

- establishes objective and repeatable decision paths
- allows the reasoning path to be audited and improved.

### Productivity

- improves performance in the making and delivery of decisions
- frees experts for further specialisation
- creates solutions faster than conventional development program tools.

Because of the considerable benefits, there are an increasing number of developments using *expert systems* to improve road safety, Bryson et al [5], Cook et al [6], Ou et al [7], Sayed et al [8], Seneviratne [9], Zhou, H. [10] and Zhou, W. [11].

## 3.0 ROAD SAFETY IN NEW ZEALAND

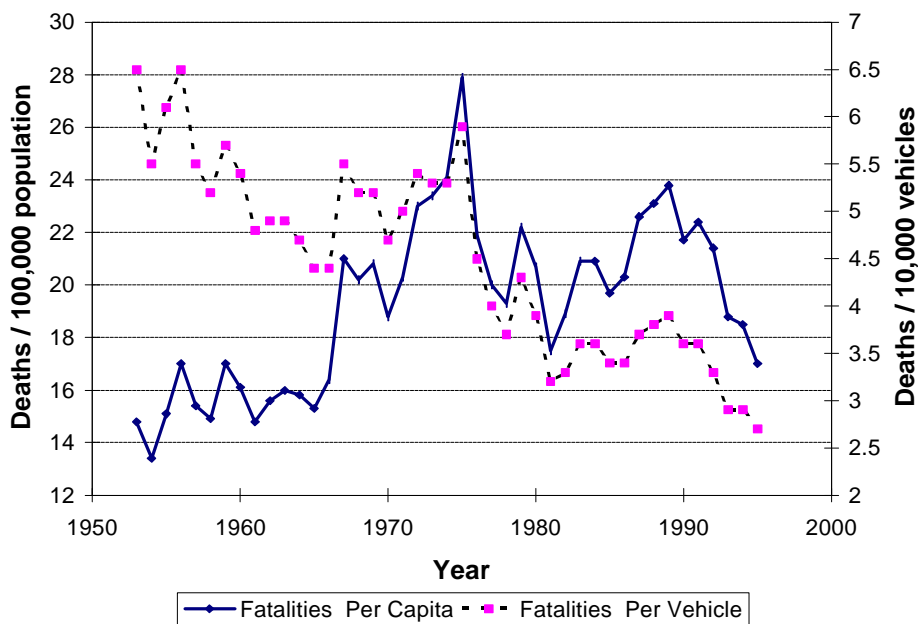
### 3.1 Introduction

New Zealand has a combined area of 268,000 square kilometres and is similar in size to Japan or the British Isles. Its population of just over 3½ million is highly motorised with a vehicle ownership rate over 650 vehicles per 1000 people.

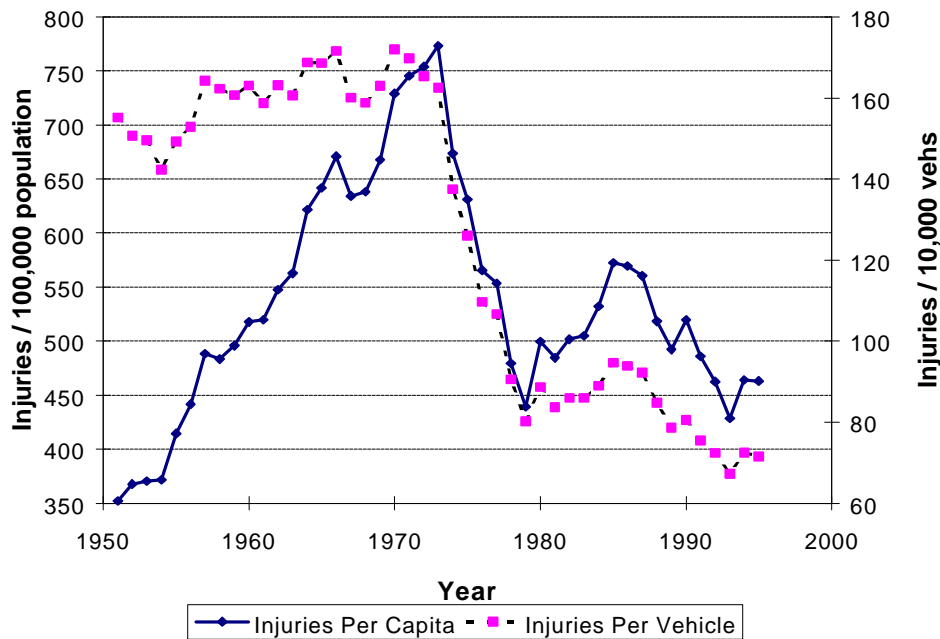
There are almost 100,000kms of roads in New Zealand of which approximately 12% are classified as State Highways administered by Transit New Zealand. The remaining 88% are the responsibility of the 75 local territorial authorities. Urban roads and State Highways in New Zealand are typically sealed, (bitumen with an aggregate chip surface) while some urban motorways and arterials are surfaced with a bituminous hotmix concrete. Many rural roads are unsealed (unbound aggregate).

### 3.2 New Zealand’s Recent Accident History - an Outline

While New Zealand deaths and injuries per vehicle have shown a general downward trend as shown in **Figures 2 and 3**, the total numbers of deaths and injuries per year began to increase again from about 1980 up until 1987, Land Transport Safety Authority [12].



**Figure 2 : Road Deaths per vehicle and per capita**



**Figure 3 : Road Injuries per vehicle and per capita**

Since 1987 there has been a significant decrease of fatalities and to a lesser degree, injuries which can be attributed to the following two major targeted safety campaigns :

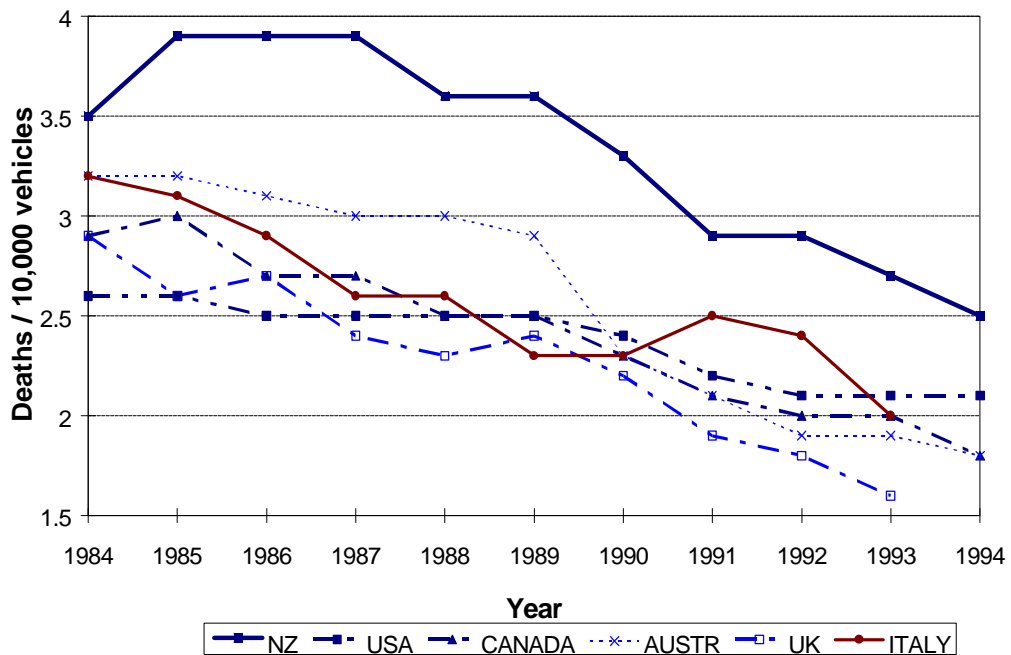
1. very publicly and graphically advertised road safety campaigns against excessive speed and drinking and driving by the Land Transport Safety Authority (LTSA) and its predecessor (The Ministry of Transport)
2. the establishment of Crash Reduction Studies by Transit New Zealand (the State Highway authority in New Zealand) that is based on two principle strategies being :
  - *Accident Prevention Studies* - the use of safety audits during differing stages of the investigation, design, construction and post construction phase to catch design faults that could cause future accidents on the roading network before they become high accident locations (accident blackspots),
  - *Accident Reduction Studies* - of the existing roading network, by analysing past recorded accidents at locations and determining commonality of accidents and preventing further occurrences by remedial works.

Furthermore, in 1990 the economic value of preventing road crashes was changed to the “willingness to pay” approach, Miller and Guria [13]. This dramatically increased the ‘benefit’ of preventing a road fatality or injury by about eight and three times respectively. Hence the benefit - cost - ratios and therefore the priorities of road safety projects increased dramatically.

While these targeted safety campaigns have contributed to a decrease in accidents over the last 10 years, there is some concern that New Zealand has still not made the same progress as other similar highly motorised countries. **Figure 4** shows the comparison that during the last 10 years other comparable countries have significantly lower deaths per vehicle and per capita than New Zealand. While the gap has reduced a little over the past few years it is still significantly higher.

The importance of reducing the social and economic cost of road accidents cannot be overstated. Worldwide, approximately half a million people are killed annually in road accidents. While accidents are "rare, random" and "multifactor events" they are "preceded by a situation in which one or more persons failed to cope with their environment", Homburger et al [14].

Accidents can be attributed from numerous contributing factors, such as the weather, light conditions, faulty design and / or inadequate maintenance on the roading network. As is outlined next, a significant proportion of reported accidents in New Zealand, occur at junctions which is most likely to hold true for other similar countries as well. Consequently, any initiatives that can be taken to reduce accidents at junctions has major social and economic benefits and incentives.



**Figure 4 : Comparison of Road Deaths to other Similar Countries**

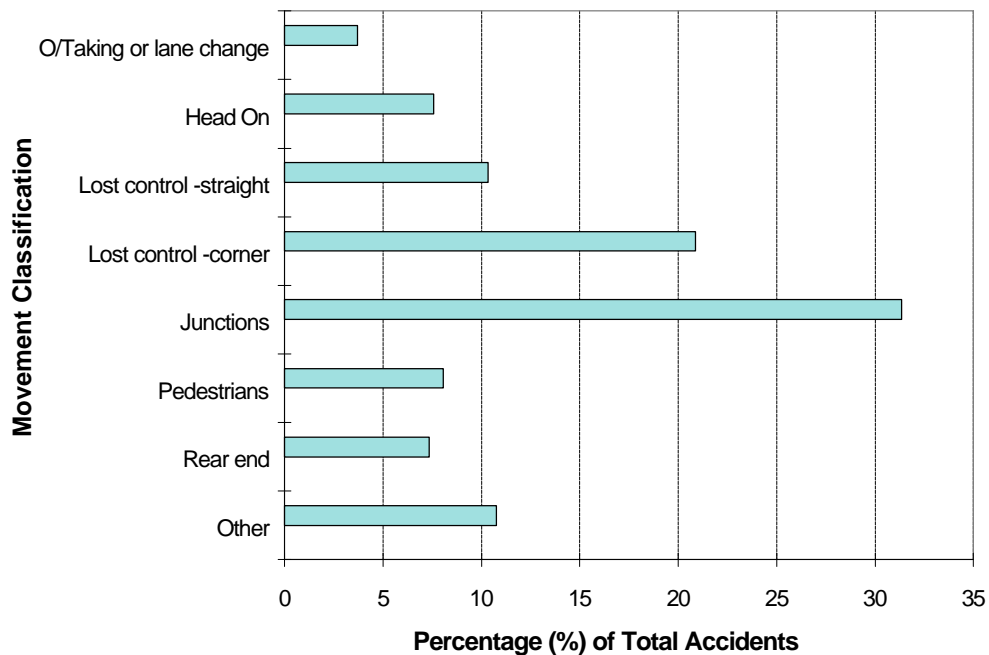
### 3.3 Accidents at Junctions in New Zealand

**Figure 5** illustrates the movement classifications of reported injury accidents in New Zealand (including fatal) during 1995. However, more significantly this

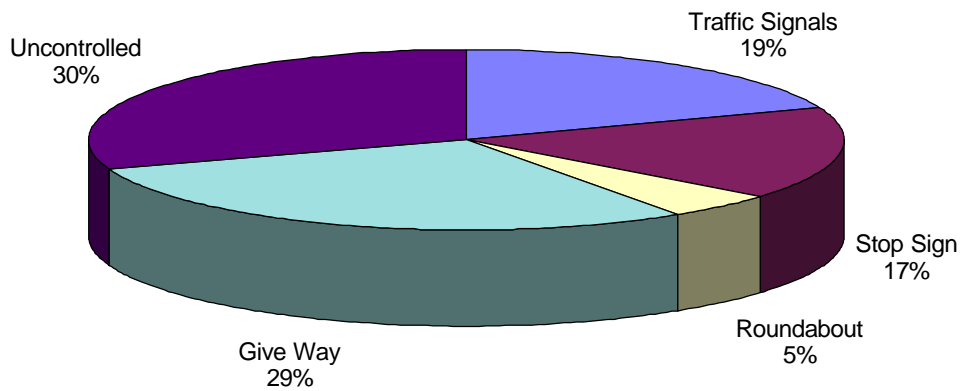
illustrates that of the 11,718 injury accidents reported, over 32% occurred at junctions, the highest single movement cause. Of the 501 fatal accidents that occurred, 12% were also at junctions.

Subsequently, any improvements in the planning, design and implementation process of junctions can significantly improve road and street safety, thereby reducing the nett injury and accident rates on transport corridors. **Figure 6** illustrates the percentages of accidents that occurred at junctions in New Zealand between the main junction types, of which urban and rural are combined.

Although the accident percentages shown in **Figure 6** give an indication of the accident rates at the differing junction types, there are a number of other parameters and inter-relating factors (other than just safety) that need consideration. One cannot isolate accident rates from the type of junction without also considering the traffic volumes, movements at the junction, capacity, delay and other parameters that are discussed in more detail later.



**Figure 5 : Movement Classifications for Injury Accidents (including Fatal)**



**Figure 6 : Accidents at Differing Junction Types (Urban and Rural)**

### **3.4 Benefits of Using Expert Systems in Road Safety**

The more recent implementation of the Accident Investigation procedures in New Zealand helps to firstly determine faults in the existing road network (*Accident Reduction Strategy*), however the most effective method is by designing and implementing the roading system right in the first instance (*Accident Prevention Strategy*). The *expert system* being developed will become an effective planning and design tool in the prevention of possible future accidents occurring at junctions by getting it ‘right the first time’.

Furthermore, the *expert system* will be able to check existing junction treatments (possibly as part of an accident blackspot analysis), the results of which may point to potentially unsafe designs, and offer an alternative and more appropriate junction design treatment.

## **4.0 DEVELOPMENT OF THE EXPERT SYSTEM**

### **4.1 Introduction**

As has been shown, the operation and safety characteristics of the road system depend more on the junctions than any other single parameter under the control of the road or traffic engineer. It is at junctions that the majority of vehicle and pedestrian conflicts occur and therefore where delays, accidents and congestion are most likely to occur.

There are considerable variations in the types of junction control used under different flow conditions within the existing roading network. The degree of junction complexity ranges from having no formal control, at the junction of two

local residential streets with low traffic volumes, to having a complicated grade-separated motorway junction. Traffic movements at grade separated junctions then have almost unhindered passage through what may otherwise be a heavily congested junction.

As there are no explicit guidelines generally available or algorithmic calculations to determine the 'right answer' but rather a number of heuristic rules (rules of thumb) and experience under certain circumstances, the choice of junction treatment has in the past suffered inconsistencies and consequently the safety of the junction has been compromised. It is in these areas of heuristic's and degrees of uncertainty that an *expert system* is seen to considerably aid designers to make quick, efficient and consistent design decisions to improve the safety and capacity at junctions.

#### **4.2 Methods of Junction Control.**

The basic methods of junction control, usually in order of increasing installation cost are :

- "uncontrolled" junctions, where priority laws apply
- major / minor priority control with STOP or GIVE WAY signs on the minor approaches
- roundabouts
- traffic signals, and
- grade separation.

All control types are suitable for a range of traffic flow conditions and unsuitable for others. Priority control can lead to low average delays and unhindered progress for vehicles on the major road, but at the expense of vehicles that suffer very high delays on the minor approaches. It is widely believed that roundabouts operate well when there are high right turning volumes, but poorly when the major flow is much greater than the minor flow. On the other hand, traffic signals generally operate poorly when the proportion of right turning volumes are high. These simple examples of heuristic rules indicate why it is important to take into account the flow conditions at a junction in determining what choice of control is appropriate.

Traffic controls can therefore be installed, or altered for a wide variety of reasons. For instance, it may be desirable to reduce delays to non-priority streams at a major/minor priority junction or to reduce queues at a signalised junction or to separate the traffic movements due to a high occurrence of accidents. Any of these, or a variety of other reasons can lead to the installation or replacement of a particular type of junction control.

#### **4.3 Design Factors that Determine Junction Control.**

It is widely acknowledged that determining the most appropriate form of junction control to achieve the junction objectives is a complex matter. A large number of factors are involved in determining the most appropriate junction control device for a particular situation. These factors and their relationships are shown

later in **Figure 7**. Details on these factors are given in many well known traffic engineering texts such as Ogden & Bennett [15] and Homburger et al [14]. However, it is the inter-relationships between these factors which are important and little understood, as is outlined later.

Under given circumstances, the suitability of the particular control types can be largely determined by only one of these factors, however in other circumstances, there will be a wide range of relevant factors which require balancing. In all cases, safety is of paramount importance, however a trade-off is often required between the construction costs and the benefits obtained, therefore safety alone cannot be the only determining factor, otherwise all junctions would be designed to the highest standard and therefore be grade separated. It would not however be the most cost effective or appropriate solution, as for example, a low traffic volumed, low approach speed junction does not require grade separation even though it is the safest junction design. Therefore, in all cases economic evaluations and budget constraints must be considered in determining the most appropriate junction control and treatment.

#### 4.4 Expert Systems and the Decision Making Process

Currently, in New Zealand and most overseas countries there are no explicit guidelines for determining the most appropriate form of control at a particular junction.

Junctions are the key points on any road network. In urban areas, they control the capacity of the arterial road network and often have a high accident record because of the many conflicting movements. At junctions, vehicle drivers and other road users are faced with complex decision-making in an all too often confusing environment.

It is important, therefore, that road planners, designers and traffic engineers have a sound knowledge and understanding of the principles and practises involved in junction design. Invariably there are conflicting requirements, where a balance or trade-off between safety, capacity and environmental impacts occur.

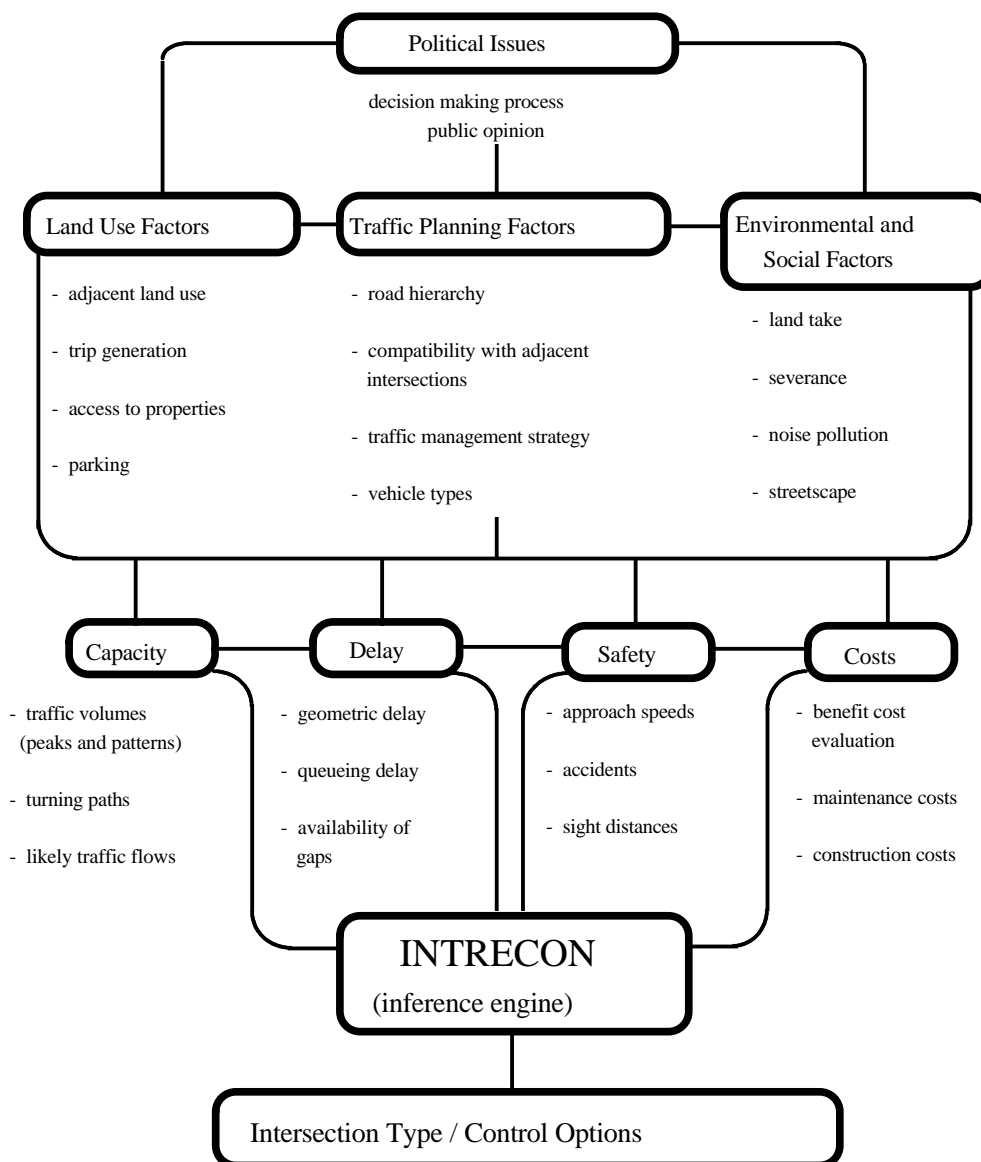
It is imperative that evaluations be made on a rational basis using both quantitative analysis and professional judgement and experience. It is in these areas of judgement that an *expert system* comes into its own, as it can be developed to give efficient, consistent and rational prioritising of the treatment options. An *expert system* has the additional benefit that it provides a most valuable check list for the designer to have at least considered all the possible factors in the decision making process.

#### 4.5 Inter-Relationships of the Knowledge Base

The basic inter relationships between the factors of the knowledge domain in the *expert system* being developed, called INTRECON (INTersection TREatment and CONtrol), are shown in **Figure 7**. This knowledge domain must be clearly

researched, structured and understood to enable the *expert system* to give an appropriate solution.

Difficulties arise in the treatment choices due to the fact that the relationships are not clear cut but overlap in areas allowing two perfectly appropriate treatment solutions. Due to these problems an *expert system* once developed, could considerably aid the user to determine quickly and efficiently the most appropriate junction treatment with the user-specified data input. In determining the appropriate treatment, the *expert system* could also conclude that one option is the most appropriate, however that another option would also be appropriate. The *expert system* could then further prompt the user to obtain more information to adequately distinguish between these two options.



**Figure 7 : Knowledge Domain of INTRECON**

## 4.6 Structuring the Knowledge Domain

A considerable number of production rules are required to describe the relationships between the variables and factors displayed in **Figure 7**. The production rules describe the operational logic, heuristic's and cause-and-effect relationships needed to make decisions to determine the most appropriate junction type and subsequent treatment. For example, production rules include:

- whether the approach speeds are low, medium or high
- what lane configurations are required to provide the adequate capacity for the input traffic volumes for each approach
- determination of delays due to hourly and seasonal changes
- determination of the past accident rates if appropriate or to consider junction safety aspects for proposed or upgraded junctions, and
- determination of economic evaluations due to the benefits versus maintenance and construction costs.

INTRECON uses both forward chaining and backward chaining. It will forward chain initially as a certain amount of data is required regardless of the junction treatment, this is called event or data driven. Once the initial input data has been collected determining such things as the number of approaches, traffic volumes, the approach lane configurations and the past accident history, the inference engine will then backward chain by setting the junction treatment options as goals and subsequently determine the information to prove the goal. This approach has the advantage that if a goal is tested to prove one treatment option and the goal is subsequently met, it does not necessarily have to continue prompting the user for information to test other options that it already knows is not the most appropriate solution.

It is in the structuring of the knowledge domain that the inter-relationships and how they effect each other must be well researched and understood. As the determination of the appropriate junction treatment and control solely relies on the production rules and the relationships developed, considerable research is required in this area to fully understand how these relationships interact. Some variation in these relationships is expected from one traffic engineering jurisdiction to another. The current work in developing INTRECON is focused in this area within the New Zealand context.

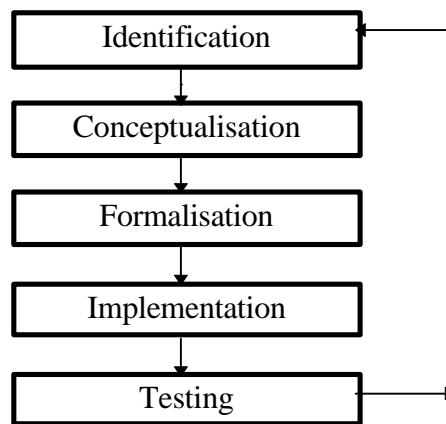
As new technology and improved techniques come on-stream, these relationships in the knowledge domain will require additions and modifications. Hence, an *expert system* package, such as INTRECON, will require continuing minor developments if it is to remain as a state-of-the-art application.

## 4.7 Expert System Development Methodology

The development of the INTRECON *expert system* has been based on the widely accepted Expert System method proposed by Waterman [16]. The

stages are highly inter-related and interdependent and is demonstrated in **Figure 8** below.

In traditional software development, the steps explained below, are essentially those of *model development* and the application of *systems analysis*. The *expert system* developmental stages are explained in some detail below with relevance to the INTRECON *expert system* being developed.



**Figure 8 : Expert system Development Stages.**

- 1) **Identification** - this is the formal task analysis stage and determines the requirements that are external to the *expert system*, such as the :
  - range of problem to be solved
  - objectives
  - final end user of the application
  - resources (e.g. human experts, reference materials)
  - costs, and
  - timeframe
  - required input and output to the Expert System and what form it will take.
  
- 2) **Conceptualisation** - the second stage of the *expert system* development involves designing the proposed programme, ensuring the specific interactions and relationships in the problem domain are understood and defined. This is the initial stage of the knowledge acquisition.

An important point to note in the development of the INTRECON *expert system*, is that there is not one or even a small number of human experts that the required expert knowledge domain can be acquired from.

This developmental stage of the process requires the knowledge engineer to identify the knowledge sources, heuristics and expert knowledge required by the domain expert, which in this particular case of developing INTRECON is the same person. The knowledge is then analysed, grouped, ranked and ordered and forms the basis of the subsequent formalisation stage.

- 3) **Formalisation** - this stage involves organising the key concepts, decision making process, subproblems, information flow and the subsequent rules into formal representations, in effect, the programme logic design stage.

It is difficult to separate the knowledge acquisition (conceptualisation) phase and the knowledge - base design (formalisation) phase and, in reality the two run in parallel.

**Figure 7** demonstrates the conceptualisation / formalisation process in the INTRECON *expert system* under development.

- 4) **Implementation** - during this stage “*the formalised knowledge is mapped or coded into the framework of the development tool to build a working prototype. The contents of knowledge structures, inference rules and control strategies established in the previous stages are organised into suitable format*”, Jones and Barrett [17].
- 5) **Testing** - the last stage involves considerably more than the traditional finding and fixing of syntax errors. It covers the verification of individual relationships, validation of programme performance and evaluation of the utility of the software package. It ensures that the knowledge is accurately duplicated by having domain experts and end users operate the programme for all possible contingencies and therefore tests for appropriate *expert system* solutions.

It is proposed for the development of the INTRECON *expert system* that on completion of ‘internal’ domain expert testing that ‘external’ users and domain ‘experts’ be allowed to test and critically review the programme and recommend any improvements.

One of the primary strengths of *expert systems* in comparison to conventional programming approaches (as discussed in Section 2.4) is its modular developmental process and the ability to develop an *expert system* by refining and expanding a prototype. This then allows a continual iterative process of the above five developmental and methodological stages.

## 5.0 SUMMARY AND CONCLUSIONS

The development of INTRECON (INTERsection TREATment and CONTROL) utilising Artificial Intelligence (AI) shows that:

- an *expert system* in this area of transportation and traffic management has considerable potential to increase the productivity of the end user
- the input requirements provide a most valuable check list of the factors which need to be considered
- the output is anticipated to provide a more consistent decision-making process within a traffic engineering design jurisdiction and therefore produce safer roads and streets.

The application of the INTRECON *expert system* is expected to be particularly useful:

- where specialist knowledge is scarce and thinly spread
- to relieve experienced staff from design considerations and free them for other tasks
- for staff training and development.

INTRECON is being developed as a prototype using an *expert system* shell. Local and international modifications and extensions can be undertaken relatively easily as further relationships are researched and developed.

It is anticipated that INTRECON will be one of many applications to appear within the various specialist engineering fields. Like other *expert system* and *Artificial Intelligence (AI)* applications, INTRECON is expected to have considerable benefits for all practitioners, from the in-experienced to the specialist.

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