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Dear Editor of Knowledge-Based Systems,

It is our pleasure to submit to your journal this original article that present a decision support systems based on Dominance-based Rough Set Approach to fix speed limits which we believe is in fully accordance with the scope and the aims of the journal.

Of course the paper is original and it has not submitted to any other journal.

Best regards,

Maria Grazia Augeri, Paola Cozzo and Salvatore Greco

DOMINANCE-BASED ROUGH SET APPROACH FOR SETTING SPEED LIMITS IN SPEED ZONES

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Abstract

Speed management represents an important strategy in order to improve road safety, also considering the link between speed and crash probability and severity. The imposition of speed limits is the main measure to control operating speeds.
Speed limits have to be safe, but they also have to be credible, meaning that road users have to regard them as logical under given conditions and the limits have to fit the image evoked by the road.
This paper describes the development of a Decision Support System (DSS) for the selection of safe and credible speed limits for speed zones. The proposed DSS is based on Dominance-based Rough Set Approach (DRSA), which presents interesting advantages in terms of transparency and manageability with respect to many other decision support competitive methodologies. In fact DRSA, after getting the preferred information necessary to set up the decision model, in terms of exemplary decisions, builds a multi-criteria model expressed in terms of *"if..., then ..."* decision rules.
The proposed multi-criteria decision approach aims to suggest to decision-makers a safe and credible speed limit for speed zones, taking into consideration factors such as accident rate, roadway geometry, roadway development, traffic and others.

Keywords

Speed limits; Decision Support System; Dominance-based Rough Set.

1. Introduction

Over the past five decades, individuals and societies have greatly benefited from a rapid improvement in road systems. At the same time, industry has manufactured and sold motor vehicles able to travel at increasingly higher speeds.
High-speed vehicle transportation has contributed to the economic development of countries, and also improved the quality of life. However, these high-speeds have had considerably adverse impact, mainly in terms of road accidents (and consequent deaths, injuries, and material damages), but also in environmental terms, including noise and exhaust emissions, and finally in terms of the comfort of residential and urban areas.
Positive and negative effects of speed make it a prime target for policy action.
Recently, the demand for strategies that reduce such adverse impacts has increased. A growing portion of the population has sought to improve road safety, to reduce adverse environmental impacts and to improve the general quality of life.
Speed management policies - which could deliver these outcomes - have become a high priority in many countries.
A method for setting speed limits with a Decision Support System (DDS) based on Dominance-based Rough Set Approach (DRSA) is presented in this paper. The methodology suggests to the decision makers a safe speed limit on the basis of a decision model set up by means of preference information in terms of exemplary decisions provided by an expert panel. At the same time the methodology produces some easily understandable decision rules that can help the decision makers to explain the reasons for the suggested speed limit.
The research work contained in this paper has been divided into seven sections. Section 2 introduces the speed management question and presents a brief literature review of the expert systems for setting speed limits; Section 3 explains the aim of the present work, the methodology and the data used for the decision model development; Section 4 presents the DRSA multi-criteria decision model for setting speed limits developing; Section 5 examines the application of the decision model; finally Section 6 provides the conclusions and some recommendations.

2. Methods for Setting Speed Limits: a review

The speed limit system is the basis of every speed management.
Establishing a set of speed limits represents a complex trade-off between several factors - such as crash and injury risks, enforceability, travel time, societal attitudes, environmental concerns and political considerations - and the relative importance assigned to everyone.
These different trades-off are variously reflected in a range of different philosophies (TRB, 1998; Elvik & Vaa, 2004; Fildes at al., 2005; Aarts et al., 2009):

- Engineering: speed limit system based on engineering and traffic characteristics (design speed); safety considerations are taken into account but not always explicitly.
- Drivers' choice: speed limit system based on the 85th percentile speed that is driven on the road (V_{85}); safety as well as a kind of credibility is taken into account.
- Economic optimization: speed limit system based on the optimal trade-off between costs and benefits of different speed related issues and policy fields; safety is one of the many issues that is or can be considered.
- Harm minimization: speed limit system based on the concept that life and health cannot be measured or traded in terms of monetary costs, and that human trauma as a crash's consequence is considered unacceptable.

- Expert systems: speed limits determined by computer programs employing decision rules operating off a well-defined knowledge base relating to road conditions, to generate speed recommendations.

The most common approach for setting speed limits is to determine them after conducting an **engineering study** of the road and traffic environment on the section of road and surrounding roads. In an engineering study information is collected on the traffic speeds, crash data, type and amount of roadside development, road geometry, and the number of type of road users. These factors allow engineers to designate a road design speed.

Alternative and very common, is the philosophy of setting speed limits by **drivers' choice** of speed, which is otherwise known as the "basic law limit". This approach leaves it up to drivers to determine what constitutes a reasonable and safe travel speed. This has been an accepted speed limit practice because it is politically popular, appeals to road users and the public in general, and is obeyed by the majority of drivers. However, speed limits arising from this philosophy often incorporate various engineering considerations, which may result in modified speeds if the speed chosen by drivers were not appropriate.

The various **economic optimization approaches** are based on setting a dollar value to all the costs associated with travel and to the burden of injury and death from motor vehicle crashes. The method relies heavily on the quality of the data used to determine the costs of each of the factors involved. The lack of a universally accepted method for determining the economic costs of each transport factor has limited the objectiveness of these approaches, which have been rarely used to determine speed limit policy. Nevertheless, the approach has gained some recognition by virtue of its emphasis on what mobility factors are actually costing society, particularly in terms of injury costs.

If economic optimizations approaches assume that it is legitimate to put a fiscal cost on human trauma, some alternative approaches are based on the argument that life and health are beyond the monetary costs associated with safety and good health and beyond the other benefits of transport. These approaches - **harm minimization approaches** - recognize that while it may not be possible to eliminate road trauma, it may be possible to create a transport system that does not view casualties and fatalities as an acceptable and inevitable cost of mobility. Examples of these philosophies are the *Swedish Vision Zero* (Tingvall & Haworth, 1999) and *Dutch Sustainable Safety* (Wegman & Aarts, 2006).

Finally, the **expert-based systems** aim to develop a uniform and consistent approach to setting speed limits while still accounting for situation specific criteria that may not be incorporated into a standard engineering analysis. Expert systems are computer programs used to solve complex problems in a given field by employing decision rules operating on a well-defined knowledge base.

Expert systems and algorithms in setting speed limits in last years become very famous. In the next sub-paragraphs SaCredSpeed algorithm and the USLIMITS expert system are described.

2.1 Harm minimization approach: SaCredSpeed algorithm

The *Dutch Sustainable Safety* have been developed in 1992 and updated on 2006 (Wegman & Aarts, 2006) by the SWOV, the Institute of Road Safety Research.

One of the key concepts in a Sustainably Safe Traffic System is safe, credible limits and good information about them. First of all safe driving speed needs to be determined in order to set the corresponding speed limit; the safe speeds assessment depends on the legal traffic situation and further road design details. Speed limits also need to be credible - *'credible speed limits'* (SWOV, 2007) - that means that the speed limit has to meet the expectations evoked by the road image, defined by the road's features and its surroundings. Road users also always have to be aware of the current speed limit, so information must be applied very consistently and, also, it must be properly explained to the road users.

Recently the SWOV have presented the initial elaboration of an algorithm that concretizes its own speed management vision based on harm minimization (Aarts et al., 2009), (Aarts et al., 2010). This algorithm, called *'SaCredSpeed'* (Safety and Credible Speed), is based on scientific knowledge about safe speed, speed management and credibility and is focused on the issues that are considered the most relevant on this; other variables such as traffic flow, environment and health are not taken into consideration.

The SaCredSpeed algorithm consists in three separate algorithms, respectively for safety, for credibility and enforcement of speed limit (Aarts et al., 2009). First algorithm uses input data of a particular stretch of road - i.e. data about road construction, road layout, legal traffic situation – and assess, applying its logical rules, a safe speed and speed limit for that particular situation. The second part of the algorithm - stating that a speed limit is credible when the limit in force is conforms to what the road user considers to be reasonable for that particular road section - determines the credibility of speed limit by a broad range of road design and road layout characteristics based on existing studies (Aarts et al., 2009). The third part of the algorithm assesses the need for additional police enforcement checking existing police enforcement situation and speed data, when available.

Finally the outcome of the three algorithms is combined resulting in possible directions for speed management, and precisely:

- an indication of the safety of the speed limit and operation speed;
- an indication of the credibility of the current speed limit on a road section;
- a set of measures to be taken in order to improve the safety and credibility of the speed limit.

SaCredSpeed nowadays is the unique approach in safe speed limits settings based on harm minimization, and is the only one that includes credibility of speed limit assessment.

The algorithm certainly can be a greater help on speed limits safety and credibility evaluation and suggestion for adaptation. Its logical rules in setting safe speed limits - based on national guidelines on infrastructure design - only take into account road design and users, and does not consider operative conditions (i.e. traffic volume, percentage of heavy vehicles, accident rate) and maintenance conditions (i.e. status of pavement and road signs), that in different national politics can have a great importance and need to be considered.

Furthermore, although users - i.e. managing authorities - know the decisional process, they cannot easily change or update it basing on their current policies, engineering criteria, practices, and experience if necessary.

2.2 Expert-based systems: USLIMITS2

The first expert-system based approach for setting speed limits in speed zones was developed in 1987 in the state of Victoria (Australia) (Jarvis & Hoban, 1988). This was a DOS-based program, called VLIMITS, developed by ARRB for Victoria State using decision rules for different road and traffic conditions, developed by a panel of experts using field measurements at 60 locations. In 1992 VLIMITS was updated (TRB, 1998) and was developed for all Australian state roads authorities and for New Zealand, modifying the name and the rules: collectively, they are called XLIMITS.

Based on the Australian XLIMITS example, the USLIMITS expert system has been developed in United States by ARRB for FHWA, adapting decision rules to North American policies and practices. All the systems developed by ARRB are considered proprietary and their logic and decision rules are not available for the user, so users are not permitted to know which, and how many, variables influence the final recommendation.

In 2006 the Final Report of NCHRP Project No. 3-67 "Expert System for recommending speed limits in speed zones" (Srinivasan et al., 2006) was presented: the Project was designed to develop an expert system to succeed USLIMITS. In contrast to all previous versions, USLIMITS2 (Srinivasan et al., 2006) (Lemer, 2007) (Srinivasan et al., 2008) is open source, available with complete information about the system's logic and factors influencing speed limits recommendations, provided by the system. The Study Report, the User Guide and the Decision Rules are available on the official website (http://www2.uslimits.org). When logging in, it is possible to question the system about the most appropriate speed limit for a specific speed zone.

In this system, although complete information about the system's logic, factors influencing speed limits and the decision rules are known, the output is only a recommended speed limit for the new road section, basing on its characteristics, putted as input. With this type of output users has difficulty to understand which road section characteristics have influenced the result or which is the cause that runs to it, because the decision process is not evident and it is not possible to evaluate or update it.

3. Problem definition

Considering the importance of speed limits in safety management and the lacks of the presented algorithms and expert-systems in terms of transparency and adaptability to different situations, the aim of the present work is the definition of a decision-support tool that can assist the decision makers in setting speed zone limits using a multi-criteria decision model.

The basic idea of the presented work is to develop an intelligible and user friendly tool that can suggest to users a safe speed limit and, at the same time, that can easily explain them the reasons of the recommendation, in order to avoid the "*black box*" effects of many alternative decision support methods. More precisely, our aim is to represent the experience of one or more experts in terms of a set of *"if …, then …"* decision rules that synthesize some exemplary decisions about speed limits supplied by the experts themselves. Furthermore, in order to consider a plurality of attributes in the decision process for setting speed limits in speed zone, a multi-criteria decision model has been used.

3.1 Methodology

The multi-criteria decision model adopted in this study is based on the Dominance-based Rough Set Approach (DRSA) (Greco et al., 1999) (Greco et al., 2001) (Greco et al., 2002b) (Greco et al., 2005) (Slowinski et al., 2005). This approach is an evolution of Classical Rough Set approach (CRSA) developed by Pawlak (Pawlak, 1991) that allows applying it in multi-criteria decision problems.

DRSA has been chosen because it has two fundamental advantages over other approaches:

- DRSA requires the preference information in terms of exemplary decisions which are very natural and easy to be supplied by the decision maker (contrary to some model parameters required by other competitive multiple criteria methods, such as weights of criteria, trade-offs between criteria, thresholds, and so on) (Fishburn, 1967) (Mousseau, 1993);
- DRSA produces a decision model expressed in terms of easily understandable "*if…, then…*" decision rules which permits to control the decision process and to avoid the *"black box"* effects of many alternative decision support methods (Greco et al., 2005) (Slowinski et al., 2009).

The multiple criteria decision support system proposed in this paper aims to suggest the managing authority the most appropriate speed limit for every speed zone taking into account its geometric and operative characteristics and maintenance conditions, on the basis of a safety police described using a set of decision rules induced from some exemplary decisions taken by one or more experts.

3.2 Data

We started the construction of a the decision-support tool with a proper data selection related to the considered problem.

Considered data are composed by a set of 100 road sections on Italian rural roads, and precisely two lane roads with statutory speed limit of 90km/h. Road sections have been selected taking into account geometric, operative, maintenance characteristics and accident rate, obtaining speed zones with homogeneous characteristics and at least 300 meters in length.

Speed zone characteristics have been defined by a set of attributes that can well describe operative conditions, geometric characteristics, and maintenance conditions of every road section. These characteristics have been registered during field observation and data collection.

The considered attributes are reported in the following, together with their value scales within parentheses:

A_1= Traffic Volume (high, moderate and low);
A_2= Percentage of heavy vehicles (high, moderate and low);
A_3= Lane width (in meters);
A_4= Shoulder width (in meters);
A_5= Road Signs (yes or no);
A_6= Pavement Condition (high, moderate and low);
A_7= Roadside Hazard Rating (1,2,3 or 4);
A_8= Accident Rate (high or low);
A_9= Adverse Alignment (yes or no).

It is important to remark that other and different attributes can be considered in speed zone definition, in relation to available data and/or Decision Maker (DM) choice.

Every attribute and its classification are described here in the following.

The attribute *"Traffic Volume"* refers to the traffic level on the investigated road section; it has been obtained from managing authorities' official data and it is classified as low, moderate and high considering as threshold 6,000 ad 20,000 vehicles/day: i.e. Traffic Volume is low if lower than 6,000 vehicles/day, it is medium if it is not smaller than 6,000 and lower than 20,000 vehicles/day, and it is high if it is not smaller than 20,000 vehicles/day.

The attribute *"Percentage of heavy vehicles*" is classified too into low, medium and high, considering low a percentage of heavy vehicles lower than 10% of the traffic volume, medium a percentage of heavy vehicles included between 10% and 20% of the traffic volume and high a value higher than 20%.

The attribute *"Lane width"* and *"Shoulder width"* respectively refer to the lane and the shoulder size (in meters).

The attribute *"Road signs"* only indicates the presence or absence of pavement markings on the investigated road section.

The attribute *"Pavement Condition"* describes the pavement condition as high, moderate and low.

The *"Roadside Hazard Rating (RHR)"* is a measure of the roadside conditions including shoulder wide and type, side slope and presence/absence of fixed objects on the roadside (Zegeer et al., 1988). Roadside hazard defined by Zegeer is ranked on a seven-point categorical scale from 1 (best) to 7 (worst). This scale has been adapted to Italian Roads and a four-point scale has been used.

The four categories of roadside hazard rating are defined as follows:

- RHR=1

  Presence of roadside barriers if required, correctly installed and by law.
  Roadside free from obstacles (trees, poles, etc.) or embankments.

Recoverable in a run-off-road situation.

- RHR=2

  Presence of roadside barriers if required, but either not properly or not legally installed.
  Possible presence of exposed trees, poles or other objects.
  Marginally recoverable in a run-off-road situation.

- RHR=3

  Limited presence of roadside barriers in flyover, steep and high slope, etc.
  Exposed rigid obstacles (trees, poles, etc.) and embankments.
  Virtually non-recoverable in a run-off-road situation.

- RHR=4

  Absence of roadside barriers.
  Cliff or vertical rock cut.
  Non-recoverable in a run-off-road situation.

The attribute *"Accident rate*" characterizes the safety conditions of each section. For each section the accident rate is defined as the ratio between the observed number of accidents (only fatal and injury crashes are taken into account) and the risk exposure (given by the product of all traffic flows in the observed period for the section length); the investigated period has to be at least two years long to be significant and no longer than five years in order to avoid non stationary phenomena. In this study a five years long period is used. The evaluation of safety level is based on a statistical procedure and it is classified as low hazardous section or high hazardous section.

Finally the *"Adverse Alignment"* attribute includes road features with vertical and/or horizontal alignment which differs significantly from the alignment of the general road. Adverse alignment segments typically reduce operating speeds below the general speed limit for the section. Examples of adverse alignment segments are: small radius curve, winding road, curve after long straight, narrow pavement widths and shoulders, road bumps, etc. The presence or the absence of an adverse alignment in the measured section has been marked.

3.3 Expert Panel selection

The set of the 100 road sections selected on Italian rural roads, each one described by the set of chosen attributes, has been submitted to an Expert Panel.

The Expert Panel function is to assess a safe speed limit for every investigated speed zone, only on the basis of its characteristics (classified as described above) and some photos. Every Expert Panel component has to select the most appropriate speed limit (in terms of safety) among 60, 70, 80 and 90 km/h - the last one is the statutory speed limit for the investigated type of roads.

Different members, with different priorities and purposes in speed limits selection, can compose the Expert Panel. For example, it can be composed by members of managing authority, road safety experts, road users, government delegates, and so on.

The final decision – i.e. a safe speed limit for each selected speed zone – can be the mean of every Expert Panel member selected value or can be selected as the value they agree on.

In the present case study the Expert Panel was composed by three safety experts among professors of the Department of Civil and Environmental Engineering of the University of Catania.

The final decision about the safe speed limit for every selected speed zone has been taken by common agreement.

It is important to remark that, using DRSA, it is also possible to consider at the same time multiple decision makers (Greco et al. 2006) with different priorities and purposes in speed limits selection, and use the decision of every decision maker (or decision maker group) in the decision table to assess decision rules.

4. Dominance Rough Set Approach to develop a multi-criteria decision model for setting speed limits

In the following subsections is presented the application of DRSA in multi-criteria decision model for setting speed limits.

4.1 Information table and Dominance Relation

The base of a Rough Set analysis is an *information table*. The rows of the table are labelled by *objects*, whereas columns are labelled by *attributes* and entries of the table are *attribute-values*, called *descriptors*.

In the present case every row of the table is a road section, and every column contains technical and functional parameters conveniently selected to describe road sections.

Formally, by an *information table* we understand the 4-tuple $S=<U,Q,V,f>$, where U is a finite set of objects, Q is a finite set of *attributes*, $V=\bigcup_{q\in Q} V_q$ and V_q is a value set of the attribute q, and $f:U\times Q\rightarrow V$ is a total function such that $f(x,q)\in V_q$ for every $q\in Q$, $x\in U$, called *information function* (Pawlak, 1991).

The set Q is, in general, divided into set C of *condition attributes* and set D of *decision attributes*. The notion of attribute differs from that of *criterion*, because scale of a criterion (its value set) has to be ordered according to decreasing or increasing preference, while the scale of a regular attribute does not have to be ordered.

In the present case, U is a set of 100 road sections on Italian rural roads, (two lane roads with statutory speed limit of 90km/h) and Q is composed by the attributes that describe them, being the condition attributes C, and the speed limit recommended by an expert panel as the most appropriate (in terms of safety) among 60, 70, 80 and 90 km/h, being the decision attribute D. The information table and the expert recommended speed limit that constitute the exemplary decision are shown in Table 1.

In our case, all the condition attributes are criteria. For example, in the examined case, where the problem is to determine speed limits, considering the RHR it will be preferable a road section with good pavement condition to a road section with bad ones, and therefore it will be assigned the higher speed limit to the first one instead of the second one.

It is important to observe that the criteria preference-order used in the presented case study are fixed by the expert panel but these can be modified according to the preference and knowledge of expert components.

Assuming that all condition attributes $q\in C$ are criteria, let $\succeq_q$ be a *weak preference* relation on U with respect to criterion q such that $x\succeq_q y$ means "*x is at least as good as y with respect to criterion q*". It is supposed that $\succeq_q$ is a total pre-order, i.e. a strongly complete and transitive binary relation, defined on U on the basis of evaluations $f(\cdot,q)$.

Furthermore, assuming that the set of decision attributes D (possibly a singleton {d}) makes a partition of U into a finite number of classes, let $Cl=\{Cl_t, t\in T\}$, $T=\{1,...,n\}$, be a set of these classes such that each $x\in U$ belongs to one and only one $Cl_t\in Cl$. Assuming that the classes are ordered, i.e., for all $r, s\in T$, such that $r>s$, the objects from Cl_r are preferred to the objects from Cl_s.

More formally, if $\succeq$ is a *comprehensive preference* relation on U, i.e., if for all $x,y\in U$, $x\succeq y$ means "x is at least as good as y": $[x\in Cl_r, y\in Cl_s, r>s] \Rightarrow [x\succeq y$ and *not* $y\succeq x]$. For example, an object *x* dominating object *y* on all considered criteria (i.e. *x* having evaluations at least as good as *y* on all considered criteria) should also dominate *y* on the decision (i.e. *x* should be

assigned to at least as good class as *y*). Objects satisfying the dominance principle are called *consistent*, and those which are violating the dominance principle are called *inconsistent*.
The above assumptions are typical for consideration of a *multiple-criteria sorting problem* (also called *ordinal classification problem*) (Greco et al., 2002a).
In the present case the set of decision D attributes is a singleton given by the attribute "recommended speed limit" which partitions the set U of the 100 road sections in the classes:

- Cl_1 composed of road sections with recommended speed limit of 60 km/h;
- Cl_2 composed of road sections with recommended speed limit of 70 km/h;
- Cl_3 composed of road sections with recommended speed limit of 80 km/h;
- Cl_4 composed of road sections with recommended speed limit of 90 km/h.

4.2 Dominance based approximation

These classes are ordered according to the preference of recommended speed limit, such that $x \succeq y$ whenever $x \in Cl_r$, $y \in Cl_s$ and $r \geq s$.
Partition of the set U in classes, respecting dominance relationship, allows to approximate sets in unions of classes, called *upward union* and *downward union* of classes, respectively:

$$Cl_t^{\geq} = \bigcup_{s \geq t} Cl_s$$

$$Cl_t^{\leq} = \bigcup_{s \leq t} Cl_s$$

with $t = \{1, 2, ..., n\}$.
Thus, the statement $x \in Cl_t^{\geq}$ means "*x* belongs to at least class Cl_t", while $x \in Cl_t^{\leq}$ means "*x* belongs to at most class Cl_t".
In the case study the *upward union of classes* are:

- $Cl_1^{\geq}$ composed of road sections with recommended speed limit "at least" 60 km/h;
- $Cl_2^{\geq}$ composed of road sections with recommended speed limit "at least" 70 km/h;
- $Cl_3^{\geq}$ composed of road sections with recommended speed limit "at least" 80 km/h;
- $Cl_4^{\geq}$ composed of road sections with recommended speed limit "at least" 90 km/h;

The *downward union of classes* are:

- $Cl_1^{\leq}$ composed of road sections with recommended speed limit "at most" 60 km/h;
- $Cl_2^{\leq}$ composed of road sections with recommended speed limit "at most" 70 km/h;
- $Cl_3^{\leq}$ composed of road sections with recommended speed limit "at most" 80 km/h;
- $Cl_4^{\leq}$ composed of road sections with recommended speed limit "at most" 90 km/h.

Let us remark that $Cl_1^{\geq} = Cl_n^{\leq} = U$, $Cl_n^{\geq} = Cl_n$ and $Cl_1^{\leq} = Cl_1$.
In the present application the upward union classes $Cl_1^{\geq}$ and the downward union classes $Cl_4^{\leq}$ contain all the 100 road sections considered: in fact for all considered road sections the speed limit is always at least 60 km/h and at most 90 km/h.
Furthermore, for *t=2,...,n*, we have: $Cl_{t-1}^{\leq} = U - Cl_t^{\geq}$ and $Cl_t^{\geq} = U - Cl_{t-1}^{\leq}$.
The key idea of rough sets is approximation of knowledge expressed in terms of decision attributes by knowledge expressed in terms of condition attributes. This means to explain the partition of the decision attribute, according to the recommended speed limits, in terms of technical and functional parameters expressed by the conditional attributes.

In DRSA, where condition attributes are criteria and classes are preference-ordered, the knowledge approximated is a collection of *upward and downward unions of classes* and the "*granules of knowledge*" are sets of objects defined using *dominance relation*.
That is *x dominates y* with respect to $P \subseteq C$ if $x \in U$, the "*granules of knowledge*" used for approximation in DRSA are:

- a set of objects dominating x, called *P-dominating set*, $D_P^+(x) = \{y \in U : yD_P x\}$
- a set of objects dominated by x, called *P-dominated set*, $D_P^-(x) = \{y \in U : xD_P y\}$

Moreover, above dominating sets and dominated sets are "*granules of knowledge*" in the sense that it is supposed that road sections dominating x should be classified with at least the same recommended speed limit than x as well as road sections dominated by x should be classified with at most the same recommended speed limit.
For instance, if the considered criteria are "*traffic volume*" and "*percentage of heavy vehicles*", both of them evaluated on three levels scale with high, moderate and low, and road section x is evaluated as moderate with respect to traffic volume as well as with respect to percentage of heavy vehicles, then:

- $D_P^+(x)$ is composed of all road sections moderate or low with respect to traffic volume and percentage of heavy vehicles,

and

- $D_P^-(x)$ is composed of all road sections moderate or high with respect to traffic volume and percentage of heavy vehicles.

For any *P*⊆*C*, we say that *x*∈*U* belongs to $Cl_t^{\geq}$ *without any ambiguity* if *x*∈ $Cl_t^{\geq}$ and, for all objects *y*∈*U* dominating *x* with respect to *P*, we have *y*∈ $Cl_t^{\geq}$, i.e. $D_P^+(x) \subseteq Cl_t^{\geq}$. For example, considering the above road section *x* and *P*={"*traffic volume*", "*percentage of heavy vehicles*"}, if *x* has a speed limit of 80 km/h, i.e. x∈Cl_3, and all road sections y belonging to $D_P^+(x)$ (because evaluated moderate or low with respect to traffic volume and percentage of heavy vehicles) have a speed limit of at least 80 km/h (i.e. $y \in Cl_3^{\geq}$ and consequently $D_P^+(x) \subseteq Cl_3^{\geq}$), then x is classified with recommended speed limit at least 80 km/h without ambiguity. In simple words, this means that according to the objects in the universe U, not worse conditions than x with respect to the two criteria "*traffic volume*" and "*percentage of heavy vehicles*" imply a recommended speed limit of at least 80 km/h. Therefore, it is reasonable to recommend a speed limit of at least 80 km/h for any new road section not originally present in the universe, if it satisfies the same conditions, i.e. it is not worse than x with respect to the two criteria "*traffic volume*" and "*percentage of heavy vehicles*".
Instead, we say that *x*∈*U could belong* to $Cl_t^{\geq}$ if there would exist at least one object *y*∈ $Cl_t^{\geq}$ such that *y* is dominated by *x* with respect to P, i.e. *y*∈ $D_P^-(x)$. For example, if considering again the above road section *x* and *P*={"*traffic volume*", "*percentage of heavy vehicles*"}, there exists at least one road sections y belonging to $D_P^-(x)$ (because evaluated moderate or high with respect to traffic volume and percentage of heavy vehicles) has a recommended speed limit of at least 90 km/h (i.e. $y \in Cl_4^{\geq}$ and consequently $D_P^-(x) \cap Cl_4^{\geq} \neq \varnothing$) and then x could be classified with recommended speed limit at least 90 km/h. In simple words, this means that according to the objects in the universe U, a recommended speed limit of at least 90 km/h could be taken into consideration in case of not worse conditions than x on the two criteria "*traffic volume*" and "*percentage of heavy vehicles*", because in the universe there is road section y that is not better than x with respect to considered criteria but has a speed limit of 90km/h. This is due to the fact that there is an ambiguity between x and y with respect to criteria from P.

Thus, with respect to $P\subseteq C$, the set of all objects belonging to $Cl_t^{\geq}$ without any ambiguity constitutes the *P-lower approximation* of $Cl_t^{\geq}$, denoted by $\underline{P}(Cl_t^{\geq})$, and the set of all objects that could belong to $Cl_t^{\geq}$ constitutes the *P-upper approximation* of $Cl_t^{\geq}$, denoted by $\overline{P}(Cl_t^{\geq})$:

$$\underline{P}(Cl_t^{\geq})=\{x\in U:\ D_P^{+}(x)\subseteq Cl_t^{\geq}\}$$
$$\overline{P}(Cl_t^{\geq})=\{x\in U:\ D_P^{-}(x)\cap Cl_t^{\geq}\neq\emptyset\}$$

for t=1,...,n.

Analogously, one can define *P-lower approximation* and *P-upper approximation* of $Cl_t^{\leq}$:

$$\underline{P}(Cl_t^{\leq})=\{x\in U:\ D_P^{-}(x)\subseteq Cl_t^{\leq}\}$$
$$\overline{P}(Cl_t^{\leq})=\{x\in U:\ D_P^{+}(x)\cap Cl_t^{\leq}\neq\emptyset\}$$

for t=1,...,n.

Observe that $\underline{P}(Cl_t^{\geq})\subseteq\overline{P}(Cl_t^{\geq})$, for all $P\subseteq C$ and for all t=1,...,n.

4.3 Decision Rules and procedures for generation of decision rules

The dominance-based rough approximations of *upward and downward unions of classes* can serve to induce a generalized description of objects contained in the information table in terms of ''*if..., then...*'' decision rules (Greco et al., 2002a) (Greco et al., 2005) (Slowinski et. al., 2005).

In DRSA, for a given *upward or downward union of classes*, $Cl_t^{\geq}$ or $Cl_s^{\leq}$, the decision rules induced under a hypothesis that objects belonging to $\underline{P}(Cl_t^{\geq})$ or $\underline{P}(Cl_s^{\leq})$ are *positive* and all the others *negative*, suggest a *certain* assignment to ''at least class Cl_t'' or to ''at most class Cl_s'', respectively; on the other hand, the decision rules induced under a hypothesis that objects belonging to the intersection $\overline{P}(Cl_s^{\leq})\cap\overline{P}(Cl_t^{\geq})$ are *positive* and all the others *negative*, are suggesting an *approximate* assignment to some classes between Cl_s and Cl_t ($s<t$).

Assuming that, for each $q\in C$, $V_q\subseteq$R (i.e. V_q is quantitative) and that, for each $x,y\in U$, $f(x,q)\geq f(y,q)$ implies $x\succeq_q y$ (i.e. V_q is preference-ordered), the following three types of decision rules can be considered:

1) D$_{\geq}$-*decision rules* with the following syntax:

   if $f(x,q_1)\geq r_{q1}$ *and* $f(x,q_2)\geq r_{q2}$ *and …* $f(x,q_p)\geq r_{qp}$, *then* $x\in Cl_t^{\geq}$,

   where $P=\{q_1,...,q_p\}\subseteq C$, $(r_{q1},...,r_{qp})\in V_{q1}\times V_{q2}\times...\times V_{qp}$ and $t\in\{2,…,n\}$;

   for example:

   if lane width is ≥ "3.75 m", road signs are "present", pavement condition are "high" and Roadside Hazard Rating is ≤ "3", then recommended speed limit have to be "at least" 80 km/h, i.e. road section x $\in Cl_3^{\geq}$.

2) D$_{\leq}$-*decision rules* with the following syntax:

   if $f(x,q_1)\leq r_{q1}$ *and* $f(x,q_2)\leq r_{q2}$ *and ...* $f(x,q_p)\leq r_{qp}$, *then* $x\in Cl_t^{\leq}$,

   where $P=\{q_1,...,q_p\}\subseteq C$, $(r_{q1},...,r_{qp})\in V_{q1}\times V_{q2}\times...\times V_{qp}$ and $t\in\{1,…,n-1\}$;

   for example:

   if shoulder width is ≤ "0.50 m", Roadside Hazard Rating is ≥ "2", accident rate is ≥ "high" and adverse alignment are present, then recommended speed limit have to be "at most" 70 km/h, i.e. road section x $\in Cl_2^{\leq}$.

An object $x\in U$ *supports* decision rule r if its description is matching both the condition part and the decision part of the rule. The decision rule r *covers* object x if it matches the condition part of the rule.

Each decision rule is characterized by its *strength*, defined as the number of objects supporting the rule. In the case of approximate rules, the strength is calculated for each possible decision class separately.
Procedures for generation of decision rules from a decision table use an inductive learning principle. The objects are considered as examples of classification. In order to induce a decision rule with an univocal and certain conclusion about assignment of an object to decision class *X*, the examples belonging to the *C*-lower approximation of *X* are called *positive* and all the others *negative*.
Analogously, in case of a possible rule, the examples belonging to the *C*-upper approximation of *X* are positive and all the others negative. Possible rules are characterized by a coefficient, called *confidence*, telling to what extent the rule is consistent, i.e. what is the ratio of the number of positive examples supporting the rule to the number of examples belonging to set *X* according to decision attributes. Finally, in case of an approximate rule, the examples belonging to the *C*-boundary of *X* are positive and all the others negative.
With respect to Table 1 (*information table*) the DRSA gives back 391 decision rules in the *"if….then…"* form, and more precisely:

- ✓ 89 decisions recommend a speed limit ≥ 90 km/h;
- ✓ 63 decisions recommend a speed limit ≥ 80 km/h;
- ✓ 53 decisions recommend a speed limit ≥ 70 km/h;
- ✓ 67 decisions recommend a speed limit ≤ 60 km/h;
- ✓ 59 decisions recommend a speed limit ≤ 70 km/h;
- ✓ 60 decisions recommend a speed limit ≤ 80 km/h.

Every decision rule specifies the recommended speed limit and the reasons why it has been recommended; for every rule it is also possible to know which objects (example cases on information table) support the rule. The possibility of recognizing the examples supporting specific decision rules allows the authority' managers to understand and discuss the set of decision rules, which can be also easily revised if required. For example, the expert can be interested to know that the rule:

*if Traffic Volume is ≤ "low", Shoulder Width is ≥ "1.00 m", Pavement Con*dition *is ≤ "medium" and Accident Rate is ≤ "low" then recommended speed limit have to be "at least" 90 km/h*

is supported by the exemplary cases n. 7, 31, 44, 46, 47, 51 and 70 of the information table.
In table 6 some examples of the 391 decision rules have been reported, indicating also the road sections from Table 1, which support the considered rule.
It is worthy noting that an algorithm specifically developed by the authors has implemented the induction of decision rules, which is based on the DRSA methodology. For the induction of decision rules it is also available a free software, called jMAF, free of charge at the web address: http://idss.cs.put.poznan.pl/site/139.html.

5. Application of the decision model

After discussion, the expert panel accepted the set of the 391 decision rules to be the decision model for setting speed limits on speed zone.
The developed Decision Support System (DSS) actually uses a software, specifically developed to easily interact with DRSA output, i.e. the decision rules.
Giving as input the characteristics of the new road section, the software uses decision rules generated by DRSA and gives back a recommended speed limit. The software also provides the most important decision rules that can help decision makers to understand the reasons of the suggested speed limit.
An example on a road section is presented herein.
The characteristics of the road section in question have been listed below:

- Traffic Volume (A_1) = High
- Percentage of heavy vehicles (A_2) = Low
- Lane width (A_3) = 3.50 m
- Shoulder width (A_4) = 1.00 m
- Road Signs (A_5) = Yes
- Pavement Condition (A_6) = Moderate
- Roadside Hazard Rating (A_7) = 3
- Accident Rate (A_8)= Low
- Adverse Alignment (A_9) = Yes

The DSS suggests 70 km/h as speed limit and returns 20 decision rules (Table 7):

- 8 of them recommend a speed limit ≥ 70 km/h;
- 2 of them recommend a speed limit ≤ 70 km/h
- 10 of them recommend ≤ 80 km/h.

The speed limit value is calculated as the value that satisfy all decision rules returned by the DRSA: for the example case, the speed limit satisfying all the three suggestions is 70 km/h, because 70 km/h is not smaller than 70 km/h, not larger than 70 km/h and not larger than 80 km/h.

If it is not possible to satisfy all decision rules, then the rules supported by larger and larger numbers of road section in the original data base need to be considered, until the set of remaining rules becomes consistent with a unique value of the speed limit. For example, let us consider a road section with the following characteristics:

- Traffic Volume (A_1) = High
- Percentage of heavy vehicles (A_2) = Low
- Lane width (A_3) = 3.50 m
- Shoulder width (A_4) = 1.00 m
- Road Signs ($A_{5)}$ = Yes
- Pavement Condition (A_6) = Moderate
- Roadside Hazard Rating (A_7) = 3
- Accident Rate (A_8)= Low
- Adverse Alignment (A_9) = No

The DSS gives 25 rules matching the considered case and more precisely:

- 13 decision rules suggesting speed limit ≥ 70 km/h,
- 5 decision rules suggesting speed limit ≥ 80 km/h,
- 2 decision rules suggesting speed limit ≥ 90 km/h,
- 1 decision rules suggesting speed limit ≤ 70 km/h,
- 4 decision rules suggesting speed limit ≤ 80 km/h.

In this case no speed limit is able to satisfy all the rules. Indeed there is not a unique speed limit value that can satisfy all the five suggestions, because does not exist a value that is at the same time not smaller than 70 km/h, not smaller than 80 km/h, and not smaller then 90 km/h, and not greater than 70 km/h, and not greater than 80 km/h.

The set of rules according to their support therefore needs to be reduced, taking progressively into account decision rules more and more supported. Taking into account decision rules supported by at least 21 road sections, the software returns:

- 11 decision rules suggesting speed limit ≥ 70 km/h,
- 1 decision rules suggesting speed limit ≥ 80 km/h,
- 1 decision rules suggesting speed limit ≤ 70 km/h,
- 4 decision rules suggesting speed limit ≤ 80 km/h.

Also in this case there is not a unique speed limit value that can satisfy all suggestions. Indeed, there does not exist a value that is at the same time not smaller than 70 km/h, not smaller than 80 km/h, and not greater than 70 km/h, and not greater than 80 km/h.

Taking into account decision rules supported by at least 22 road sections, the software returns:

- 7 decision rules suggesting speed limit ≥ 70 km/h,
- 1 decision rules suggesting speed limit ≥ 80 km/h,
- 4 decision rules suggesting speed limit ≤ 80 km/h.

In this case exist a speed limit that can satisfy all the three suggestions which is 80 km/h.

The decision rules aim to explain to the decision-maker the reasons why the expert panel suggests a specific speed limit for the considered road section. Obviously it is not reasonable to submit too many decision rules to the decision maker, so only the most supported rules recommending the exact value of the speed limit (and precisely the lower and the upper limit) are presented to the decision maker.
For the first example case the final output is presented in table 8.

Our methodology can be used also in case the information of some road section characteristic is not available (for example traffic or crash data) as explained by the following examples.
Let us consider a road section, for which accident rate data is not available, with characteristics listed below:

- Traffic Volume (A_1) = High
- Percentage of heavy vehicles (A_2) = Low
- Lane width (A_3) = 3.50 m
- Shoulder width (A_4) = 1.00 m
- Road Signs (A_5) = Yes
- Pavement Condition (A_6) = Moderate
- Roadside Hazard Rating (A_7) = 3
- Accident Rate (A_8)= **not available**
- Adverse Alignment (A_9) = Yes

In this case, it is necessary to assign a value to the accident rate data. We decide to work in behalf of security, putting the less favorable value (in terms of road security) of accident rate, i.e. A_8= High. In this case our methodology suggests a 60 km/h speed limit and returns 21 decision rules:

- 2 of them recommend a speed limit ≤ 60 km/h;
- 3 of them recommend a speed limit ≤ 70 km/h;
- 16 of them recommend ≤ 80 km/h.

If we decide to put in the other possible value of accident rate (i.e. A_8= Low) we return at the first example case, where recommended speed limit is 70 km/h.
So, it is possible to insert some conjectured value for the characteristics with missing data and apply the proposed procedure. However, it is clear that the solution suggested by the software is strongly dependent on the conjectured values. Instead it could be interesting to try to get a result that, maintaining a cautionary principle, accepts that there is some missing value.
Observe that in some cases, assigning different values to the missing data, the results may change (as in the above example), or may not change as in the following example:

- Traffic Volume (A_1) = **not available**
- Percentage of heavy vehicles (A_2) = **not available**
- Lane width (A_3) = 3.50 m
- Shoulder width (A_4) = 1.00 m
- Road Signs (A_5) = Yes
- Pavement Condition (A_6) = Moderate
- Roadside Hazard Rating (A_7) = 3

- Accident Rate (A_8)= Low
- Adverse Alignment (A_9) = Yes

Using the less favorable values (in terms of road security) of both attributes, i.e. A_1= High and A_2= High, our methodology suggests 70 km/h as speed limit and returns 21 decision rules:

  - 8 of them recommend a speed limit ≤ 70 km/h;
  - 4 of them recommend a speed limit ≥ 70 km/h;
  - 18 of them recommend ≤ 80 km/h.

Therefore, in this case, the recommended speed limit does not depend on the value assigned to the missing data (although the corresponding decision rules are different).

Discussion

Thus, on the basis of some assignments of speed limits that one or more experts fixed on a sample of road sections, described according to some pertinent characteristics such as lane width, road sign, pavement condition and so on, the presented model get some decision rules in the following form: *"if road section characteristics are …, then the recommended speed limit have to be at least/can be at most …"*. That means that, taking into account a new road section, every time that the antecedents, i.e. the *"if-part*" conditions, are satisfied, also the consequence, i.e. the "*then-part*", is satisfied.

Moreover, for each decision rule, it is possible to know which are the exemplary decisions, which it is based, i.e. which are the exemplary decisions that the given rule is describing. This information is important because these are important elements permitting that the decision maker (DM) could critically evaluate the decision rules. If the DM is not convinced by some decision rule, possibly there is some example to which should correspond a different decision in terms of recommended speed limits, such that after revising the not convincing exemplary decisions a new set of decision rules can be induced and again submitted to the approval of the DM until she is satisfied by the set of decision rules. This is concordant with posterior rationality of March (March, 1978), which advocates discovery of intentions of a decision maker instead of the interpretation of a priori position. In simple words for the experts is easier to give some examples of good decisions rather than explain the reasons for which a decision is good.

In this sense the methodology we adopt, which is the Dominance-based Rough Set Approach (DRSA), asks to the experts what for them is easier, i.e. a set of exemplary decisions, and gives them what for them is more difficult, i.e. a set of explanations about the goodness of the decisions. Moreover this explanation is expressed in a clear way that permits the experts to see what are the exact relations between the provided information and the final recommendation. In fact, many statistical methods such as those one of the regression approach, express their results through a technical formulation that the users cannot understand without a specific background and consequently, very often those results are perceived as a *black box* whose recommendations have to be accepted because the "scientific authority" of the model guarantees that the result is "right". In this context, the aspiration of the DM to find good reasons to make decision is frustrated and rises the need for a more transparent methodology in which the relation between the original information and the final recommendation is clearly shown. Such a transparent methodology searched for has been called *glass box* (Slowinski et al., 2009) and DRSA has proved to be its typical representative.

So, the aim of the presented work is to develop a decision-support tool that can provide decision rules, that synthesize some exemplary decisions about speed limits supplied by the experts, in a very natural and clear form (like the *"if… then…"* form), easy to understand without a specific statistical background.

The system periodically can also be evaluated and updated if necessary, basing on the managing authority's current policies, engineering criteria, practices, and experience.
In fact, the DRSA permits a simple and transparent system revision because it only requires updating the set of exemplary decisions from which the "*if…, then…*" decision rules are induced. The rules explain the decision policy adopted in the examples and, after acceptance, can be used to support new decisions.

6. Conclusion

The first version of a multi-criteria decision support instrument to suggest the most appropriate speed limits for speed zones to managing authority has been presented in this paper.
The model developed herein provides to decision makers a safe speed limit using geometric and operative characteristics and maintenance conditions; it provides also some easily understandable decision rules that can help to explain the reasons for the suggested speed limit for the investigated road section.
The developed Decision Support System is based on Dominance-based Rough Set Approach (DRSA) which requires basic input information in terms of evaluation examples, i.e. exemplary decision about speed limits, and express the results of the decision analysis in a very understandable way using *"if… then…"* rules.
The adopted Dominance-based Rough Set Approach presents several advantages over other approaches in terms of transparency and manageability and has permitted to develop an intelligible and user-friendly multi-criteria decision model for setting speed limits in speed zone.
In fact DRSA produces a decision model expressed in terms of easily understandable "*if… then…*" decision rules which permits to control the decision process and to avoid the "black box" effects of many alternative decision support methods, ensuring a high degree of transparency. The DRSA also permits a simple revision of the decision model because it only requires to update the set of exemplary decisions from which the "*if… then…"* decision rules are induced. So, on the basis of the managing authority's current policies, engineering criteria, practices, and experience, the system can periodically be evaluated and updated. Moreover the model can be easily modified using different "condition attributes", or using a "decision attribute" representing different decision makers with different purposes and priorities. In this way the system can be adapted to take into consideration different objectives and strategies.
In this paper it is also presented a sample application of the built Decision Support System that uses a specifically developed software which can easily interface with the DRSA output. Putting as input the investigated road section characteristics, the software gives back a recommended speed limit and only the more important decision rules that can help decision makers to understand the reasons of the suggested speed limit. The obtained results are very encouraging and were found to be very interesting for decision makers, because they are clear and very helpful in decision-making process.
The developed Decision Support System aims the similar purpose of the above-mentioned models, i.e. USLIMITS and SaCredSpeed, but presents some important difference with them.
The first difference is the adopted method for the DSS developing, because in the presented model a Dominance-based Rough Set Approach (DRSA) has been used, which offers the numerous advantages presented above in terms of transparency and manageability.
In the final output the developed DSS, besides recommending a speed limit value (like USLIMITS), also provides some decision rules that can help decision makers to understand the reasons of the suggested speed limit and so help them to discover the most appropriate measure to improve road safety and drivers' compliance with speed limits.

Finally, because of its versatility, the methodology we are proposing can be adapted to every road management strategy only changing the attributes and/or the decision examples that form the information table.
Many different possible scenarios in future possible development and improvement of the proposed methodology can be considered. One of these possible improvements is a Decision Support System which would also consider dynamics attributes in order to suggest "dynamic speed limits", that are speed limits that change repeatedly over time to appropriate levels, depending on such variable conditions as weather, traffic or other unstable conditions. Another possible improvement is a GIS interfaced-Decision Support System, in order to provide to users a more complete instrument in the decision making process of speed management.

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Table(s)

Table 1: Information table of exemplary decision

Road sections	Attributes									Recom. Speed Limit
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	
	Traffic Vol.	% heavy veh.	Lane width	Shoulder width	Road Signs	Pavement Condition	RHR	Accident Rate	Adverse Alignment	
1	H	H	3.25	0.00	Y	M	1	L	N	80
2	H	M	3.25	1.00	Y	H	1	H	N	90
3	M	M	3.50	1.00	Y	L	2	L	N	90
4	L	L	3.50	1.00	Y	M	4	H	Y	70
5	L	M	3.50	0.00	N	H	2	L	N	90
6	M	M	3.50	1.00	Y	H	1	L	Y	90
7	L	H	3.50	1.25	Y	H	2	L	N	90
8	H	H	3.50	0.00	N	L	4	H	Y	60
9	M	H	3.75	0.00	N	M	2	L	Y	80
10	H	M	3.75	0.75	Y	L	3	H	Y	60
….	…	…	…	…	…	…	…	…	…	…
….	…	…	…	…	…	…	…	…	…	…
….	…	…	…	…	…	…	…	…	…	…
91	M	L	3.00	0.00	N	H	3	H	Y	60
92	L	M	3.75	0.00	N	M	1	H	N	90
93	M	H	3.75	0.50	Y	M	4	H	N	70
94	H	L	3.75	1.00	Y	L	3	L	N	80
95	L	M	3.50	0.00	N	M	2	H	N	80
96	L	L	3.75	1.00	Y	H	4	H	Y	70
97	M	M	3.50	1.25	Y	H	2	H	N	90
98	L	M	3.00	1.00	Y	L	1	L	Y	80
99	H	L	3.00	0.70	Y	M	2	H	Y	80
100	H	H	3.00	0.00	N	H	3	H	Y	70

Table 2: Examples of discovered decision rules

If...	then...	Objects (road sections) that support the rules
Traffic Volume ≤ "low" and *Shoulder Width* ≥ "1.00 m" and *Pavement Condition* ≤ "medium" and *Accident Rate* ≤ "low"	$Speed\ Limit \geq 90\ km/h$	7,31,44,46,47,51,70
Lane Width ≥ "3.75 m" and *Road Signs* are "present" and *Pavement Condition* = "high" and *Roadisde Hazard Rating* ≤ "3"	$Speed\ Limit \geq 80\ km/h$	18,19,36,46,80,85
Traffic Volume ≤ "low" and *Percentage of Heavy Vehicles* ≤ "moderate" and *Shoulder Width* ≥ "0.70 m" and *Pavement Condition* ≤ "medium"	$Speed\ Limit \geq 70\ km/h$	4,26,31,44,46,47,51,70,83,96
Lane Width ≤ "3.25 m", *Shoulder Width* ≤ "0.70 m" and *Roadisde Hazard Rating* ≥ "4"	$Speed\ Limit \leq 60\ km/h$	14,15,22,37,45,69,77,88
Shoulder Width ≤ "0.50 m" and *Roadisde Hazard Rating* ≥ "2" and *Accident Rate* ≥ "high" and *Adverse Alignment* are present	$Speed\ Limit \leq 70\ km/h$	8,14,24,41,45,69,73,75,91,100
Traffic Volume ≥ "medium" and *Road Signs* are "absent" and *Accident Rate* ≥ "high"	$Speed\ Limit \leq 80\ km/h$	8,24,41,65,86,91,100

Table 3: Decision Rules for the Example

Rule	If...	then...	Objects (road sections) that support the rules
R_1	*Percentage of Heavy Vehicles* ≤ ”low” and *Lane Width* ≥ ”3.50 m” and *Accident Rate* ≤ ”low”	$Speed\ Limit \geq 70\ km/h$	16,18,29,31,44,46,47,50,54,56,80,94
R_2	*Percentage of Heavy Vehicles* ≤ ”moderate” and *Shoulder Width* ≥ ”0.75 m” and *Accident Rate* ≤ ”low”	$Speed\ Limit \geq 70\ km/h$	3,6,12,18,29,30,31,34,44,46,47,48,51,55,70,72,80,87,89,94,98
R_3	*Lane Width* ≥ ”3.50 m” and *Shoulder Width* ≥ ”0.50 m” and *Accident Rate* ≤ ”low”	$Speed\ Limit \geq 70\ km/h$	3,6,7,12,18,19,27,29,30,31,34,44,46,47,51,53,58,70,80,87,94
R_4	*Lane Width* ≥ ”3.50 m” and *Road Signs* = ”present” and *Accident Rate* ≤ ”low”	$Speed\ Limit \geq 70\ km/h$	3,6,7,11,16,17,18,19,23,27,29,30,31,34,36,44,46,47,51,53,56,58,70,80,87,94
R_5	*Percentage of Heavy Vehicles* ≤ ”moderate” and *Pavement Condition* ≤ ”medium” and *Accident Rate* ≤ ”low”	$Speed\ Limit \geq 70\ km/h$	16,18,29,31,44,46,47,50,54,55,56,72,80
R_6	*Percentage of Heavy Vehicles* ≤ ”moderate” and *Road Signs* = ”present” and *Pavement Condition* ≤ ”medium” and *Accident Rate* ≤ ”low”	$Speed\ Limit \geq 70\ km/h$	6,11,16,18,29,30,31,36,44,46,47,48,51,53,55,56,70,72,80,87,89
R_7	*Shoulder Width* ≥ ”0.75 m” and *Roadside Hazard Rating* ≤ ”3” and *Accident Rate* ≤ ”low”	$Speed\ Limit \geq 70\ km/h$	3,6,7,12,18,19,27,29,31,44,46,47,48,51,55,70,72,80,87,94,98
R_8	*Road Signs* = ”present” and *Pavement Condition* ≤ ”medium” and *Roadside Hazard Rating* ≤ ”3” and *Accident Rate* ≤ ”low”	$Speed\ Limit \geq 70\ km/h$	1,6,7,16,18,19,27,29,31,36,44,46,47,48,51,53,55,56,70,72,80,87
R_9	*Traffic Volume* ≥ ”medium” and *Lane Width* ≤ ”3.50 m” and *Shoulder Width* ≤ ”1.00 m” and *Roadside Hazard Rating* ≥ ”3”	$Speed\ Limit \leq 70\ km/h$	8,15,25,28,29,30,33,34,35,37,38,39,42,45,57,64,74,82,89,91,100
R_{10}	*Roadside Hazard Rating* ≥ ”3” and *Adverse Alignment* are present	$Speed\ Limit \leq 70\ km/h$	4,8,10,11,13,14,15,16,21,24,25,27,28,29,33,35,37,39,41,42,43,45,50,62,64,69,74,75,77,82,88,89,91,96,100
R_{11}	*Traffic Volume* ≥ ”high” and *Lane Width* ≤ ”3.50 m” and *Pavement Condition* ≥ ”medium”	$Speed\ Limit \leq 80\ km/h$	1,8,15,25,33,35,37,38,42,48,60,61,64,73,74,79,89,99
R_{12}	*Traffic Volume* ≥ ”high” and *Lane Width* ≤ ”3.50 m” and *Roadside Hazard Rating* ≥ ”2”	$Speed\ Limit \leq 80\ km/h$	8,13,15,25,33,35,37,38,42,48,60,61,64,73,74,79,89,90,99,100
R_{13}	*Shoulder Width* ≤ ”1.20 m” and *Roadside Hazard Rating* ≥ ”3”	$Speed\ Limit \leq 80\ km/h$	4,8,10,11,14,15,16,17,22,23,24,25,27,28,29,30,33,34,35,37,38,39,41,42,43,45,49,50,57,62,64,66,69,74,75,76,77,82,88,89,91,93,94,96,100
R_{14}	*Traffic Volume* ≥ ”high” and *Pavement Condition* ≥ ”medium” and *Roadside Hazard Rating* ≥ ”3”	$Speed\ Limit \leq 80\ km/h$	8,10,15,21,24,25,27,33,35,37,38,41,42,48,64,74,89,94
R_{15}	*Traffic Volume* ≥ ”high” and *Adverse Alignment* are present	$Speed\ Limit \leq 80\ km/h$	8,10,13,15,21,24,25,27,33,35,37,41,42,50,61,64,67,73,74,79,85,89,99,100
R_{16}	*Traffic Volume* ≥ ”high” and *Pavement Condition* ≥ ”medium” and *Adverse Alignment* are present	$Speed\ Limit \leq 80\ km/h$	8,9,10,15,21,24,25,27,28,29,32,33,35,37,39,41,42,45,61,64,67,73,74,79,82,89,99

R_{17}	*Lane Width* ≤ ”3.50 m” and *Shoulder Width* ≤ ”1.00 m” and *Pavement Condition* ≥ ”medium” and *Adverse Alignment* are present	$Speed\ Limit \leq 80\ km/h$	4,8,11,14,15,16,25,28,29,32,33,35,37,39,42,45,61,62,64,69,73,74,79,82,88,89,98,99
R_{18}	*Roadside Hazard Rating* ≥ ”3” and *Adverse Alignment* are present	$Speed\ Limit \leq 80\ km/h$	4,8,10,11,13,14,15,16,21,24,25,27,28,29,33,35,37,39,41,42,43,45,50,62,64,69,74,75,77,82,88,89,91,96,100
R_{19}	*Traffic Volume* ≥ ”medium” and *Roadside Hazard Rating* ≥ ”2” and *Adverse Alignment* are present	$Speed\ Limit \leq 80\ km/h$	8,9,10,13,15,21,24,25,27,28,29,32,33,35,37,39,41,42,45,50,61,64,67,73,74,79,82,84,89,91,99,100
R_{20}	*Pavement Condition* ≥ ”medium” and *Roadside Hazard Rating* ≥ ”2” and *Adverse Alignment* are present	$Speed\ Limit \leq 80\ km/h$	4,8,9,10,11,14,15,16,21,24,25,27,28,29,32,33,35,37,39,41,42,43,45,61,62,64,67,69,73,74,75,79,82,88,89,99

Table 4: Final output for the Example

Recommended Speed Limit	**70 km/h**
Decision Rules	***"If the lane width is ≥ 3.50 m and road signs are present and accident rate is low then Speed Limit can be ≥ 70 km/h"***
	"If the Roadside Hazard Rating is ≥ 3 and Adverse Alignment are present then Speed Limit have to be ≤ 70 km/h"