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FACULTAD DE INGENIERÍA CIVIL

A FUZZY MODEL OF ASSETS CONDITION ASSESSMENT FOR MAINTENANCE AND RISK MANAGEMENT OF ROAD NETWORKS

T E S I S

QUE PARA OBTENER EL TÍTULO DE:

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A mis papás, mi novia y hermanas.

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Abstract

The management of a road network needs performance evaluation models that handle the uncertainty of the data of its different types of road assets to identify problems and/or damages that require attention within the conservation plans. Most of the existing evaluation systems are limited due to the need for an expert to evaluate the data, the lack of a classification of fixed and dynamic properties, and they consider only individual evaluation of the assets.

This work presents the development of a fuzzy model for the integral evaluation of the state of road networks. The assets considered are flexible pavements, surface drainage, geotechnical, horizontal, vertical marking, safety devices, cuts, and embankments. For the development of the model, we generate catalogs of the properties for each asset at inventory and performance levels. In addition, individual assessment models were proposed at a modular level to identify their impairments. The membership functions selected to describe the fuzzy sets that describe the behavior of asset properties were triangular and trapezoidal. The inference engine for the evaluation of all the rules is a Mandami model.

The integral evaluation model developed considers the relationships between the state of the different assets of the red highway and their interaction with the environment in which they are located. We divide the integral evaluation into three levels: 1) individual asset evaluation, 2) evaluation of highway sections, and 3) evaluation of highway segments.

The use of fuzzy logic to determine the state of assets allows more approximate modeling of the degree of deterioration of the assets that make up the road network than classical logic. This will enable you to evaluate with better granularity and establish relationships between different assets to observe changes in the state (deterioration) of the network. We present a hypothetical case study to evaluate the feasibility of the evaluation model, where three road sections were evaluated: section level, embankment, and cut.

Keywords: Assets, Integral Evaluation, Fuzzy logic, Damages, Road Networks

Resumen

La gestión de una red vial necesita modelos de evaluación del desempeño que manejen la incertidumbre de los datos de sus diferentes tipos de activos viales, con el fin de identificar problemas y/o daños que requieran atención dentro de los planes de conservación. La mayor parte de los sistemas de evaluación existentes están limitados debido a la necesidad de un experto que evalué los datos obtenidos, la falta de clasificación de las propiedades fijas y dinámicas, así como la consideración de una evaluación individual de los activos.

Este trabajo presenta el desarrollo de un modelo difuso de evaluación integral del estado de activos carreteros. Como parte de los activos considerados se encuentran: pavimentos flexibles, drenaje superficial, geotécnicos, señalamiento horizontal y vertical, dispositivos de seguridad, cortes y terraplenes. Para el desarollo del modelo se generaron catalogos de las propiedades a nivel inventario y desempeño de cada activo. Además, se propusieron modelos de evaluación individual a nivel modular para identificar sus deterioros. Las funciones de membresía seleccionadas para describir los conjuntos difusos que describan el comportamiento de las propiedades de los activos fueron triangulares y trapezoidales. El motor de inferencia para la evalución de todas las reglas es un modelo Mandami.

El modelo de evaluación integral desarrollado contempla las relaciones que existen entre el estado de los diferentes activos de la red carretera, así como su interacción con el medio ambiente en que se encuentran. La evaluación integral se divide en tres niveles: 1) evaluación individual de activos, 2) evaluación de secciones carreteras y 3) evaluación de segmentos carreteros.

El uso de lógica difusa para la determinación del estado de los activos permite modelar de una manera más aproximada el grado de deterioro de los activos que conforman la red carretera que con el uso de lógica clásica. Esto permite evaluar con una mejor granularidad y establecer las relaciones entre distintos activos para observar los cambios de estado (deterioros) de la red. Para evaluar la viabilidad modelo de evaluación se presenta un caso de estudio hipótetico, donde se evaluan tres secciones carreteras: a nivel, terraplén y corte.

Palabras Clave: Activos Carreteros, Evaluación Integral, Lógica Difusa, Deterioro, Red Carretera

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Chapter 1

Introduction

Mexican Rad Network (MRN) is one of the fundamental pillars of the national economy.[1] MRN is the most crucial network to move loads and people throughout the country. According to SCT, in 2019, MRN was used to move 94% of passengers and 56% of the country´s loads. [2]

Considering the importance mentioned above, Road Network (RN) administrators have recognized the requirement of tools and procedures to guarantee its integral operation. According to PIARC in their publication "Innovative approaches to asset management" [3] It has taken more importance after to publication of the norm ISO55000.

To ensure the correct integral operation of the Road Networks, it is necessary that all the road network assets, composed of pavements, bridges, tunnels, cuts, embankments, drainage works, signs, safety devices, and intelligent transport systems, be in optimum conditions. Hence, it is important to invest in their conservation. [4]

Asset Management is a set of business decision-making processes that allow communicating the Road Network necessities and conditions to all the involucrate actors. The management assets should not be confused with a computational system or management systems for pavements or bridges. [5]

The relevance of having adequate management is related to optimizing the available economic resources because they are always limited [6]

The number of managed assets differs for each International Road Network administrator. Nevertheless, they consider that it is important to include most of the assets in their management system. In countries like England, Spain, or France, the paradigm of only managing pavements and bridges has been left behind. [7] [8] [9]

1.1 Problem Statement

Road Networks are composed of a set of assets classified in Pavement, Structures, Geotechnical, Drainage, and Safety Devices. The adequate road operation requires that all their assets be in optimal conditions. It demands a lot of economic resources, which generally are limited. Therefore it is necessary to have adequate management of maintenance resources to assure the correct operation of the road networks, prioritizing the attention of the essential needs. Asset Management Systems are a tool to do this task.

To determine the attention priorities in road networks maintenance planning. Asset Management Systems should solve two main issues: 1) Asset Individual Condition State, and 2) Relationships among these. The first one is related to establishing how to evaluate the assets to understand their state in the network. The second one determines how the state of the assets impacts the Road Network. It allows an entire road network diagnostic to plan maintenance works as a function of the most significant necessities.

In Mexico, the management road network is based only on the management of pavements and bridges. However, more assets are present in the road network, as we can show in Image 1.1 where we can observe pavement, tunnel, drainage works, safety devices, signs, cuttings, and intelligent transport systems (ITS). Moreover, the management of bridges and pavements is made separately, and they have not considered their relationships.

Figure 1.1: Mexican Road Asset Management

It has only been considered the management of pavements and bridges, which has resulted in many road problems. An example is the undermining in “Paso Expres de Cuernavaca”. In 2017, after three months of the inauguration of the ampliation and modernization of a section in Mexico-Acapulco freeway suddenly appeared a bigger undermine Image 1.2 provoking that a car fell; unfortunately, car users lost their lives in this incident.

Months later, investigations derived from this incident revealed the cause. It was provoked by a culvert damaged during the building process Image 1.3. This preexisting culvert was not considered on the modernization project. The project just scrutinized the pavement works, although there were more assets in the road network.

Figure 1.2: Undermining Paso Expres

Figure 1.3: Undermining Paso Expres Culvert

This situation is an example of extensive and expensive projects that have failed because road network administrators did not consider all the road network assets integrally. The lack of an integral evaluation has generated inefficient projects and has derived from a misuse of the limited economic resources, resulting in an expensive and inefficient road network.

1.2 Solution Proposal

Diagnosis Systems are a crucial part of the Road Management System and allow determining the state of the evaluated element to identify attention needs. Based on the evaluation of Road Assets and Road Network, we can design a maintenance plan.

We propose in this thesis the design of a fuzzy model of assets condition assessment for maintenance and risk management of road networks as a solution for the described problem.

The design of the proposed system considers first the road's environment, taking into account the road type, weather, and land characteristics. Once we determine the environment, we evaluate the inventory and diagnosis the asset operation. Inventory evaluation allows identifying the asset that generally should configure the road and the initial char-

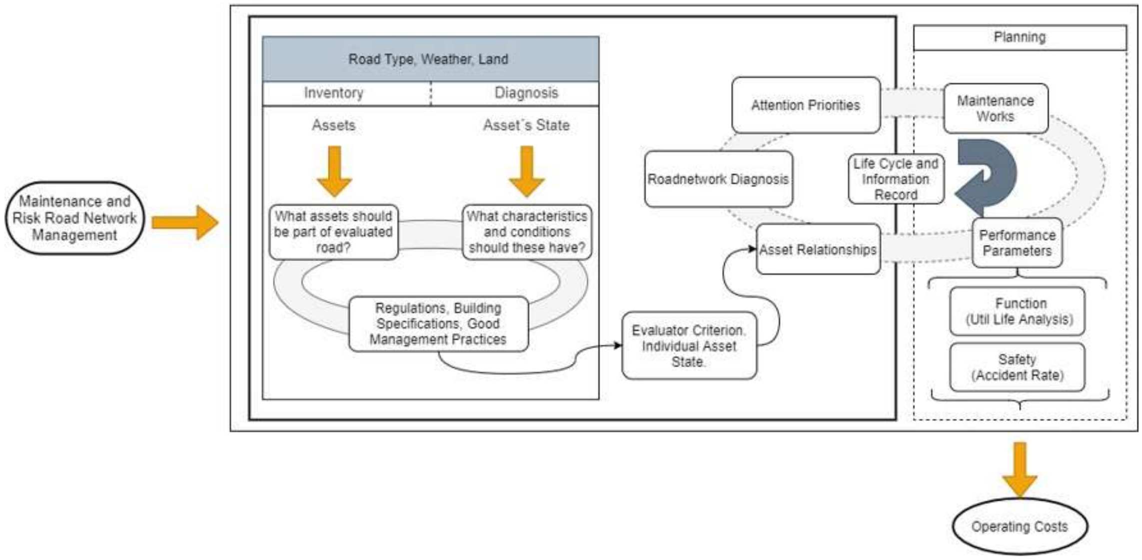


Figure 1.4: Solution Proposal Diagram

acteristics of those. This evaluation should be done in the construction phase or the first time that the system is implemented. On the diagnosis evaluation, operation properties are identified. It considers a comparison between the inventory values and diagnosis values of the properties that can change over time. It allows identifying the attention needs.

Road network evaluation should answer two principal questions. What assets should be part of the evaluated road? And What characteristics and conditions should these have? To answer these questions, we consider regulations, building specifications, and good management practices. Based on these documents, good values are determined.

Once the values are identified, the expert criterion establishes every characteristic to determine the individual asset state. Individual states and assets that should be part of the road are integrated to establish relationships.

The diagnosis of the road network can be made taking into account the relationships and asset evaluation values. We can identify the attention priorities by analyzing the assets interaction and particular values on the determination of the road network state.

Implementation of the proposed system helps to plan maintenance works to accomplish the performance parameters for the correct functioning of the road network. The cyclic evaluations feed the system to identify and verify the damages evolution and asset relationships doing an evaluation life cycle system. It makes the road network evaluation a perfectible time process.

1.3 Objectives

1.3.1 General objective

The general objective of this research is to develop an integral evaluation fuzzy model that includes pavement, drainage, safety and geotechnical assets evaluation with the purpose of diagnose the global state of road networks.

1.3.2 Specific objectives

Some objectives that allow achieving the main objective are the following:

- Identify the functional importance and properties of the individual vial assets to choose the state diagnosis metrics that helps to guide the evaluation process.
- Design individual fuzzy evaluation models for the assets pavement, drainage, safety, and geotechnical based on established metrics (standards and good practices) to evaluate the individual asset status identifying the relationships between them.
- Design an integral fuzzy evaluation model that combines the relationships between the individual evaluation models to diagnose the global state of road networks.

1.4 Scopes

Management information is divided on three evolutive levels: Inventory, Diagnosis and Planning. This project is focus on diagnosis level with the objective to be a formal base for the planning.

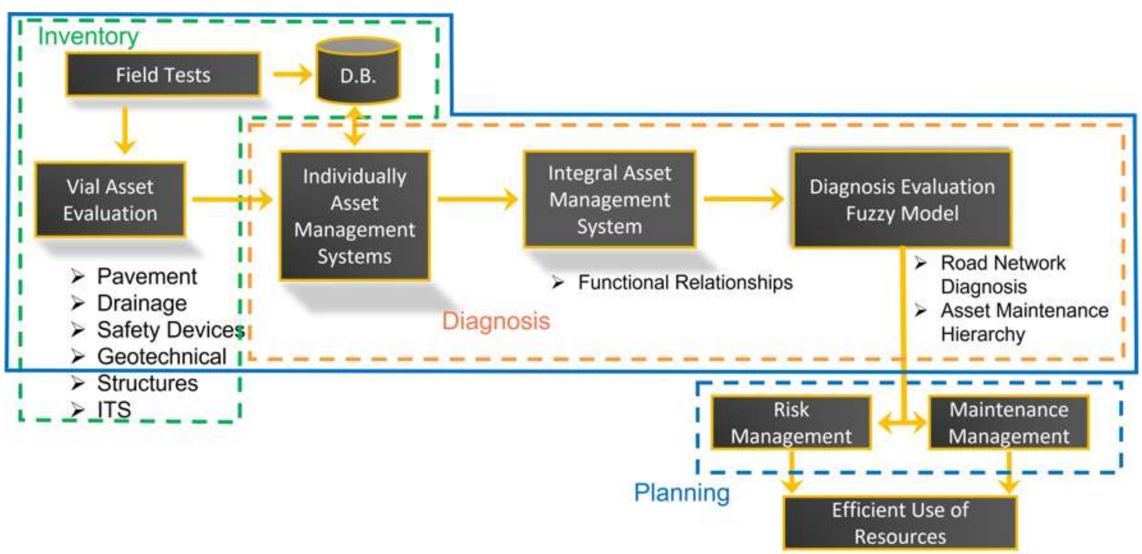


Figure 1.5: Project Scopes

Figure 1.5 presents the components of this research schematically. As mentioned above, this project is focused on the management diagnosis level; however, an inventory level is required to implement the diagnosis level. The proposed model includes the Field Tests for the management inventory, which are recorded on a Data Base and used to make the individual evaluation of Pavements, Drainage, Safety Devices, and Geotechnical Assets. Inventory data are integrated and analyzed using as a framework for the individually Asset Evaluation System, taking into account the regulated and specificated performance values. Based on information of the Individually Asset Evaluation Systems, a Road Network Evaluation System can be designed, establishing the asset relationships on the integral functioning of it. Finally, using the Individual Asset Evaluation as a base according to performance values, the Integral Diagnosis Evaluation is made to generate a Road Network Diagnosis, which is helpful to determine the Hierarchy Asset Maintenance Needs. The proposed evaluation implementation allows a formal methodology to diagnose the Road Network problems, which is necessary to plan the Risk and Maintenance operation works.

Even Asset Road Networks include Pavements, Drainage, Safety Devices, Geotechnical Assets, Structures, and Intelligent Transportation Systems (ITS). The presented research doesn't consider Structures an ITS due to complexity evaluation and the disposable time for its development. However, it is necessary to consider that all the assets are particularly important to the Road Network functioning. So authors are convinced that the research is not complete and should be complemented in the future.

The research purpose is to propose a Diagnosis Fuzzy Model that could be used as a tool for evaluating Road Networks. Implementation of the proposed model there is not contemplated.

1.5 Use of Fuzzy Logic

Generally, Evaluation Road Network Asset Information is ambiguous and uncertain. The principal source of ambiguity is that many of the parameters are not measured directly; because it is very complicated and expensive work. Additionally, measures are done just for representative elements, and finally, they are generalized. As a result, the Evaluation Information is partial and specific, giving uncertainty to a general evaluation.

The Status Determination Process (SDP) is the process by which an evaluator determines the state of the evaluated element. Since Road Network Assets have to be made with uncertainty and ambiguity information, as mentioned before, SDP should consider the evaluator criterion and performance parameters tolerances.

SDP implements logic rules to determine the state, comparing the obtained with the specified parameters measures. There are two ways to do it, classic logic rules or fuzzy logic rules. Figure 1.6 shows it schematically.

When it is made with a classical focus, the parameter's measures are compared with metrics and tolerances established, evaluating if this condition is satisfied or not. This way considers a correct status into the set defined with tolerances established or a failed status outside of it. Because this way squares the answer, it is impossible to establish the asset status considering their deterioration cycles.

Using fuzzy logic rules makes it possible to evaluate the compliance grade into the set

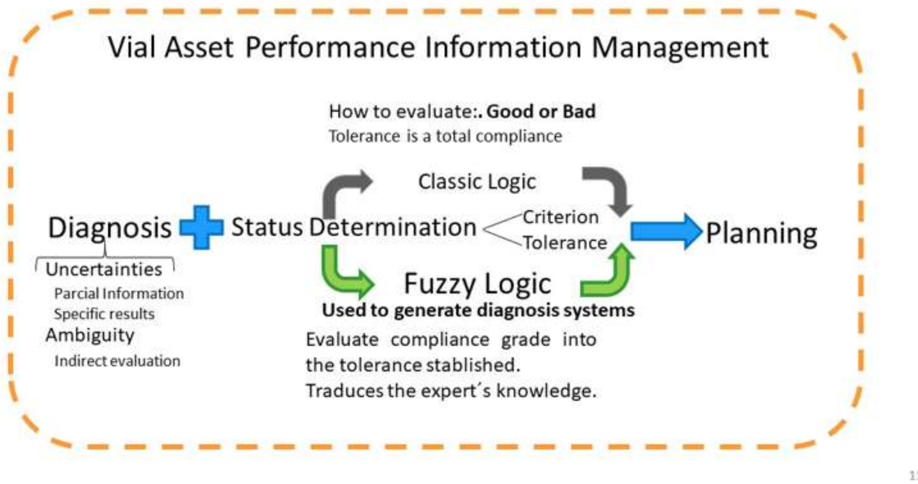


Figure 1.6: Status Determination Process

defined with tolerances established. It permits determining how well an asset's status is satisfied, showing their deterioration cycles. Additional to tolerances, when the fuzzy sets are defined, it is possible to consider the expert's criterion modifying their membership functions shapes that describe better the asset status; since it is possible to represent their not lineal comportment.

Considering the mentioned characteristics of the Evaluation Asset Information, the advantages of using Fuzzy Logic to interpret it, and the relation with the evaluator criterion, the research project has been developed with Fuzzy Logic.

1.6 Methodology

A global methodology to develop a fuzzy diagnosis model is presented below.

- Establishment of Asset Status Diagnostic Metrics (ASDM). The road network's asset characterization, including their deterioration and failure types, evaluation forms, function, and asset relationships, is the base to establish the ASDM. ASDM defines the characteristics that help to determine the correct asset functioning.

- Select Management System by Asset (SMSA). The use of the existing management systems decreases the fuzzy model's development time because it uses their management structures. To design the SMSA, we consider the ASDM defined above, considering the most established metrics in the literature.

- Asset geo-functional Relationships into the road network System Model. (ARSM) After selecting the asset management systems, develop a functional model of the system, taking into account each asset's function and influence space. The ARSM establishes all the asset relationships. ARSM is the base to determine the weight of assets in the fuzzy model

- Development of an evaluation fuzzy model based on the geo-functional relationships model. The design of fuzzy sets is based on the asset life cycles taking into account their deterioration process. Developing the fuzzy evaluation model will create the membership functions based on the ARSM and the ASDM. Besides, the fuzzy evaluation model identifies the road network maintenance necessities whit an integral and systematic focus.

The proposed methodology has been divided into five steps.1) Asset recognition, 2) Information management, 3) Selection of individual systems, 4) Design of an integral road network model 5) Develop of the evaluation fuzzy model. For each step, have been defined the activities presented below.

1. Asset recognition. Because each asset has a life cycle and different functioning is necessary to work with them individually. To establish road network asset relationships, we consider their individual performance parameters and deterioration causes.
    - Individual asset functional technical documentation research to establish the theoretical bases for the evaluation system
    - The individual asset, international and national, technical field of research to establish the practical bases for the evaluation system. It considers the criterion and tolerances that experts have on practice, taking into account the different social, technician, and methodologic contexts.
    - Asset performance metrics selection, identifying, corroborating, and adapting basic asset information to establish metrics to evaluate the functional asset performance.
2. Information Management. Information of Asset tests should be used and transformed to obtain their diagnostic evaluation. To treat this information has been developed different management systems at the world. We ordered and gathered sufficient information for the correct implementation because all the generated data is not organized most of the time. To use this invaluable information, we have proposed to organize this on an adequate database and a correct and util geographic representation using a Geographical Information System.
3. Selection of individually systems. Because there is not a single management system is necessary to select the most adequate considering the institutional objectives.
    - Road network asset management systems technical documental research to identify and contrast different systems.
    - A technical-functional research at a national and international level for road network asset management systems to identify preferences and practical advantages identified by experts. Whit these, experts select and implement the asset management system that they consider most appropriate considering social, technical, organizational, and road particular context.

- Selection of individual systems as a result of the documental and practical research to select the most suitable management systems.

4. Design of an integral road network model. Because asset management systems are individually for each asset, they do not consider the asset relationships. It has been derived in maintenance projects that only consider the affected asset without considering the failure cause. As the fail cause is not solved a lot of times is necessary to do the maintenance works repeatedly. To avoid it is necessary to consider the asset relationships and their importance on the global performance of the road network.

   - Design of geo-functional asset relationships. It should consider their ubication respect other assets and the functional relationships between them. These aspects permit the determination of the asset interaction space.
   - Design of management systems information relationships. Commonly management system (MA) information is repletely between different MA. Integrating MA considering their relationships helps to reduce these reworks acquiring and registering information just one time.

5. Develop of the fuzzy model evaluation. Design of fuzzy sets and membership functions. There are two levels of fuzzy models. The first model makes the asset performance's fuzzification, and the second model makes the fuzzification of the road network performance considering the asset relationships. For each fuzzy model, five evaluation levels have been defined (very good, good, regular, bad, very bad). Designed fuzzy sets and membership functions to design the inference mechanism implementation algorithm. It traduces the expert's knowledge to diagnose the origin of identified problems and to rank the attention necessities.

Chapter 2

Theoretical Framework

The first step in research works is to establish the elemental concepts that determine the base of the developed products. This chapter presents the main concepts of Road Network, Asset Management, Modeling, and Fuzzy Logic Process. This chapter's principal objective is to familiarize the reader with the basic features applied in this research.

2.1 Road Network

Road network is one of the larges community assets. It is predominately government-owned [10] Although private participation has been increased in recent years.

Road Network (MRN) is one of the fundamental pillars of national economies. [1] It is because is regularly is the way most important to move passengers and loads throughout countries.

Road Networks are composed of different assets as a function of the environment, weather, topography, soil, and expected transit. Assets that can be part of the Road Network can be classified as road pavement, structures, roadside facilities, and electromechanical equipment.[3]

2.2 Asset Management

Application of Asset Management assures that organizational objectives can be achieved. Asset Management translates the organizational objectives on technical and financial decisions, plans, and activities. It is focused on the value that assets can provide to the organization. [11]

Asset Management is "A systematic process of maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing tools to facilitate a more organized and flexible approach to making the decisions necessary to achieve the public's expectations."

Road administrators are now required to implement asset inventory, valuation, and standardized depreciation processes to have correct road network management.

Asset Management Systems have been recognized because they permit engineers to be able to communicate with financial managers clearly. [10]

"An asset management is a systematic way of identifying the optimal allocation of resources". Management requires evaluations to establish the inventory and condition state. Evaluations should be reported and analyzed by a qualified engineer. [12]

The asset management cycle considers the asset operation, inspection, assessment, business case, scheduling of works, and renewal or maintenance. [13] Asset management database should include static data, condition data, and actions recommended. [14]

Asset management activities are targeted at the conceptual, technological, and organizational levels.

The basis for asset management is information. There are three levels of information. The core information (inventory), Diagnostic based on asset condition information, and Planning interventions based on decision-making. [15]

Because information levels are upgradeable is possible to implement them on different levels as a function of organizational development. To implement the major planning level, the organization must implement the first two levels: inventory and diagnosis.

- Inventory level permits to identify all the assets that are part of the road network managed. Also, to represent the results of diagnostic and planning levels.

- Diagnosis level permits to determine the asset performance status. Asset performance status is the base for the level of planning. The planning level considers the asset life cycle to determine how the works of maintenance improve an adequate road network operation.

2.3 Modeling

A model is an abstraction of something. It hides the non-essential characteristics to simplify the system.[16] Object-Oriented Process analyses and defines system requirements identifying elemental objects to represent the system. [17] Object Modeling Technique is an object-based modeling methodology. It identifies element relationships allowing to establish the subsequent relationships easily. Methodology phases are: Analysis, System and Object Design, and Implementation.

The analysis objective phase is to understand and model the application and domain in which the system operates. Problem statements and objects are identified in this phase.

The design phase includes System and Object model construction. The first is concerned with the overall architecture of the system. The object design phase attempts to produce a practical design; focused on conceptual objects.

The implementation phase considers how the design should be implemented.[18]

There are three model types to use in the design phase. Object Model, Dynamic Model, and Functional Model Object Model is a static structure; it represents the system objects and relationships. It contains object classes organized hierarchically. Dynamic Model describes the comportment system aspects that change over time. It specifies control system parameters, establishing the system operation sequences. Functional Model describes values transformations in the system. It contents the data flow diagrams.[19]

2.4 Fuzzy Logic

Fuzzy models proposed apply the Mandami inference mechanism, which is based on equation 2.1 and contemplates the following elements:

$$\begin{aligned} TruthValue(X\; is\; C\; and\; X\; is\; D \mid X = x) = min(TruthValue(X\; is\; C \mid X = x), \\ TruthValue(X\; is\; D|X = x) = min(\mu C(x),\ \mu D(x)) \end{aligned} \tag{2.1}$$

2.4.1 Fuzzification

It considers the selection of the membership functions set that represents the specific behavior of each evaluated property. We identify two types of values of the geotechnical data: qualitative and quantitative. When factors are quantitative, the ranges of the fuzzy sets are established based on the normative or a technical document that determines their minimum and/or maxim values. When characteristics are qualitative, fuzzy sets are created based on performance descriptions and assign a qualification for the different performance states considering the evolution of damages. The fuzzification process contemplates two main groups of sets.

- Input sets. The data are obtained from measures or tests carried out in situ. Each input factor has different limits based on its behavior.
- Output sets. They depend on the characteristic to evaluate based on their impact or status.

Fuzzification allows associating quantitative and qualitative data by assigning linguistic labels to each fuzzy set. The shape of the fuzzy sets must represent the particular behavior of each evaluated characteristic. Shape functions proposed include triangular and trapezoidal functions. Functions are presented in equation 2.2, and 2.3.

$$f(x; a, b, c) = max(min(\frac{x-a}{b-a}, \frac{c-x}{c-b}), 0) \tag{2.2}$$

Equation 2.2: Asset set triangular function

$$f(x; a, b, c, d) = max(min(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}), 0) \tag{2.3}$$

Equation 2.3: Asset set trapezoidal function

2.4.2 Definition and rules evaluation

We Generated rules of the type If x is A, and y is B, then z is C. They have been generated from the combination of the linguistic labels assigned to each input factor considering the relationship of states and impacts between the evaluated properties. Finally, a Mamdani inference mechanism evaluates the rules.

2.4.3 Defuzification

Defuzzification process assign a single number to the output aggregated fuzzy set. In this research, We use the centroid method for defuzzification. Mathematical fundament is presented in equation 2.4. It allows to have an interpretation of the outputs based on the x-axis values of the center of gravity of the corresponding fuzzy set.

$$x^* = \frac{\int \mu_{\tilde{A}}(x) \cdot x dx}{\int \mu_{\tilde{A}}(x) \cdot dx} \tag{2.4}$$

2.4.4 Interpretation of results

We define the output description as a conclusion of the geotechnical asset state from the exit of the defuzzification process. We describe the state of the asset to help the engineers to determine the task or process to follow to increase the security or operation of the asset.

Chapter 3

Related Work: Assets in Road Network

In the research process, it is essential to consider the previous work developed by several researchers to evaluate and construct road networks. Hence, in this chapter, we present some related works to road assets evaluations particularly. We divide their description into the following areas: pavement, drainage, safety devices, and geotechnical assets. We first present the assets description, following a proposal of how we consider each asset in our work.

3.1 Pavement

Asset management combines engineering principles with economic theory and business practices. It has closed the gap between the pavement condition and user expectations. It is why its implementation has increased. [62]

Pavement is the most managed and evaluated road asset. HDM-4 is one of the most used pavement management systems in the world. The World Bank has developed it. HDM-4 takes into account Roughness changes. The progression model used in the HDM-4 Stablishes the rutting, cracking, potholes, and environmental factors as components of the IRI growth as is shown in equation 3.1 [65]

$$\Delta RI = K_r(\Delta RI_s + \Delta RI_c + \Delta RI_r + \Delta RI_t) + \Delta RI_e \tag{3.1}$$

Where:
ΔRI IRI growth
K_r Calibration constant
ΔRI_s Structural deterioration
ΔRI_c Cracking component
ΔRI_r Rutting component
ΔRI_t Potholes component
ΔRI_e Environment component

The pavement evaluation process is considered uncertain. Generally, its evaluation requires experts. They make the pavement evaluation based on more or less clear terms used to describe pavement condition. General evaluations consider the pavement performance evaluation classifying it as bad, poor, good, and excellent. [60] [66] [67] [68]

3.1.1 Pavement condition assessment

Due to the uncertainty in the pavement evaluation, there are some proposes of fuzzy pavement evaluations.

In 1988 D.J. Elton presented a Fuzzy Evaluation of Asphalt Pavement System. With fuzzy triangular sets. He establishes the importance of an evaluation system because of the large turnover in pavement engineering. [60]

Some authors have proposed an evaluation model using the weighted average operation to consider each parameter's evaluation importance. They proposed to use the evaluation parameters: roughness, alligator, transverse and longitudinal cracks, cracking ratio, and rutting. [60] [61]

Singh has utilized the IRI, surface modulus, ruth depth, and friction coefficient to make the pavement assessment. Membership functions have been developed based on a Hierarchy Process and Weighted Average. The general configuration of proposed memberships functions includes triangular in the center and trapezoidal in limits.[63]

Chen C. has proposed a fuzzy evaluation of pavements based on qualitative parameters: Present Serviceability Index and Pavement Condition Index. Proposed fuzzy sets use triangular and trapezoidal memberships. [62]

Diew Thi Xuan Duong developed a pavement management model. He proposes the pavement status evaluation based on four parameters potholes, cracks, rutting, and IRI. Diew uses triangular membership functions to represent the parameters. Based on the evaluation, he proposed some maintenance works. Finally, he compares the results with the HDM-4, obtaining similar proposes with fewer input parameters. [69]

Lu Sun has proposed five linguistic labels to determine the pavement condition for the roughness, deflections, surface deteriorations, rutting, and skid resistance. He establishes the necessity of dividing the road network into pavement segments to implement the pavement assessment. He assigns weights to level conditions to analyze their influence on the integral pavement evaluation. [64]

3.1.2 Pavement environment influence

Generally, proposed works consider the evaluation of pavement conditions by making direct measures. However, some external factors have an impact on the pavement asset, as could be observed in equation 3.1, where the transit and environmental conditions influence the pavement condition.

Mohd Rosli quantifies the effects of mean annual precipitation and temperature using the Mechanistic-Empirical Design Guide for Pavementes (MEPDG) software and takes into account the Mechanistic-Empirical design. MEDPG Inputs are traffic, foundation, climate, and material properties. [59]

Climate parameters in the MEPDG are Air temperature, precipitation, wind speed, percentage sunshine, and relative humidity.[70]

3.1.3 Proposal

In the evaluation model proposed first division takes into account the Inventory and Performance evaluations. Generally, pavement management systems only take into consideration the performance condition. Inventory pavement conditions are the basis of its behavior. Pavement performance is an interaction between the construction characteristics and operating conditions. It is crucial to know the opening characteristics.

For the pavement evaluation model, the inventory evaluation, material quality, and design transit are considered to identify the road importance and construction quality.

The proposed performance evaluation is based on the model of the HDM-4. Unlike our evaluation proposed includes the section pavement condition assessment. We consider that Road Roughness is not at the same level that deflections and structural or surface deteriorations. The Road Roughness, as is shown in equation 3.1, is the result of a combination of these parameters. In this sense, we have proposed groping the pavement deteriorations to determine the Road Roughness. Finally, the interaction between Road Roughness and Friction is analyzed.

Environment parameters influence is considered in the integral road evaluation model.

Searcher	IRI	Structural	Cracking	Rutting	Potholes	Friction	Environment	Fuzzy Logic
HDM-4	✓					✗		✗
Elton D.J.	✓	✗	✓	✓	✓	✗	✗	✓
Joni Arliansyah	✓	✗	✓	✓	✗	✗	✗	✓
Singh A.P.	✓	✓	✗	✓	✗	✓	✗	✓
Duong D.T.	✓	✗	✓	✓	✓	✗	✗	✓
Lu Sun	✓	✓	✓	✓	✓	✓	✗	✓
Mohd Rosli	✓	✗	✓	✓	✗	✗	✓	✓
Carlos Gallegos	✗	✓	✓	✓	✓	✓	✓	✓

Table 3.1: State of Art Pavement

3.2 Drainage

Drainage road assets have as principal purposes to minimizing effects of flooding in the road, enhancement of road safety to users, to protect road assets and to mitigate adverse environmental impacts. Their design should consider the road geometry (horizontal and vertical alignment) and their relationships with environment and existing streams. Performance drainage is determined based in the scour, erosion and sediments.[86]

Water is one of the major causes of road damages. It is the reason because the drainage management could be considered as priority. A visual operation monitoring is desirable at least once or twice times per year.[92]

Managing road surface flows is an important component of road drainage. Road Drainage is classified in minor and major systems. Minor system includes kerbs, inlets, surface channels, underground pipes, culverts, and retention and sedimentation facilities.

Major system are used when capacity of minor drainage is exceeded. One of the main aspects in road drainage design is the ultimately dispose of water. [87] [93]

Drainage systems are divided in surface and subsurface. Surface system take the surface water flows and drive these out of road. It is subdivided in longitudinal, and transverse. Longitudinal drainage, drive water flows parallel to road way. Transverse drainage allows to restore natural streams blocked by the road. Subsurface drainage prevent the water infiltration to the pavement layers. [88]

Effective surface water drainage is essential to maintaining a desirable level of road service and safety. Recent works in road drainage research have applied computational modeling for their characterization.[89]

The FHWA have developed a new culvert inspection manual to renew the manual of 1986. The new inspection manual has been developed into the NCHRP Project 14-26. It includes an evaluation of culverts methodology making an analysis of entrance, barrel and exit parts of culvert and their relationships with the embankment and existing stream. [90] [91]

Evaluation of culvert should include the size, shape, slope, land use, geology, soil type, infiltration and storage.[94]

3.2.1 Proposal

General research works related to road drainage are focused in the design process and road construction necessities. Works related to determination of asset status are developed just for culverts.

When drainage assets are considered like a system, importance of evaluation of the different assets that composed it is noted. The proposed road drainage evaluation for the surface drainage includes pumping, kerb, road ditch, cutting ditch, batter chutes and culvert assets.

As base of evaluation. Asset dimensions have been considers appropriate to the road and environment conditions. An inventory and a performance evaluation methodology is proposed. Inventory evaluation is focused in determines the impact of geometry conditions in the drainage assets. Performance evaluation divides assets in two principal characteristics: Channel, and Structure. For the channel characteristic water way is evaluated. In structure, the asset condition is evaluated.

For the integral road evaluation continuity between the assets that compose a road section is evaluated.

3.3 Safety Devices

Safety Devices are elements that increase the safety in the road transit. These have taken on a particular importance principally next of the first and second resolution of ONU respect to the decade of action for road safety in 2010 and in 2020.[95]

Roadway and traffic conditions are main factors that affect the traffic accidents. Speed, surface conditions and geometric factors have a direct influence in the road susceptibility accidents. [99]

iRAP Methodology is one of used evaluation methodology. It classify the road safety with stars. In it evaluation five stars is the best qualification for the road safety. Road evaluation is made in segments of 100 m. Geometry, and infrastructure conditions are considered for the road qualification. It is a management system to planning the safety works required to have a better star qualification. Evaluation elements include vehicles, users and roads.[96] [97]

Road signs are an essential road safety elements. Generally countries have regulations for these. Regulations establish the type, size, placement and manufacture of road signs. However in-service performances generally is not mandated.[98]

In Mexico, regulations related to road safety devices include the NOM-008-SCT2-2013 (Shock-absorbers) NOM-034-SCT2-2018 (Horizontal and Vertical Marking) NOM-036-SCT2-2016 (Braking Ramps) NOM-037-SCT2-2012 (Protection Barriers).

Furthermore a methodology of road safety audits has been developed. In these geometry, and assets conditions are evaluated. Audits monitor the road safety in the feasibility, draft project, executive project, beginning of operation and in operation stages.[100]

3.3.1 Proposal

Safety devices evaluation include the inventory and performance evaluation of protection barriers, braking ramps, horizontal and vertical marking. Geometry, location and sign status are evaluated. Proposed evaluation of safety devices consider the specifications established in the Mexican regulations and the signs retroreflectivity levels recommended by the FHWA.

3.4 Geotechnical Assets

Geotechnical Assets are man-made or natural earthwork below the road pavement layers and the adjacent land beside the road. [72]

Geotechnical Assets need to be well maintained to ensure they are safe and serviceable. It is necessary to program inspections to evaluate de actual asset conditions to identify priorities of attention. Inspection frequency depends on the importance and performance of the asset. Captured information should have a defined purpose. For the management process of geotechnical assets, it is sufficient to model these as lines or points. The most important is the information that they contain. [71]

Geotechnical Assets support the continued function of the road network. Suppose they do not have adequate attention; they can fail, causing mobility delays, threatening user safety, and generating very high user costs. [74]

Highways England company has a Geotechnical Data Management System that considers inventory and condition information. Inventory information is essentially static. It includes location, geology, geometry, and condition information, with a time limit to consider it vital. Condition information includes geotechnical features as tension cracks, rock falls, and elements that affect the asset as water influence. Information obtained is analyzed and qualified by an expert.[73]

We can find the embankments, cuttings, reinforced slopes, subgrade, retaining walls, and structural foundations between the different geotechnical assets.[75]

3.4.1 Slopes

As noted above, slopes are part of the geotechnical assets. These include road cuttings and embankments with or without reinforcement. Following is a summary of the best evaluation systems found in the bibliographic review.

Jared McGinn proposes a ranking of selection of geotechnical assets as a function of their slope, height, soil, groundwater, road traffic, and the relations between pavements, drainage system, and geotechnical asset conditions. [76]

Salcedo, based on the principle "Today and past are keys to the future" and considering that future landslides will have the same water, geological, and geomorphological factors as those already in the past proposed a hierarchical analysis of causal factors. $f(x)=0.379\ x1+0.246\ x2+0.159\ x3+0.102\ x4+\ 0.0545+\ 0.036\ x6+\ 0.024x7$ where the variables are: pending, lithology, precipitation, distance to geological faults, distance to rivers, distance to roads, vegetation cover.Daniela Salcedo has made a classification of road landslides causal factors into condition (topography, structural geology, lithology, soil type, drainage, and vegetation coverage) and triggers (earthquakes, precipitation intensity, natural or anthropic erosion). [77]

Considering the imprecision of input data due to scattering and systematic errors in geotechnical information, Ghassem Habibagahi used fuzzy sets to represent the approximations of soil parameters and their statical distributions to calculate the safety factor. [78]

Due to uncertainties and ambiguities in data to determine the stability factor value in highway slopes, Xiarong Zhou proposed a weighted scoring method to model the required experience of experts and construction personnel to make a qualitative analysis of highway slope stability. He obtained the fuzzy membership functions with a half-lower trapezoidal formula, using the linguistic labels more stable, stable, less stable, and unstable. He considered the stability factors: height, slope, lithology, rock structure, weak formation, weathering degree, groundwater, and average annual rainfall.[79]

Zhang has organized 18 evaluation indices on five proposed types of evaluation: slope body, swell-shrink grade, hydraulic and meteorological characteristics, supporting and improvement measures, and other factors. Following his analysis, the most influential factors are the hydraulic and meteorological conditions followed by the condition of slope body, support and improvement measures, and swell-shrink grade. [80]

Sai Samanth has applied the fuzzy theory to evaluate de slope stability. He proposes the implementation of the triangular fuzzy set shape to represent the geotechnical parameters that define the Safety Factor in slope stability.[81]

Tsung Lin proposes the use of neural networks to assess highway slope failures. As a result, he has established an evaluation methodology based on gradient angle, slope height, cumulative precipitation, daily rainfall, the strength of materials, joint number, vegetation, and slope direction. [82]

Garnica developed an evaluation system for cuttings and embankments with an exponential scale based on the England evaluation system. He had adapted to Mexican conditions taking into account slope characteristics, weather, and geology. For each evaluated characteristic, he has proposed a qualification interval defining four classes based on danger: very high, high, medium, low. [83]

Darren Beckstand made a conversion of exponential RHRS scores to a linear condition index. He analyzed the relationships between de two different evaluation systems, and finally, he has defined five classes with regular intervals of 20 points.[74]

3.4.2 Retaining walls

Additionally to slopes, geotechnical assets include retaining walls. Generally, these are part of an improvement system reinforcing and making slopes smarter.

Oliver Brutus presents the required information to management earth retaining structures considering their function, structural, historical, and failure consequences data. [84]

Retaining walls evaluation can be based on wall function, wall type, architectural facing, surface treatment, and wall elements. Scott A Anderson. [85]

3.4.3 Proposal

As each of the reviewed systems suggests a particular way of evaluation with a similar objective, a combination of the characteristics of each one makes it possible to generate a more detailed evaluation system. In the bibliography presented, condition evaluation systems do not utilize fuzzy logic. The majority of these propose an evaluation taking into account just the performance or operating condition. Stability evaluation systems have demonstrated that fuzzy logic helps make an evaluation more approximated to reality. The evaluation system developed in this research, which will be presented on a section of the fuzzy model, proposes fuzzy logic to do a condition evaluation divided into two phases, inventory and performance. It has been made based on each system's advantages, making a combination of evaluated factors or ways to evaluate them.

Searcher / Organization	Inventory	Operation	Material	Geometry	Stabilization	Road protection	Vegetal coverage	Fuzzy Logic
Highways England	✓	✓						✗
Paul Garnica	✓	✗	✓	✓	✗	✓	✓	✗
Jared Mc Ginn	✓	✗	✓	✓	✗	✗	✗	✗
Daniela Salcedo	✓	✗	✓	✓	✗	✗	✓	✓
Ghassem Habibagahi	✓	✗	✓	✓	✗	✗	✗	✓
Xiarong Zhou	✓	✗	✓	✓	✗	✗	✗	✓
Jian Zhang	✓	✗	✓	✓	✓	✗	✗	✓
Sai Samanth	✓	✗	✓	✓	✓	✓	✗	✓
Tsung Lin	✓	✗	✓	✓	✗	✗	✓	✓
Carlos Gallegos	✓	✓	✓	✓	✓	✓	✓	✓

Table 3.2: State of Art Geotechnical Assets

Chapter 4

Fuzzy Model Development

Once we have described the basic concepts and the related works have been analyzed, we present the core of the proposal in this chapter. We focus on the description of the general process for the fuzzy model evaluation for road networks. In the first section, we describe the processing of information. Next, the modeling process of the different road elements is established. Finally, the fuzzification process and the inference mechanism for the road networks evaluation are described detailed.

4.1 Fuzzy Model Description

Figure 4.1 presents a diagram of the methodology to generate a fuzzy evaluation model. First, the element to evaluate should be identified and represented. Next, an evaluation system should be defined to classify and establish relationships between the data describing the asset functioning. Finally, based on the evaluation system, the fuzzy model is generated, taking into account limit values, relationships, and influences of the evaluation parameters defined previously.

For this project, a road network model has been defined. Data evaluation has been classified in inventory and performance. The first includes fixed and initial values of dynamic characteristics. It is defined during the design, construction, or first evaluation phase. Performance includes dynamic characteristics. Comparison between initial and performance values of the dynamic characteristics allows identifying deteriorations and damages evolution.

4.2 Road Network Modeling

Road Network evaluation should considerer the own and external evaluation parameters that have an influence on it. External parameters (transit, weather, and soil) have been defined for this project as the environment. It has an influence on Road Network evaluation because the road network requirements are a function of it.

Own parameters are defined by the characteristics and describe the properties of the Road Network (road type, geometry). These are defined as a function of the environment

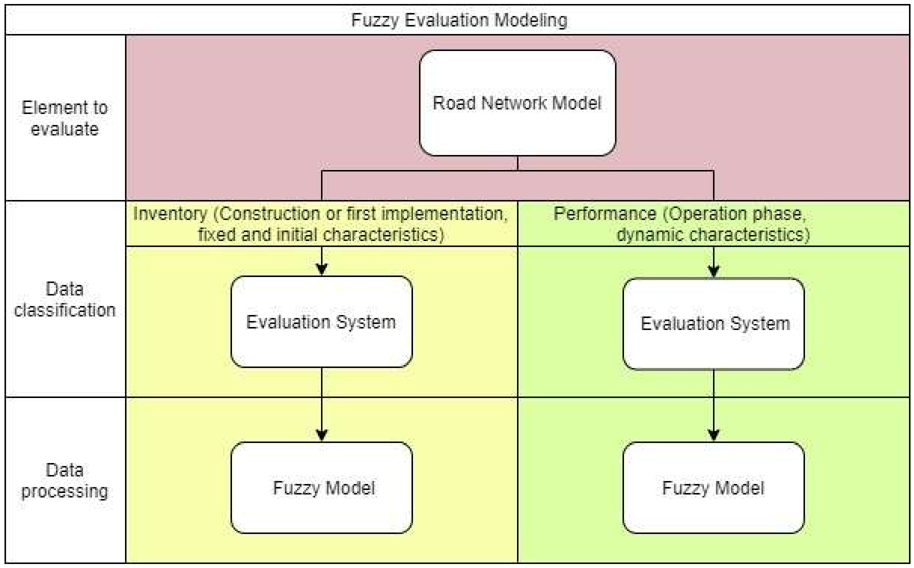


Figure 4.1: Fuzzy Evaluation Modeling

characteristics. It allows evaluating road networks ubicated at any location, taking into account performance differences due to characteristics of the place.

To make the Road Network (RN) performance evaluation easier, We have proposed its division on two levels. The first level divides RN into Road Sections (RS). The second level divides RS into Road Assets. RS is composed of a set of assets as a function of the own and external parameters defined before. Figures 4.2 and 4.3 show this division.

Road Sections are classified in Earthworks and Structures sections. First, include the sections that are positioned on natural land, cuttings, or embankments. These represent the basis sections because they just include pavement, drainage safety devices, and geotechnical assets. Last, include positioning a structure on the section; generally, it represents an interaction with an external system as in the case of bridges and over or underpasses. Sections of each class are presented below.

Earthworks	Structures
*Level Section	*Bridge
**Embankment	*Overpass
**Cutting	*Underpass
**Cutting/Embankment	*Tunnel

Road Network is a continuous road section system to obtain an integral evaluation of it. It is required to integrate the Asset Evaluation, making land measures or visual evaluations that allow determining their status. Next, establish asset relationships in the defined road sections. And finally, define relationships between the different Road Sections.

Figure 4.2 shows aerial photography of the highway Atlacomomulco-Guadalajara, behind are specified road section divisions for the presented road stretch.

a)Curve Level Section b)Underpass c)Cutting d)Tangent Level section

Figure 4.3 is a photography of the cutting section of the figure 4.2. It shows some of the different assets that compose the road section: cutting, ditch, horizontal and vertical marking, pavement.

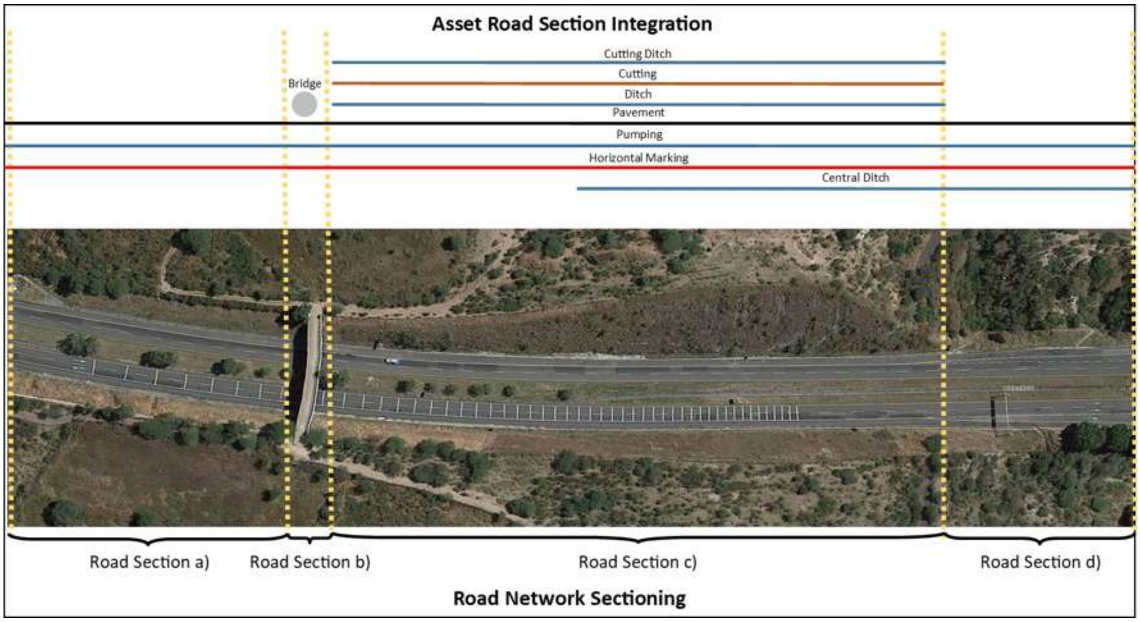


Figure 4.2: Road Network Modeling

Figure 4.3: Road Section Modeling

A road network can be composed of an unlimited number of road sections, so considering the total Road Network evaluation is a complex job. To simplify the assessment, Road Network can be divided into Road Sections Sets. Road Section Sets have been defined as a series of three road sections: entrance, intermediate, and exit section. It allows establishing the existing Road Section relationships, which are defined as a function of three continuous support subsystems: Drainage, Pavement, and Safety Devices. It can be observed at the top of figure4.2 where the lines of pavement, pumping, and horizontal marking are continuous in the four presented sections.

Good road network performance requires a correct performance of subsystems that are part of it. Road section evaluation is the basis for the Road Network Evaluation, so "to ensure that a road network operates all their road sections must operate well." We use the curve or tangent to divide the road network into road sections. After identifying curve and tangent sections, considering the eight road sections presented before, a second division is made.

Three road sections form the set of road sections. This set allows analyzing the relationships between the entrance and exit sections with the intermediate section. Interaction between intermediate and entrance or exit sections can be different by the geometry influence and road direction. Figure 4.4 presents the defined relationships for the Road Section Sets formed by level sections toward entrance and exit. Relationships have been defined considering that the functioning of Road Subsystems requires geographic continuity.

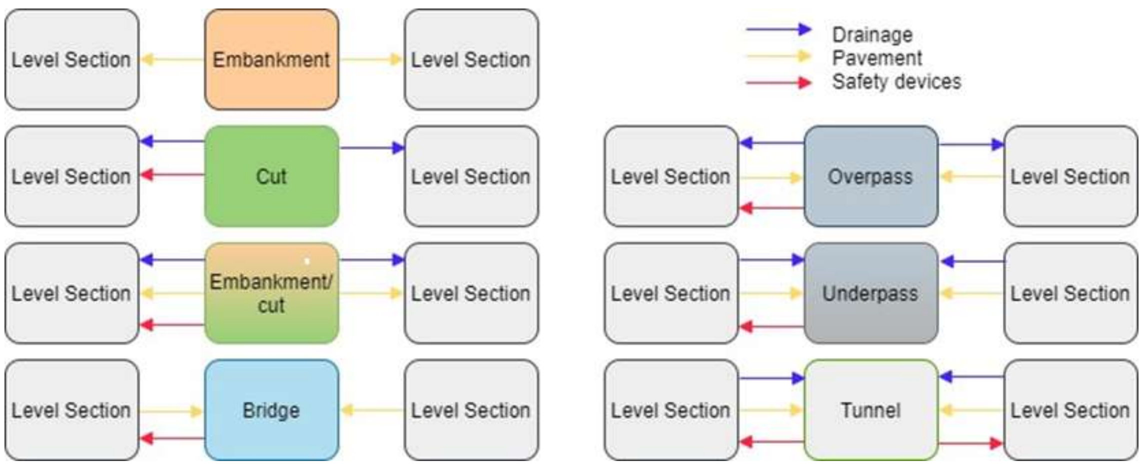


Figure 4.4: Road Sections Relationships

Surface road drainage operates with the hydraulic channel principle. Water flush goes from the tallest to the lowest level. In the pavement system, changes on the land can generate deformations on the surface. Land changes are present principally in embankments. Structures are a special case. Maintenance works on pavements generally consider asphalt over layers; it is complicated because it would change the vertical clearance gauge or the structure dead weight on the structure sections. It normally generates changes in the transition between sections. Safety device system considers principally road-user communication signs and their ubication related to the point of change that should communicate to the user, which is the main reason that only has relation with the entrance section.

4.3 Road Sections Modeling

Road sections are a road stretch with a particular asset configuration with the same geometric and condition characteristics. Modeling Road Sections has been established based on graph diagrams where nodes are the asset class, and the arcs represent the functional influence between the assets. It allows establishing the relationships between the assets in the road sections.

Figure 4.5 shows a unidirectional influence between two assets. It means that Asset A has an influence on the functioning of Asset B. If Asset A is worst, it is going to affect Asset B. Besides, if Asset A is well, it will contribute to the good functioning of Asset B. Finally, if Asset B is well or worst, it does not influence Asset A functioning.

Figure 4.6 shows a Bidirectional influence between two assets. It means that Asset A has an influence on the functioning of Asset B, and Asset B has an influence on the functioning of Asset A. If some Asset is worst, it is going to affect the other Asset. In the same sense, if some Asset is well, it will contribute to the other Asset's good functioning.

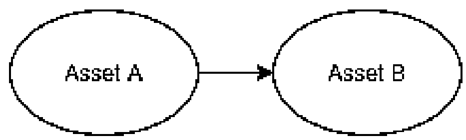


Figure 4.5: Unidirectional Asset Relationship

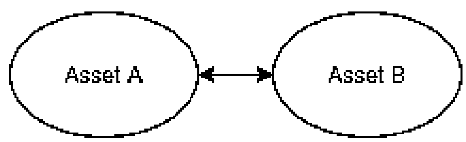


Figure 4.6: Bidirectional Asset Relationship

Road sections have been defined based on the classification of road assets in five classes:

a) Pavement b) Drainage c) Safety Devices d) Geotechnical Assets e) Structures

Figure 4.7 y Figure 4.8 show assets that form the road sections defined in the last section, as well as relationships that exist between these. Relationships between the assets have been defined considering their functional influence.

The level section is the base of all defined sections. It just includes pavement, safety devices, and drainage assets. Relationships defined for this section show that pavement is the principal and most basic road asset. The rest of the assets complements pavement assets to warranty the correct road operation. Safety devices and drainage are basically complementary assets. These have a direct influence on the function of the rest road section assets.

The remaining sections are based on the level section and complement with additional assets. They are complex because they have been created to save some topography, environmental, or transit problems.

For the rest of Earthworks Road Sections (figure 4.7), additional asset (cutting, and/or embankment) has influence from the safety and drainage assets, and it influences pavement and drainage. On sections with embankments, there is a bidirectional influence between it and pavement. Bidirectional influence means that both assets can affect and change their functioning.

Structure road sections (figure 4.8) are special cases because, in these, there is an intersection between two different systems. It adds an external element to the road section defined. For these cases, we should evaluate the interactions of the external system and section elements to warranty both systems' correct functioning.

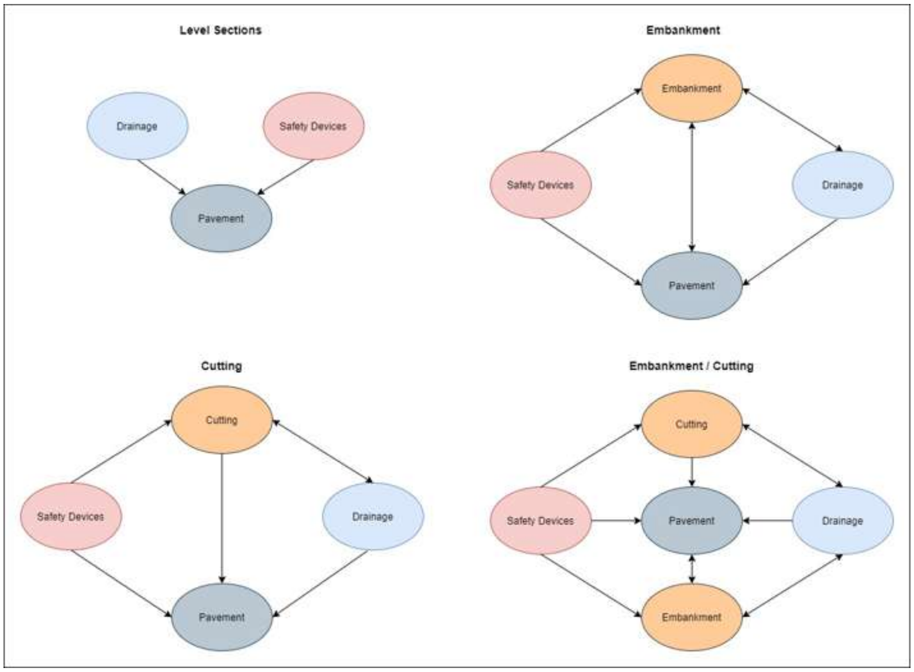


Figure 4.7: Earhtworks Road Sections

Pavement	Drainage	Safety DevicesImprovement	Geotechnical	Structures
Flexible pavement	Pumping	Braking Ramp	Cutting	Bridge
	Kerb	Safety Barrier	Embankment	Tunnel
	Batter Chute	Vertical Marking		
	Ditch	Horizontal Marking		
	Cutting Ditch			
	Culvert			

Table 4.1: Asset Classes

4.4 Road Asset Modeling

As has been defined before, Road Assets are the basic elements of the road network. We defined the classes before including the elements presented below. The Multi-level Road Network evaluation proposed requires to know detailed the individual asset performance.

Road Asset Modeling should take into account their ubications and space to identify them as punctual or lineal assets. Punctual Assets are assets wich ubication is a point; they can be located with a coordinate on the Road Network: Batter Chutes, Culverts, Transversal Structures, Vertical Marking, and some Horizontal Marking. Linear assets are ubicated at the road length. They require two coordinates on the road defining where they start and end: pavement, Kerbs, Ditches, Braking Ramps, Safety Barriers, Embankments, Cuttings, and longitudinal Structures. At the top of figure 4.2 can be observed the representation of the linear and punctual of the upper road body.

As mentioned, all the assets are just a part of the system, and their performance is the basis of road network functioning. Road Network braking down in road sections and road

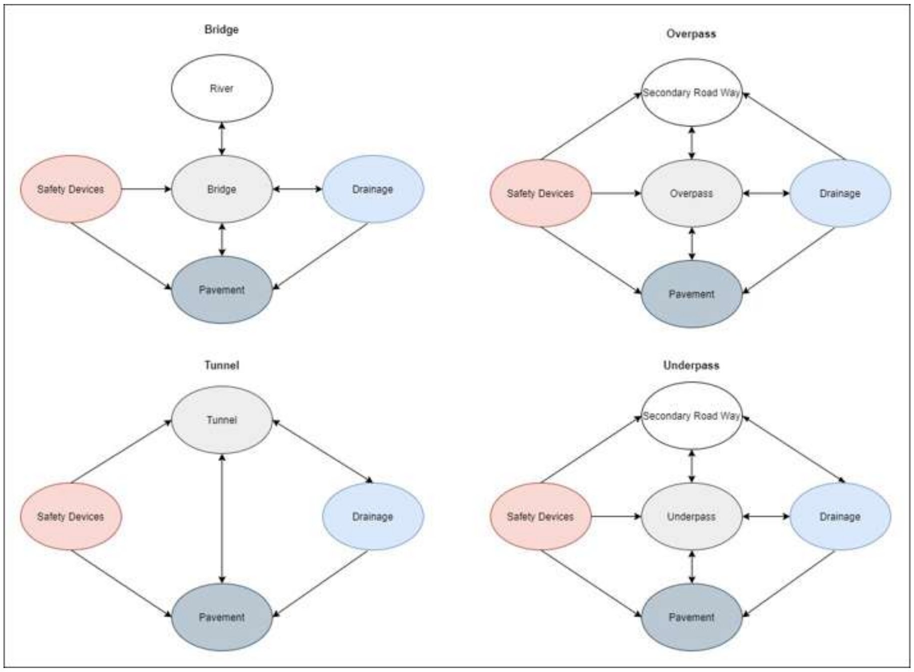


Figure 4.8: Structure Road Sections

assets allows us to evaluate any Road Network. We evaluate the smallest element (asset selected), and we can define any asset set to form the Road Sections that compose the Road Network evaluation. Also, this division allows road administrators to select which evaluation level they require (Road Network, Road Section, or Asset) as a function of the management phase.

4.5 Road Asset Evaluation

We define the Evaluation Mechanism based on the modeling of the Road network, Sections, and Assets. The evaluation Mechanism begins with the basic road elements, Assets. Asset evaluation is based on land measures and visual evaluations of the asset parameters.

4.5.1 Road Asset Catalog

The asset catalogs have been defined to identify asset parameters that should be evaluated for each asset. Figure 4.9 shows a general canvas used as a base to generate each asset catalog.

The proposed general asset catalog has five basic definition classes:

- Environment. It includes Weather, Soil, and Transit. For each asset type, Environment elements and the principal influences of each one are defined.
- Importance characteristic. It is presented as a vertical bar at the left of figura 4.9. It represents the principal asset characteristic that defines its importance level.

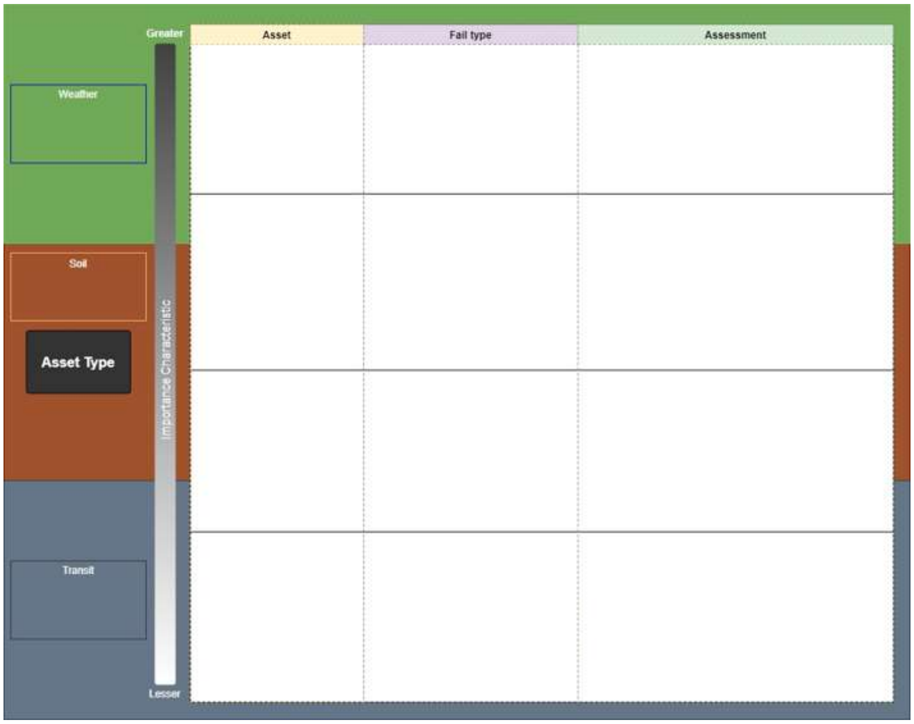


Figure 4.9: Catalog canvas

- Asset section. It presents the different assets that compose the asset class defined on the diagram.
- Fail type section. It presents the principal mechanisms of fail for the different assets presented. It is the base of evaluation and describes the asset fail evolution.
- Assessment section. It includes the evaluation parameters based on the failure mechanism of the presented assets. Evaluation parameters define the asset performance.

4.5.2 Evaluation Model

Once identified assets, fail mechanism, and evaluation parameters that describe their performance, the evaluation model, can be defined. The evaluation model classifies evaluation parameters making a modular evaluation. Modular evaluation is based on relationships between the asset evaluation parameters that describe asset characteristics and properties. Modular evaluation allows the inspector to select the asset properties that must be considered on the specific road network.

Evaluation Modules are established based on asset property evaluations. They are formed by an evaluation sequence where the minimal elements are the direct asset evaluations. These are obtained from the project for an inventory evaluation or from land measures for a performance evaluation. Next, the sequence elements are asset characteristics, defined based on the relationships of evaluation elements. These can be evaluated on different levels describing the general asset functioning. Then, asset properties are evaluated based on relationships of the most prevalent characteristics evaluation. Finally, inventory or performance evaluation is obtained from the interaction of asset properties. The principal differentiating between inventory or performance evaluation is the data origin.

The general sequence of asset properties evaluation is described with equations 4.1 to 4.4. These equations show the entrance elements set for each evaluation level. We describe each one as follows:

Evaluation set {E} is a vectorial set. It is formed by a variable number of evaluations "h" based on the evaluation parameters of each asset. Equation 4.1.

$$E = \{e_1, e_2, e_{...}, e_h\} \tag{4.1}$$

Characteristics set {C} is a matrix-set n x j, where n is the number of levels of characteristics evaluations and j is the number of elements of the first evaluation level. The definition of the elements that compose the characteristics set has two special cases. In the first level of evaluation characteristics, entrance elements are a subset of the Evaluation set {E}, next levels of evaluation characteristics have as entrance a subset of the previous evaluation level {C}. The number of elements of a superior evaluation level should be less than for the previous level. Equation 4.2.

$$C_{i,k} = \begin{cases} \{C_{i,k} \subseteq E\} & \text{i=1, } 1 < k \leq j \\ \{C_{i,k} \subseteq C_{i-1,k}\} & 1 < i \leq n,\ 1 < k \leq |Ch_{i-1,k}| - 1 \end{cases} \tag{4.2}$$

Properties set {P} is a vectorial set. It is formed by a subset of the last characteristics evaluation level {C}. As for the superior evaluation levels of the characteristics set, the number of properties' elements should be less than the previous evaluation level. Equation 4.3.

$$P = \{P \subseteq C_{n,k)}\} : |P| < |C_{n,k}| \tag{4.3}$$

Finally, the Results set {R}, has as entrance elements the properties set {P}. Elements of the results set are Inventory or Performance according to the evaluation carried out. Equation 4.4.

$$R = \{P\} \tag{4.4}$$

Figure 4.10 shows a general schematic diagram to define the asset evaluation model and represent the equations described before. It includes at right the evaluation result, asset inventory, or performance. It is defined based on all asset properties that describe the asset functioning. Asset Properties are defined based on subsets of the last level of Characteristics evaluation. The number of elements that form each subset is variable; it is represented with the subscripts m' and k. Characteristic evaluation is divided into a variable number of levels, represented with the subscript n. The first level of evaluation characteristics is based on subsets of the Evaluations set. As for the case of the last evaluation level, the number of elements of the basis subset is variable for each evaluation level. It is represented with different math literals.

Vertical lines in figure 4.10 show the evaluation division sets, evaluations, characteristics, properties, and results. Horizontal lines form boxes wich outline the tree branches that represent the modular evaluation.

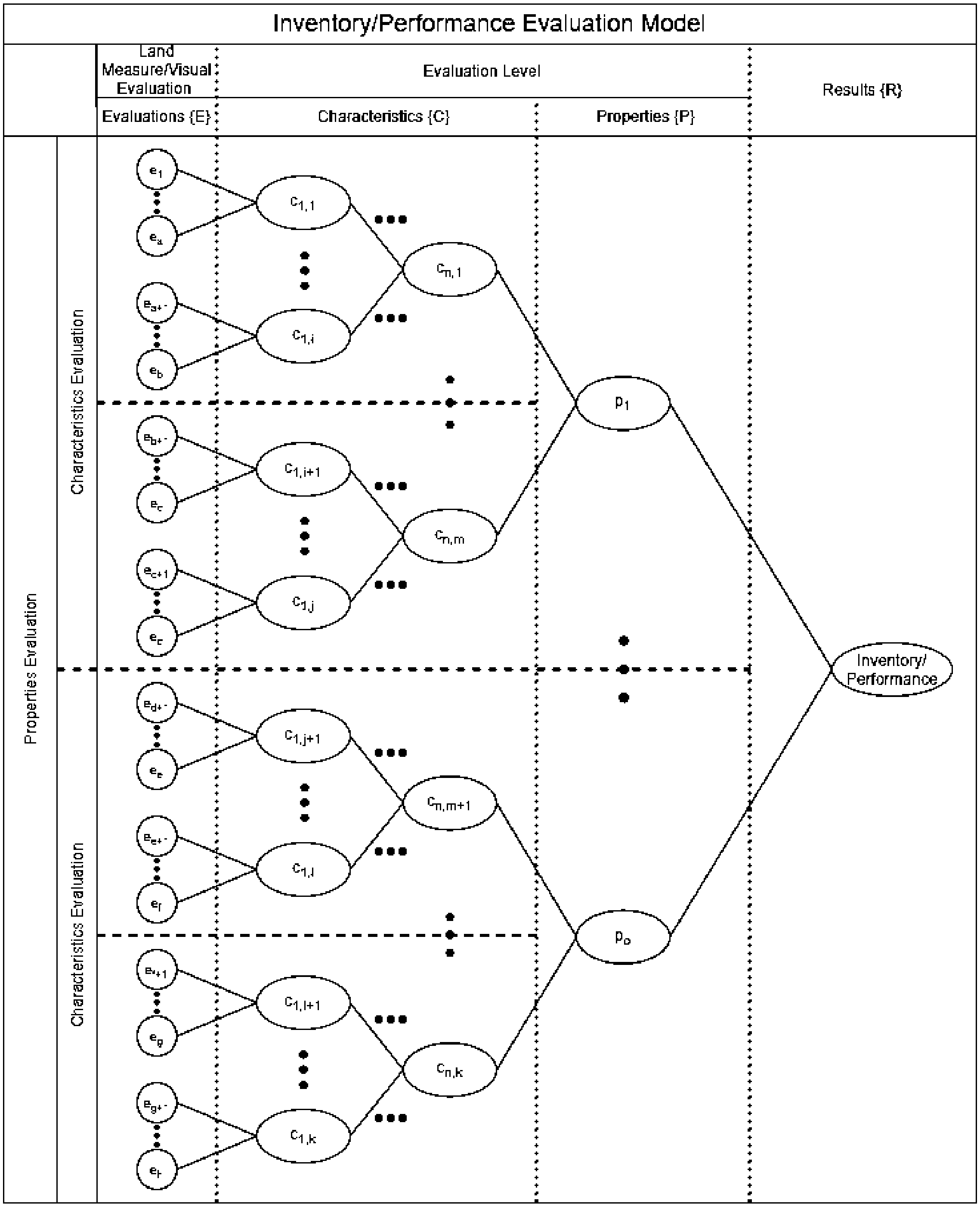


Figure 4.10: Evaluation Model

Physical meaning of the evaluation division sets is presented below.

- Evaluations. It includes parameters that could be evaluated on the project or measured on land. It is based on the Assessment section of the asset catalog. In figure 4.10 these are at left represented with circles.
- Characteristics. It represents a multilevel evaluation grouping the evaluation parameters based on their relationships.
- Properties. It represents the most general asset evaluation division that describes the asset functioning.
- Results. It has two elements, Inventory, and Performance evaluation. First evaluates the asset properties that determine asset environment resistance. Performance evaluation evaluates the asses status at the evaluation time.

4.5.3 Fuzzy Control

As has been mentioned before, equations 4.1 to 4.4 represent the entry sets for the fuzzy controls for the evaluation module. From figure 4.10 just left circles to represent physical evaluations. The remaining nodes represent fuzzy controls of the evaluation results as the entrance of the fuzzy control of the superior level.

Fuzzy control is composed of three principal phases.

1. Fuzzification. In this phase, fuzzy sets are defined. These should represent the behavior of the evaluated element. It allows making a qualitative evaluation based on a quantitative evaluation.
2. Rules evaluation. These are the base for implementing the inference mechanism and represent the existing relationships between the evaluated elements.
3. Defuzzification. Once we evaluated the rules by the fuzzy inference mechanism, we should describe the obtained results to make a correct result interpretation.

Road network evaluation needs the inspector to interpret the obtained measures considering the behavior of the evaluated element and its relationships with the other aspects of the road network. It is the principal cause of the implementation of the Mamdani mechanism on this project. Mamdani inference system allows modeling the approximate reasoning. In it, fuzzy rules are based on the experience of experts that design the model. The fuzzy inference mechanism is described in equation 4.5.

$$TruthValue(X\ is\ C\ and\ X\ is\ D|X = x) = \\ min(TruthValue\ (X\ is\ C|X = x), TruthValue\ (X\ is\ D|X = x)) = min\ (\mu\, C(x), \mu\, D(x) \tag{4.5}$$

The inference mechanism is the motor of the evaluation model. It evaluates the defined rules based on the relationships of the fuzzified measures and allows to represent the interactions between the characteristics of the assets. The elements that are part of the evaluation are described below.

4.5.4 Fuzzy Sets

The evaluation of asset parameters begins by defining a fuzzy set for each one. The fuzzy sets are defined by a membership function set that represents the specific behavior of the evaluated parameter. Fuzzy sets establish the classification of the possible values obtained for the evaluation of asset parameters by assigning them linguistic labels that describe their behavior. The possible values are assigned as a function of how the asset would be if the evaluated parameter has a value in a defined range or how it would affect the asset functioning.

In fuzzy sets, at least one limit is diffused. It allows taking into account the nearest meaning of the measured value. On it, tolerances could be evaluated as an improvement or a decrease of the evaluated parameter. The crisp set represents the value range where the measure describes the defined class (linguistic label). The intersection of fuzzy sets represents the range where the evaluated parameters could belong to various sets as a function of the inspector interpretation. For the fuzzy evaluation models, we define two classes of fuzzy sets:

- Input sets. These represent the evaluation data that the fuzzy mechanism will evaluate. For this project, the first level of input sets should represent the parameter behavior. Set ranges are defined based on the normal values that could be obtained on the asset parameters evaluations. Values ranges are divided into classes that describe the parameter status. On this level, evaluation data could be quantitative (land or project measures) or qualitative (visual asset evaluations). From the second evaluation level, input sets are the output set of the previous evaluation level.

- Output sets. They represent the result of interaction between the input sets. Data described by these sets is qualitative. Range values for this project go from 0 to 10, where 0 represents the worst state, and 10 represents the better state.

The fuzzification of the parameters allows classifying the evaluation data assigning linguistic labels and a range of values to each fuzzy set. The shape of the defined fuzzy sets must represent the particular behavior of each evaluated parameter. Shape functions used in this project are triangular and trapezoidal.

In triangular membership functions, there is just a crisp value (figure 4.11. It could have two fuzzified limits (equation 4.6) or one fixed limit and one fuzzified limit to left of crisp value (equation 4.7) or a right limit of the crisp value (equation 4.8).

In Trapezoidal membership functions, there is a range of values for the crisp set (figure 4.12. It could have two fuzzified limits (equation 4.9) or one fixed limit and one fuzzified limit to left of crisp values range (equation 4.10) or a right limit of crisp values range (equation 4.11).

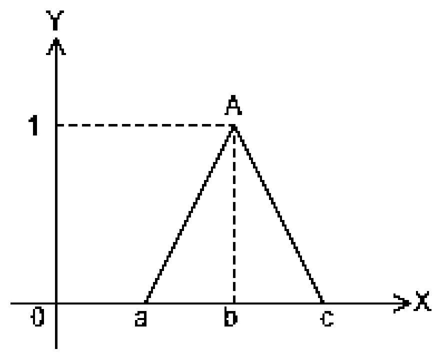


Figure 4.11: Triangular fuzzy sets

$$\mu_A(x) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a < x \leq b \\ 1, & x = b \\ \frac{c-x}{c-b}, & b < x \leq c \\ 0 & x \geq c \end{cases} \tag{4.6}$$

$$\mu_A(x) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a < x \leq b \\ 1 & x = b = c \\ 0, & x > c \end{cases} \tag{4.7}$$

$$\mu_A(x) = \begin{cases} 0, & x < a \\ 1, & x = a = b \\ \frac{c-x}{c-b}, & b < x \leq c \\ 0 & x \geq c \end{cases} \tag{4.8}$$

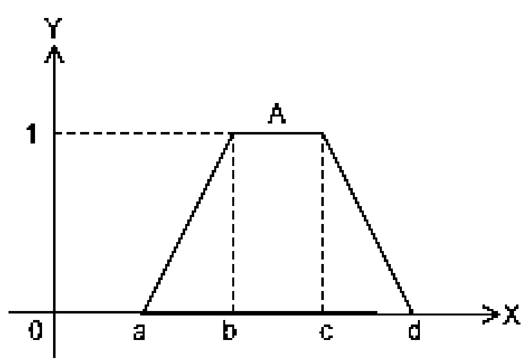


Figure 4.12: Trapezoidal fuzzy sets

$$\mu_A(x) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a < x \leq b \\ 1, & b \leq x \leq c \\ \frac{c-x}{c-b}, & c < x \leq d \\ 0 & x \geq d \end{cases} \tag{4.9}$$

$$\mu_A(x) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a < x \leq b \\ 1 & b \leq x \leq d, c = d \end{cases} \tag{4.10}$$

$$\mu_A(x) = \begin{cases} 1, & a = b, a \leq x \leq c \\ \frac{c-x}{c-b}, & c < x \leq d \\ 0 & x \geq d \end{cases} \tag{4.11}$$

Once the normal range of values for the evaluated parameters is identified, a set of fuzzy sets is designed to assign the membership function nearest to the parameter behavior for each range of values that describes the defined classes. The guidelines considered on the design of the set of fuzzy sets in the proposed model are presented below.

- Values range for the different asset parameters has been divided from two to five classes. A number of classes for each one is defined as a function of the behavior stages of the evaluated parameter. A greater number of classes should be defined when the normal values range is wide, or the status parameter has a lot of variations. Few classes are defined when range values are too closer, or the status parameter has very few variations on the values range. In this project, general linguistic labels describe the behavior stages as Very Good, Good, Regular, Bad, and Very Bad. We can make different linguistic labels combinations based on the best description of the evaluated parameter.

- Fuzzy membership function assigned to the defined classes is triangular when existing a particular value that describes the asset evaluation status. Trapezoidal sets are used when existing a values range that describes the asset evaluation status.

- Fuzzified limits represent an improvement or worsening of the evaluated parameter. Fixed limits in the triangular membership function are used when just a maximum or minimum specified value exists for a measure. Trapezoidal sets with a fixed limit have been used when there is no change in the asset status if the value increases in its direction.

- Fuzzified limits represent an improvement or worsening of the evaluated parameter. Fixed limits in the triangular membership function are used when just a maximum or minimum specified value exists for a measure. Trapezoidal sets with a fixed limit have been used when there is no change in the asset status if the value increases in its direction.

- Asset evaluation data is classified in qualitative and quantitative. When it is quantitative, the ranges of the fuzzy sets are established based on the normative or technical documents that determine their minimum and/or maxim values. When it is qualitative, fuzzy sets are created based on performance descriptions and assign a qualification for the different performance states considering the evolution of damages.

Qualitative parameters and outputs evaluations sets have been designed with a scale from 0 to 10. Where 0 represents the worst parameter state and 10 is the best parameter state. To guide visual evaluations, evaluation classes for qualitative parameters have been described. Descriptions allow the inspector to select the state of the asset, comparing his observations with these. The inspector should evaluate how much description is closer to the visual evaluation. Next, inspector should assign a qualification from 0 to 10 at the class to better describe the visual state evaluation. When the evaluation state is worse than the status class description, but better than the previous status class description. Inspector assigns an evaluation value between 0 and 5. When the observed condition is completely described by the class description a qualification of 5 is assigned. Finally if observed condition is better that class description but worst that next status description, inspector should assign an evaluation value between 5 and 10.

Figure 4.13 shows the qualitative and output set of fuzzy sets implemented on the developed model. Class limits values have been determined calibrating the memberships configuration proposed in the evaluation range. It includes trapezoidal with a fixed limit and triangular memberships functions. Trapezoidal functions are on the evaluation extremes. These represent that a point from an improvement or worsening state does not influence the evaluation. Central sets are triangular. These represent a point where the description is closer to evaluation, and from it, the state can improve or worsen. Below, individual sets show the location of the evaluation value that can be assigned to the evaluation classes. For the triangular sets, it is easy to observe that there is just a value that corresponds to the class description. From this point, adjacent classes are symmetrically intersected. It allows modeling the improvement or worsening state getting away from the description class and closer to the description of the adjacent class. For trapezoidal sets, an interval that corresponds to the class description exists because an improvement in the VGood set or a worsening in the VBad set does not influence the asset status.

For the qualitative class description, ranges values and the shape of fuzzy sets of the evaluation parameters have been designed based on normative or technical documents. Documents used to establish the fuzzy sets for the different asset classes are:

- Environment. Catálogo de Secciones Estructurales de Pavimentos para la República Mexicana [20], N-CMT-4-05-004/18 [21]. Wind Beaufort Scale[22] Data of Weather Stations CONAGUA [23], AASTHTO GUIDE FOR Design of Pavement Structures [24], Anejo Norma 6.1 IC:Secciones de Firmes [25], N-CMT-1-03/02 [26].

- Geometry. Manual de Proyecto Geométrico de Carreteras 2018 [27]

- Pavement. N-CMT-1-01/21: Materiales para Terraplén [28] N-CMT-1-02/21: Materiales para Subyacente[29],N-CMT-1-03/21:Materiales para subrasante [26], N-CMT-4-02-001/21: Materiales para subbase [30], N-CMT-4-02-002/21:Materiales para base

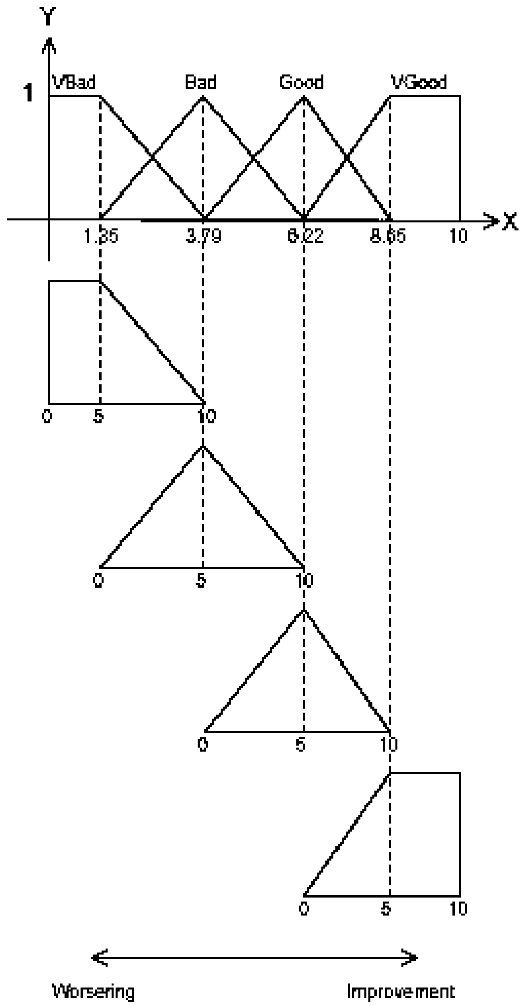


Figure 4.13: Response set

hidráulica [31], N-CMT-4-05-003/02:Calidad de mezclas asfálticas para carreteras [32], PA-CR 01/2016 México. Diseño, fabricación y colocación de mezclas para capas de rodadura elaboradas en caliente AMAAC. [33], AASTHTO GUIDE FOR Design of Pavement Structures [24], Catálogo de Secciones Estructurales de Pavimentos para la República Mexicana [20], N-CSV-CAR-1-03-007/2017: Determinación del Coeficiente de Fricción [34], N-CSV-CAR-1-03-006/2020: Determinación de la Macrotextura [35], N-CSV-CAR-1-03-008/2018: Determinación de Deterioros Superficiales de los Pavimentos (DET) [36], N-CSV-CAR-1-03-009/2016: Determinación de Profundidad de Roderas [37], Anexo 4 Estándares de Desempeño APP Conservación Pirámides-Tulancingo-Pachuca [38], Performance Prediction Model HDM-4 [39], Cátalogo de deterioros de pavimentos flexibles [40], Distres identification manual [41].

- Drainage. Manual de proyecto geométrico de carreteras 2018 [27], N-PRY-CAR-4-02-003 2016: Diseño elementos de obras complementarias de drenaje [42] AASHTO Culvert and Storm Drain System Inspection Guide [43], Propuesta de indicadores para la gestión de taludes de corte y de terraplén [44], Anexo 4 Estándares de Desempeño APP Conservación Pirámides-Tulancingo-Pachuca [38].

- Safety Devices. NOM-034-SCT2-2018: Señalamiento Horizontal y Vertical de Carreteras y Vialidades Urbanas [45], NOM-036-SCT2-2016:Rampas de Emergencia para frenado en carreteras[46], NOM-037-SCT2-2012: Barreras de Protección en Carreteras y Vialidades Urbanas [47], Manual de proyecto geométrico de carreteras 2018 [27], Maintaining Sign Retroreflectivity FHWA[48], Anexo 4 Estándares de Desempeño APP Conservación Pirámides-Tulancingo-Pachuca [38]

- Geotechnical assets.Propuesta de indicadores para la gestión de taludes de corte y de terraplén [44]. Risk assessment model slope stability [56], Rock Mass Rating [58], Anexo 4 Estándares de Desempeño APP Conservación Pirámides-Tulancingo-Pachuca [38] N-CMT-1-01/21: Materiales para Terraplén [28].

4.5.5 Fuzzy Rules Definition

Fuzzy rules are the guidelines for the inference mechanism. These consider the interaction that exists between the status of input elements. Defined fuzzy rules for this project are of the type If A is x And B is y Then R is w. They have been generated from the combination of the classes assigned to input elements considering the relationship and impacts between the evaluated properties.

The number of fuzzy rules for the fuzzy controls is determined based on the multiplication principle. Taking into account that the status of the entrance elements is independent, the number of fuzzy rules is calculated with equation 4.12

$$|R| = |E_1| \times |E_2| \times ... \times |E_n| \tag{4.12}$$

Where: {R} Fuzzy Rules set.

$$\{E_i\}$$

Entrance Element sets

Rules definition is based on the interaction of the entrance elements status. The output result is determined considering that the status of entrance elements can affect the output status in three ways:

- Entrance elements status goes in the same sense: The status of entrance elements is similar and tuning. The impact of entrance status is added to the output status. It is valid for positive or negative sense. If the entrance status is good, output status will be good. If the entrance status is bad, output status will be bad.

- Impact of the evaluated status goes in the opposite sense: Status of entrance elements are opposed, not tuning. Impacts of entrance status are diminished. It reduces the individual effect that they can have on the output status. Output status will be improved or worsened with respect to the principal entrance status. If an entrance status is good and another entrance status is bad, output status will be intermediate.

- Impact of evaluated status goes on independent senses: Status of entrance elements are independent, or influence of secondary elements is not sufficient to generate a different output status. Output status will be determined by the individual status of the principal entrance element. The status of the principal element has no variation by the status of the remaining entrance elements.

As general rule can be stablished that when first case is present, output class result will be the same class of entrance elements. For the second case, the output class result will be the adjacent evaluation class of the most important entrance element at the sense of the other entrance status. When the third case is present, the output class result will be still the principal entrance element status.

Table 4.2 presents the fuzzy rules defined for the pavement performance evaluation. It is characterized by two pavement properties: Roughness and Friction. Properties status are categorized into four classes: VGood, Good, Bad, and VBad. Implementing equation 4.12 it is possible to determine that number of fuzzy rules for this fuzzy control is 16. Considering that between roughness and friction properties, roughness is the principal: Rules 1, 6, 11, 12, and 16 are an example of the first way, entrance elements status in the same sense. Rules 3, 4, 7, 8, and 13 are examples of the second way; the entrance elements' status goes in the opposite sense. Rules 2, 5, 9, 10, 14, 15 are examples of the third way; the entrance elements' status goes on independently.

Pavement Performance			
No.R	Roug	Frict	
1	V.G.	V.G.	VG
2	V.G.	G	VG
3	V.G.	B	G
4	V.G.	VB	B
5	G	V.G.	G
6	G	G	G
7	G	B	B
8	G	VB	B
9	B	V.G.	B
10	B	G	B
11	B	B	B
12	B	VB	VB
13	VB	V.G.	B
14	VB	G	VB
15	VB	B	VB
16	VB	VB	VB

Table 4.2: Pavement Performance Fuzzy Rules

4.5.6 Fuzzy Rules Evaluation

At this point, entrance parameters have been fuzzified, establishing the status classes in the normal value range. Fuzzy rules have been defined considering the relationships between the entrance parameters. The next step is to evaluate the fuzzy rules.

Evaluation of fuzzy rules is based on the implementation of the Mamdani inference mechanism (equation 2.1). Evaluation of fuzzy rules has, as a result, a fuzzy output surface. It is formed up of summation of the surfaces formed by the response sets intersected by the minimum height of the entrance sets. The height of the entrance sets is obtained as a grade belonging to an entrance set of a particular value. The belonging grade is the value of the fuzzy membership at the evaluated value. Outputs sets surface is cut by a horizontal line projected from the mínimum belonging grade of the input sets. Finally, cut surfaces are added to form a fuzzy output surface.

Evaluation of fuzzy rules, of the pavement performance, presented in table 4.2 and described as follows:

Input and output fuzzy sets configuration for this fuzzy control are like presented in figure 4.13. To show the process of evaluation of fuzzy rules, the evaluation values 8 and 4 for the properties of roughness and friction are assigned, respectively.

Figure 4.14 shows the assigned values like a vertical line in the configuration of evaluation fuzzy sets.

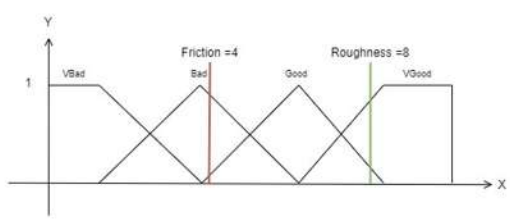


Figure 4.14: Evaluation Values

The belonging grade of the proposed values to define the classes status is determined by the intersection of the vertical lines in the proposed values with the membership functions of the evaluation fuzzy sets.

The assigned value to friction property belongs in the most superior grade to class Bad and a lower grade to class Good. It can be interpreted as a big degradation status of friction property in the good class, but it is still considered good. The value assigned to Roughness belongs in most superior grade to VGood class, and lower grade to class Good. It can be interpreted as a short degradation status in the VGood class.

Figure 4.15 shows the 16 defined fuzzy rules of the fuzzy control graphically. It shows the fuzzy set that corresponds to the linguistic label contained in table 4.2 and their intersection with the assigned values.

Figure 4.16 shows the four evaluation rules activated. Activated rules are the rules that consider the combination of the status defined by the assigned values. In the explained case, the activated rules are the 2, 3, 6, and 7. These rules include the combination between classes VGood and Good for the Roughness evaluation and classes Good and Bad for Friction evaluation.

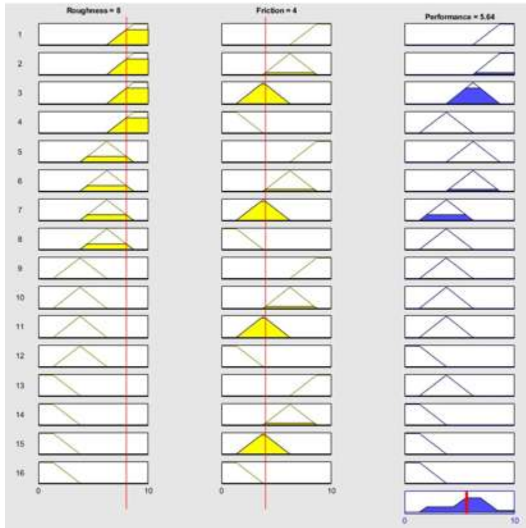


Figure 4.15: Response set

The belonging grade is the value of the membership function evaluated in the assigned input values. It is geometrically represented in figure 4.16 like the intersection of the vertical lines with the fuzzy input sets of the activated rules.

The minimum belonging grade of each activated rule is used as the height for generating the individual output surface. In figure 4.16 intersection of input memberships and assigned values are projected by the horizontal lines to the output membership functions. The surface below the intersection of the horizontal lines and the output membership functions is the individual output surface of the evaluated rule. The final result is the output surface integrated by the superposition of the individual surfaces of the activated rules.

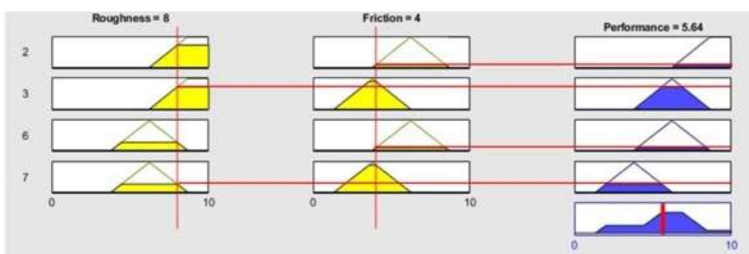


Figure 4.16: Actived Rules

4.5.7 Defuzzification

As mentioned in the last section, the result of a fuzzy control evaluation is an output surface. It is formed based on the evaluation of the fuzzy rules to obtain a specific value for the final result. The output surface should be defuzzified. Defuzzification is the process of obtaining a representative value of the output surface. In fuzzy terms, the final value could be considered the crisp value of the output surface.

In the developed model, the Centroid defuzzification process has been employed. The mathematical foundation is presented in equation 4.13. As can be inferred from the process name, it determines the x coordinate of the surface centroid. The Centroid x value is considered the characteristic value of the output surface. It is the final result of the fuzzy evaluation process.

$$x^* = \frac{\int \mu_{\tilde{A}}(x) \cdot x dx}{\int \mu_{\tilde{A}}(x) \cdot dx} \tag{4.13}$$

Figure 4.17 shows the final surface and x value of its coordinate obtained for the example described in the last section. From it, it can be concluded that the evaluation result of the pavement performance is 5.64 for evaluation values 8 for the Roughness property and 4 for the Friction property.

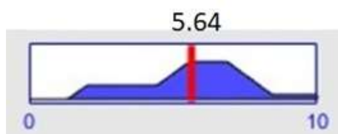
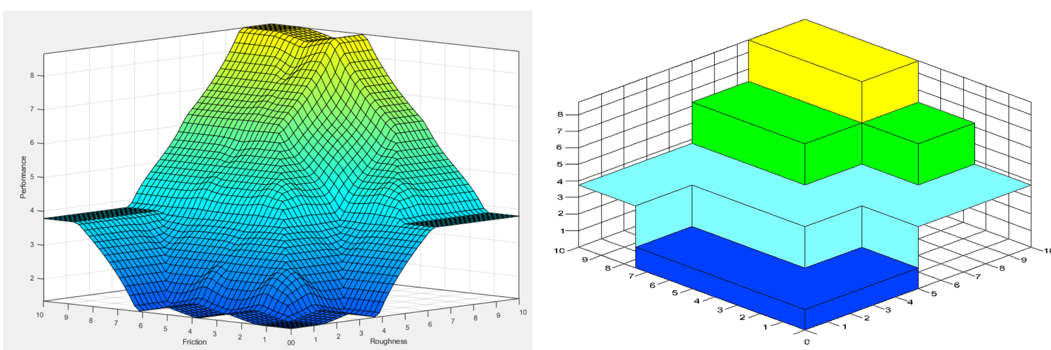


Figure 4.17: Defuzzification

Figure 4.18a shows the response surface for the pavement performance evaluation with the fuzzy mechanism proposed. It is a three-dimensional graphic of the possible values obtained in the pavement performance evaluation based on the possible properties values. Figure 4.18b shows the response surface for the pavement performance evaluation using classical logic in the evaluation of the rules proposed in the evaluation mechanism.

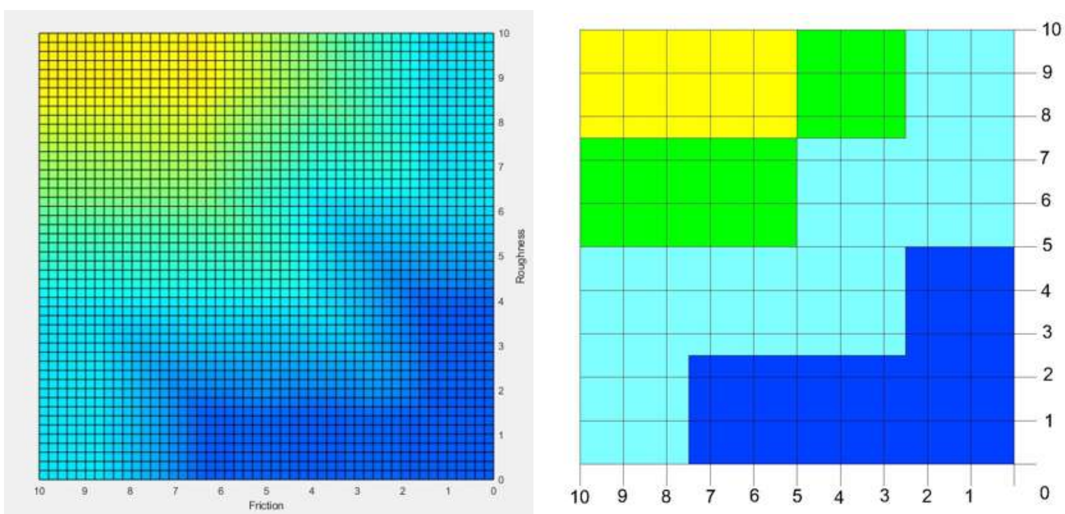


(a) Fuzzy response surface (b) Classical response surface

Figure 4.18: Classical and fuzzy Pavement performance response surfaces.

Figure 4.18 contrasts differences between the use of fuzzy and classical logic in the asset condition assessment. When a fuzzy evaluation is used, the response surface is continuous. On it, evaluation value varies proportionally to the status of the input elements. It makes it possible to model the asset condition deterioration process closely to reality due to status change is progressive. It is possible because the belonging grade of the input evaluation values varies with respect to the specific value that represents the general condition of the respective status class. When classical logic is used in the evaluation, a discontinuous surface is generated. It occurs because all the values of a status class belong completely to it. The belonging grade of all the class elements is 1. It means that opposite limit values of the same class have the same impact on the evaluation. It generates an ambiguous status determination because it is possible that representative variations in the input values do not generate variations in results. Or that small variations in input values generate big changes in evaluation. No variation in belonging grade generates that Status Class changes are suddenly. Changes between classes are proportionate to the class range. A representative value is defined for each class. In figure 4.18b representative value is the center of the class. Classic evaluation tends to make an underestimated qualification with respect to better values and an overestimate qualification with respect to worse values.

In fuzzy evaluation, changes between the defined classes are not the same for all the ranges of values. Figure 4.19a shows a superior view of the response surface for the fuzzy evaluation. It is easy to identify the fuzzified limits between the evaluation classes. They are not firmly defined, as the color gradation shows it.



(a) Superior view of fuzzy evaluation

(b) Superior view of classical evaluation

Figure 4.19: Superior view of Classical and fuzzy evaluation.

The behavior of fuzzy and classical logic evaluations are similar as can be observed in the comparison between the figure 4.19a and figure 4.19b where the principal classes VGood, Good, Bad, and Very Bad behaviors are represented by colors yellow, green, water and blue respectively. The difference between both figures is the limits of each class. Fixed and specified for classical evaluation and blurred for fuzzy evaluation.

4.5.8 Interpretation of results

As mentioned in the last section, the final result of the fuzzy evaluation model is a punctual value. It is obtained from the defuzzification process. Implementation of the evaluation model in the management process requires interpreting and understanding the final result.

There are two principal and complementary senses in the interpretation of the final value:

Status causes. Evaluation classes are described based on the status of input elements and fuzzy rules. The multi-description status includes the different scenarios that have to describe the evaluation result as the status class. The importance of this interpretation is to identify the class in which belongs the final result. It is ubicated in the status class that contains the value obtained for identifying the different input statuses that could generate it. Identification of input elements status allows defining detailed evaluation necessities. A detailed evaluation is the first step to developing the maintenance plan.

Status deterioration. It is based on the general behavior of the element evaluated. The importance of this interpretation is to identify the ubication of the final result in the class it belongs. It helps to identify the deterioration level of the evaluated element with respect to the representative value of the class. In the proposed model, the right value ubication means that the status of the evaluated element is going to the description class. In this case, element status is better than the described class. When the evaluation value is at the left of the representative value, the element status has deteriorated with respect to the class description.

Both interpretation ways are complementary. The first interpretation aids in identifying the input elements that require maintenance attention. The second interpretation aids in defining the time and deterioration level, which is necessary to implement the maintenance plans.

Figure 4.20 shows the final result for the example of the pavement performance evaluation. The first step in result interpretation is to establish the status class limits. In this project status, class limits are ubicated in the intersection between the fuzzy limits of the adjacent classes. It allows that evaluations are symmetric with respect to the representative class values.

Figure 4.20: Final result

Description of status classes is defined based on the fuzzy rules that result from each class. For example, final result 5.64 is ubicated in the status class Good. Table 4.3 shows the fuzzy rules for the status class Good. From this, it is possible to make the general evaluation class description. *Good class is defined by Very Good status of Roughness means* *that there are no deteriorations in the pavement layers. A Bad status of friction means that values of Friction Coefficient and/or Macrotexture are not adequate but are not completely deteriorated. Or a fewer deterioration in pavement layers whit Friction Coefficient and/or Macrotexture at least in desirable values.*

Pavement Performance			
No.R	Roug	Frict	
3	V.G.	B	G
5	G	V.G.	G
6	G	G	G

Table 4.3: Status Good Pavement Performance Fuzzy Rules

Once ubicated, the final result is in the respective status class; it should be evaluated if it is at the right or left of the representative value. If the final value is ubicated at the left of the representative value, the status deterioration is bigger than the general class description. If the final value is ubicated at right, status deterioration is fewer than the general class description. Priority attention is biggest when value is at left and lowest when it is at right. In the example, the final result is ubicated at the left of the representative class value (6.22). It means that the final status of pavement performance can be considered good but deteriorated. For decision-makers, it represents a road deterioration, but that could be considered acceptable.

4.6 Road Section Evaluation

Road section evaluation integrates the individual asset status. The integral evaluation considers the existing relationships between the assets that compose them. Road section included in the evaluation model developed in this research are:

- Level
- Cutting
- Embankment
- Cutting/Embankment

To develop the road section evaluation model, the first step is to identify the general assets that are part of them. Next, asset statuses are grouped to evaluate their interactions. Asset groups are formed based on three road capacities evaluation: user transit, road-user communication, and user protection.

User transit capacity evaluates the conditions that allow a road user to transit on it. The analyzed road sections could be formed by three evaluation modules: road surface, geotechnical elements, and horizontal marking. First is the surface where the user's car travels. It includes the pavement status and its interactions with the road geometry, environment, and drainage system. Geotechnical elements allow to keep the longitudinal road slope; it includes the Cutting and/or Embankment condition and their interactions with the drainage system and environment. Horizontal marking delimits the transit directions and road surface. Evaluation of drainage system has been divided into the road surface and geotechnical subsystems. In both cases, its evaluation considers the geometry, environment, and drainage asset status interactions to evaluate it.

Road-User Communication capacity, evaluates the horizontal and vertical marking adequacy. The road sign's purpose is to inform the user of special road conditions. Road-user communication allows users to keep a correct drive behavior. Markings restrict, advise or inform users. The first two purposes have a direct impact on road safety. The last purpose influences the user transit. It is necessary that road markings are ubicated in the correct site, be the correct sign, and have good visibility. An incorrect message transmission may be causing traffic accidents.

User protection capacity evaluates the road system that has the purpose of protecting road user when he loses driver control of the vehicle or when it has braking problems. It is directly related to road safety. It is the road capacity to forgive users' mistakes. Evaluated elements include central, limit, and object barriers and braking ramps. Asset evaluations are related to the environment and geometry, analyzing the importance of good condition.

Figure 4.21 shows the Road Section evaluation process schematically. It is divided into four sections: Asset Evaluations, Evaluation Modules, Road Capacities, and Maintenance and Risk evaluation.

Asset Evaluation is the input information for the road section evaluation model. It is obtained from the final results of the Road Asset Evaluation Model presented in the last section.

The evaluation modules section groups the input information. Defined evaluation modules are Road Surface, Geotechnical Elements, and the Drainage subsystem for each one. These analyze the interactions between the different assets that compose the road section with the environment and road geometry.

Road capacities are the basis of integral evaluation. They represent the road characteristics that determine the road operation and safety status.

Final road evaluation results analyze the road capacities status interactions. Two final results are obtained in this model: Road Operation and Road Safety. These could be used as the basis information in the planning management process.

As figure 4.10, figure 4.21 is an input diagram of the fuzzy evaluation model. The first level evaluation, the left section, is composed of the asset evaluation results. From it to the right, each one of the diagram nodes represents a fuzzy control.

Due to road section evaluation begins with the result of a fuzzy evaluation, input and output sets of fuzzy sets for all the fuzzy controls in the diagram presented in figure 4.21 are the response set of fuzzy sets defined in figure 4.13.

When an inspector just needs to know the status of a specific road section, the four evaluation sections should be applied. If the inspector makes a Road Network evaluation, Road section evaluation ends in the road capacities section. These results are the input information in the road network evaluation.

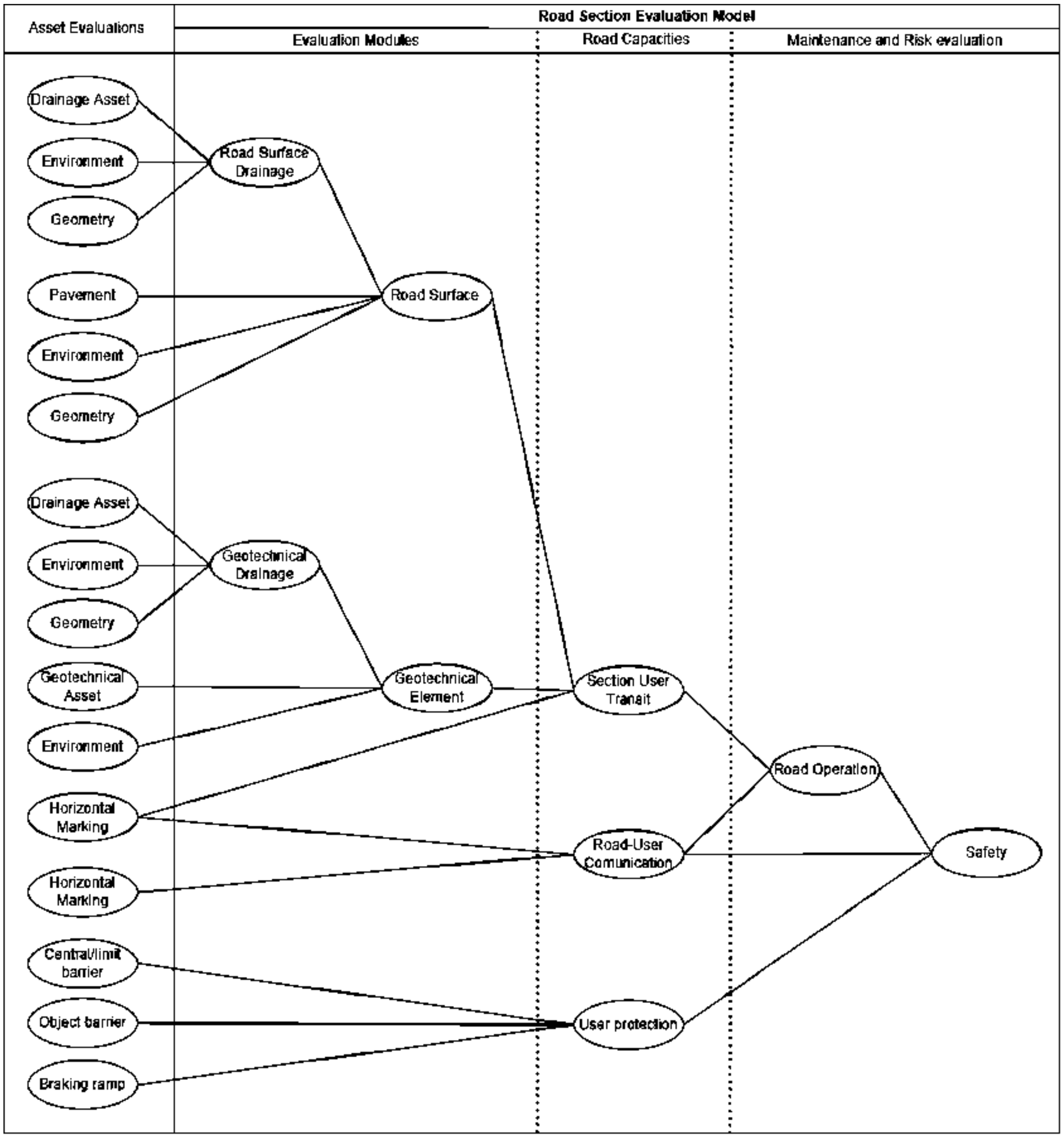


Figure 4.21: Road Section Evaluation

4.7 Road Network Evaluation

Road Network Evaluation is the highest evaluation level of the proposed model; it allows the evaluation of road segments. A road segment is a road section set. It includes three road sections: entrance, intermediate, and exit, as has been described in section Road Network Modeling and shown in figure 4.4. Evaluation of a road network is based on a continuous series of road segments to form a Road Network, the exit section of a segment is the entrance section of the next segment, and so forth.

Figure 4.22 shows the Road Network Evaluation Model diagram. As the Road Section Evaluation, Road Network Evaluation is based on the road capabilities of the road sections that compose a road segment. Evaluation of road section capabilities obtained in the last section is the input information for this model.

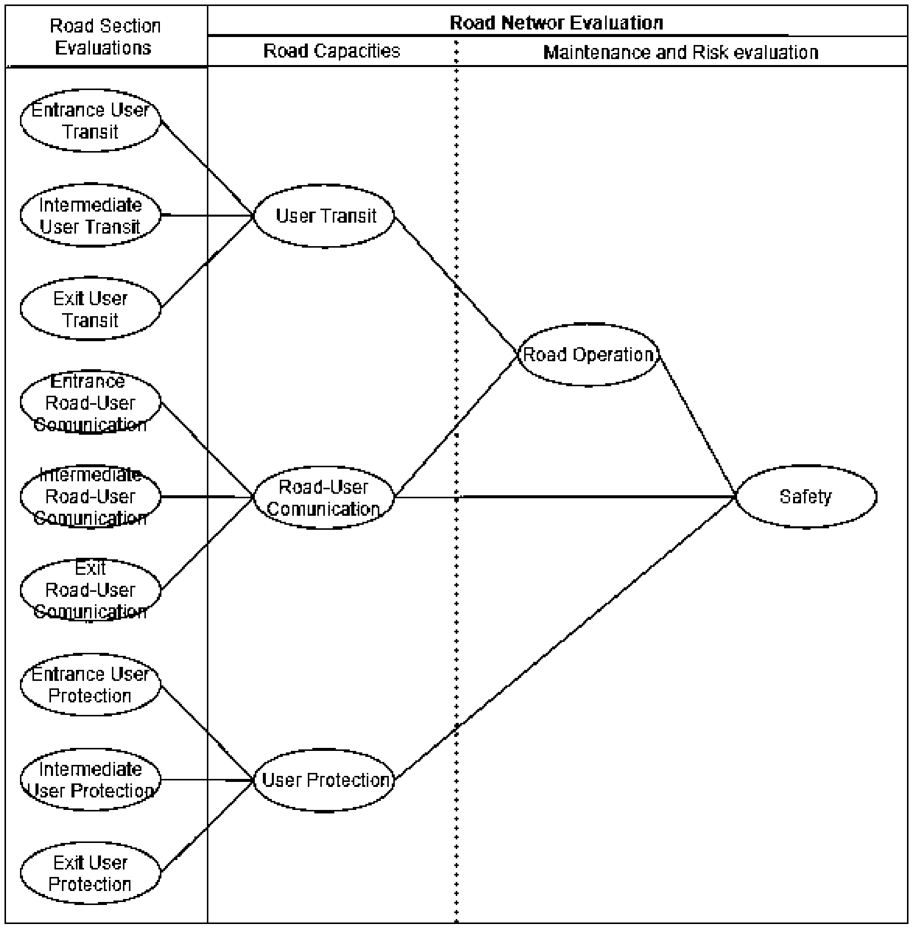


Figure 4.22: Road Network Evaluation

As in figures 4.10 and 4.21 Figure 4.22 includes de evaluation fuzzy controls. It is composed of two evaluation levels: Road Capabilities and Maintenance and Risk Evaluation. In the first level, fuzzy evaluation rules are based on geographical and functional interactions between the road section capabilities. Fuzzy controls have, as a result, the general road capabilities status. In the second level, fuzzy controls analyze the road capabilities' interaction to obtain a Road Operation and Road Safety evaluation.

Road Operation analyzed the interactions between the user transit and road user communication capacities. It evaluates the road functionality and answers two principal questions: 1) Can road user circulates on it? 2) Circulation roadway is clear?

Road Safety is a superior evaluation level. Besides, it evaluates if a user can circulate the road it evaluates if the circulation is reliable. It analyzes the interactions between the Road Operation result, Road-User Communication, and User Protection.

The integral evaluation process is composed of three principal levels. The first level evaluates the road assets as a function of their deterioration process, and it is based on parameters measurables on the site. The second level evaluates the road section as a function of the road section capabilities, and it is based on the road section assets relationships. The last level evaluates the Road Network as a function of the road segment capabilities, and it is based on the geographical and functional relationships between the road sections that integrate the evaluated road segment.

Chapter 5

Fuzzy Model Application

This chapter presents a hypothetical case of study to apply the developed fuzzy model and show its usefulness. We present the evaluation of three sections by combining pavement, drainage, geotechnical, and safety assets with horizontal, and vertical curves geometry, by considering weather, transit, and soil environment parameters.

5.1 Application of the Fuzzy Model Evaluation for Road Networks

In Tables 5.1, 5.2, and 5.3 we show the evaluation diagrams of the level section in a horizontal curve, an embankment in a vertical curve, and sedimentary rock cutting in a vertical curve, respectively.

At the left of the tables, in the first column, we list the values of the interval evaluation parameters. The next column shows the status related to the analysis value used in the section evaluation. The third column shows the value of the analysis applied in the evaluation. We define the input evaluation values randomly for each parameter considered as part of the asset. The next column includes the evaluation parameters applied to determine the asset status as part of the evaluated section.

We present the sequence of fuzzy controls employed in the section evaluation in the remaining columns. We organize the fuzzy evaluations hierarchically, assembling the evaluation modules. The evaluation modules are a set of fuzzy controls that evaluate a particular road network aspect. These modules allow the evaluation of different levels of the assets. The first levels evaluate the assets individually. While the evaluation stage increased, we made a comprehensive relationship among the individual evaluations. Final evaluation levels make the integral evaluation. This process determines the general road section status.

Fuzzy modules have the nearest relation with the management levels. At the highest levels of the management process, we must know the road network's general status. These levels are focused on the budget administration. An integral evaluation is needed to determine the investment requirements. At the basic levels, we concentrate on the attention of the road network maintenance constraints. These levels require to know what is wrong to make the maintenance works planning.

The tables 5.1, 5.2, and 5.3 include the results for each fuzzy control, allowing us to observe the progressive evaluation based on the relationships of the previous evaluation. We remark, as has been described in the Fuzzy Model Develop section, that we can carry out a result interpretation based on the response set of fuzzy sets. Figures 5.1 and 5.2 shows the results for the Operation and Safety Performance of the evaluated sections respectively.

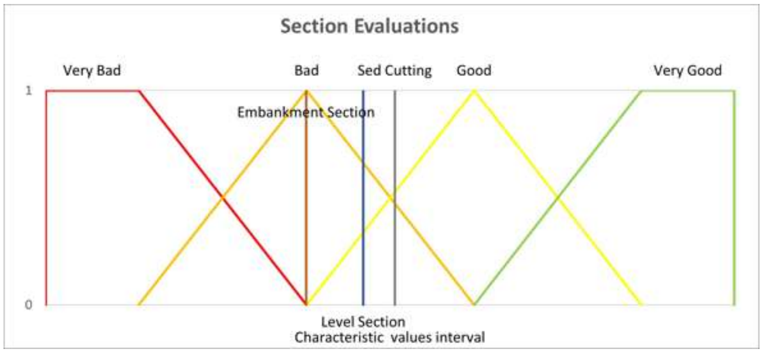


Figure 5.1: Section Operation Performance Evaluation

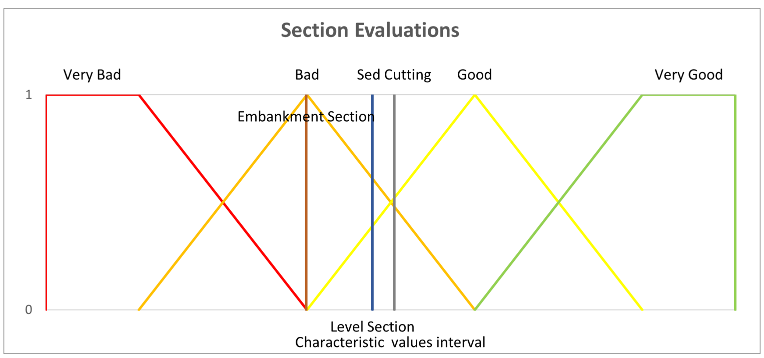


Figure 5.2: Section Safety Performance Evaluation

We present a comparison between the Operation and Safety Performance of the evaluated sections. In figures 5.1 and 5.2. We can observe that the sedimentary cutting section is the best evaluated. Table 5.3 shows the evaluation results obtained for both elements. The final evaluation results are 5.0727 for the Operation Performance and 5.0551 for the Safety Performance. These general qualifications show that the status of the section is good but with a deterioration level near to a bad condition, which means that some assets require attention.

After the evaluation, based on the data shown in table 5.3, we can detect the following deficiencies:

- The road ditch requires attention to solve the drainage pavement problems.
- Mound slopes of the braking ramp need to be reduced.
- The road surface needs attention to solve the surface deterioration problems.

- A relocation of the vertical marking is necessary to improve the Road-User Communication.

The level section is the second-best evaluated results showed in table 5.1 are: 4.6116 in Operation Performance and 4.7376 in Safety Performance. It is located in the bad status nearest to a good status.

The principal deficiencies in the level section are observed in:

- Pavement drainage.
- Pavement geometry.

Finally, the embankment section has been evaluated with 3.7794 in Operation Performance and 3.7828 in Safety Performance, as could be observed in table 5.2. These evaluations represent a bad section status.

The main deficiencies found for the embankment section are observed in:

- Entrance of culvert.
- Body surface of the embankment.

In the proposed hypothetical case of study, we can detect the necessity of integral evaluations. Pavement performance conditions have prevailed to show the impact of status variation in the rest of the assets. The prioritization of maintenance works should take into account.

In this example, the priorities of attention are culvert, geometry, and relocation of vertical markings. If maintenance works are just focused on the pavement performance, we could ignore other necessities of attention.

In the three evaluated sections, the Pavement Performance status is better than the Operation and Safety Performance. If just pavement performance is evaluated, the status of sections is good with deterioration to bad. But mainly show a good performance.

Therefore, evaluating the relationships between the status of the different assets that compose the road is the core strength of our proposed model. It is crucial to notice that the proposed model makes the road evaluation. Application in the planning management process requires the human interpretation component.

Level Section/Horizontal Curve												
Values Interval		Status	Analysis Value	Evaluation Parameter	Fuzzy Controls							
0	1	A-G	0.62	Friction Coefficient	Friction 6.5910			Pavement Performance 5.1953	Pavement 4.3466	User Transit 4.4420	Operation Performance 4.6116	Safety Performance 4.7376
50	110	G-R	88	Macrotexture								
0	60	G-B	3	Cracking Area	Structural Deterioration 6.2043	Structural Performance 6.1927	Roughness 4.8431					
0	5	G	0	Potholes								
0	50	A-B	12	Patching Area								
0	30	A-G	7	Road Depth								
0	1	G-A	0.28	Deflections								
0	50	A-B	10	Cracking Area	Surface Deterioration 4.8086							
0	10	A	1	Potholes								
0	50	A-B	12	Patching Area								
0	30	A-B	10	Road Depth								
0	6	G-B	4	Pumping	Asset 5.0797 Geometry 1.3487			Drainage 2.8613				
70	130	VB	70	Over Elevation								
90	250	G-Me	200	Transversal	Slopes 6.5920	Environment 6.5017						
1	10	Me-H	3	Horizontal								
0	600	N-M	100	Rain Fall 8.5457								
0	100	M-H	35	ESAL´S	Transit 6.5233	Environment 6.8011						
0	5000	M-L	700	IMDp								
0	100	G-VG	35	Liquid Limit	Soil 6.8606							
0	80	G-R	18	CBR								
20	60	M-L	36	Temperature	Weather 7.4294							
70	130	G-VB	70	Over Elevation	Horizontal Curve Performance	Geometry 3.7734						
70	130	G-B	105	Over Sizing								
70	130	G	100	Geometric Points								
0	1	G-VG	0.4	Retroreflectivity			Line 6.2211	Horizontal Marking 6.2211				
0	6	G	5	Indiviual Lenght	Pattern 8.6483 Adequacy 6.2203	Mark 6.2206						
9	11	G	10	Separation								
10	30	G	20	Width								
-30	40	G	0	Lenght								
0	1	G	1	Button Separation								
1.5	2.8	G-B	2.3	Height	Location 6.33044		Inventory 4.7706	Vertical Marking 4.8120				
0	2	G-A	0.7	Lateral Separation						Road-User Comunication 4.8468		
0.5	2	G-F	1.1	Longitudinal Distance								
0	1	G-VG	0.4	Retroreflectivity	Signal 6.9937	Visibility 6.8243	Performance 6.6853					
0	1	G-A	0.2	Luminance								
0	10	VG-G	8	Obstruction								
1.5	2.8	G-B	2.3	Height	Position 6.3234							
70	90	G-A	88	Verticallity								
0	100	Low	20	Wind	Environment							
-5	5	G-Btall	2	Height	Barrier 5.9230	Assets 3.7837				User Protection 5.2235		
0	10	Good-Bad	6	Integrity								
0	2.5	G-B	1.2	Lane Distance	Location 3.7864							
-5	30	B	5	Lenght								
0	100	M-H	35	ESAL´S	Transit	Environment 7.8403						
0	600	N-M	100	Rain Fall	Weather							
70	120	B	105	G Máx	Horizontal Curve Inventory	Geometry 4.9950						
80	120	R-G	105	R Mín								
0	30	VG-G	9	Consistency								

Table 5.1: Level Section Evaluation

Embankmentl Section/Vertical Curve																
Values Interval		Status	Analysis Value	Evaluation Parameter	Fuzzy Controls											
0	1	A-G	0.62	Friction Coefficient	Friction 6.5910				Pavement Performance 5.1953	Pavement 5.1542			Assets 3.7750	User Transit 3.7865	Operation Performance 3.7828	Safety Performance 3.7794
50	110	G-R	88	Macrotexture												
0	60	G-B	3	Cracking Area	Structural Deterioration 6.2043	Structural Performance 6.1927	Roughness 4.8431									
0	5	G	0	Potholes												
0	50	A-B	12	Patching Area												
0	30	A-G	7	Road Depth												
0	1	G-A	0.28	Deflections												
0	50	A-B	10	Cracking Area	Surface Deterioration 4.8086											
0	10	A	1	Potholes												
0	50	A-B	12	Patching Area												
0	30	A-B	10	Road Depth												
0	6	VG-G	2	Pumping 7.4847				Asset 5.0327	Drainage 6.2206							
0	10	VG-G	8	Surface Det	Channel 4.0874		Kerb 4.2586									
0	10	B-G	4	Obstruction												
0	10	G-B	0.05	Width	Cracks 8.0725	Structure 7.3530										
0	10	VS-RS	8.5	Spacing												
0	10	VG	9	Road Surf Sep												
0	10	VG	0	Depth	Spalls 8.6483											
0	10	Vsep	10	Spacing												
0	10	VG	4	Long Slope	Geometry 8.5569											
90	250	G-Me	200	Transversal	Slopes 6.5920	Environment 6.5017										
1	10	Me-H	3	Horizontal												
0	600	N-M	100	Rain Fall 8.5457												
0	100	M-H	35	ESAL´S	Transit 6.5233	Environment 6.8023										
0	5000	M-L	700	IMDP												
0	100	G-VG	35	Liquid Limit	Soil 6.8606											
0	80	G-R	18	CBR												
20	60	M-L	36	Temperature	Weather 7.4294											
70	130	G-B	105	Geometric Points	Vertical Curve Performance		Geometry 5.9948									
0.9	1.1	G	1	Height	Geometry 6.2203			Embankment Performance 3.7794				Embankment 3.7781				
0.8	1.2	G-VG	0.98	Slope												
0	5	M	1.5	Height	Vegetal Coverage											
0	100	M-F	20	% Area												
0	10	A-G	7	Scour			Body Surface 3.7832									
0	25	VG-G	3	Deeper	Longitudinal Displacements 8.4708	Soil 3.7864										
0	15	VG	0	Width												
0	10	VS	10	Spacing												
0	25	B-VB	13	Deeper	Grooves 3.7863											
0	15	B	5	Width												
0	10	RS-VS	8.5	Spacing												
0	10	VG-G	8	Lateral Scour	Around 8.3495		Inlet 7.5661	Batter Chute 7.3378		Assets 3.7824	Drainage 3.7807					
0	10	VG	0.05	Road Separation												
0	10	VG	9	Surface Det	Channel 7.7923											
0	10	G-VG	8	Obstruction												
80	115	G	100	Transverse Area												
0	10	G-B	0.05	Width	Cracks 8.0725	Structure 7.8758										
0	10	VS-RS	8.5	Spacing												
0	10	VG	0.05	Depth	Spalls 8.2931											
0	10	VG	8.5	Spacing												
0	10	G-VG	8	Lateral Scour	Around		Batter Chute 7.5661									
0	10	VG	9	Surface Det	Channel 7.7923											
0	10	G-VG	8	Obstruction												
80	115	G	100	Transversal Area												
0	10	G-B	0.05	Width	Cracks 8.0725	Structure 7.8758										
0	10	VS-RS	8.5	Spacing												
0	10	VG	0.05	Depth	Spalls 8.2931											
0	10	VG	8.5	Spacing												
0	10	B-G	4.5	Alignement	Channel 5.3097			Entrance 2.3160	Culvert 3.7860							
0	10	G-VG	7	Waterway												
0	10	G-B	0.02	Width	Cracks 8.3399	Head 7.9893	Structures 7.7802									
0	10	RS-VS	8.5	Spacing												
0	10	G-B	1	Depth	Spalls 7.2128											
0	10	VS	10	Spacing												
0	10	G-B	0.02	Width	Cracks 8.3399	Protection 7.9893										
0	10	RS-VS	8.5	Spacing												
0	10	G-B	1	Depth	Spalls 7.2128											
0	10	VS	10	Spacing												
0	10	VB-B	2	Erosion, Scour				Barrel 5.9230								
0	10	B-G	4	Infiltration, Exfiltration												
0	10	G-B	6	Fasterner	Joints 6.5214		Structure 3.7862									
0	10	G-VG	7	Alignement												
0	10	VB	1	Corrosion	Damage 2.7876	Deterioration 2.9890										
0	10	G-B	5	Surface												
0	10	G-VG	8	Abrasion												
0	10	B-VB	3	Shape												
0	10	G-VG	8	Alignement												
0	10	VG	9	Deformation	Deterioration 8.6483	Spillway 8.6455										
0	10	VG	9	Corrosion												
0	10	VG	9	Settlement/Rotation												
0	10	G-B	0.02	Width	Cracks 8.3399	Head 7.9893	Structures 7.7802	Exit 8.4835								
0	10	RS-VS	8.5	Spacing												
0	10	G-B	1	Depth	Spalls 7.2128											
0	10	VS	10	Spacing												
0	10	G-B	0.02	Width	Cracks 8.3399	Protection 7.9893										
0	10	RS-VS	8.5	Spacing												
0	10	G-B	1	Depth	Spalls 7.2128											
0	10	VS	10	Spacing												
0	10	VG	9	Erosion, Scour												
90	250	G-Me	200	Transversal	Slopes 6.5920	Environment 6.5017										
1	10	Me-H	3	Horizontal												
0	600	N-M	100	Rain Fall												
0	100	M-H	35	ESAL´S	Transit 6.5233		Environment 6.7794									
0	5000	M-L	700	IMDP												
90	250	G-Me	200	Transversal	Slopes 6.5920	Soil 6.9469										
1	10	Me-H	3	Horizontal												
0	80	G-R	18	Liquid Limit												
20	60	M-L	36	CBR												
0	600	N-M	100	Rain Fall	Weather 8.5457											
0	1	G-VG	0.4	Retroreflectivity			Line 6.2211	Horizontal Marking 6.2211								
0	6	G	5	Indiviual Lenght	Pattern	Mark 6.2206										
9	11	G	10	Separation												
10	30	G	20	Width	Adequacy 6.2203									Road-User Comunication 4.8468		
-30	40	G	0	Lenght												
0	1	G	1	Button Separation												
1.5	2.8	G-B	2.3	Height	Location 6.3304		Inventory 4.7706	Vertical Marking 4.8120								
0	2	G-A	0.7	Lateral Separation												
0.5	2	G-F	1.1	Longitudinal Distance												
0	1	G-VG	0.4	Retroreflectivity	Signal 6.9937	Visibility 6.8243	Performance 6.6853								User Protection 6.2067	
0	1	G-A	0.2	Luminance												
0	10	VG-G	8	Obstruction												
1.5	2.8	G-B	2.3	Height	Position 6.3234											
70	90	G-A	88	Verticallity												
0	100	Low	20	Wind	Environment											
0	20	G-A	12	Entrance	Thickness 7.8403	Braking Ramp 6.2203	Assets 3.7819									
40	120	VG-G	85	Body												
0	5	VB	2	Mound Slope												
-5	5	G-Btall	2	Height	Barrier 5.9230	Barrier Performance 3.7837										
0	10	Good-Bad	6	Integrity												
0	2.5	G-B	1.2	Lane Distance	Location 3.7864											
-5	30	B	5	Lenght												
0	100	M-H	35	ESAL´S	Transit	Environment 7.8403										
0	600	N-M	100	Rain Fall	Weather											
70	130	VG	120	Min	Lenght 8.2014	Geometry 8.5569										
70	130	VG	75	Max												
0	10	VG	4	Long Slope	Slopes											

Table 5.2: Embankment Section Evaluation

Cutting Section/Horizontal Curve Global stabilization/Road Protection					
Values interval		Status	Analysis Value	Evaluation Parameter	Fuzzy Controls
0	1	A-G	0.62	Friction Coefficient	Friction
50	110	G-R	88	Macrotexture	
0	60	G-B	3	Cracking Area	Structural; Structural
0	5	G	0	Potholes	Deterioration; Performance; Pavement
0	50	A-B	12	Patching Area	Performance
0	30	A-G	7	Road Depth	6.2043; Roughness
0	1	G-A	0.28	Deflections	6.1927
0	50	A-B	10	Cracking Area	Surface; 4.8431; 5.1953
0	10	A	1	Potholes	Deterioration
0	50	A-B	12	Patching Area	
0	30	A-B	10	Road Depth	4.8086
0	6	VG-G	2	Pumping 7.4847	
0	10	G-VG	7	Lateral Scour	Around
0	10	G-B	2	Road Separation	
0	10	B-VB	3	Surface Det	Channel; Pavement
0	10	VG	9	Obstruction	Ditch; Asset
80	115	G	100	Transverse Area	3.7861
0	10	G-B	0.05	Width	Cracks; Structure; 3.7829; 3.7790; Drainage; 5.1542
0	10	VS-RS	8.5	Spacing	
0	10	VG	0	Depth	Spalls; 6.2038
0	10	Vsep	10	Spacing	7.8758
0	10	VG	4	Long Slope	Geometry 8.5569
90	250	G-Me	200	Transversal	Slopes; Environment
1	10	Me-H	3	Horizontal	
0	600	N-M	100	Rain Fall	8.5457; 6.5920; 6.5017
0	100	M-H	35	ESAL´S	Transit
0	5000	M-L	700	IMDP	Environment
0	100	G-VG	35	Liquid Limit	Soil
0	80	G-R	18	CBR	6.8023
20	60	M-L	36	Temperature	Weather 7.4294
70	130	G-B	105	Geometric Points	Vertical Curve Performance; Geometry 5.9948
0.8	1.2	G	1	Height	Geometry
0.8	1.2	VG-G	0.95	Inclination Angle	Assets
0	5	S-M	0.8	Height	Body; Vegetal; User
0	100	R-H	20	% Area	Coverage; 5.1210; Transit
0	5	M	1.8	Height	Crown; Structure; 5.0944; Operation
0	100	R-H	40	% Area	7.0086; Performance
0	25	B	15	Deeper	Scour; Body; 5.1210; Sedimentary
0	60	B-VB	35	Width	Cutting Performance
0	10	VS	10	Spacing	3.7861; Surface; 5.0727
0	25	B	10	Deeper	Grooves; 6.1346
0	15	B-VB	8	Width	
0	10	RS	6	Spacing	3.7835
0	10	VG	10	Integrity	Bolts; Improvement
0	10	VG	10	Body Cutting	Safety
0	10	VG	9	Cleaning	Road Protection; Performance
0	10	VG	9	Screen	8.6455
0	10	G-VG	7	Lateral Scour	Around; Cutting; 5.0551
0	10	B-VB	3	Surface Det	Channel
0	10	VG	9	Obstruction	
80	115	G	100	Transversal Area	3.7861; Ditch; 6.0880
0	10	G-B	0.05	Width	Cracks
0	10	VS-RS	8.5	Spacing	Structure; 6.2131
0	10	VG	0	Depth	Spalls; Drainage
0	10	Vsep	10	Spacing	7.8758; Assets; Cutting
0	10	VG	9	Lateral Scour	Around; Drainage
0	10	VG-G	8	Surface Det	Channel; 8.1750
0	10	VG	9	Obstruction	Batter; 7.9981
80	115	VG	108	Transversal Area	8.5349; Chute
0	10	G-B	0.05	Width	Cracks
0	10	VS-RS	8.5	Spacing	Structure; 8.3268
0	10	VG	0	Depth	Spalls
0	10	Vsep	10	Spacing	7.8758
0	600	N-M	100	Rain Fall	Weather; Environment 8.5457
0	100	M-H	35	ESAL´S	Transit
0	5000	M-L	700	IMDP	Environment
0	1	G-VG	0.4	Retroreflectivity	
0	6	G	5	Indivial Lenght	Pattern; Mark; Line; Horizontal Marking
9	11	G	10	Separation	
10	30	G	20	Width	Adequacy; 6.2206; 6.2211; 6.2211
-30	40	G	0	Lenght	
0	1	G	1	Button Separation	
1.5	2.8	G-B	2.3	Height	Location; Inventory
0	2	G-A	0.7	Lateral Separation	Road-User
0.5	2	G-F	1.1	Longitudinal Distance	4.7706; Comunication
0	1	G-VG	0.4	Retroreflectivity	Signal; Visibility; Vertical Marking
0	1	G-A	0.2	Luminance	Performance; 4.8468
0	10	VG-G	8	Obstruction	4.8120
1.5	2.8	G-B	2.3	Height	Position; 6.6853
70	90	G-A	88	Verticallity	
0	100	Low	20	Wind	Environment
0	20	G-A	12	Entrance	Thickness; Braking Ramp
40	120	VG-G	85	Body	
0	5	VB	5	Mound Slope	3.7863; Assets
-5	5	G-Btall	2	Height	Barrier; Barrier
0	10	Good-Bad	6	Integrity	Performance; 3.7819; User Protection
0	2.5	G-B	1.2	Lane Distance	Location
-5	30	B	5	Lenght	3.7837
0	100	M-H	35	TDPA	Transit; Environment; 6.0707
0	600	N-M	100	Rain Fall	Weather
70	130	VG	120	Min	Lenght; Geometry
70	130	VG	75	Max	
0	10	VG	4	Long Slope	8.5569

Table 5.3: Sedimentary Rock Cutting Section Evaluation

Chapter 6

Conclusions

In this thesis, we developed a fuzzy evaluation model for an integral evaluation of the Road Networks conditions. The results of this model are an evaluation analysis of the state of the different assets that compose a road section. The model contemplates the relationships and influence of the asset status evaluated. The final result reflects the global status of the road sections in two ways: Road Operation and Road Safety Status. We can interpreted the results like a diagnosis of the evaluated road section.

We defined the functional importance and properties of road assets to determine the evaluation parameters and metrics. In this sense, we developed catalogs to contemplate the failure types and evaluation parameters proposed for five types of assets: 1) pavement, 2) geotechnical, 3) drainage, 4) safety, and 5) structures. Then, we classified the elements selected in the catalogs in two segments inventory and performance evaluation parameters. The inventory parameters are fixed or correspond to the initial asset properties. We associate this parameter with asset resilience and its interaction with environmental conditions. In contrast, the performance parameters are the asset properties during the evaluation time, which we related to asset behavior and its interactions with the environment and other asses status.

For the fuzzy evaluation model, we selected membership functions (triangular and trapezoidal) that associate the metrics and behavior of the evaluation parameters. Therefore, the fuzzy sets shape the behavior of the assets such as environment, flexible pavements, pavement drainage, cuttings, surface cutting drainage, embankments, vertical and horizontal marking, barriers, and braking ramps.

For the individual evaluation model of the assets, we have selected evaluation parameters based on the analysis of existing evaluation models. Besides, we complement the existing evaluation models to form a more extensive evaluation of the modules that describe the asset behavior, including evaluation parameters of different proposes.

To generate an integral evaluation, we analyze and propose relationships between the properties of the different assets. We define the fuzzy evaluation rules for the different fuzzy control modules employed in the integral evaluation. We define the integral performance evaluation associating the asset and environment status through the following road properties: User Transit, Road-User Communication, User protection, Operation Performance, and Safety Performance.

Hence, the integral evaluation model is developed based on the individual asset evaluations modules. We include the evaluation of the assets that form road sections and their relationships. In this sense, to generate the evaluation, the status qualification limits of each parameter have been diffused to estimate the belonging grade of the evaluation values to the status classes, which produces a continuous set of responses. Modules classification allows us to evaluate the road properties and identify what is bad. Also, facilitate the definition of relationships between parameters, dividing them into road characteristics with internal and inter characteristics relationships.

Progressive evaluation generates evaluation outcomes at different management levels simplifying the general visualization of results and providing enough details to identify the status of the individual parameters.

The solution proposed to carry out an integral evaluation of the assets that compose a road network compared with previous evaluation models does not limit the asset evaluation models to a particular aspect or characteristics of an asset. Another difference is that we contemplate the asset relationships with the environmental properties.

Implementing fuzzy logic in our model allows us to obtain an evaluation similar to an expert that visualizes a global panorama of the behavior of the assets. Therefore, our solution allows an administrator to identify the attention priorities, evaluating the status of the road in a global and/or individual state: determining how well or bad is their condition.

Furthermore periodic implementation of the developed model allows to describe better the road deterioration process. Because evaluation outcomes are continuous. Then evolution of deterioration process can be observed. Unlike employing classic logic. It generates, the same results for a defined status interval so their results are discrete. The aforementioned, makes challenging to identify attention priorities of road sections classified into the same status because all have the same evaluation.

The developed model is the first proposal that makes an integral evaluation of assets that compose a road section. We establish in this thesis the base to develop an integral approach to evaluate of the assets condition assessment for maintenance and risk management of road networks.

Chapter 7

Future Work

Research job is a continuous process of evolution. All works need to be complemented or adapted to embrace them in different applications. Some of the future works identified in this research are the following.

- We should improve the proposed model by including assets such as road structures evaluation, road rights, and intelligent road systems, also adding their relationships.
- An analysis to calibrate the proposed model and the land interpretation of results for different scenarios should be done.
- A software implementation of the proposed model to process the road network evaluation in real-time should be done, considering the databases' design that collects the parameters described in the catalogs.
- To obtain the parameters measures in an automatic way several technologies and applications should be explored.
- The planning process can obtain benefits from the automatization of the model results interpretations. Besides, we can implement protection tools of data based on blockchain.

I think that research without future works is a death investigation. Hence, the contributions presented in this thesis are just the origin of a very long road.

Chapter 8

Annex A

8.1 Environment

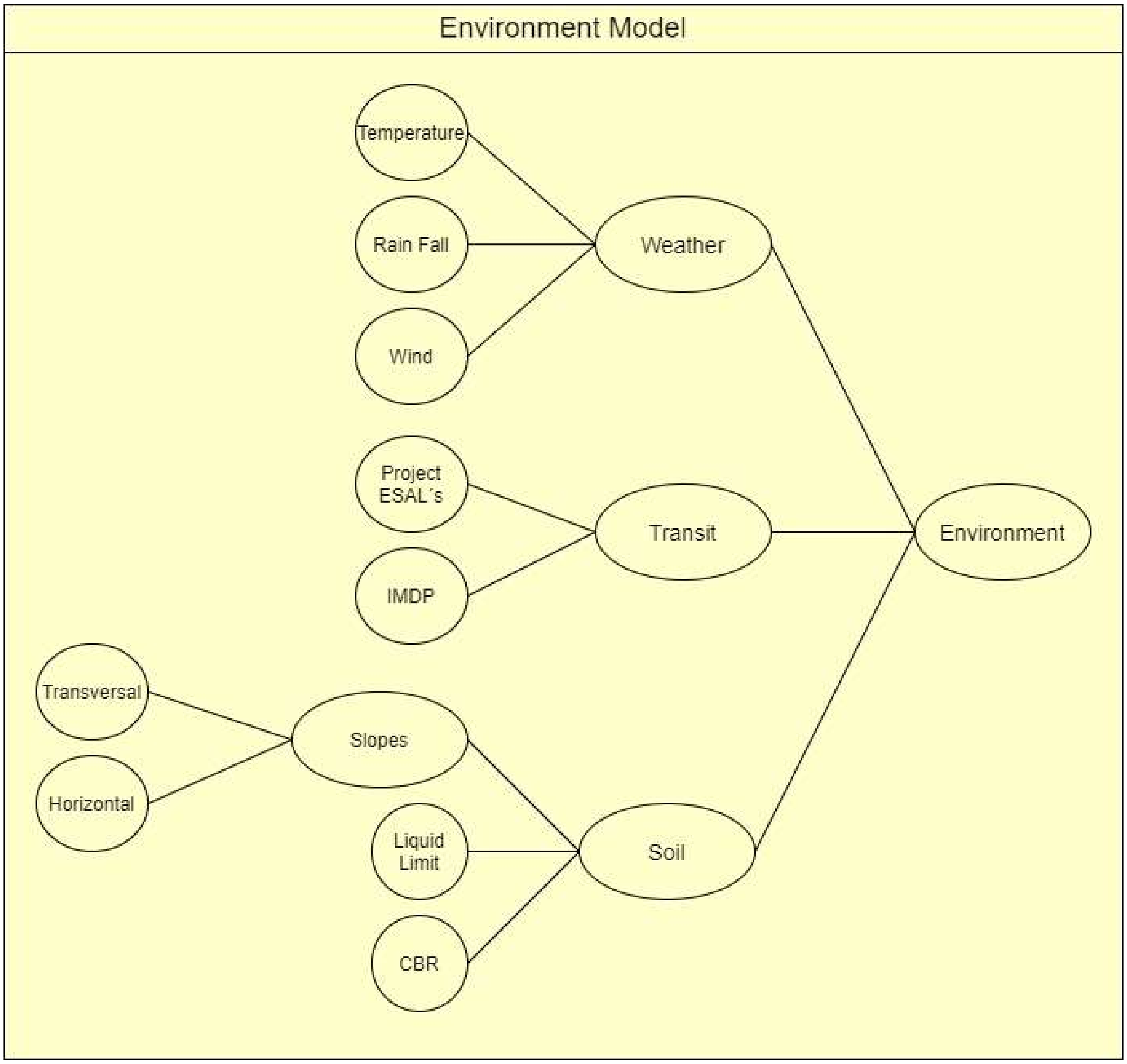


Figure 8.1: Environment Model

Weather

- Temperature. Average temperature of the warming seven consecutive days.
- Rain Fall. Total annual precipitation.
- Wind. Average wind speed.

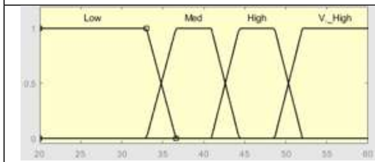
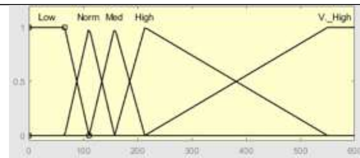
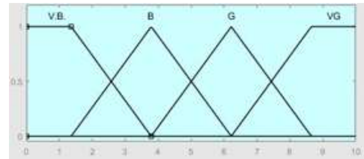
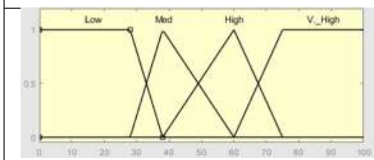
Temperature	Rain Fall	Weather
		
Wind		
		

Table 8.1: Weather Fuzzy Sets

Weather											
Temp	RainF	Wind		Temp	RainF	Wind		Temp	RainF	Wind	
L	L	L	VG	M	M	M	B	H	VH	H	VB
L	N	L	G	M	H	M	B	H	L	VH	VB
L	M	L	G	M	VH	M	VB	H	N	VH	VB
L	H	L	B	M	L	H	G	H	M	VH	VB
L	VH	L	VB	M	N	H	B	H	H	VH	VB
L	L	M	G	M	M	H	B	H	VH	VH	VB
L	N	M	G	M	H	H	B	VH	L	L	G
L	M	M	G	M	VH	H	V.B	VH	N	L	G
L	H	M	B	M	L	VH	B	VH	M	L	B
L	VH	M	VB	M	N	VH	B	VH	H	L	VB
L	L	H	G	M	M	VH	B	VH	VH	L	VB
L	N	H	G	M	H	VH	VB	VH	L	M	G
L	M	H	B	M	VH	VH	VB	VH	N	M	B
L	H	H	B	H	L	L	G	VH	M	M	B
L	VH	H	VB	H	N	L	G	VH	H	M	VB
L	L	VH	B	H	M	L	B	VH	VH	M	VB
L	N	VH	B	H	H	L	B	VH	L	H	B
L	M	VH	B	H	VH	L	VB	VH	N	H	B
L	H	VH	VB	H	L	M	G	VH	M	H	VB
L	VH	VH	VB	H	N	M	B	VH	H	H	VB
M	L	L	G	H	M	M	B	VH	VH	H	VB
M	N	L	G	H	H	M	B	VH	L	VH	VB
M	M	L	G	H	VH	M	VB	VH	N	VH	VB
M	H	L	B	H	L	H	G	VH	M	VH	VB
M	VH	L	VB	H	N	H	B	VH	H	VH	VB
M	L	M	G	H	M	H	B	VH	VH	VH	VB
M	N	M	G	H	H	H	B				

Table 8.2: Weather Fuzzy Rules

Transit

- ESAL´s. Project million ESAL´s. AASHTO 1993.

- IMDp. Project IMDp. Regulation 6.1 Spain.

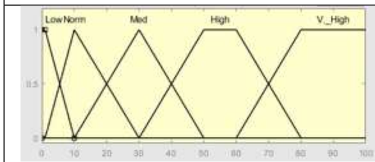
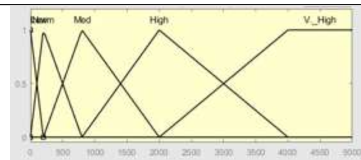
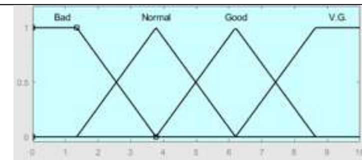
ESAL´s	IMDp	Transit
		

Table 8.3: Transit Fuzzy Sets

Transit										
ESAL´s	IMDP			ESAL´s	IMDP			ESAL´s	IMDP	
L	L	VG		M	L	VG		VH	L	N
L	N	G		M	N	VG		VH	N	N
L	M	N		M	M	G		VH	M	N
L	H	B		M	H	N		VH	H	B
L	VH	B		M	VH	B		VH	VH	B
N	L	VG		H	L	G				
N	N	G		H	N	G				
N	M	N		H	M	G				
N	H	B		H	H	N				
N	VH	B		H	VH	B				

Table 8.4: Transit Fuzzy Rules

Slopes

- Transversal. Degrees slope.
- Longitudinal. Percentage slope.

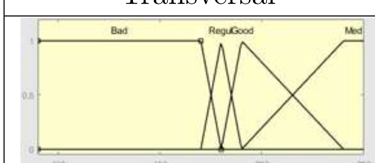
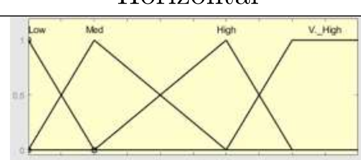
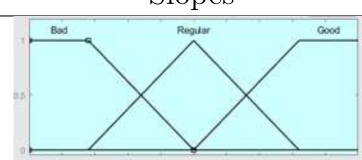
Transversal	Horizontal	Slopes
		

Table 8.5: Soil Slopes Fuzzy Sets

Slopes						
Trans	Hor			Trans	Hor	
B	L	B		G	L	G
B	M	R		G	M	G
B	H	G		G	H	G
B	V.H	R		G	V.H	B
R	L	B		M	L	G
R	M	G		M	M	R
R	H	R		M	H	B
R	V.H	R		M	V.H	B

Table 8.6: Slopes Fuzzy Rules

Soil

- Slopes. Horizontal and Transversal evaluation.
- Liquid Limit. Geotechnical property.
- CBR. Geotechnical property.

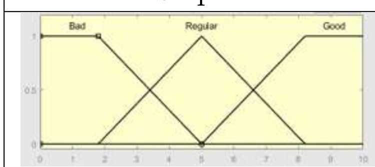
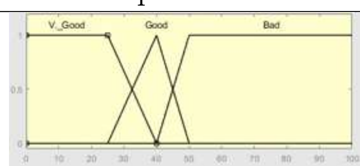
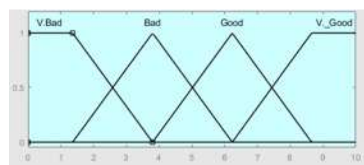
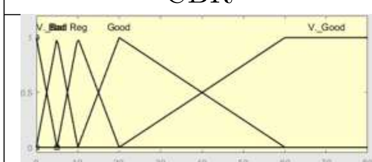
Slopes	Liquid Limit	Soil
		
CBR		
		

Table 8.7: Soil Fuzzy Sets

Environment

- Weather. Rain fall, temperature and wind evaluation.
- Transit. ESAL´s and IMDp evaluation.
- Soil. Geotechnical properties and Slopes evaluation.

Soil													
LL	CBR	Slp			LL	CBR	Slp			LL	CBR	Slp	
B	VB	B	VB		G	VB	B	VB		V.G.	VB	B	VB
B	VB	R	VB		G	VB	R	VB		V.G.	VB	R	VB
B	VB	G	VB		G	VB	G	VB		V.G.	VB	G	VB
B	B	B	B		G	B	B	B		V.G.	B	B	B
B	B	R	B		G	B	R	B		V.G.	B	R	B
B	B	G	B		G	B	G	B		V.G.	B	G	B
B	R	B	B		G	R	B	B		V.G.	R	B	B
B	R	R	B		G	R	R	G		V.G.	R	R	G
B	R	G	B		G	R	G	G		V.G.	R	G	G
B	G	B	B		G	G	B	B		V.G.	G	B	B
B	G	R	B		G	G	R	G		V.G.	G	R	G
B	G	G	G		G	G	G	G		V.G.	G	G	VG
B	V.G.	B	B		G	V.G.	B	B		V.G.	V.G.	B	G
B	V.G.	R	G		G	V.G.	R	G		V.G.	V.G.	R	VG
B	V.G.	G	G		G	V.G.	G	VG		V.G.	V.G.	G	VG

Table 8.8: Soil Fuzzy Rules

Environment													
Weat	Trans	Soil			Weat	Trans	Soil			Weat	Trans	Soil	
VG	VG	VG	VG		G	G	B	G		B	N	VB	VB
VG	VG	G	VG		G	G	VB	B		B	B	VG	G
VG	VG	B	G		G	N	VG	G		B	B	G	B
VG	VG	VB	B		G	N	G	G		B	B	B	B
VG	G	VG	VG		G	N	B	B		B	B	VB	VB
VG	G	G	G		G	N	VB	B		VB	VG	VG	G
VG	G	B	B		G	B	VG	G		VB	VG	G	G
VG	G	VB	B		G	B	G	G		VB	VG	B	B
VG	N	VG	VG		G	B	B	B		VB	VG	VB	VB
VG	N	G	G		G	B	VB	B		VB	G	VG	G
VG	N	B	G		B	VG	VG	G		VB	G	G	G
VG	N	VB	B		B	VG	G	G		VB	G	B	B
VG	B	VG	G		B	VG	B	B		VB	G	VB	VB
VG	B	G	G		B	VG	VB	B		VB	N	VG	G
VG	B	B	B		B	G	VG	G		VB	N	G	B
VG	B	VB	B		B	G	G	G		VB	N	B	B
G	VG	VG	VG		B	G	B	B		VB	N	VB	VB
G	VG	G	G		B	G	VB	VB		VB	B	VG	B
G	VG	B	G		B	N	VG	G		VB	B	G	B
G	VG	VB	B		B	N	G	B		VB	B	B	B
G	G	VG	G		B	N	B	B		VB	B	VB	VB
G	G	G	G										

Table 8.9: Environment Fuzzy Rules

Chapter 9

Annex B

9.1 Geometry

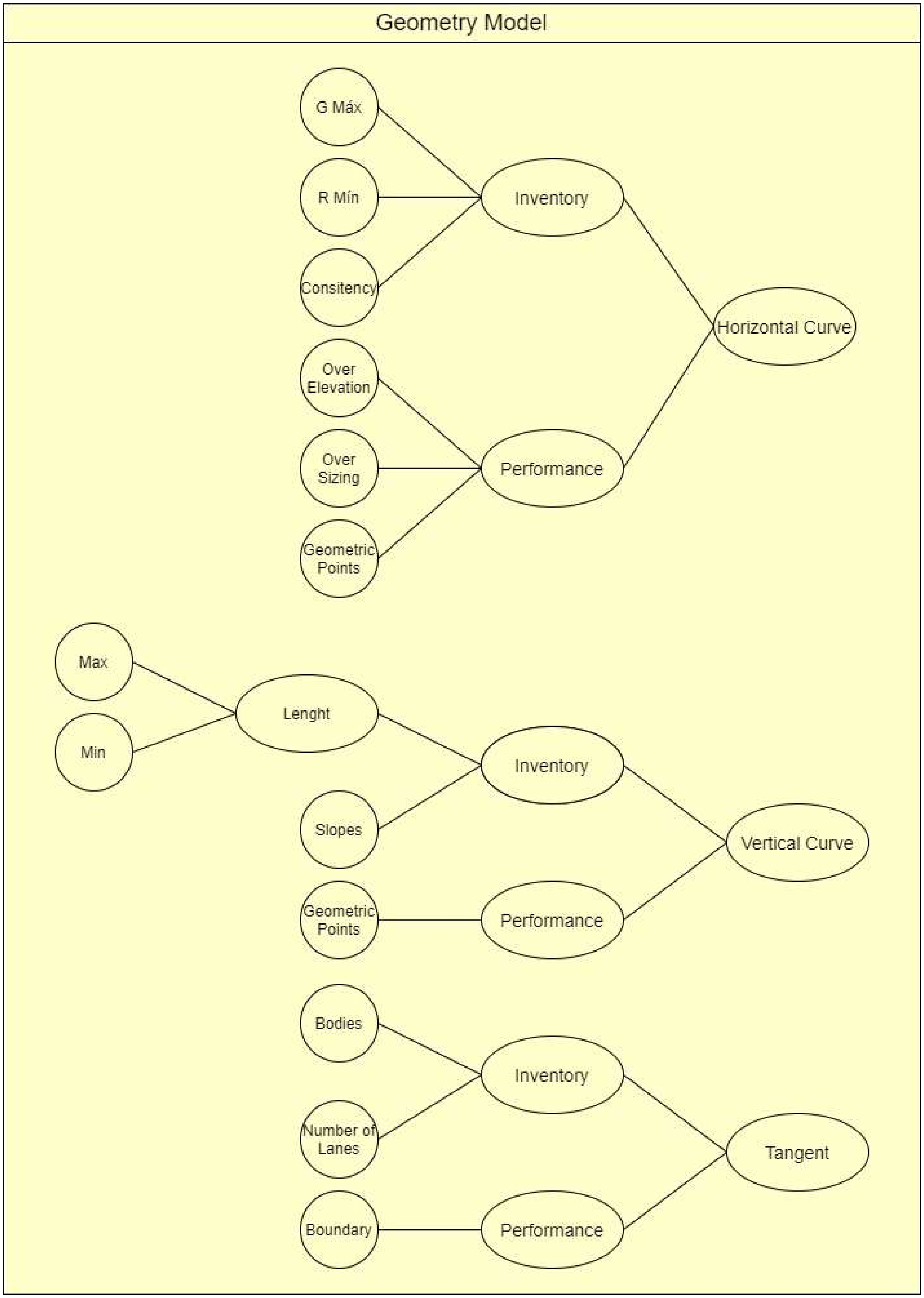
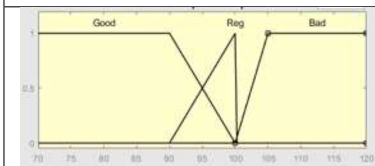
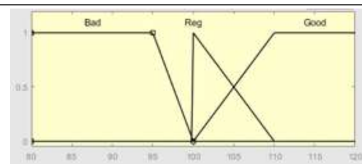
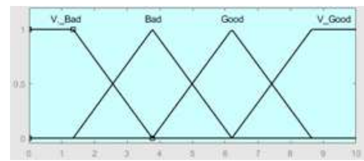


Figure 9.1: Geometry Model

Horizontal Curve Inventory

- G Max. Percentage of project curvature degree in relation with max curvature degree
- R Min. Percentage of project turning radio in relation with min turning radio.
- Consistency. Curve consistency PIARC

<table>
<tr><th>G Max</th><th>R Min</th><th>Horizontal Curve Inventory</th></tr>
<tr><td>
</td><td>
</td><td rowspan="3">
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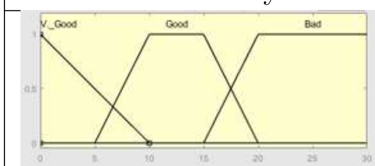
<tr><td>
</td><td></td></tr>
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Table 9.1: Inventory Horizontal Curve Fuzzy Sets

Horizontal													
Grad	Rat	Cons			Grad	Rat	Cons			Grad	Rat	Cons	
G	G	VG	VG		R	G	VG	G		B	G	VG	G
G	G	G	G		R	G	G	G		B	G	G	G
G	G	B	G		R	G	B	B		B	G	B	B
G	R	VG	VG		R	R	VG	G		B	R	VG	G
G	R	G	G		R	R	G	G		B	R	G	B
G	R	B	G		R	R	B	B		B	R	B	B
G	B	VG	G		R	B	VG	G		B	B	VG	B
G	B	G	G		R	B	G	B		B	B	G	B
G	B	B	B		R	B	B	B		B	B	B	VB

Table 9.2: Horizontal Curve Fuzzy Rules

Horizontal Curve Performance

- Over Elevation. Land over elevation in relation with project over elevation.
- Over Sizing. Land over sizing in relation with project over sizing.
- Geometric Points. Land ubication of Pc, Cc, Pt

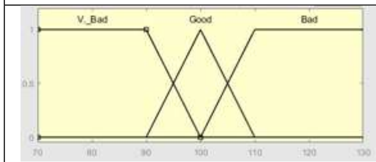
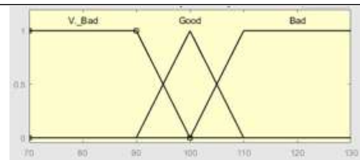
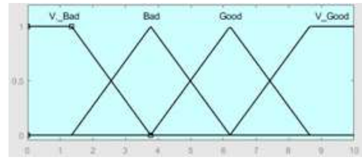
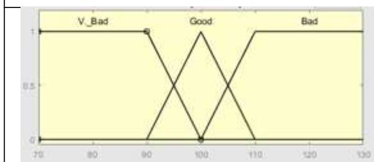
Over Elevation	Over Sizing	Horizontal Curve Performance
		
Geometric Points		
		

Table 9.3: Performance Horizontal Curve Fuzzy Sets

Horizontal											
O.E.	O.S.	G.P.		O.E.	O.S.	G.P.		O.E.	O.S.	G.P.	
VB	VB	VB	VB	G	VB	VB	VB	B	VB	VB	VB
VB	VB	G	B	G	VB	G	B	B	VB	G	B
VB	VB	B	VB	G	VB	B	B	B	VB	B	B
VB	G	VB	VB	G	G	VB	B	B	G	VB	B
VB	G	G	B	G	G	G	VG	B	G	G	G
VB	G	B	B	G	G	B	G	B	G	B	B
VB	B	VB	VB	G	B	VB	B	B	B	VB	VB
VB	B	G	B	G	B	G	G	B	B	G	B
VB	B	B	VB	G	B	B	B	B	B	B	B

Table 9.4: Performance Horizontal Curve Fuzzy Rules

Lenght

- Min. Land tangen lenght in relation with minimum lenght. Geometric design.
- Max. Land tangen lenght in relation with maximum lenght. Geometric design.

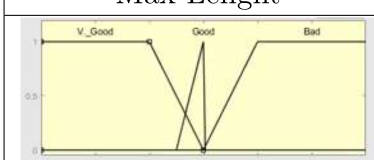
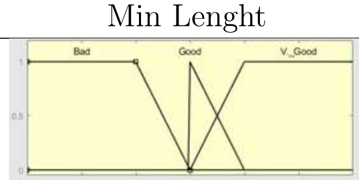
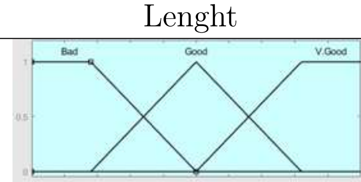
Max Lenght	Min Lenght	Lenght
		

Table 9.5: Lenght Fuzzy Sets

Lenght		
Min	Max	
VG	V.G.	V.G
VG	G	G
VG	B	B
G	VG	G
G	G	G
G	B	B
B	VG	B
B	G	B
B	B	B

Table 9.6: Lenght Fuzzy Rules

Vertical Curve Inventory

- Lenght. Land lenght in relation with project lenght.
- Slope. Percentage longitudinal slope.

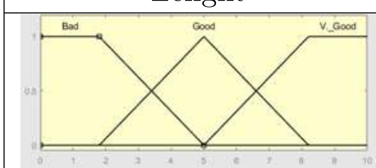
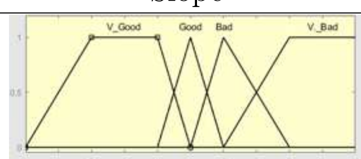
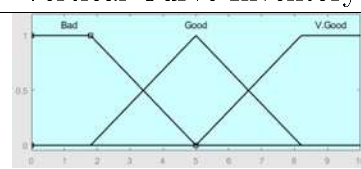
Lenght	Slope	Vertical Curve Inventory
		

Table 9.7: Vertical Curve Inventory Fuzzy Sets

Vertical						
Lgth	Slop			Lgth	Slop	
VG	VG	VG		G	B	B
VG	G	VG		G	VB	VB
VG	B	G		B	VG	B
VG	VB	B		B	G	B
G	VG	VG		B	B	B
G	G	G		B	VB	VB

Table 9.8: Vertical Curve Inventory Fuzzy Rules

Tangent Inventory

- Bodies. Number of road bodies.

- Number of lanes. Number of lanes of road

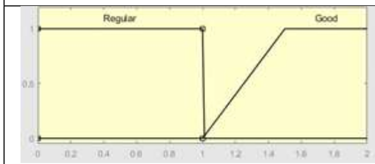
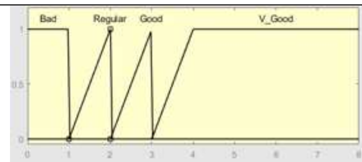
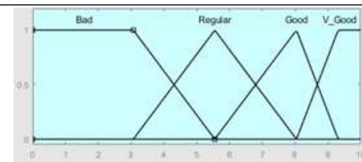
Bodies	Number of Lanes	Tangent Inventory
		

Table 9.9: Tangent Inventory Fuzzy Sets

Tangent		
Bod	Lan	
R	B	B
R	R	R
R	G	R
R	VG	G
G	B	B
G	R	G
G	G	VG
G	VG	VG

Table 9.10: Tangent Inventory Fuzzy Rules

Chapter 10

Annex C

10.1 Pavements

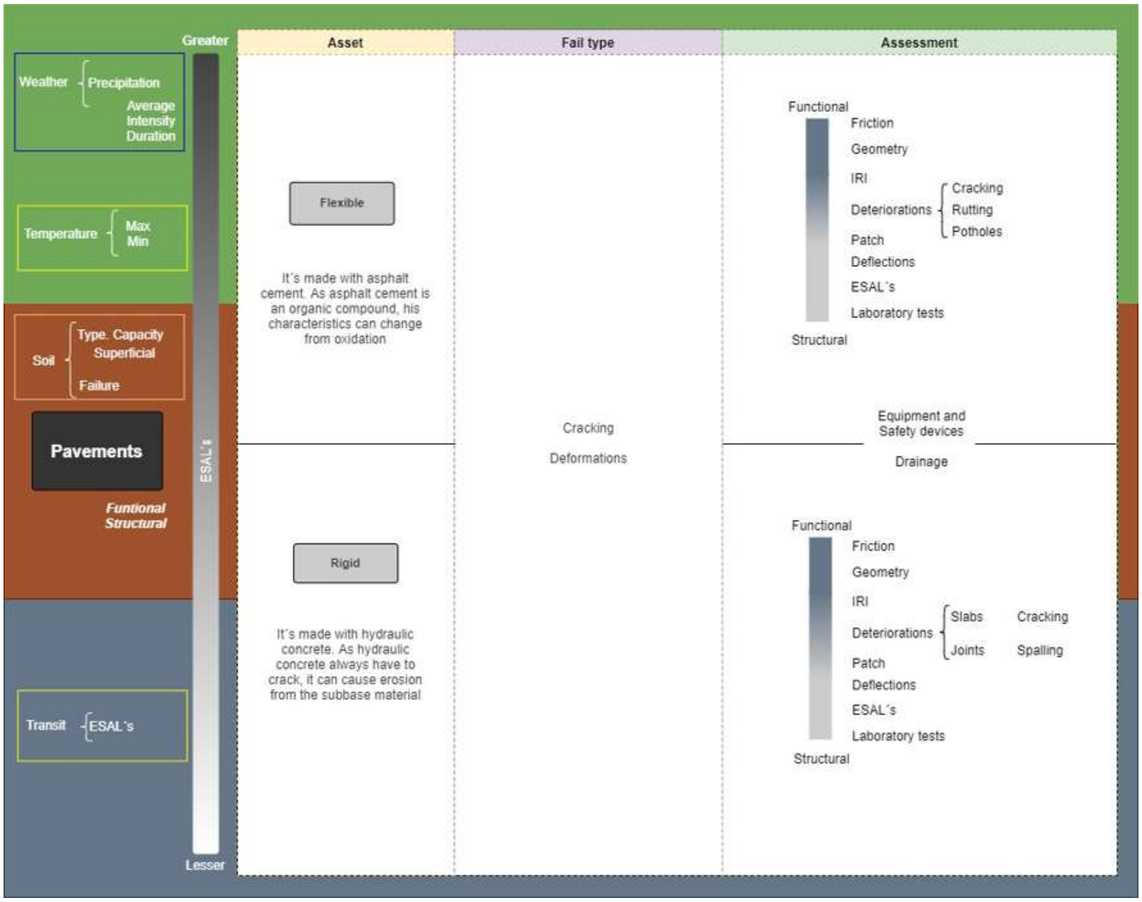


Figure 10.1: Pavement Evaluation Dates

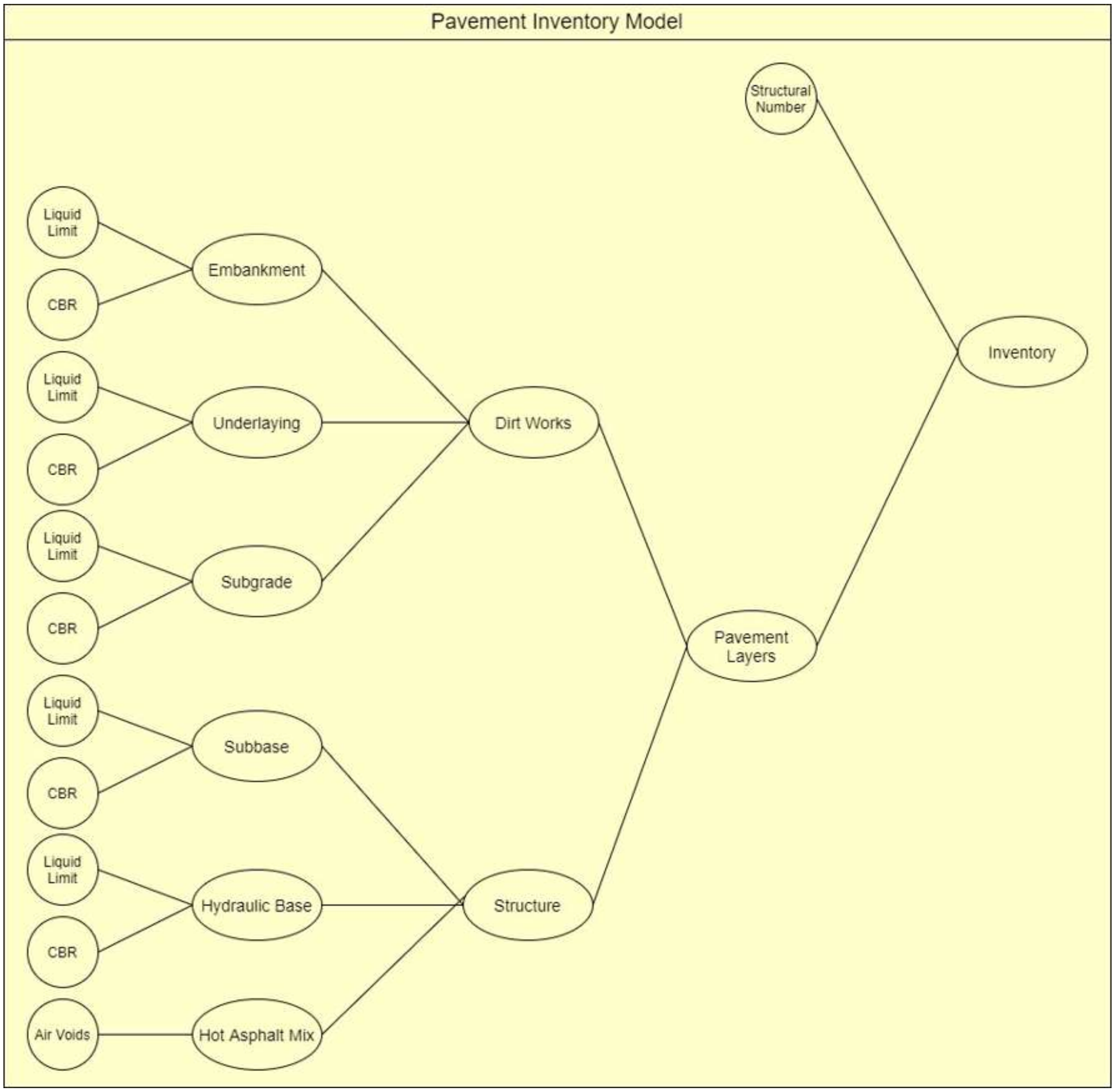


Figure 10.2: Pavement Inventory Model

Inventory Embankment Layers

- Liquid Limit. Geotechnical property embankment material.
- CBR. Geotechnical property embankment material.

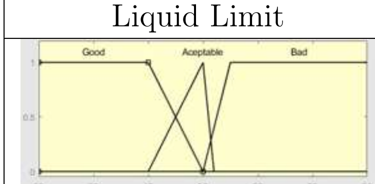
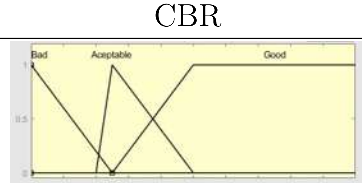
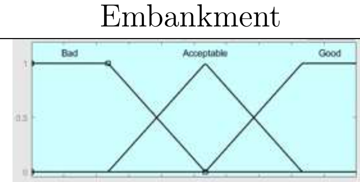
Liquid Limit	CBR	Embankment
		

Table 10.1: Inventory Embankment Fuzzy Sets

Embankment		
LL	CBR	
G	G	G
G	A	A
G	B	B
A	G	A
A	A	A
A	B	B
B	G	B
B	A	B
B	B	B

Table 10.2: Inventory Embankment Fuzzy Rules

Inventory Underlaying Layers

- Liquid Limit. Geotechnical property embankment material.
- CBR. Geotechnical property embankment material.

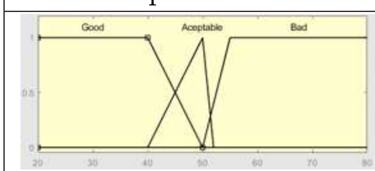
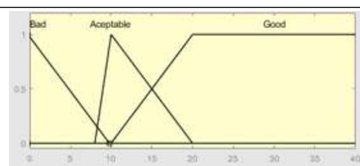
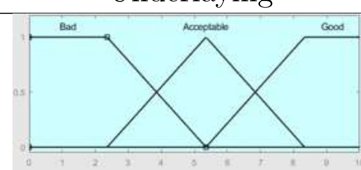
Liquid Limit	CBR	Underlaying
		

Table 10.3: Inventory Underlaying Fuzzy Sets

Underlying		
LL	CBR	
G	G	G
G	A	A
G	B	B
A	G	A
A	A	A
A	B	B
B	G	B
B	A	B
B	B	B

Table 10.4: Inventory Underlaying Fuzzy Rules

Inventory Subgrade Layers

- Liquid Limit. Geotechnical property embankment material.
- CBR. Geotechnical property embankment material.

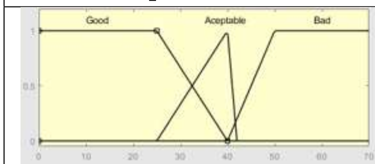
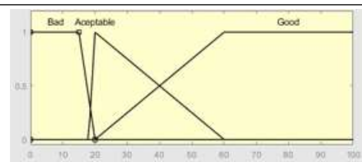
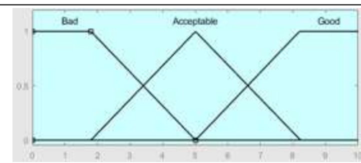
Liquid Limit	CBR	Subgrade
		

Table 10.5: Inventory Subgrade Fuzzy Sets

Subgrade		
LL	CBR	
G	G	G
G	A	A
G	B	B
A	G	A
A	A	A
A	B	B
B	G	B
B	A	B
B	B	B

Table 10.6: Inventory Subgrade Fuzzy Rules

Inventory Dirt Works

- Embankment. Liquid Limit and CBR material evaluation.
- Underlaying. Liquid Limit and CBR material evaluation
- Subgrade. Liquid Limit and CBR material evaluation.

Dirt Works 1											
Emb	Undly	Subgr		Emb	Undly	Subgr		Emb	Undly	Subgr	
G	G	G	G	A	G	G	G	B	G	G	A
G	G	A	A	A	G	A	A	B	G	A	A
G	G	B	B	A	G	B	B	B	G	B	B
G	A	G	G	A	A	G	G	B	A	G	A
G	A	A	A	A	A	A	A	B	A	A	A
G	A	B	B	A	A	B	B	B	A	B	B
G	B	G	B	A	B	G	B	B	B	G	B
G	B	A	B	A	B	A	B	B	B	A	B
G	B	B	B	A	B	B	B	B	B	B	B

Table 10.7: Inventory Dirt Works 1 Fuzzy Rules

Dirt Works 2		
Emb	Subgr	
G	G	G
G	A	A
G	B	B
A	G	G
A	A	A
A	B	B
B	G	A
B	A	B
B	B	B

Dirt Works 3		
Undly	Subgr	
G	G	G
G	A	A
G	B	B
A	G	G
A	A	A
A	B	B
B	G	A
B	A	B
B	B	B

Table 10.8: Inventory Dirt Works 2 y 3 Fuzzy Rules

Inventory Sub Base Layers

- Liquid Limit. Geotechnical property sub base material.
- CBR. Geotechnical property sub base material.

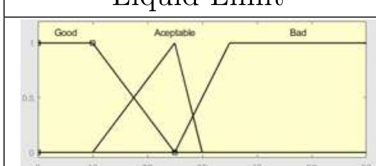
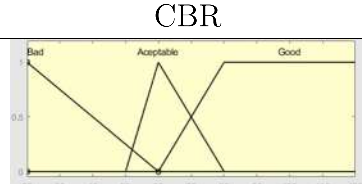
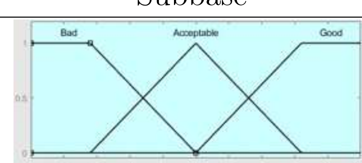
Liquid Limit	CBR	Subbase
		

Table 10.9: Inventory Sub-base Fuzzy Sets

Sub-base		
LL	CBR	
G	G	G
G	A	A
G	B	B
A	G	A
A	A	A
A	B	B
B	G	B
B	A	B
B	B	B

Table 10.10: Inventory Sub-base Fuzzy Rules

Inventory Hydraulic base Layers

- Liquid Limit. Geotechnical property hydraulic base material.
- CBR. Geotechnical property hydraulic base material.

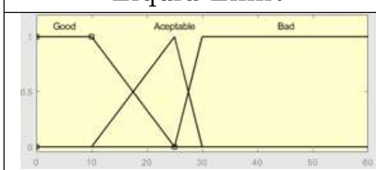
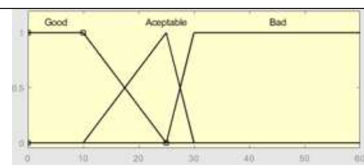
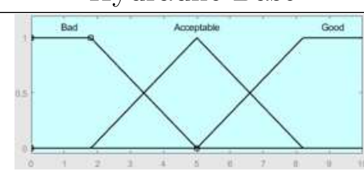
Liquid Limit	CBR	Hydraulic Base
		

Table 10.11: Inventory Hydraulic Base Fuzzy Sets

Hydraulic Base		
LL	CBR	
G	G	G
G	A	A
G	B	B
A	G	A
A	A	A
A	B	B
B	G	B
B	A	B
B	B	B

Table 10.12: Inventory Hydraulic Base Fuzzy Rules

Inventory Hot asphalt mix.

- Air Voids. Air voids in asphalt layers.

Air Voids

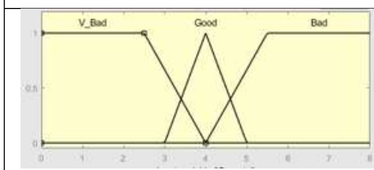


Table 10.13: Inventory Hot Asphalt Mix Fuzzy Set

Inventory Pavement Structure

- Sub base. Liquid limit and CBR material evaluation.
- Hydraulic base. Liquid limit and CBR material evaluation.
- Hot asphalt mix. Air voids asphalt asphalt layers evaluation

Structure 1														
S Bas	H Bas	A Mix			S Bas	H Bas	A Mix			S Bas	H Bas	A Mix	
G	G	G	G		A	G	G	A		B	G	G	A
G	G	B	A		A	G	B	B		B	G	B	B
G	G	VB	B		A	G	VB	B		B	G	VB	B
G	A	G	A		A	A	G	A		B	A	G	A
G	A	B	B		A	A	B	B		B	A	B	B
G	A	VB	B		A	A	VB	B		B	A	VB	B
G	B	G	B		A	B	G	B		B	B	G	B
G	B	B	B		A	B	B	B		B	B	B	B
G	B	VB	B		A	B	VB	B		B	B	VB	B

Table 10.14: Inventory Structure 1 Fuzzy Rules

Structure 2		
H Base	A mix	
G	G	G
G	B	B
G	VB	B
A	G	A
A	B	B
A	VB	B
B	G	B
B	B	B
B	VB	B

Table 10.15: Inventory Structure 2 Fuzzy Rules

Inventory Pavement Layers

- Dirt Works. Embankment layers evaluation.
- Pavement Structure. Pavement structure layers evaluation.

Pavement		
D Works	Struct	
G	G	G
G	A	A
G	B	B
A	G	G
A	A	A
A	B	B
B	G	B
B	A	B
B	B	B

Table 10.16: Inventory Pavement Layers

Inventory Pavement

- Structural Number. Determined based in AASHTO 1993.
- Pavement layers. Embankment and structural layers evaluation.

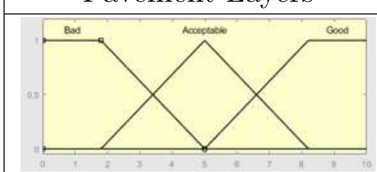
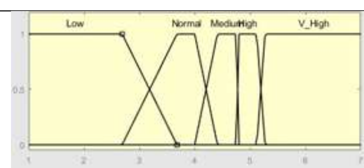
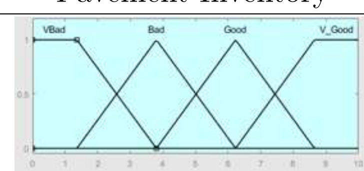
Pavement Layers	Structural Number	Pavement Inventory
		

Table 10.17: Inventory Pavement Fuzzy Sets

Inventory						
Str N	Pav			Str N	Pav	
L	G	VG		M	B	B
L	A	VG		H	G	VG
L	B	G		H	A	G
N	G	VG		H	B	VB
N	A	G		V.H.	G	VG
N	B	B		V.H.	A	G
M	G	VG		V.H.	B	VB
M	A	G				

Table 10.18: Inventory Pavement Fuzzy Rules

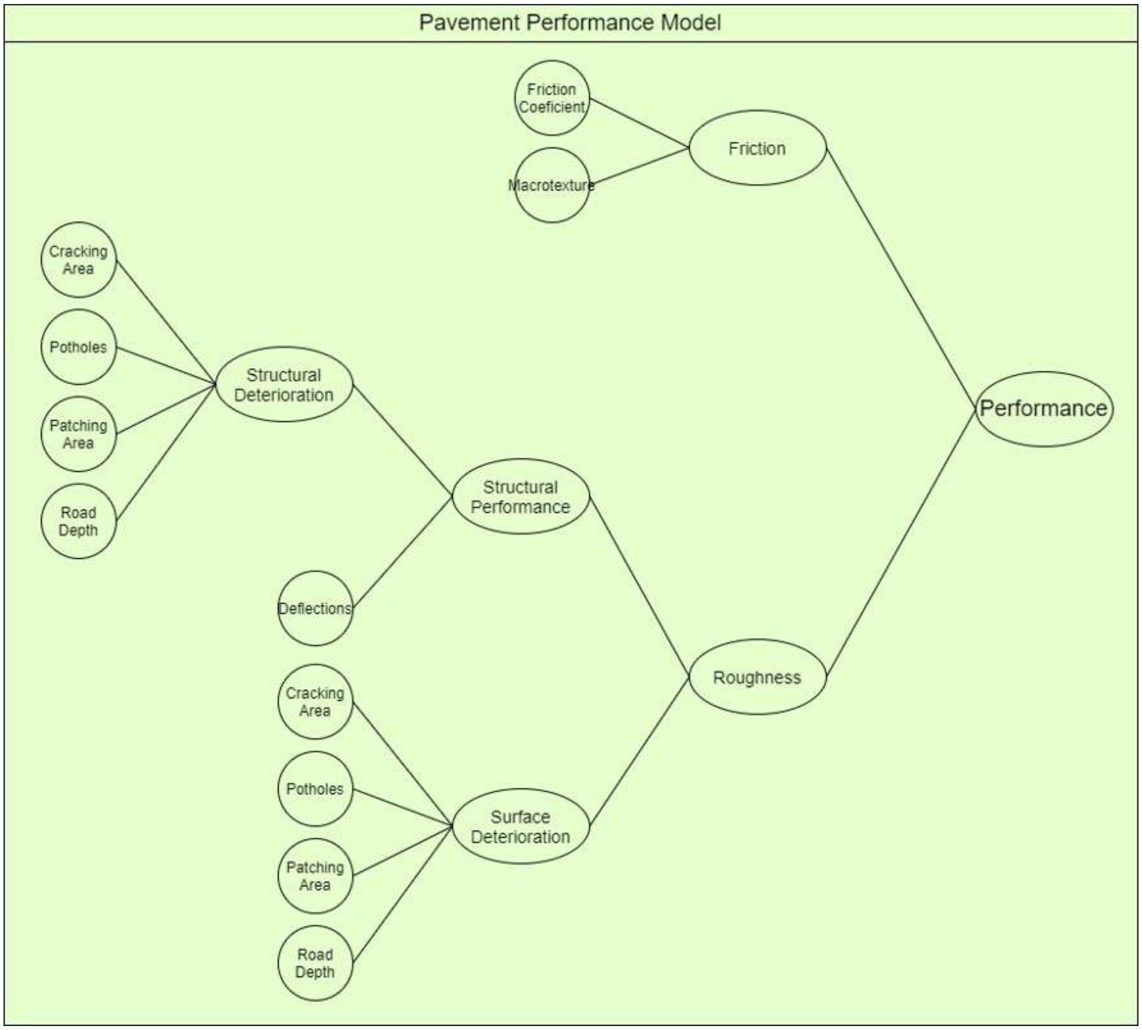


Figure 10.3: Pavement Performance Model

Friction Pavement

- Friction coefficient. Average land friction coefficient.
- Macrotexture. Medium texture depth

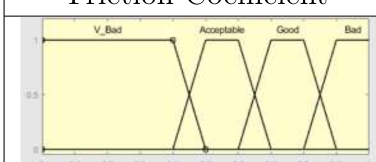
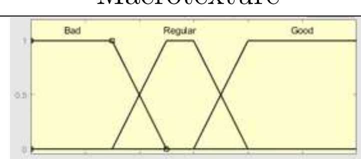
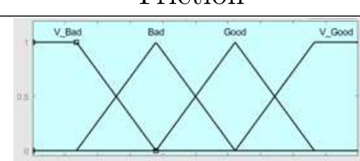
Friction Coefficient	Macrotexture	Friction
		

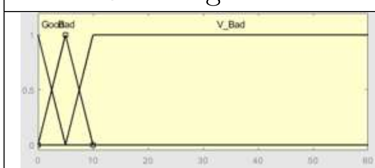
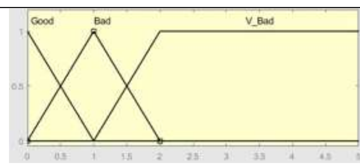
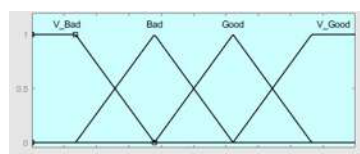
Table 10.19: Performance Friction Fuzzy Sets

Friction						
F Coef	Mactx			F Coef	Mactx	
G	G	VG		B	G	B
G	R	G		B	R	B
G	B	B		B	B	B
A	G	G		V.B.	G	B
A	R	G		V.B.	R	V.B
A	B	B		V.B.	B	V.B

Table 10.20: Performance Friction Fuzzy Rules

Structural Deterioration

- Cracking area. Percentage area of structural cracking, longitudinal, transverse, alligator, block.
- Potholes. Number of structural potholes.
- Patching area. Percentage area of structural patching.
- Road depth. Average road depth (mm)

<table>
<tr><td>Cracking Area</td><td>Potholes</td><td>Structural Deterioration</td></tr>
<tr><td>
</td><td>
</td><td rowspan="3">
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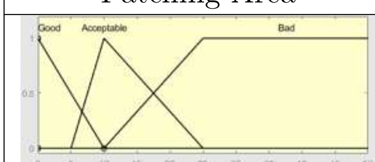
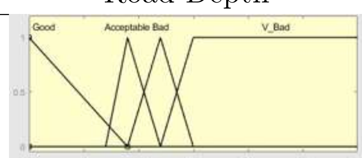
<tr><td>Patching Area</td><td>Road Depth</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Table 10.21: Performance Structural Deterioration Fuzzy Sets

Structural Deterioration																
S.C.A.	Poth	Patch	R.Dep.			S.C.A.	Poth	Patc	R.D			S.C.A.	Poth	Patc	R.D	
G	G	G	G	V.G		B	G	G	G	G		V.B.	G	G	G	B
G	G	G	A	G		B	G	G	A	G		V.B.	G	G	A	B
G	G	G	B	G		B	G	G	B	B		V.B.	G	G	B	B
G	G	G	V.B	B		B	G	G	V.B	VB		V.B.	G	G	V.B	VB
G	G	A	G	V.G.		B	G	A	G	G		V.B.	G	A	G	B
G	G	A	A	G		B	G	A	A	B		V.B.	G	A	A	B
G	G	A	B	B		B	G	A	B	B		V.B.	G	A	B	B
G	G	A	V.B	B		B	G	A	V.B	VB		V.B.	G	A	V.B	VB
G	G	B	G	G		B	G	B	G	B		V.B.	G	B	G	B
G	G	B	A	G		B	G	B	A	B		V.B.	G	B	A	B
G	G	B	B	B		B	G	B	B	B		V.B.	G	B	B	B
G	G	B	V.B	V.B.		B	G	B	V.B	VB		V.B.	G	B	V.B	VB
G	B	G	G	G		B	B	G	G	B		V.B.	B	G	G	B
G	B	G	A	G		B	B	G	A	B		V.B.	B	G	A	B
G	B	G	B	B		B	B	G	B	B		V.B.	B	G	B	B
G	B	G	V.B	VB		B	B	G	V.B	VB		V.B.	B	G	V.B	VB
G	B	A	G	G		B	B	A	G	B		V.B.	B	A	G	B
G	B	A	A	B		B	B	A	A	B		V.B.	B	A	A	B
G	B	A	B	B		B	B	A	B	B		V.B.	B	A	B	B
G	B	A	V.B	B		B	B	A	V.B	VB		V.B.	B	A	V.B	VB
G	B	B	G	B		B	B	B	G	B		V.B.	B	B	G	B
G	B	B	A	B		B	B	B	A	B		V.B.	B	B	A	B
G	B	B	B	B		B	B	B	B	B		V.B.	B	B	B	VB
G	B	B	V.B	VB		B	B	B	V.B	VB		V.B.	B	B	V.B	VB
G	V.B.	G	G	B		B	V.B.	G	G	B		V.B.	V.B.	G	G	VB
G	V.B.	G	A	B		B	V.B.	G	A	B		V.B.	V.B.	G	A	VB
G	V.B.	G	B	B		B	V.B.	G	B	VB		V.B.	V.B.	G	B	VB
G	V.B.	G	V.B	VB		B	V.B.	G	V.B	VB		V.B.	V.B.	G	V.B	VB
G	V.B.	A	G	B		B	V.B.	A	G	B		V.B.	V.B.	A	G	VB
G	V.B.	A	A	B		B	V.B.	A	A	B		V.B.	V.B.	A	A	VB
G	V.B.	A	B	B		B	V.B.	A	B	VB		V.B.	V.B.	A	B	VB
G	V.B.	A	V.B	VB		B	V.B.	A	V.B	VB		V.B.	V.B.	A	V.B	VB
G	V.B.	B	G	B		B	V.B.	B	G	B		V.B.	V.B.	B	G	VB
G	V.B.	B	A	B		B	V.B.	B	A	VB		V.B.	V.B.	B	A	VB
G	V.B.	B	B	B		B	V.B.	B	B	VB		V.B.	V.B.	B	B	VB
G	V.B.	B	V.B	VB		B	V.B.	B	V.B	VB		V.B.	V.B.	B	V.B	VB

Table 10.22: Performance Structural Deterioration Fuzzy Rules

Structural Deterioration

- Structural deterioration. Structural cracking area, potholes, patching area and road depth evaluation.
- Deflections. Land measure (mm)

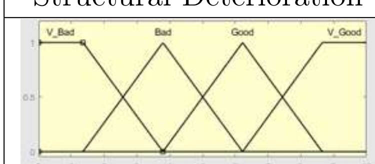
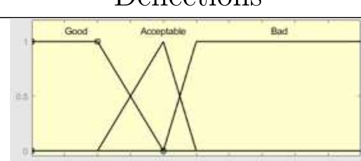
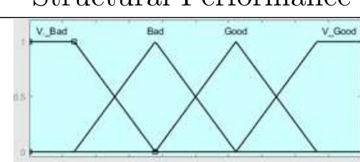
Structural Deterioration	Deflections	Structural Performance
		

Table 10.23: Structural Performance Fuzzy Sets

Structural Performance		
StrDet	Def	
VG	G	VG
VG	R	G
VG	B	B
G	G	G
G	R	G
G	B	B
B	G	G
B	R	B
B	B	B
VB	G	B
VB	R	VB
VB	B	VB

Table 10.24: Structural Performance Fuzzy Rules

Structural Deterioration

- Cracking area. Percentage area of superficial cracking, longitudinal, transverse, alligator, block.
- Potholes. Number of superficial potholes.
- Patching area. Percentage area of superficial patching.
- Road depth. Average superficial road depth (mm).

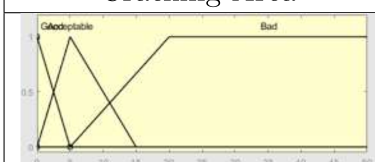
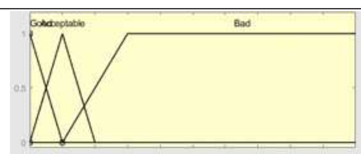
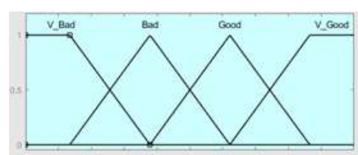
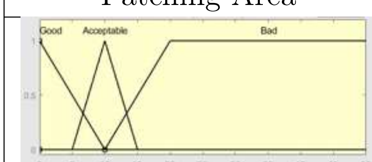
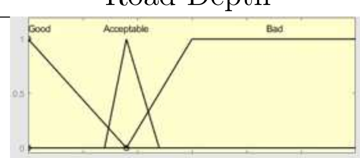
Cracking Area	Potholes	Surface Deteriorations
		
Patching Area	Road Depth	
		

Table 10.25: Performance Surface Deterioration Fuzzy Sets

Surf. Deter.														
C.A.	Poth	Patc	R.D.		C.A.	Poth	Patc	R.D.		C.A.	Poth	Patc	R.D.	
G	G	G	G	VG	R	G	G	G	G	B	G	G	G	B
G	G	G	R	G	R	G	G	R	G	B	G	G	R	B
G	G	G	B	B	R	G	G	B	B	B	G	G	B	B
G	G	R	G	VG	R	G	R	G	G	B	G	R	G	B
G	G	R	R	G	R	G	R	R	G	B	G	R	R	B
G	G	R	B	B	R	G	R	B	B	B	G	R	B	B
G	G	B	G	G	R	G	B	G	B	B	G	B	G	B
G	G	B	R	B	R	G	B	R	B	B	G	B	R	B
G	G	B	B	B	R	G	B	B	B	B	G	B	B	B
G	A	G	G	G	R	A	G	G	G	B	A	G	G	B
G	A	G	R	G	R	A	G	R	G	B	A	G	R	B
G	A	G	B	B	R	A	G	B	B	B	A	G	B	B
G	A	R	G	G	R	A	R	G	G	B	A	R	G	B
G	A	R	R	G	R	A	R	R	G	B	A	R	R	B
G	A	R	B	B	R	A	R	B	B	B	A	R	B	B
G	A	B	G	B	R	A	B	G	B	B	A	B	G	B
G	A	B	R	B	R	A	B	R	B	B	A	B	R	B
G	A	B	B	B	R	A	B	B	B	B	A	B	B	VB
G	B	G	G	B	R	B	G	G	B	B	B	G	G	B
G	B	G	R	B	R	B	G	R	B	B	B	G	R	B
G	B	G	B	B	R	B	G	B	B	B	B	G	B	VB
G	B	R	G	B	R	B	R	G	B	B	B	R	G	B
G	B	R	R	B	R	B	R	R	B	B	B	R	R	B
G	B	R	B	B	R	B	R	B	B	B	B	R	B	VB
G	B	B	G	B	R	B	B	G	B	B	B	B	G	B
G	B	B	R	B	R	B	B	R	B	B	B	B	R	VB
G	B	B	B	B	R	B	B	B	B	B	B	B	B	VB

Table 10.26: Performance Surface Deterioration Fuzzy Rules

Roughness

- Structural performance. Structural deterioration and deflections evaluation.
- Superficial deterioration. Superficial cracking, potholes, patching area and road depth.

Roughness					
St P	SfDet		St P	SfDet	
VG	VG	VG	B	VG	B
VG	G	VG	B	G	B
VG	B	B	B	B	B
VG	VB	B	B	VB	VB
G	VG	G	VB	VG	B
G	G	G	VB	G	B
G	B	B	VB	B	VB
G	VB	VB	VB	VB	VB

Table 10.27: Performance Roughness Fuzzy Rules

Pavement Performance

- Roughness. Road deterioration evaluation.
- Friction. Friction coefficient and macro-texture evaluation.

Pavement Performance						
Roug	Frict			Roug	Frict	
V.G.	V.G.	VG		B	V.G.	B
V.G.	G	VG		B	G	B
V.G.	B	G		B	B	B
V.G.	VB	B		B	VB	VB
G	V.G.	G		VB	V.G.	B
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 10.28: Performance Pavement Fuzzy Rules

Chapter 11

Annex D

11.1 Drainage

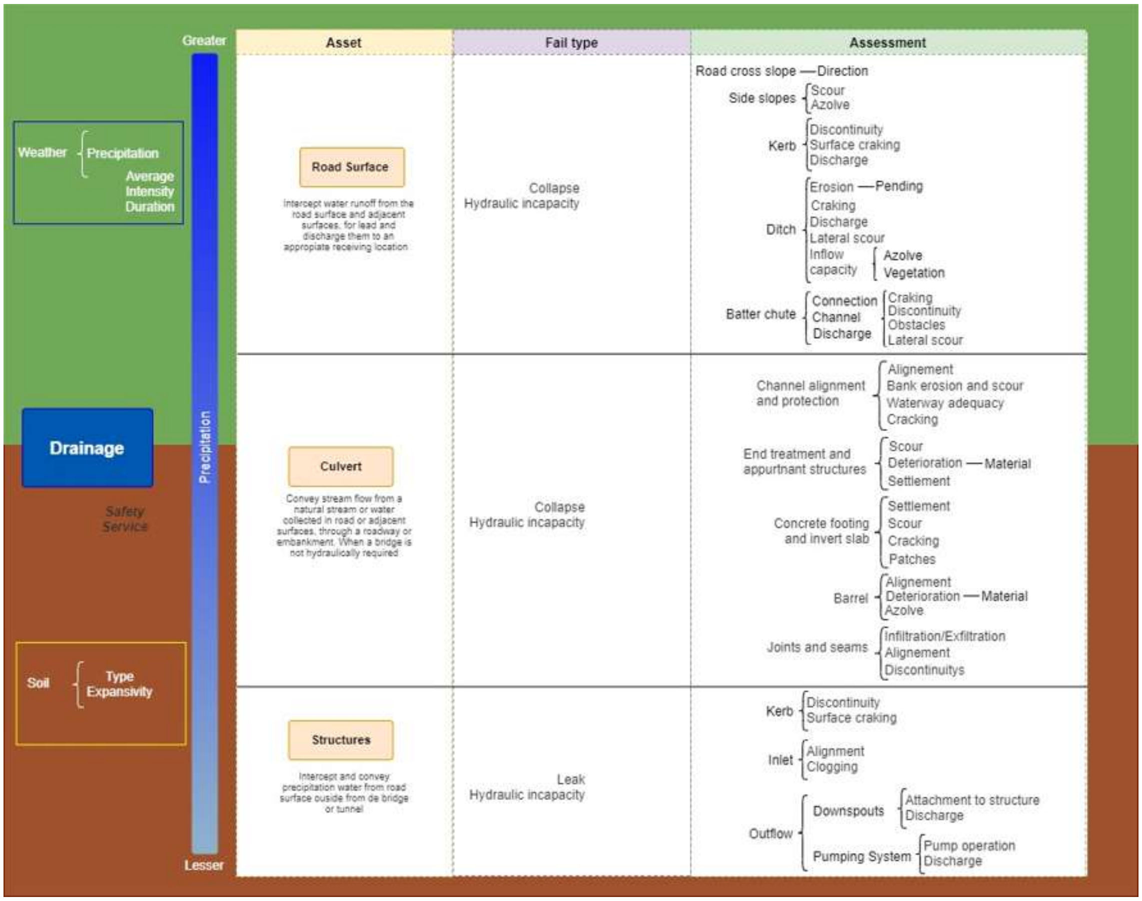


Figure 11.1: Drainage Evaluation Dates

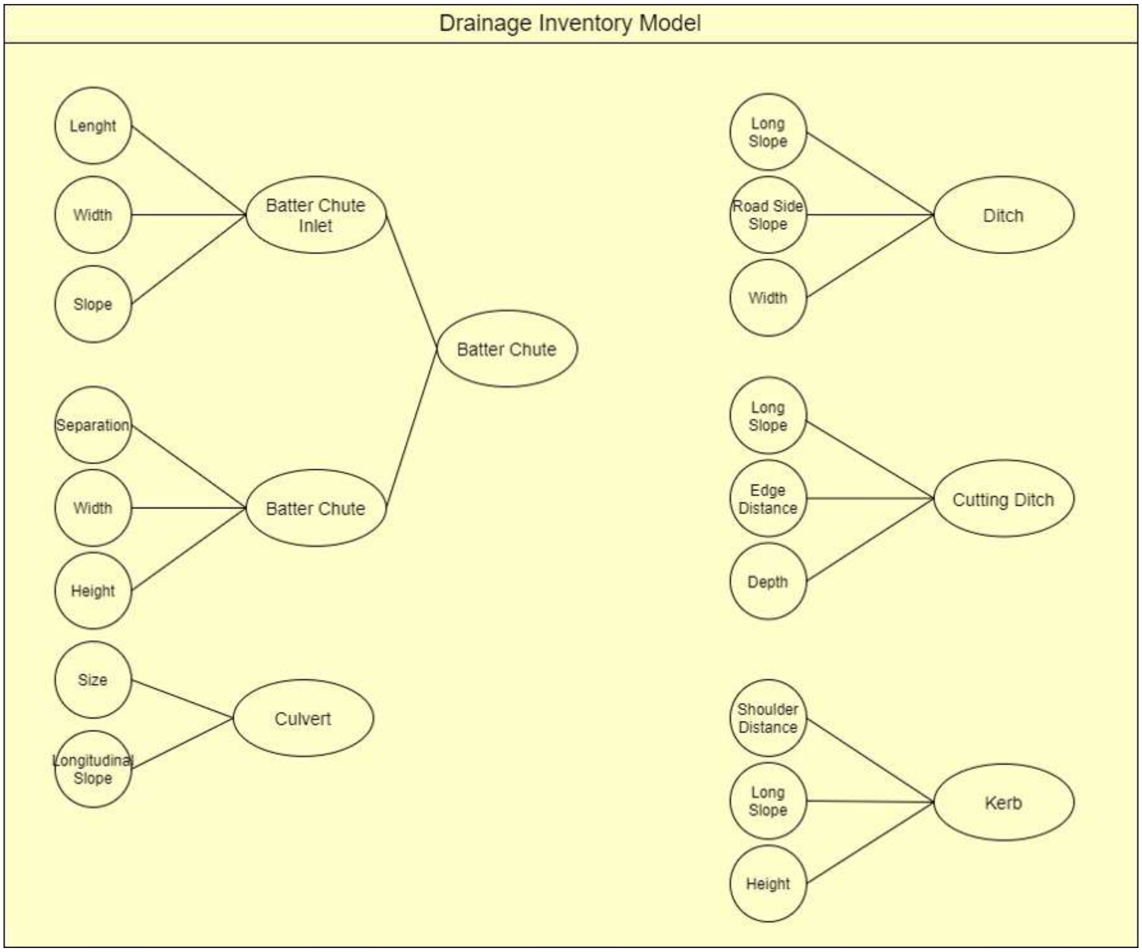


Figure 11.2: Drainage Inventory Model

Batter Chute Inlet

- Length. Land measure inlet length (m).
- Width. Land measure inlet width (m).
- Slope. Land measure inlet percentage slope.

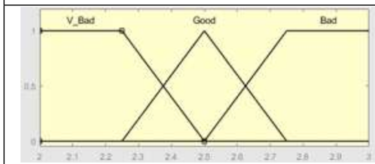
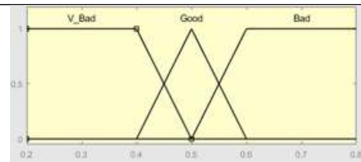
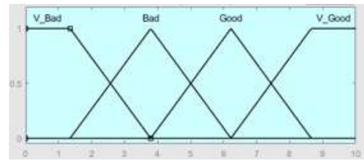
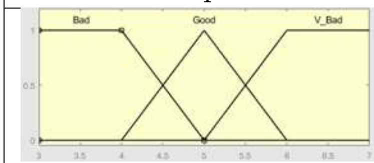
Length	Width	Batter Chute Inlet
		
Slope		
		

Table 11.1: Batter Chute Inlet Inventory Fuzzy Sets

Batter Chute Inlet											
Lenght	Width	Slope		Lenght	Width	Slope		Lenght	Width	Slope	
B	B	B	B	G	B	B	B	VB	B	B	B
B	B	G	G	G	B	G	G	VB	B	G	G
B	B	VB	B	G	B	VB	B	VB	B	VB	B
B	G	B	B	G	G	B	B	VB	G	B	B
B	G	G	G	G	G	G	VG	VB	G	G	B
B	G	VB	B	G	G	VB	B	VB	G	VB	B
B	VB	B	B	G	VB	B	B	VB	VB	B	VB
B	VB	G	B	G	VB	G	B	VB	VB	G	VB
B	VB	VB	VB	G	VB	VB	B	VB	VB	VB	VB

Table 11.2: Inventory Batter Chute Inlet Fuzzy Rules

Batter Chute Channel

- Separation. Percentage distance between batter chute related to drainage project.
- Width. Land measure inlet width (m).
- Height. Batter chute height (m).

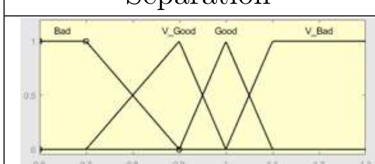
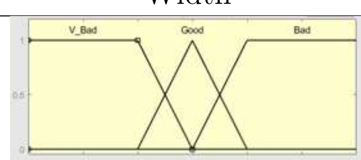
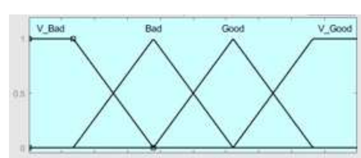
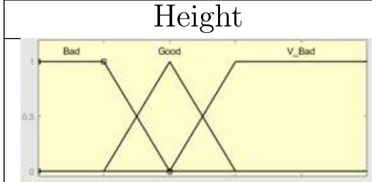
Separation	Width	Batter Chute Channel
		
Height		
		

Table 11.3: Batter Chute Channel Inventory Fuzzy Sets

Channel Batter Chute														
Separ	Width	Height			Separ	Width	Height			Separ	Width	Height	
VG	G	G	VG		G	B	G	G		B	VB	G	B
VG	G	B	VG		G	B	B	G		B	VB	B	B
VG	G	VB	G		G	B	VB	B		B	VB	VB	B
VG	B	G	VG		G	VB	G	B		VB	G	G	B
VG	B	B	G		G	VB	B	B		VB	G	B	B
VG	B	VB	G		G	VB	VB	VB		VB	G	VB	VB
VG	VB	G	B		B	G	G	G		VB	B	G	B
VG	VB	B	G		B	G	B	G		VB	B	B	B
VG	VB	VB	B		B	G	VB	B		VB	B	VB	B
G	G	G	G		B	B	G	G		VB	VB	G	VB
G	G	B	G		B	B	B	G		VB	VB	B	B
G	G	VB	B		B	B	VB	B		VB	VB	VB	VB

Table 11.4: Inventory Channel Batter Chute Fuzzy Rules

Batter Chute

- Inlet. Land inlet batter chute geometry evaluation.
- Channel. Land channel batter chute geometry and capacity evaluation.

Batter Chute						
Inlet	Chan			Inlet	Chan	
VG	VG	VG		B	VG	G
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	VG		VB	VG	G
G	G	G		VB	G	B
G	B	B		VB	B	B
G	VB	VB		VB	VB	VB

Table 11.5: Inventory Batter Chute Fuzzy Rules

Ditch

- Longitudinal Slope. Percentage longitudinal slope
- Road Side Slope. Grade longitudinal slope of ditch side of lateral road.
- Width. Land measure width related to project width.

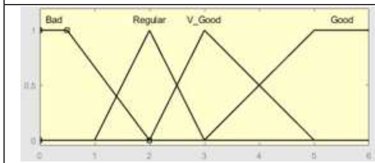
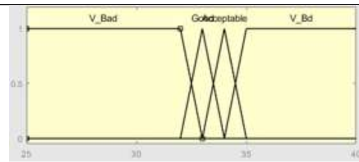
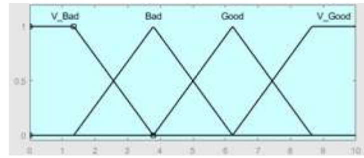
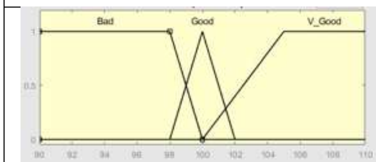
Long Slope	Road Side Slope	Ditch
		
Width		
		

Table 11.6: Ditch Inventory Fuzzy Sets

Ditch Inventory											
L Slp	RSSlp	Width		L Slp	RSSlp	Width		L Slp	RSSlp	Width	
VG	G	VG	VG	G	A	G	G	R	B	B	B
VG	G	G	VG	G	A	B	G	R	VB	VG	B
VG	G	B	B	G	B	VG	G	R	VB	G	B
VG	A	VG	VG	G	B	G	G	R	VB	B	VB
VG	A	G	VG	G	B	B	G	B	G	VG	B
VG	A	B	B	G	VB	VG	G	B	G	G	B
VG	B	VG	G	G	VB	G	G	B	G	B	VB
VG	B	G	G	G	VB	B	B	B	A	VG	B
VG	B	B	B	R	G	VG	G	B	A	G	B
VG	VB	VG	B	R	G	G	G	B	A	B	VB
VG	VB	G	B	R	G	B	B	B	B	VG	B
VG	VB	B	B	R	A	VG	G	B	B	G	B
G	G	VG	VG	R	A	G	G	B	B	B	VB
G	G	G	VG	R	A	B	B	B	VB	VG	VB
G	G	B	G	R	B	VG	G	B	VB	G	VB
G	A	VG	G	R	B	G	B	B	VB	B	VB

Table 11.7: Inventory Ditch Fuzzy Rules

Cutting Ditch

- Longitudinal slope. Percentage slope of land cutting.
- Edge distance. Distance between the cutting ditch and cutting edge (m).
- Depth. Land measure depth (cm).

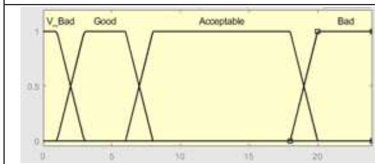
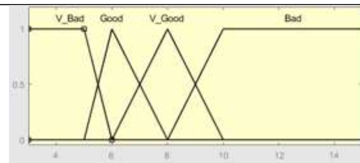
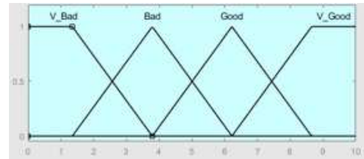
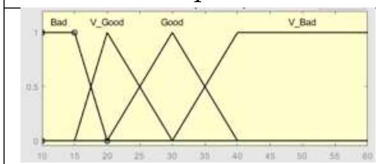
Long Slope	Edge Distance	Cutting Ditch
		
Depth		
		

Table 11.8: Cutting Ditch Inventory Fuzzy Sets

Cutting Ditch											
L Slp	E Dist	Depth		L Slp	E Dist	Depth		L Slp	E Dist	Depth	
G	VG	VG	VG	A	G	B	B	B	B	VB	G
G	VG	G	VG	A	G	VB	B	B	VB	VG	B
G	VG	B	VB	A	B	VG	B	B	VB	G	B
G	VG	VB	B	A	B	G	G	B	VB	B	B
G	G	VG	G	A	B	B	B	B	VB	VB	VB
G	G	G	G	A	B	VB	VB	VB	VG	VG	B
G	G	B	B	A	VB	VG	B	VB	VG	G	B
G	G	VB	B	A	VB	G	B	VB	VG	B	VB
G	B	VG	B	A	VB	B	B	VB	VG	VB	B
G	B	G	B	A	VB	VB	VB	VB	G	VG	B
G	B	B	B	B	VG	VG	G	VB	G	G	B
G	B	VB	VB	B	VG	G	G	VB	G	B	VB
G	VB	VG	G	B	VG	B	B	VB	G	VB	B
G	VB	G	B	B	VG	VB	B	VB	B	VG	VB
G	VB	B	B	B	G	VG	G	VB	B	G	B
G	VB	VB	VB	B	G	G	G	VB	B	B	VB
A	VG	VG	G	B	G	B	B	VB	B	VB	B
A	VG	G	G	B	G	VB	B	VB	VB	VG	VB
A	VG	B	B	B	B	VG	B	VB	VB	G	VB
A	VG	VB	B	B	B	G	G	VB	VB	B	VB
A	G	VG	G	B	B	B	B	VB	VB	VB	VB
A	G	G	G								

Kerb

- Shoulder distance. Distance between kerb and road shoulder (cm).
- Longitudinal slope. Road percentage slope
- Height. Kerb height (cm).

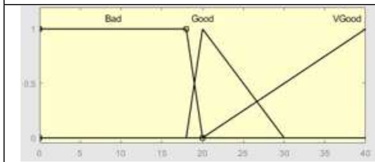
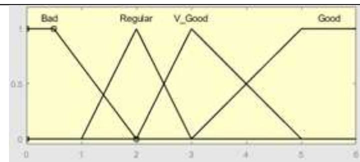
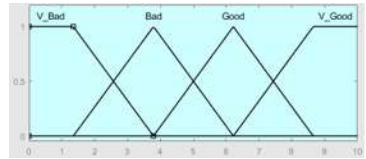
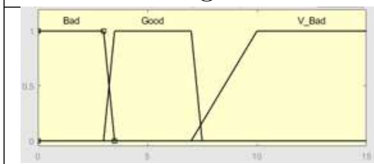
Shoulder Dist	Long Slope	Kerb
		
Height		
		

Table 11.9: Kerb Inventory Fuzzy Sets

kerb inventory													
ShDis	L Slp	Height			ShDis	L Slp	Height			ShDis	L Slp	Height	
VG	G	VB	G		G	G	VB	G		B	G	VB	B
VG	G	G	VG		G	G	G	G		B	G	G	G
VG	G	B	VG		G	G	B	B		B	G	B	B
VG	VG	VB	G		G	VG	VB	B		B	VG	VB	B
VG	VG	G	VG		G	VG	G	VG		B	VG	G	B
VG	VG	B	G		G	VG	B	B		B	VG	B	B
VG	R	VB	B		G	R	VB	B		B	R	VB	VB
VG	R	G	G		G	R	G	G		B	R	G	B
VG	R	B	G		G	R	B	B		B	R	B	B
VG	B	VB	B		G	B	VB	VB		B	B	VB	VB
VG	B	G	B		G	B	G	B		B	B	G	VB
VG	B	B	B		G	B	B	B		B	B	B	VB

Table 11.10: Inventory Kerb Fuzzy Rules

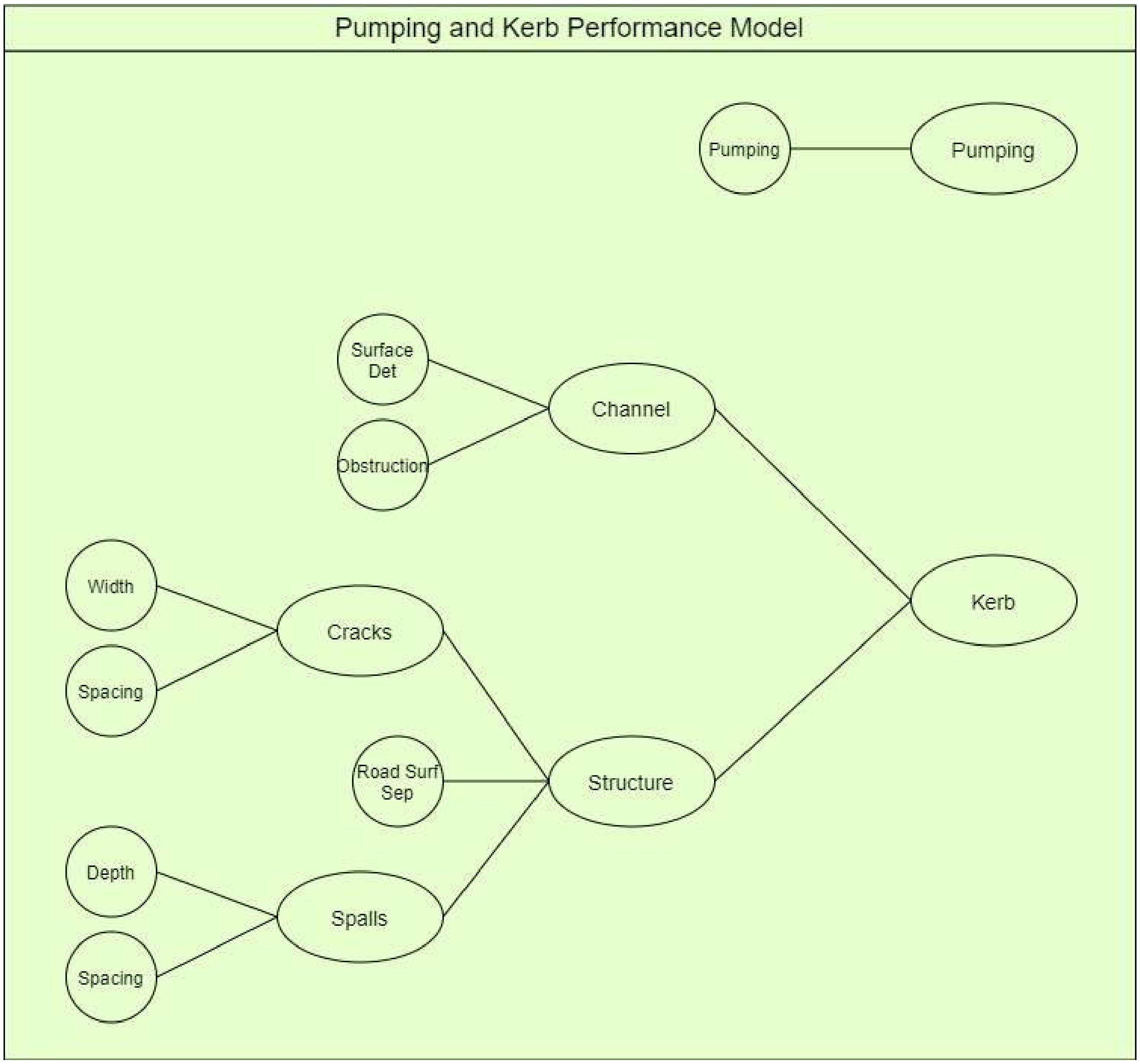


Figure 11.3: Pumping and Kerb Performance Model

Pumping

- Slope. Percentage road transverse slope.

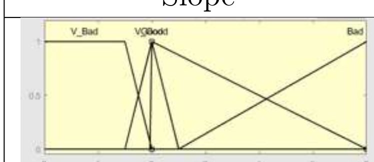
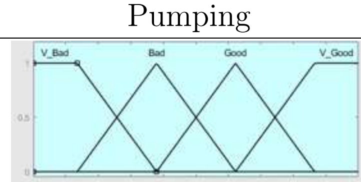
Slope	Pumping
	

Table 11.11: Pumping Fuzzy Sets

Evaluated Element	Very Good Qualification from 7.4 to 10	Good Qualification from 5.0 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad Qualification from 0 to 2.56
Channel Road Surface Deterioration	No wear in canal surface.	Surface slightly wearing. There are not exposure of aggregates.	Moderately rough surface. Few aggregates loss. There are not significant scour.	Very rough surface with significant loss of particles. New water way due to scour.
Obstruction	Surface free of obstructions. If any, these are very small. They do not obstruct significantly hydraulic area.	Light garbage or Transported materials generate an hydraulic area obstruction up to 10%.	Garbage or Transported materials generate an hydraulic area obstruction up to 30%.	Garbage or Transported materials generate an hydraulic area obstruction greater than 30%.
Cracking	Surface free of cracks. Or surface with sealed fissures without water infiltration.	Few cracks of width minor to 3 mm. They do not generate discontinuities in the drainage asset.	Cracks of 3 to 10 mm wide. There are exposure of aggregates or vegetation presence. Elements are not completely separated.	Cracks with width greater to 10 mm. There are exposure of aggregates or vegetation presence. Elements are completely separated.
Spalls	Isolated spalls with depth and/or length of up to 1 cm.	Isolated spalls with depth of up to 1 cm and length of up to 5 cm.	Spalls with depth of up to 3 cm and length of up to 15 cm.	Spalls with depth of greater to 3 cm and length of up to 15 cm.
Road Surface Separation	Drainage asset and road completely bonded. There are not infiltations.	Joint separation of up to 1 mm in isolated sections.	Light join separations greater to 1 mm.	Drainage asset separated from road surface. There are great filtration.
Lateral Scour	Drainage asset without infiltrations or spills. Land surrounding dry and without deformations.	Small infiltrations or spills. Land surrounding is humid without deformations.	There are significantly infiltratios and/or spills. There are light deformations, scour or channel formations in Land surrounding .	There are significantly infiltratios and/or spills. There are deformations, scour or channel formations in Land surrounding.

Kerb Channel

- Surface deterioration. Visual evaluation of kerb channel surface
- Obstruction. Percentage of kerb hydraulic surface obstructed.

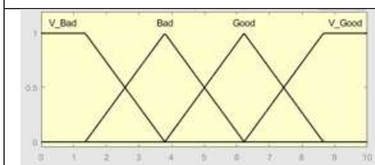
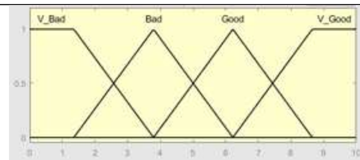
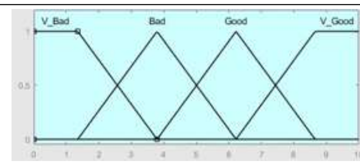
Surf Det	Obstruction	Channel
		

Table 11.12: Kerb Channel Fuzzy Sets

Kerb Channel						
S Det	Obst			S Det	Obst	
VG	VG	VG		B	VG	G
VG	G	G		B	G	G
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 11.13: Performance Kerb Channel Fuzzy Rules

Cracking evaluation

- Width. Land measure (mm)
- Spacing. Visual evaluation of cracking continuity.

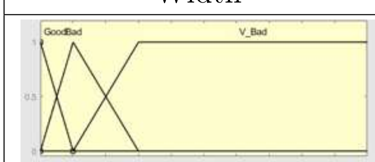
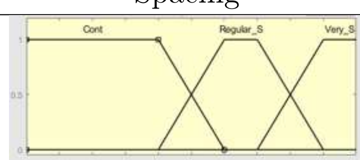
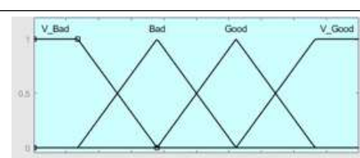
Width	Spacing	Cracks
		

Table 11.14: Cracks Fuzzy Sets

Cracks		
Width	Spac	
G	VS	VG
G	RS	VG
G	Cont	G
B	VS	G
B	RS	B
B	Cont	B
VB	VS	B
VB	RS	VB
VB	Cont	VB

Table 11.15: Performance Cracks Fuzzy Rules

Spalls evaluation

- Depth. Land measure (cm)
- Spacing. Visual evaluation of cracking continuity.

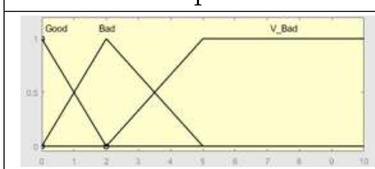
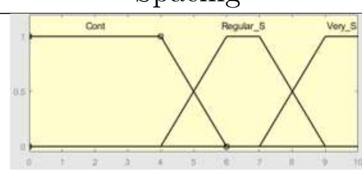
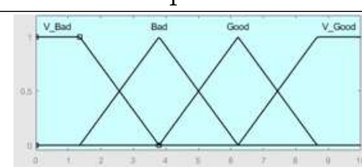
Depth	Spacing	Spalls
		

Table 11.16: Spalls Fuzzy Sets

Spalls		
Depth	Spac	
G	VS	VG
G	RS	VG
G	Cont	VG
B	VS	G
B	RS	B
B	Cont	B
VB	VS	B
VB	RS	VB
VB	Cont	VB

Table 11.17: Performance Spalls Fuzzy Rules

Kerb structure

- Cracks. Width and separation evaluation.
- Spalls. Depth and separtation evaluation
- Road Surface Separation. Visual evaluation

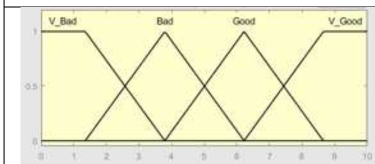
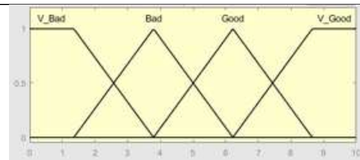
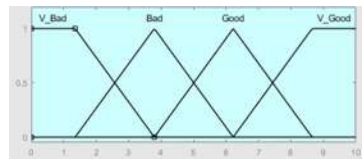
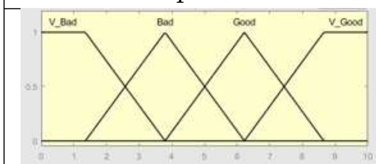
Cracks	Road Surf Sep	Structure
		
Spalls		
		

Table 11.18: Performance Kerb Structure Fuzzy Sets

Kerb structure											
Crack	Spalls	R S S		Crack	Spalls	R S S		Crack	Spalls	R S S	
VG	VG	VG	VG	G	G	B	B	B	B	VB	VB
VG	VG	G	G	G	G	VB	B	B	VB	VG	B
VG	VG	B	B	G	B	VG	B	B	VB	G	B
VG	VG	VB	B	G	B	G	B	B	VB	B	VB
VG	G	VG	VG	G	B	B	B	B	VB	VB	VB
VG	G	G	G	G	B	VB	B	VB	VG	VG	B
VG	G	B	B	G	VB	VG	B	VB	VG	G	B
VG	G	VB	B	G	VB	G	B	VB	VG	B	B
VG	B	VG	G	G	VB	B	B	VB	VG	VB	VB
VG	B	G	B	G	VB	VB	B	VB	G	VG	B
VG	B	B	B	B	VG	VG	G	VB	G	G	B
VG	B	VB	B	B	VG	G	G	VB	G	B	B
VG	VB	VG	B	B	VG	B	B	VB	G	VB	VB
VG	VB	G	B	B	VG	VB	B	VB	B	VG	B
VG	VB	B	B	B	G	VG	G	VB	B	G	B
VG	VB	VB	B	B	G	G	G	VB	B	B	B
G	VG	VG	VG	B	G	B	B	VB	B	VB	VB
G	VG	G	G	B	G	VB	B	VB	VB	VG	VB
G	VG	B	B	B	B	VG	B	VB	VB	G	VB
G	VG	VB	B	B	B	G	B	VB	VB	B	VB
G	G	VG	G	B	B	B	B	VB	VB	VB	VB
G	G	G	G								

Table 11.19: Performance Kerb Structure Fuzzy Rules

Kerb performance

- Channel. Surface deterioration and obstruction evaluation
- Structure. Structure deterioration evaluation

Kerb Performance						
Chan	Str			Chan	Str	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 11.20: Performance Kerb Fuzzy Rules

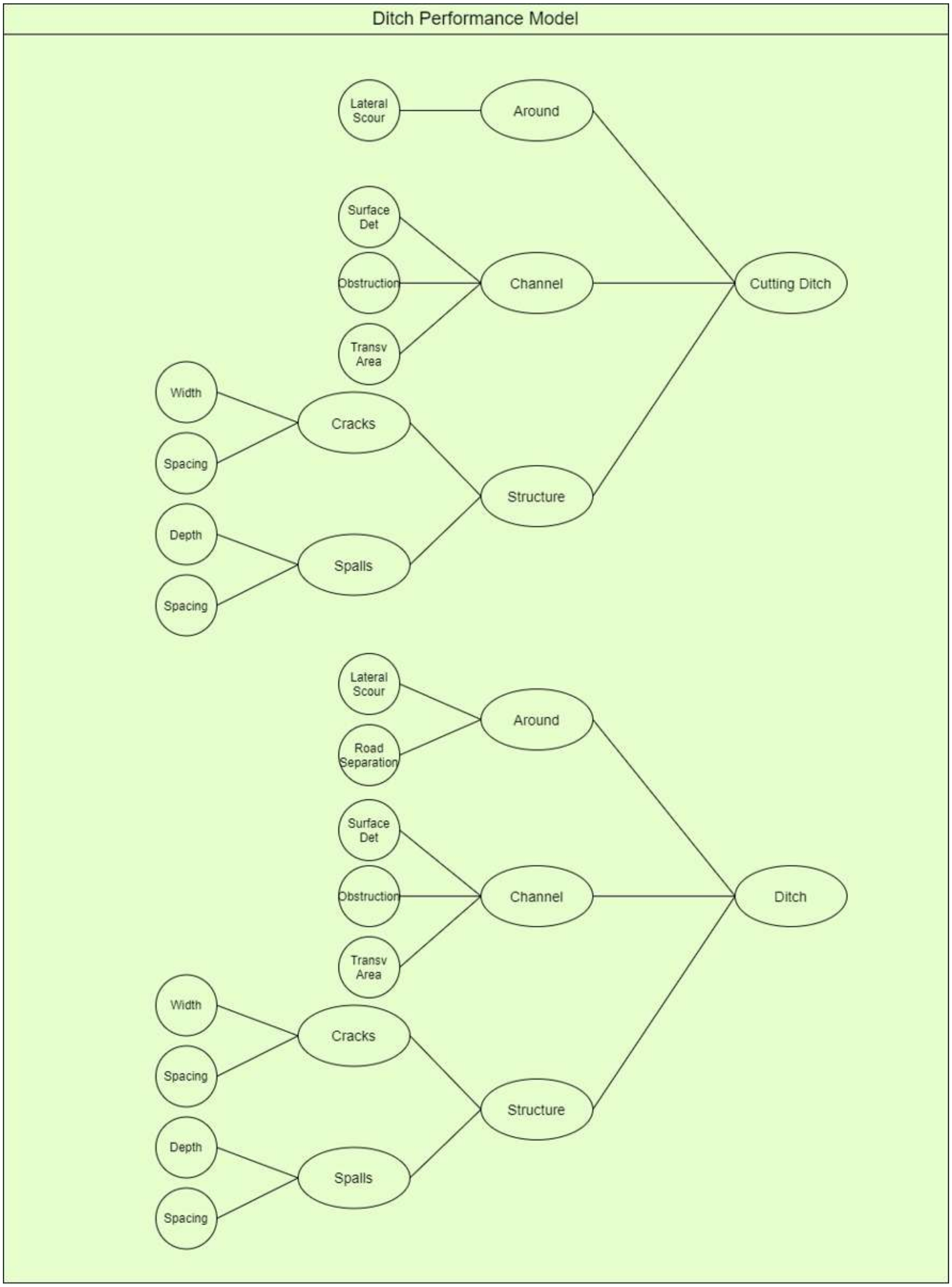


Figure 11.4: Ditch Performance Model

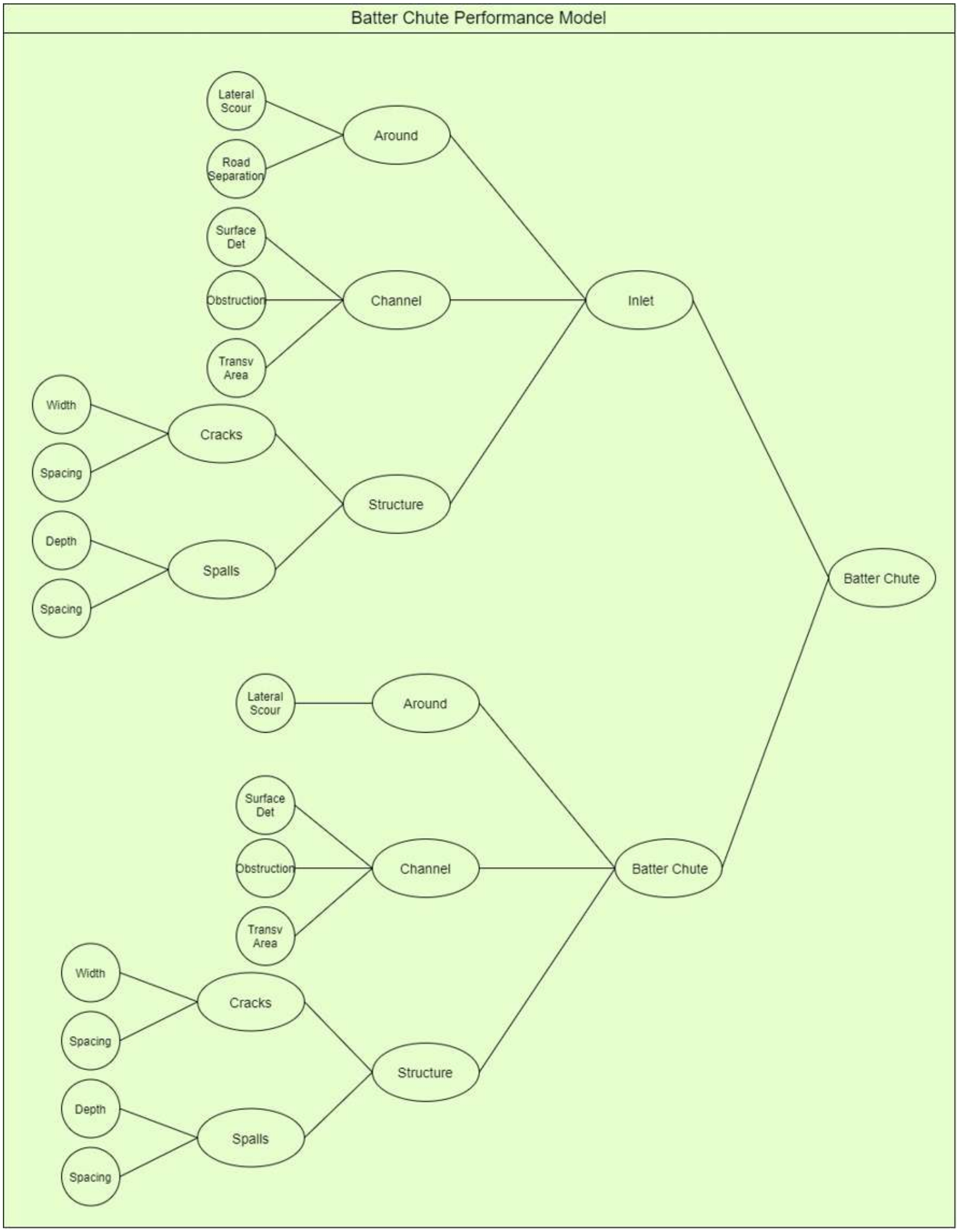


Figure 11.5: Batter Chute Performance Model

Around

- Lateral scour. Land surrounding visual evaluation.
- Road Separation. Drainage asset and road surface separation evaluation.

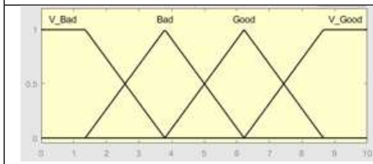
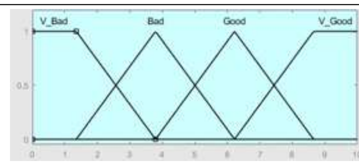
Lateral Scour	Cutting Ditch
	

Table 11.21: Around Cutting Ditch/Batter Chute Fuzzy Sets

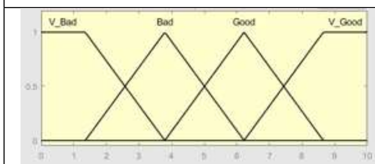
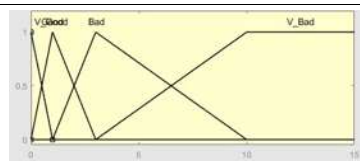
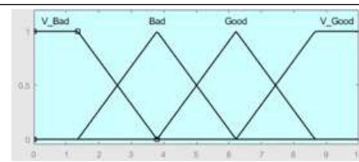
Lateral Scour	Road Separation	Around
		

Table 11.22: Around Ditch/Batter Chute Inlet Fuzzy Sets

Ditch/Batter Chute Inlet Around						
L Sc	R Sp			L Sc	R Sp	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	G		B	B	B
VG	VB	B		B	VB	VB
G	VG	VG		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 11.23: Around Ditch Fuzzy Rules

Drainage Asset Channel

- Surface deterioration. Visual evaluation of channel surface.
- Obstruction. Visual evaluation of water way.
- Transverse area. Asset land measure related to project.

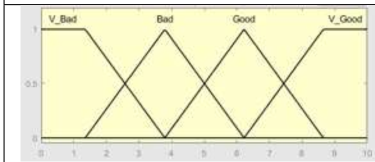
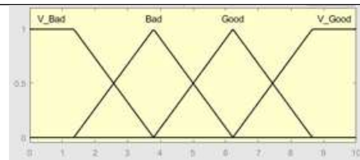
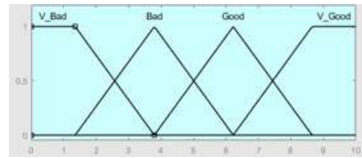
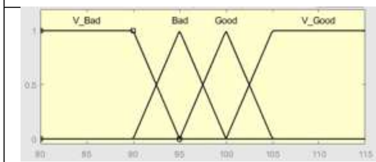
Surf Det	Obstruction	Drainage asset channel
		
Transverse Area		
		

Table 11.24: Channel Fuzzy Sets

Channel											
S D	Obst	Tr Ar		S D	Obst	Tr Ar		S D	Obst	Tr Ar	
VG	VG	VG	VG	G	G	B	B	B	B	VB	VB
VG	VG	G	VG	G	G	VB	B	B	VB	VG	B
VG	VG	B	G	G	B	VG	G	B	VB	G	B
VG	VG	VB	B	G	B	G	B	B	VB	B	VB
VG	G	VG	VG	G	B	B	B	B	VB	VB	VB
VG	G	G	G	G	B	VB	B	VB	VG	VG	B
VG	G	B	G	G	VB	VG	B	VB	VG	G	B
VG	G	VB	B	G	VB	G	B	VB	VG	B	B
VG	B	VG	B	G	VB	B	VB	VB	VG	VB	VB
VG	B	G	B	G	VB	VB	VB	VB	G	VG	B
VG	B	B	B	B	VG	VG	B	VB	G	G	B
VG	B	VB	VB	B	VG	G	B	VB	G	B	B
VG	VB	VG	B	B	VG	B	B	VB	G	VB	VB
VG	VB	G	B	B	VG	VB	B	VB	B	VG	B
VG	VB	B	VB	B	G	VG	B	VB	B	G	B
VG	VB	VB	VB	B	G	G	B	VB	B	B	VB
G	VG	VG	VG	B	G	B	B	VB	B	VB	VB
G	VG	G	G	B	G	VB	B	VB	VB	VG	B
G	VG	B	B	B	B	VG	B	VB	VB	G	B
G	VG	VB	B	B	B	G	B	VB	VB	B	VB
G	G	VG	VG	B	B	B	B	VB	VB	VB	VB
G	G	G	G								

Table 11.25: Performance Channel Fuzzy Rules

Structure

- Cracks. Visual evaluation
- Spalls. Visual evaluation

- Road Surface Separation. Visual separation

Structure											
Crack	Spalls	R S S		Crack	Spalls	R S S		Crack	Spalls	R S S	
VG	VG	VG	VG	G	G	B	B	B	B	VB	VB
VG	VG	G	G	G	G	VB	B	B	VB	VG	B
VG	VG	B	B	G	B	VG	B	B	VB	G	B
VG	VG	VB	B	G	B	G	B	B	VB	B	VB
VG	G	VG	VG	G	B	B	B	B	VB	VB	VB
VG	G	G	G	G	B	VB	B	VB	VG	VG	B
VG	G	B	B	G	VB	VG	B	VB	VG	G	B
VG	G	VB	B	G	VB	G	B	VB	VG	B	B
VG	B	VG	G	G	VB	B	B	VB	VG	VB	VB
VG	B	G	B	G	VB	VB	B	VB	G	VG	B
VG	B	B	B	B	VG	VG	G	VB	G	G	B
VG	B	VB	B	B	VG	G	G	VB	G	B	B
VG	VB	VG	B	B	VG	B	B	VB	G	VB	VB
VG	VB	G	B	B	VG	VB	B	VB	B	VG	B
VG	VB	B	B	B	G	VG	G	VB	B	G	B
VG	VB	VB	B	B	G	G	G	VB	B	B	B
G	VG	VG	VG	B	G	B	B	VB	B	VB	VB
G	VG	G	G	B	G	VB	B	VB	VB	VG	VB
G	VG	B	B	B	B	VG	B	VB	VB	G	VB
G	VG	VB	B	B	B	G	B	VB	VB	B	VB
G	G	VG	G	B	B	B	B	VB	VB	VB	VB
G	G	G	G								

Table 11.26: Performance Structure Fuzzy Rules

Drainage Asset Performance

- Channel. Water way evaluation.
- Structure. Asset evaluation
- Around. Deterioration effects in surrounding land.

Cutting Ditch/Ditch/Inlet/Batter Chute Performance														
Chan	Str	Arnd			Chan	Str	Arnd			Chan	Str	Arnd	
VG	VG	VG	VG		G	G	B	B		B	B	VB	VB
VG	VG	G	VG		G	G	VB	VB		B	VB	VG	B
VG	VG	B	B		G	B	VG	G		B	VB	G	B
VG	VG	VB	VB		G	B	G	G		B	VB	B	B
VG	G	VG	VG		G	B	B	B		B	VB	VB	VB
VG	G	G	G		G	B	VB	VB		VB	VG	VG	G
VG	G	B	B		G	VB	VG	B		VB	VG	G	G
VG	G	VB	VB		G	VB	G	B		VB	VG	B	B
VG	B	VG	G		G	VB	B	B		VB	VG	VB	VB
VG	B	G	G		G	VB	VB	VB		VB	G	VG	G
VG	B	B	B		B	VG	VG	G		VB	G	G	G
VG	B	VB	VB		B	VG	G	G		VB	G	B	B
VG	VB	VG	B		B	VG	B	B		VB	G	VB	VB
VG	VB	G	B		B	VG	VB	VB		VB	B	VG	B
VG	VB	B	VB		B	G	VG	G		VB	B	G	B
VG	VB	VB	VB		B	G	G	G		VB	B	B	B
G	VG	VG	G		B	G	B	B		VB	B	VB	VB
G	VG	G	G		B	G	VB	VB		VB	VB	VG	B
G	VG	B	B		B	B	VG	G		VB	VB	G	B
G	VG	VB	VB		B	B	G	G		VB	VB	B	VB
G	G	VG	G		B	B	B	B		VB	VB	VB	VB
G	G	G	G										

Table 11.27: Performance Ditch, Cutting Ditch, Inlet Batter Chute Fuzzy Rules

Batter chute

- Inlet. Evaluation of water entrance structure.
- Channel. Evaluation of water way in batter chute.

Performance Batter Chute						
Inlet	Chan			Inlet	Chan	
VG	VG	VG		B	VG	B
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	VG		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 11.28: Performance Batter Chute

Chapter 12

Annex E

12.1 Culvert

Status descriptions presented in this section are based in the evaluation descriptions proposed in the AASHTO Culvert and Storm Drain System Inspection Guide. [43]

Culvert inventory

- Size. Land diameter (m).
- Longitudinal slope. Percentage slope of culvert

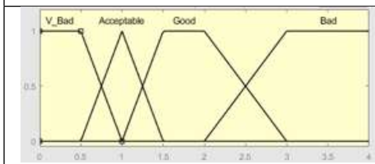
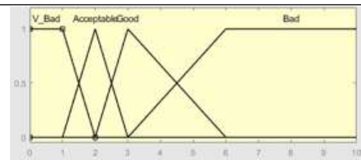
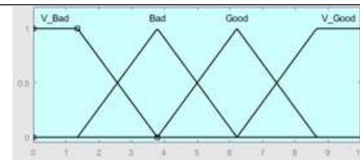
Size	Long. Slope	Culvert
		

Table 12.1: Culvert Inventory Fuzzy Sets

Culvert						
Size	L Slp			Size	L Slp	
G	G	VG		B	G	G
G	A	G		B	A	G
G	B	G		B	B	B
G	VB	B		B	VB	B
A	G	G		VB	G	B
A	A	G		VB	A	B
A	B	B		VB	B	VB
A	VB	B		VB	VB	VB

Table 12.2: Inventory Culvert Fuzzy Rules

12.1.1 Entrance Performance

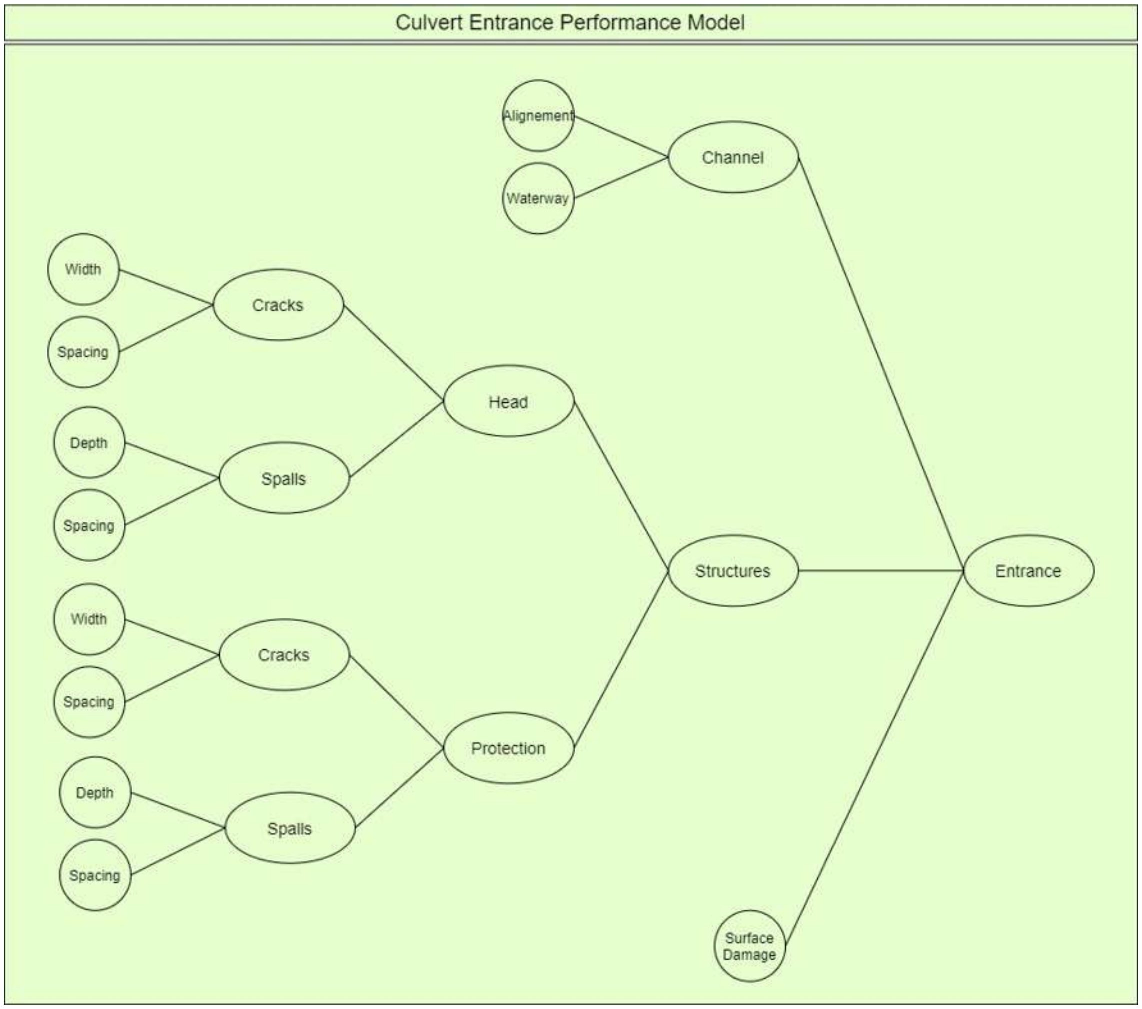


Figure 12.1: Culvert Entrance Performance Model

Evaluated Element	Very Good Qualification from 7.4 to 10	Good Qualification from 5.0 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad Qualification from 0 to 2.56
Channel Alignement	Channel is aligned with culvert (horizontally and vertically). It does not present potential erosion or flow restrictions.	Channel stream is at slight angle or offset relative to culvert centerline but does not affect flow capacity. Small ponding.	Alignement beginning to change, causing embankment erosion and undercuttirng barrel. Ponding at inlet. Stream at moderate angle.	Channel flow severely misaligned causing severe bank erosion. Channel directed at bank with threat of immediate collapse.
Waterway Adequacy	Waterway is open and free flowing with noobstructions.	Minor sedimentation or debris accumulation. Depth of blockage less than 10% of pipe diameter. No scour. Ponding.	Partial blockage of channel. Depth of blockage between 10 % and 30% of pipe diameter. Ponding deeper than 10% of diameter.	Culvert blocked or severely restricted. Depth of blockage greater than 30% of pipe diameter. Frequent flooding, roadway marks of high water flows.
Scour	No indications of bank erosion or scour.	Structure remains stable but with intermittent bank erosion or local scour. It does not exposure previously buried features.	General bank erosion, local scour or headcutting near outlet, or signs of downstream scour. Undercutting and sod-root overhangs.	Bank, culvert end treatment structure, and/or roadway weakened by scour, danger of collapse with next flood event.

Culvert entrance channel

- Alignment. Visual evaluation.
- Waterway. Visual evaluation

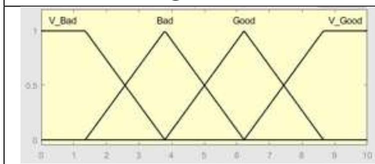
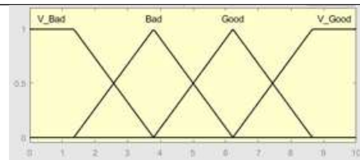
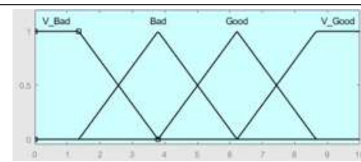
Alignment	Waterway	Channel
		

Table 12.3: Culvert Entrance Channel Fuzzy Sets

Channel						
Alig	WWAd			Alig	WWAd	
VG	VG	VG		B	VG	G
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	VG		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 12.4: Performance Entrance Culvert Channel Fuzzy Rules

Cracks

- Width. Land measure (mm)
- Spacing. Visual evaluation

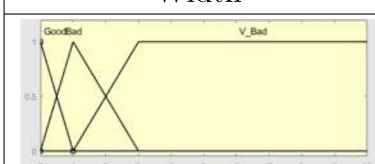
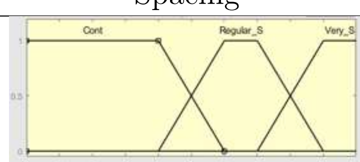
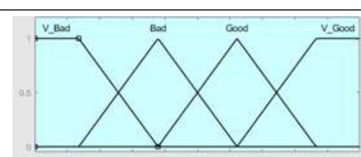
Width	Spacing	Cracks
		

Table 12.5: Cracks Fuzzy Sets

Cracks		
Width	Spac	
G	VS	VG
G	RS	VG
G	Cont	G
B	VS	G
B	RS	B
B	Cont	B
VB	VS	B
VB	RS	VB
VB	Cont	VB

Table 12.6: Performance Cracks Fuzzy Rules

Spalls evaluation

- Depth. Land measure (cm)
- Spacing. Visual evaluation of cracking continuity.

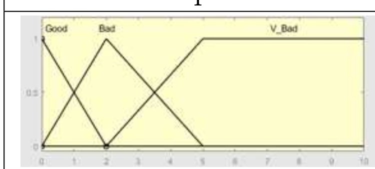
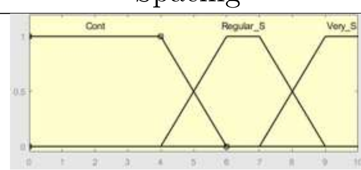
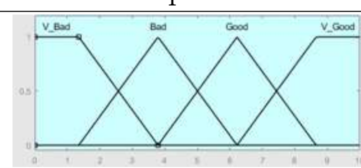
Depth	Spacing	Spalls
		

Table 12.7: Spalls Fuzzy Sets

Spalls		
Depth	Spac	
G	VS	VG
G	RS	VG
G	Cont	VG
B	VS	G
B	RS	B
B	Cont	B
VB	VS	B
VB	RS	VB
VB	Cont	VB

Table 12.8: Performance Spalls Fuzzy Rules

Head/Protection structures

- Crack. Width and spacing evaluation
- Spalls. Depth and spacing evaluation

Head/Protection						
Crack	Spalls			Crack	Spalls	
VG	VG	VG		B	VG	G
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 12.9: Performance Culvert Head/Protection Fuzzy Rules

Structures

- Head. Crack and spalls evaluation
- Protection. Crack and spalls evaluation

Structures						
Head	Prot			Head	Prot	
VG	VG	VG		B	VG	B
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 12.10: Performance Culvert Structures Fuzzy Rules

Culvert Entrance

- Channel. Alignment and water way adequacy evaluation.
- Structures. Head and protection structures evaluation.
- Erosion/Scour. Visual evaluation.

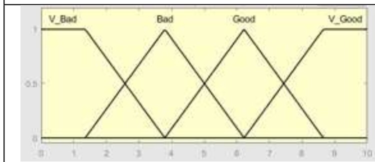
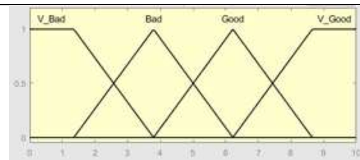
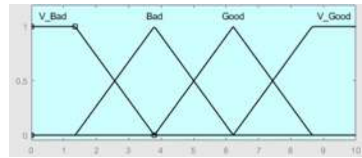
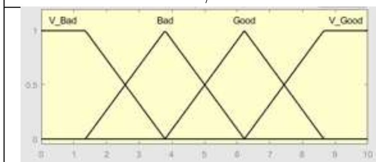
Channel	Structures	Entrance
		
Erosion/Scour		
		

Table 12.11: Culvert Entrance Fuzzy Sets

Entrance													
Chanl	Str	Er/Sc			Chanl	Str	Er/Sc			Chanl	Str	Er/Sc	
VG	VG	VG	VG		G	G	B	B		B	B	VB	VB
VG	VG	G	VG		G	G	VB	VB		B	VB	VG	B
VG	VG	B	B		G	B	VG	B		B	VB	G	B
VG	VG	VB	VB		G	B	G	B		B	VB	B	VB
VG	G	VG	G		G	B	B	B		B	VB	VB	VB
VG	G	G	G		G	B	VB	VB		VB	VG	VG	B
VG	G	B	B		G	VB	VG	B		VB	VG	G	B
VG	G	VB	VB		G	VB	G	B		VB	VG	B	B
VG	B	VG	G		G	VB	B	VB		VB	VG	VB	VB
VG	B	G	B		G	VB	VB	VB		VB	G	VG	B
VG	B	B	B		B	VG	VG	G		VB	G	G	B
VG	B	VB	VB		B	VG	G	G		VB	G	B	B
VG	VB	VG	B		B	VG	B	B		VB	G	VB	VB
VG	VB	G	B		B	VG	VB	VB		VB	B	VG	B
VG	VB	B	VB		B	G	VG	G		VB	B	G	VB
VG	VB	VB	VB		B	G	G	G		VB	B	B	VB
G	VG	VG	VG		B	G	B	B		VB	B	VB	VB
G	VG	G	G		B	G	VB	VB		VB	VB	VG	VB
G	VG	B	B		B	B	VG	B		VB	VB	G	VB
G	VG	VB	VB		B	B	G	B		VB	VB	B	VB
G	G	VG	VG		B	B	B	B		VB	VB	VB	VB
G	G	G	G										

Table 12.12: Performance Culvert Entrance Fuzzy Rules

12.1.2 Barrel Performance

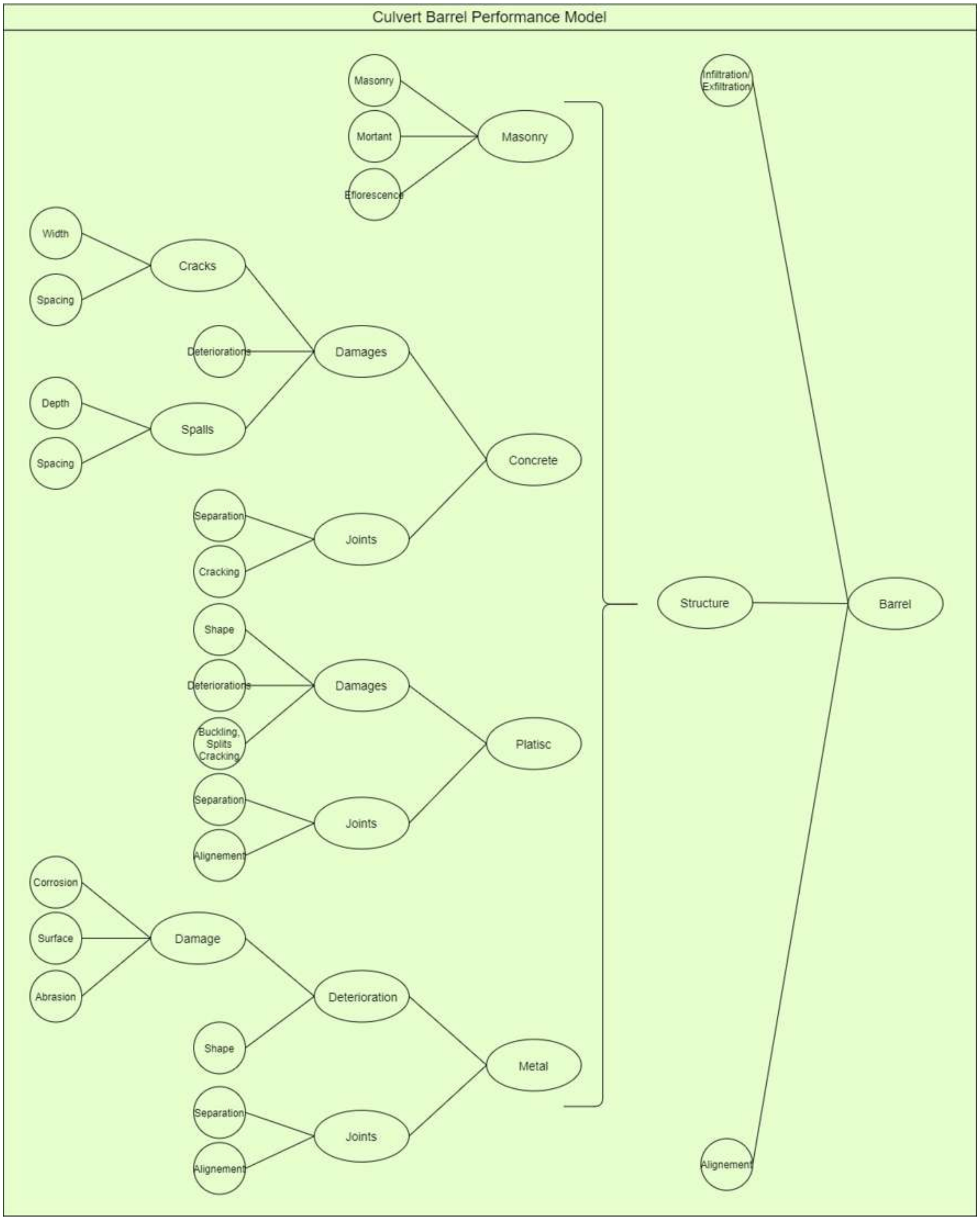


Figure 12.2: Culvert Barrel Performance Model

Evaluated Element	Very Good Qualification from 7.4 to 10	Good Qualification from 5.0 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad Qualification from 0 to 2.56
Separation	Joints are tightly installed with proper alignment and functioning well.	Joint separation, offset, or rotation with no indication of distress. Gasket not exposed.	Joint separation, offseet, or rotation in one or more joints, with exposed or missing gasket materials.	Joint separation , offset, or rotation with exposed backfill material. Multiple locations of exposed or missing gaskets.
Joint Cracking	No joint cracking.	Longitudinal cracks of 0.25 mm to 1 mm wide emanating from joint. No spalling. Small spalls along edge of spigot end that do not expose reinforcing or joint sealant.	Longtitudinal cracks of 1 mm to 3 mm wide emanating from joint. Moderated spalls along edge of spigot end, possible exposed reinforcing or joint sealant.	Longitudinal cracks greater than 3 mm wide emanating from joint. Large spalls along edge of spigot end with associated structural cracking.
Alignment	No visible misalignment.	Slight cocked seams without cusp effect, but does not affect cross section shape.	Cocked seams such that it affects cross section shape. Cusped effect with local wall bending.	Cocked seams severely affecting cross section shape. Cusp affect with seam cracking. Seam capacity loss imminent.
Fasteners	No loose or missing bolts/fasteners.	Less than 5% loose or missing bolts in any seam.	5% to 15% of loose or missing bolts in any seam.	Greater than 15% loose or missingt bolts in any seam.

Barrel joint

- Separation. Visual evaluation.
- Cracks. Width and spacing evaluation.
- Alignment. Visual evaluation
- Fasteners. Visual evaluation.

Joints								
Concrete Barrel			Plastic Barrel			Metal Barrel		
Sep	Crack		Sep	Alig		Fstnr	Alig	
VG	VG	VG	VG	VG	VG	VG	VG	VG
VG	G	VG	VG	G	G	VG	G	G
VG	B	B	VG	B	B	VG	B	B
VG	VB	VB	VG	VB	VB	VG	VB	VB
G	VG	G	G	VG	VG	G	VG	VG
G	G	G	G	G	G	G	G	G
G	B	B	G	B	B	G	B	B
G	VB	VB	G	VB	VB	G	VB	VB
B	VG	B	B	VG	G	B	VG	G
B	G	B	B	G	B	B	G	B
B	B	B	B	B	B	B	B	B
B	VB	VB	B	VB	VB	B	VB	VB
VB	VG	VB	VB	VG	B	VB	VG	G
VB	G	VB	VB	G	B	VB	G	B
VB	B	VB	VB	B	B	VB	B	VB
VB	VB	VB	VB	VB	VB	VB	VB	VB

Table 12.13: Performance Joints Fuzzy Rules

Evaluated Element	Very Good qualification from 7.4 to 10	Good Qualification from 5.0 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad Qualification from 0 to 2.56
Units	No cracking, split or missing masonry units. No displaced masonry units. No surface deterioration. No measurable cross sectional distortion.	Cracking of isolated individual units. Surface weathering or spalling. No movement of masonry units.	Split or cracked masonry units. Large areas of moderate spalling, scaling or weathering. Pronounced movement or dislocation of masonry units but does not warrant engineering evaluation.	Widespread cracking splitting, or crushing of masonry units or missing units. Large areas of heavy spalling, scaling, or weathering. Holes through structure wall. Significant movement of individual units. Visible movement or distortion of cross sectional shape, structure appears unstable.
Mortar	Mortar is intact with no deterioaration.	Localized cracked or missing mortar. Widespread areas of shallow mortar deterioration, possible minor water infiltration or exfiltration through joints.	Extensive missing mortar. Extensive mortar deterioration, small flow but no soil/fines, infiltration or exfiltration through joints. Vegetation sprouting from between units	Missing mortar with backfill infiltration, possible voids in roadway.
Efflorescence	Localized areas of efflorescence less than 25 cm^2.	Widespread areas of efflorescence without rust staining.	Heavy buildup of efflorescence with rust staining.	

Masonry Barrel Performance

- Units. Visual evaluation of masonry elements.
- Mortar. Visual evaluation of masonry joints.
- Efflorescence. Visual evaluation of deterioration.

Masonry Barrel											
Units	Mort	Efflo		Units	Mort	Efflo		Units	Mort	Efflo	
VG	VG	VG	VG	G	G	G	G	B	B	B	VB
VG	VG	G	VG	G	G	B	G	B	VB	VG	VB
VG	VG	B	G	G	B	VG	B	B	VB	G	VB
VG	G	VG	VG	G	B	G	B	B	VB	B	VB
VG	G	G	G	G	B	B	B	VB	VG	VG	B
VG	G	B	G	G	VB	VG	B	VB	VG	G	B
VG	B	VG	B	G	VB	G	B	VB	VG	B	VB
VG	B	G	B	G	VB	B	VB	VB	G	VG	B
VG	B	B	B	B	VG	VG	B	VB	G	G	B
VG	VB	VG	B	B	VG	G	B	VB	G	B	VB
VG	VB	G	B	B	VG	B	B	VB	B	VG	VB
VG	VB	B	VB	B	G	VG	B	VB	B	G	VB
G	VG	VG	VG	B	G	G	B	VB	B	B	VB
G	VG	G	VG	B	G	B	VB	VB	VB	VG	VB
G	VG	B	G	B	B	VG	B	VB	VB	G	VB
G	G	VG	G	B	B	G	B	VB	VB	B	VB

Table 12.14: Performance Barrel Masonry Damage Fuzzy Rules

Evaluated Element	Very Good Calification from 7.4 to 10	Good Calification from 5.0 to 7.3	Bad Calification from 2.57 to 4.99	Very Bad Calification from 0 to 2.56
Cracking	No cracks.	Longitudinal cracks from 0.25 mm to 1 mm wide with spacing of 1 m or more. Some circumferential cracks with no infiltration. Efflorescence but no rust staining emanating from cracks.	Longitudinal cracks from 1 mm to 3 mm wide. Spacing from 0.3 m to 1 m. Water infiltration through circumferential cracks. Efflorescence and/or rust staining emanating from cracks. No cracks with vertical offset. No increase in cracking from previous inspection.	Longitudinal cracks greater than 3 mm wide, exposed rebar, significant water infiltration and/or soil migration. Cracks with vertical offset Large areas of rust staining emanating from cracks
Slabbing, Spalling Delamination Patches	No spalling or slabbing. No delamination. Patched areas that are sound.	Localized spalls less than 10 mm depth and less than 15 cm in diameter. No exposed rebar. No slabbing. Small delaminations indicated by hollow sounds at patches but pathc stable.	Spalling and or delamination from 10 mm to 20 mm depth and larger than 15 cm in diameter. No exposed rebar. Some rust staining from spalled areas, structure stable. No slabbing. Pathed areas deteriorated.	Widespread spalling greater than 2 cm in depth or delamination with exposed rebar, structure unstable. Slabbing of concrete.
Deterioration	No scaling, abrasion, or other surface damage.	Light or moderate scaling. Abrasion less than 5 mm deep over less than 20% of pipe surface. Localized superficial impact damage. No rebar exposed. Multiple plugged weep holes	Moderate to severe scaling. Abrasion between 5 mm and 10 mm deep over more than 30% of pipe surface. Impact damage with exposed rebar.	Extensive surface damage and aggregate pop-out. Includes exposed and/or corroded rebar. Complete invert deterioration and loss of pipe wall section.

Concrete Barrel Performance

- Cracking. Visual evaluation.
- Deterioration. Visual evaluation.
- Slabbing/Spalling. Visual evaluation.

Concrete Barrel											
Crack	Det	Sl/Sp		Crack	Det	Sl/Sp		Crack	Det	Sl/Sp	
VG	VG	VG	VG	G	G	B	B	B	B	VB	VB
VG	VG	G	G	G	G	VB	VB	B	VB	VG	VB
VG	VG	B	B	G	B	VG	G	B	VB	G	VB
VG	VG	VB	VB	G	B	G	B	B	VB	B	VB
VG	G	VG	VG	G	B	B	B	B	VB	VB	VB
VG	G	G	G	G	B	VB	VB	VB	VG	VG	B
VG	G	B	B	G	VB	VG	B	VB	VG	G	B
VG	G	VB	VB	G	VB	G	B	VB	VG	B	VB
VG	B	VG	G	G	VB	B	VB	VB	VG	VB	VB
VG	B	G	G	G	VB	VB	VB	VB	G	VG	B
VG	B	B	B	B	VG	VG	G	VB	G	G	B
VG	B	VB	VB	B	VG	G	G	VB	G	B	VB
VG	VB	VG	B	B	VG	B	B	VB	G	VB	VB
VG	VB	G	B	B	VG	VB	VB	VB	B	VG	VB
VG	VB	B	VB	B	G	VG	G	VB	B	G	VB
VG	VB	VB	VB	B	G	G	B	VB	B	B	VB
G	VG	VG	VG	B	G	B	B	VB	B	VB	VB
G	VG	G	G	B	G	VB	VB	VB	VB	VG	VB
G	VG	B	B	B	B	VG	B	VB	VB	G	VB
G	VG	VB	VB	B	B	G	B	VB	VB	B	VB
G	G	VG	G	B	B	B	B	VB	VB	VB	VB
G	G	G	G								

Table 12.15: Performance Barrel Concrete Damage Fuzzy Rules

Evaluated Element	Very Good Qualification from 7.4 to 10	Good Qualification from 5.0 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad Qualification from 0 to 2.56
Shape	Barrel maintains roud shape with no local wall flattening. Vertical deformation less than 5% of original inside diameter.	Minor wall flattening. Vertical deformation 5%-7.5% of original inside diameter.	Significant wall flattening or increased wall curvature. Vertical deformation 7.5% to 10% of original inside diameter. Visual out-of-roundness.	Extrem wall flattening with reversal of curvature, and/or kinks. Vertical deformation greater than 10% of original inside diameter. Significant visual out-of-roundness.
Surface Damage	No indication of wear, abrasion, impact damage or UV degradation.	Minor wear, abrasion, less than 10% of wall thickness. Minor staining or UV degradation. Blistering over less than 25% of pipe inner surface.	Wear, abrasion that exceeds 10% of wall whtickness. UV degradation causing discoloration. Blistering over greater than 25% of pipe inner surface.	Wear, abrasion that exceeds 25% of wall thickness. UV degradation resulting in cracked or broken pipe wall.
Bucking, Splits and Cracking	Smooth interior wall. No splits in welded seams or cracking in wall.	Initiation of local buckling indicated by rippling in wall. Wall cracking or splits, less than a quarter of circumference. No infiltration. No longitudinal cracking	Advanced and widespread wall buckling indicated by extensive interior surface rippling. Wall cracking or splits up to half of circumference. Minor water infiltration but no soil infiltration. Longitudinal cracking less than 30 cm in length.	Kinks though the full wall thickness. Pipe wall buckles inward locally. Wall cracking or splits greater than hals of pipe circumference. Longitudinal cracking more than 30 cm in length. Cracks with indication of soil infiltration.

Plastic Barrel Performance

- Shape. Visual evaluation of plastic shape.
- Surface damage. Visual evaluation of plastic damage.
- Buckling, splits and cracking. Visual evaluation.

Plastic Barrel											
Shp	Det	B, S, C		Shp	Det	B, S, C		Shp	Det	B, S, C	
VG	VG	VG	VG	G	G	B	G	B	B	VB	VB
VG	VG	G	VG	G	G	VB	B	B	VB	VG	VB
VG	VG	B	G	G	B	VG	G	B	VB	G	VB
VG	VG	VB	B	G	B	G	G	B	VB	B	VB
VG	G	VG	VG	G	B	B	B	B	VB	VB	VB
VG	G	G	G	G	B	VB	VB	VB	VG	VG	B
VG	G	B	G	G	VB	VG	B	VB	VG	G	B
VG	G	VB	B	G	VB	G	B	VB	VG	B	VB
VG	B	VG	G	G	VB	B	VB	VB	VG	VB	VB
VG	B	G	G	G	VB	VB	VB	VB	G	VG	B
VG	B	B	B	B	VG	VG	G	VB	G	G	B
VG	B	VB	VB	B	VG	G	G	VB	G	B	VB
VG	VB	VG	B	B	VG	B	B	VB	G	VB	VB
VG	VB	G	B	B	VG	VB	VB	VB	B	VG	VB
VG	VB	B	VB	B	G	VG	G	VB	B	G	VB
VG	VB	VB	VB	B	G	G	B	VB	B	B	VB
G	VG	VG	VG	B	G	B	B	VB	B	VB	VB
G	VG	G	G	B	G	VB	VB	VB	VB	VG	VB
G	VG	B	G	B	B	VG	B	VB	VB	G	VB
G	VG	VB	B	B	B	G	B	VB	VB	B	VB
G	G	VG	G	B	B	B	B	VB	VB	VB	VB
G	G	G	G								

Table 12.16: Performance Barrel Plastic Damage Fuzzy Rules

Evaluated Element	Very Good Qualification from 7.4 to 10	Good Qualification from 5.0 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad Qualification from 0 to 2.56
Corrosion	Isolated areas of freckled rust.	Freckled rust, corrosion of pipe wall material. No loss of section, no through-wall penetration from corrosion	Corrosion of pipe material and widespread section loss less than 10% of wall thickness. Localized deep pitting. Several holes less than 2.5 cm diameter. Penetration possible with hammer pick strike.	Widespread through-wall penetration. Invert missing in localized sections. Through-wall penetrations present. Holes greater than 2.5 cm diameter or many smaller holes grouped closely.
Surface Damage	No dents or other localized damage.	Small dents or impact damage to pipe wall or end section with no wall breaches.	Large dents or impact damage to pipe wall or end section with localized wall breaches, no more than one corrugation over circumferential length of 15 cm.	Dents or damage that warrant engineering evaluation. Through wall holes greater than one corrugation over a length more than 15 cm allowing unimpeded soil infiltration.
Abrasion	No damage due to abrasion.	Small or local abrasion of wall or coating with no breaches in the coating exposing structural wall or signs of corrosion.	Widespread abrasion of protective coating with breaches exposing the pipe wall material and allowing through wall penetration during inspection probing with a pick.	Abrasion has worn large holes through the metal pipe greater than one corrugation in length for more than 15 cm around the circumference.

Metal Barrel Damage

- Corrosion. Visual evaluation of metal barrel.
- Surface damage. Visual evaluation of metal damage.
- Abrasion. Visual evaluation of metal barrel.

Metal Damage											
Corr	Srf	Abr		Corr	Srf	Abr		Corr	Srf	Abr	
VG	VG	VG	VG	G	G	B	G	B	B	VB	VB
VG	VG	G	VG	G	G	VB	B	B	VB	VG	VB
VG	VG	B	G	G	B	VG	B	B	VB	G	VB
VG	VG	VB	B	G	B	G	B	B	VB	B	VB
VG	G	VG	VG	G	B	B	B	B	VB	VB	VB
VG	G	G	G	G	B	VB	VB	VB	VG	VG	B
VG	G	B	G	G	VB	VG	B	VB	VG	G	B
VG	G	VB	B	G	VB	G	B	VB	VG	B	VB
VG	B	VG	B	G	VB	B	VB	VB	VG	VB	VB
VG	B	G	B	G	VB	VB	VB	VB	G	VG	B
VG	B	B	B	B	VG	VG	B	VB	G	G	B
VG	B	VB	VB	B	VG	G	B	VB	G	B	VB
VG	VB	VG	B	B	VG	B	B	VB	G	VB	VB
VG	VB	G	B	B	VG	VB	VB	VB	B	VG	VB
VG	VB	B	VB	B	G	VG	B	VB	B	G	VB
VG	VB	VB	VB	B	G	G	B	VB	B	B	VB
G	VG	VG	G	B	G	B	B	VB	B	VB	VB
G	VG	G	G	B	G	VB	VB	VB	VB	VG	VB
G	VG	B	G	B	B	VG	B	VB	VB	G	VB
G	VG	VB	B	B	B	G	B	VB	VB	B	VB
G	G	VG	G	B	B	B	B	VB	VB	VB	VB
G	G	G	G								

Table 12.17: Performance Metal Damage Fuzzy Rules

Evaluated Element	Very Good Qualification from 7.4 to 10	Good Qualification from 5.0 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad Qualification from 0 to 2.56
Shape	Smooth curvature in barrel, deformation less than 5% of inside diameter.	Top half smooth. Minor bulges or flattening of bottom. Deformations 5% to 10% of original inside diameter.	Significant distoritions or flattening. Lower third may be kinked. Deformation 10% to 15% of original inside diameter. Visible out-of-roundness.	Extreme distortion throughout pipe, local area of reverse curvature and kinks. Deformation greater than 15% of original inside diameter. Significant out-of-roundness.

Metal Barrel Performance

- Damage. Corrosion, surface damage and abrasion evaluation.
- Shape. Visual evaluation of barrel deformations.

Metal Barrel						
Dmg	Shp			Dmg	Shp	
VG	VG	VG		B	VG	G
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	VG		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 12.18: Performance Barrel Metal Damage Fuzzy Rules

Barrel Structure

- Material Deterioration. Deterioration barrel evaluation.
- Joints. Alignment and deterioration joints evaluation.

Barrel Structure						
M Det	Joints			M Det	Joints	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	G		B	B	B
VG	VB	B		B	VB	VB
G	VG	VG		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 12.19: Performance Barrel Structure Fuzzy Rules

Evaluated Element	Very Good Qualification from 7.4 to 10	Good Qualification from 5.0 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad Qualification from 0 to 2.56
Infiltration/ Exfiltration	No signs of infiltration or exfiltration.	Minor water infiltration through leak resistant seams but no soil infiltration.	Significant water infiltration and evidence of fine soils infiltrating.	Coarse soil infiltration through seam openings. Possible hollow sounds behind structure wall near seams indicating loss of back fill support. Evidence of piping due to exfiltration.
Alignment	Horizontal alignment shows no signs of movement from installed condition. Vertical alignment shows no sagging or heaving.	Horizontal alignment shows small visible deviations from installed condition that does not affect joints or barrel. Vertical alignment has minor sagging or heaving.	Horizontal alignment with deviations from installed condition that may affect joints or barrel. Vertical misalignment causing ponding/sediment accumulation between 10% and 30% of diameter.	Distress at joints or in barrel due to vertical or horizontal misalignment with pipe section offsets. Vertical misalignment causes ponding/sediment accumulation of more than 30% of diameter. Significant flow restriction.

Barrel Performance

- Barrel structure. Deterioration barrel evaluation.
- Infiltration/Exfiltration. Visual evaluation.
- Alignment. Visual evaluation.

Barrel											
Barr	In/Ex	Alig		Barr	In/Ex	Alig		Barr	In/Ex	Alig	
VG	VG	VG	VG	G	G	B	B	B	B	VB	VB
VG	VG	G	VG	G	G	VB	B	B	VB	VG	VB
VG	VG	B	B	G	B	VG	B	B	VB	G	VB
VG	VG	VB	B	G	B	G	B	B	VB	B	VB
VG	G	VG	G	G	B	B	B	B	VB	VB	VB
VG	G	G	G	G	B	VB	VB	VB	VG	VG	B
VG	G	B	B	G	VB	VG	VB	VB	VG	G	B
VG	G	VB	B	G	VB	G	VB	VB	VG	B	VB
VG	B	VG	B	G	VB	B	VB	VB	VG	VB	VB
VG	B	G	B	G	VB	VB	VB	VB	G	VG	B
VG	B	B	B	B	VG	VG	G	VB	G	G	B
VG	B	VB	VB	B	VG	G	G	VB	G	B	VB
VG	VB	VG	VB	B	VG	B	B	VB	G	VB	VB
VG	VB	G	VB	B	VG	VB	B	VB	B	VG	VB
VG	VB	B	VB	B	G	VG	G	VB	B	G	VB
VG	VB	VB	VB	B	G	G	B	VB	B	B	VB
G	VG	VG	G	B	G	B	B	VB	B	VB	VB
G	VG	G	G	B	G	VB	VB	VB	VB	VG	VB
G	VG	B	B	B	B	VG	B	VB	VB	G	VB
G	VG	VB	B	B	B	G	B	VB	VB	B	VB
G	G	VG	G	B	B	B	B	VB	VB	VB	VB
G	G	G	G								

Table 12.20: Performance Barrel Fuzzy Rules

12.1.3 Exit Performance

Evaluation of properties in this section are based in descriptions presented above, in section Entrance Performance.

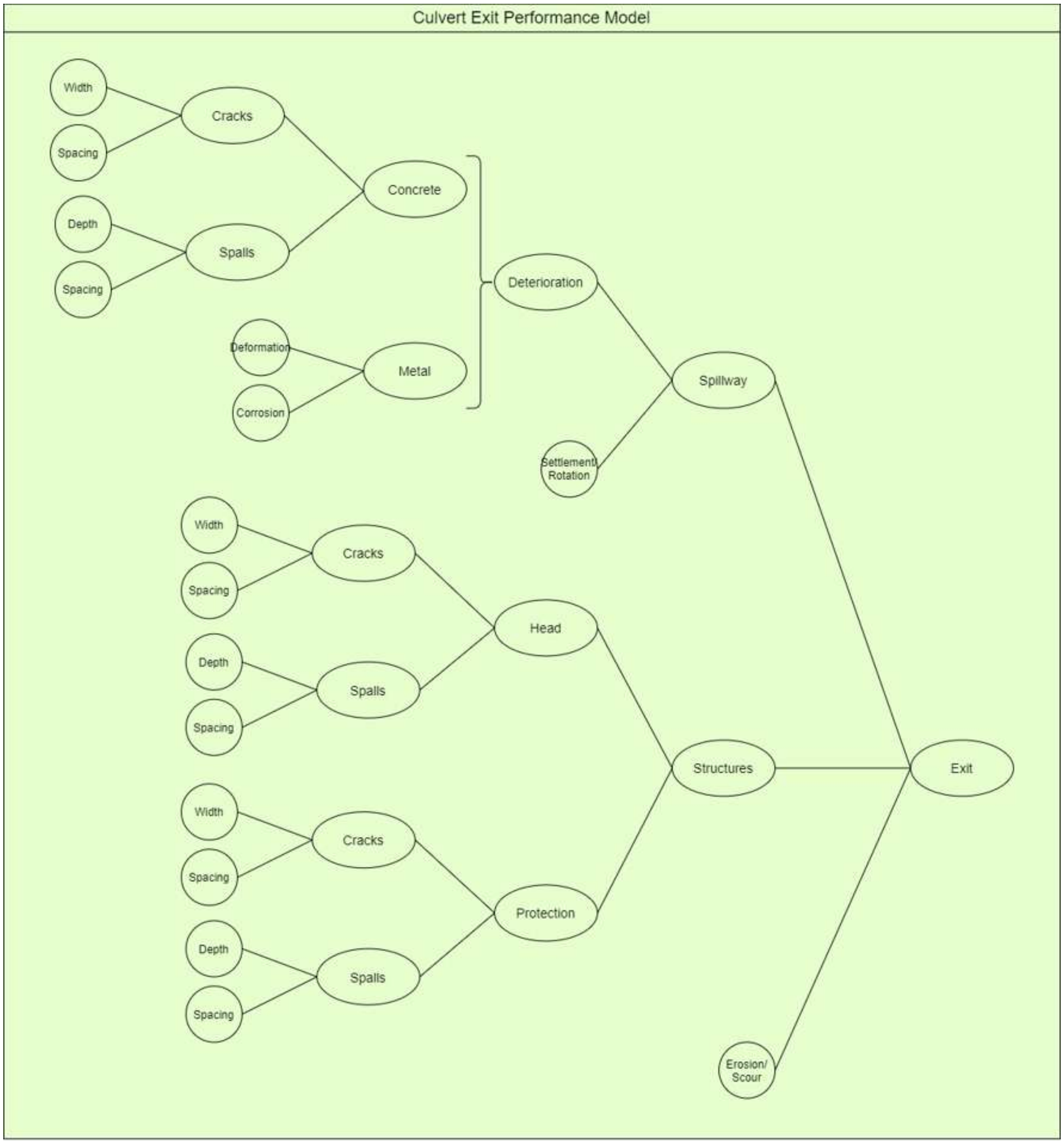


Figure 12.3: Culvert Exit Performance Model

Concrete deterioration

- Cracks. Visual evaluation.
- Surface Damage. Visual evaluation.

Concrete Deterioration/Head/Protection						
Crack	S Dmg			Crack	S Dmg	
VG	VG	VG		B	VG	G
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 12.21: Performance Concrete Deterioration/Head/Protection Fuzzy Rules

Metal deterioration

- Deformation. Visual evaluation.
- Corrosion. Visual evaluation.

Metal Deterioration						
Def	Corr			Def	Corr	
VG	VG	VG		B	VG	G
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	VG		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 12.22: Performance Metal Deterioration Fuzzy Rules

Spillway

- Material deterioration. Concrete or metal evaluation.
- Settlement/Rotation. Visual evaluation.

Spillway						
Det	S/R			Det	S/R	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 12.23: Performance Spillway Fuzzy Rules

Structures

- Head. Visual evaluation.
- Protection. Visual evaluation.

Structures						
Head	Prot			Head	Prot	
VG	VG	VG		B	VG	B
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 12.24: Structures Fuzzy Rules

Exit

- Structures. Head and protection evaluation.
- Spillway. Material deterioration and deformation evaluation.
- Scour. Visual Evaluation.

Exit														
Str	Spwy	Scour			Str	Spwy	Scour			Str	Spwy	Scour	
VG	VG	VG	VG		G	G	B	B		B	B	VB	VB
VG	VG	G	G		G	G	VB	VB		B	VB	VG	B
VG	VG	B	B		G	B	VG	G		B	VB	G	B
VG	VG	VB	VB		G	B	G	B		B	VB	B	VB
VG	G	VG	VG		G	B	B	B		B	VB	VB	VB
VG	G	G	G		G	B	VB	VB		VB	VG	VG	B
VG	G	B	B		G	VB	VG	B		VB	VG	G	B
VG	G	VB	VB		G	VB	G	B		VB	VG	B	VB
VG	B	VG	G		G	VB	B	B		VB	VG	VB	VB
VG	B	G	G		G	VB	VB	VB		VB	G	VG	B
VG	B	B	B		B	VG	VG	G		VB	G	G	B
VG	B	VB	VB		B	VG	G	B		VB	G	B	VB
VG	VB	VG	B		B	VG	B	B		VB	G	VB	VB
VG	VB	G	B		B	VG	VB	VB		VB	B	VG	B
VG	VB	B	B		B	G	VG	G		VB	B	G	VB
VG	VB	VB	VB		B	G	G	B		VB	B	B	VB
G	VG	VG	VG		B	G	B	B		VB	B	VB	VB
G	VG	G	G		B	G	VB	VB		VB	VB	VG	VB
G	VG	B	B		B	B	VG	B		VB	VB	G	VB
G	VG	VB	VB		B	B	G	B		VB	VB	B	VB
G	G	VG	G		B	B	B	B		VB	VB	VB	VB
G	G	G	G										

Table 12.25: Performance Exit Fuzzy Rules

Culvert Performance

- Entrance. Alignement and structures status evaluation.
- Barrel. Joints and barrel evaluation
- Exit. Exit structures status evaluation

Culvert											
Entrance	Barrel	Exit		Entrance	Barrel	Exit		Entrance	Barrel	Exit	
VG	VG	VG	VG	G	G	B	B	B	B	VB	VB
VG	VG	G	VG	G	G	VB	B	B	VB	VG	VB
VG	VG	B	B	G	B	VG	B	B	VB	G	VB
VG	VG	VB	B	G	B	G	B	B	VB	B	VB
VG	G	VG	G	G	B	B	B	B	VB	VB	VB
VG	G	G	G	G	B	VB	VB	VB	VG	VG	B
VG	G	B	B	G	VB	VG	B	VB	VG	G	B
VG	G	VB	B	G	VB	G	B	VB	VG	B	B
VG	B	VG	B	G	VB	B	VB	VB	VG	VB	B
VG	B	G	B	G	VB	VB	VB	VB	G	VG	B
VG	B	B	B	B	VG	VG	B	VB	G	G	B
VG	B	VB	B	B	VG	G	B	VB	G	B	B
VG	VB	VG	B	B	VG	B	B	VB	G	VB	B
VG	VB	G	B	B	VG	VB	B	VB	B	VG	B
VG	VB	B	VB	B	G	VG	B	VB	B	G	B
VG	VB	VB	VB	B	G	G	B	VB	B	B	B
G	VG	VG	VG	B	G	B	B	VB	B	VB	VB
G	VG	G	G	B	G	VB	B	VB	VB	VG	VB
G	VG	B	B	B	B	VG	B	VB	VB	G	VB
G	VG	VB	B	B	B	G	B	VB	VB	B	VB
G	G	VG	G	B	B	B	B	VB	VB	VB	VB
G	G	G	G								

Table 12.26: Performance Culvert Fuzzy Rules

Chapter 13

Annex F

13.1 Safety Devices

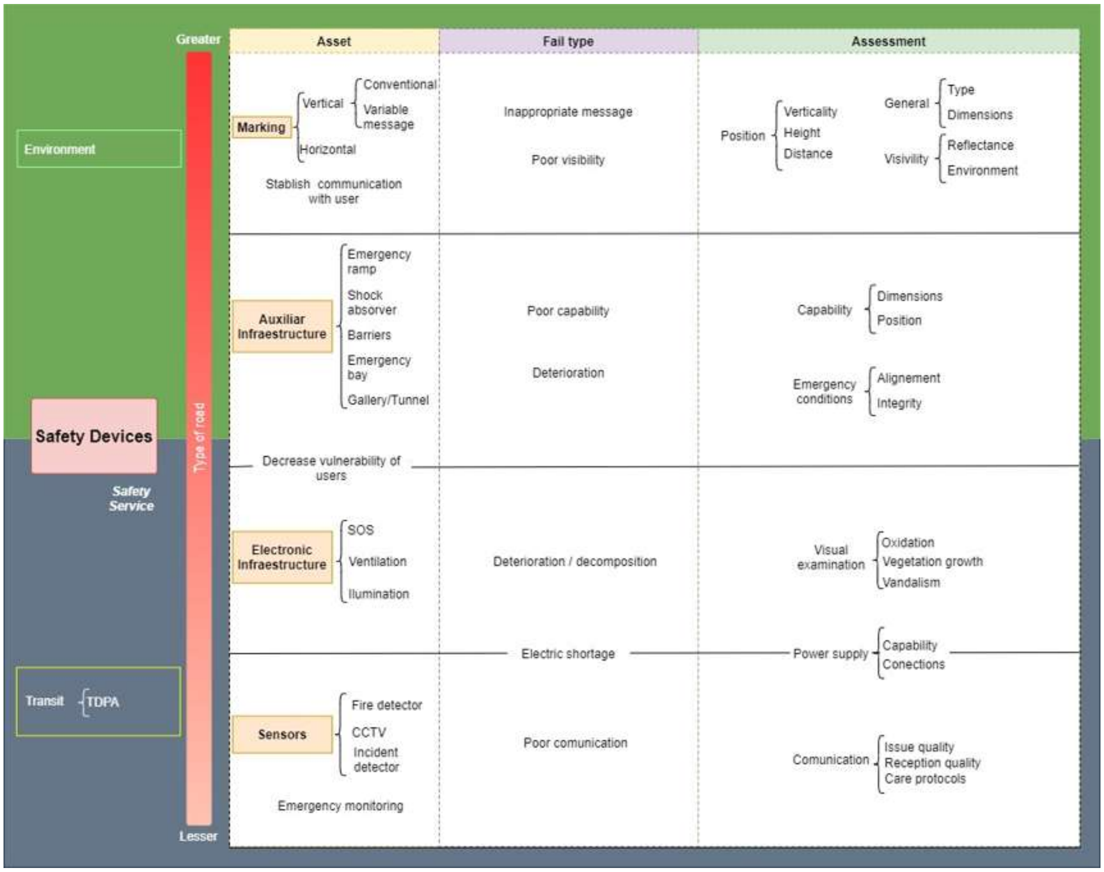


Figure 13.1: Safety Devices Evaluation Parameters

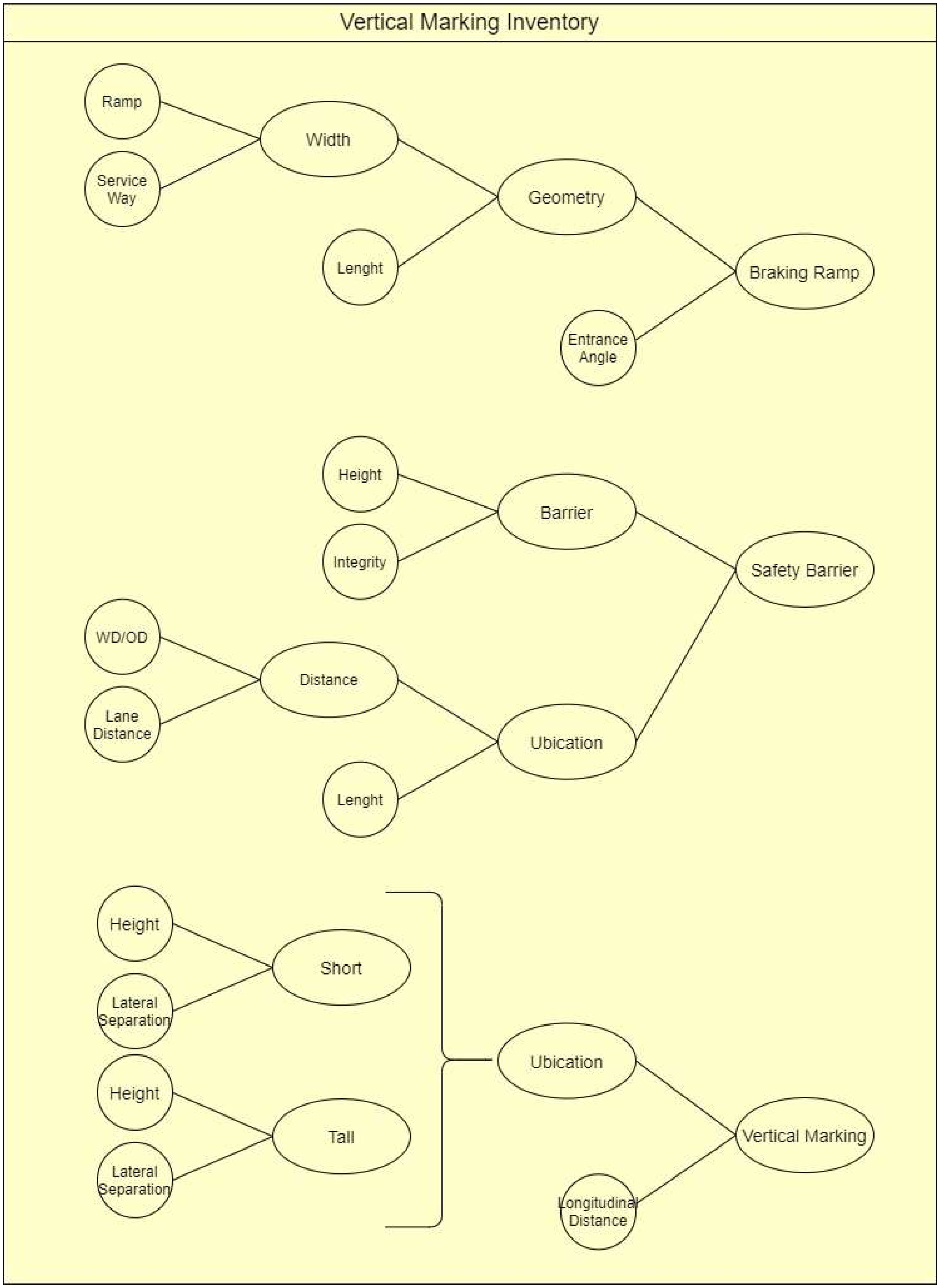


Figure 13.2: Safety Devices Inventory Model

Width

- Ramp. Land measure of ramp width (m)
- Service Way. Land measure of service way (m)

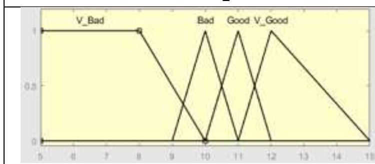
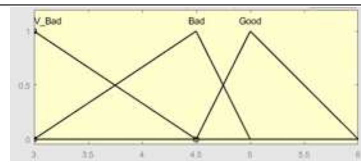
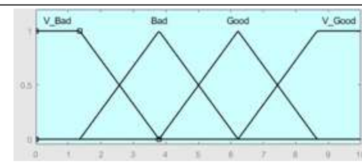
Ramp	Service Way	Width
		

Table 13.1: Width Braking Ramp Fuzzy Sets

Width						
Ramp	SWay			Ramp	SWay	
VG	G	VG		B	G	G
VG	B	B		B	B	G
VG	VB	B		B	VB	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 13.2: Width Braking Ramp Fuzzy Rules

Geometry

- Width. Ramp and service way width evaluation.
- Length. Percentage land length respect to length project.

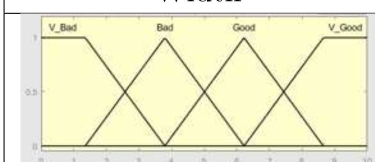
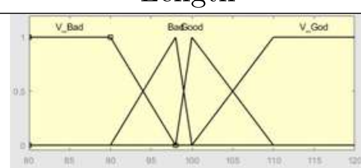
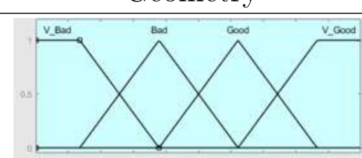
Width	Length	Geometry
		

Table 13.3: Geometry Braking Ramp Fuzzy Sets

Geometry						
Wdth	Lnght			Wdth	Lnght	
VG	VG	VG		B	VG	G
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 13.4: Geometry Braking Ramp Fuzzy Rules

Inventory braking ramp

- Geometry. Width and length evaluation.
- Entrance angle. Grades angle between ramp entrance and roadway.

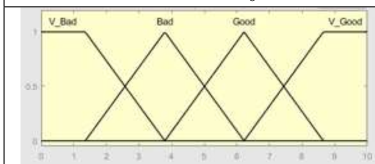
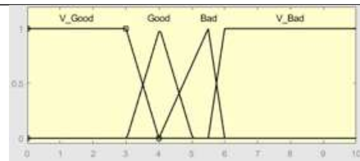
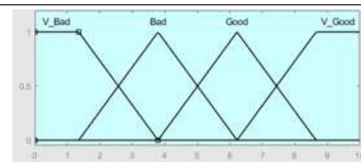
Geometry	Entrance Angle	Braking Ramp
		

Table 13.5: Braking Ramp Fuzzy Sets

Braking Ramp Fuzzy Rules						
Geo	E An			Geo	E An	
VG	VG	VG		B	VG	G
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	VG		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 13.6: Braking Ramp Fuzzy Rules

Barrier Geometry

- Height. Land height difference respect project height.
- Visual status evaluation.

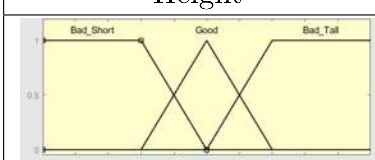
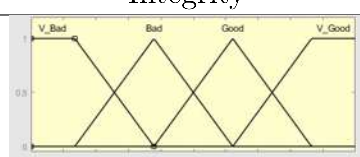
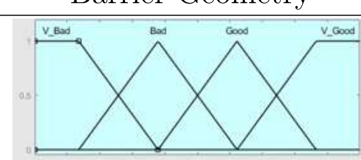
Height	Integrity	Barrier Geometry
		

Table 13.7: Barrier Geometry Fuzzy Sets

Barrier Geometry						
Hgh	Int			Hgh	Int	
B S	VG	B		G	B	B
B S	G	B		G	VB	B
B S	B	VB		B T	VG	G
B S	VB	VB		B T	G	G
G	VG	VG		B T	B	B
G	G	G		B T	VB	VB

Table 13.8: Barrier Fuzzy Rules

Barrier Distance

- Work distance/Object distance. Proportion of specified work distance and object distance.
- Lane distance. Distance between barrier and lane limit.

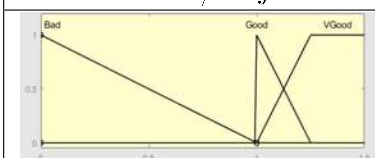
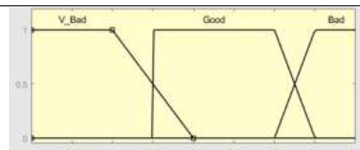
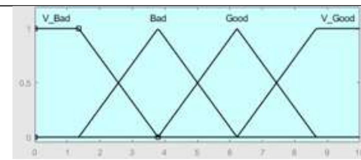
Work Dist/Obj Dist	Lane Distance	Distance
		

Table 13.9: Distance Barrier Fuzzy Sets

Distance		
O D	L D	
B	VB	VB
B	G	B
B	B	B
G	VB	VB
G	G	G
G	B	B
VG	VB	B
VG	G	VG
VG	B	B

Table 13.10: Distance Barrier Fuzzy Rules

Barrier Location

- Barrier distance. Work, object and lane distance evaluation.
- Length. Additional barrier length respect to object length. (m)

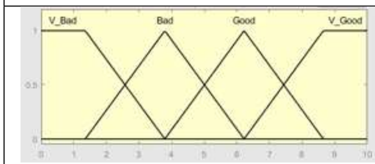
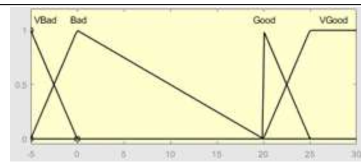
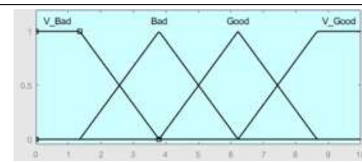
Distance	Length	Location
		

Table 13.11: Location Barrier Fuzzy Sets

Location						
Dst	Lngt			Dst	Lngt	
VG	VB	B		B	VB	VB
VG	B	B		B	B	B
VG	G	G		B	G	B
VG	VG	VG		B	VG	B
G	VB	B		VB	VB	VB
G	B	B		VB	B	VB
G	G	G		VB	G	VB
G	VG	VG		VB	VG	VB

Table 13.12: Location Barrier Fuzzy Rules

Safety Barrier

- Barrier geometry. Height and integrity barrier evaluation.
- Location. Distance and length barrier evaluation.

Safety Barrier						
Bar	Loc			Bar	Loc	
VG	VG	VG		B	VG	G
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 13.13: Safety Barrier Fuzzy Rules

Short vertical marking location.

- Height. Land measure height (m)
- Lateral separation. Land measure between sign and road. (m)

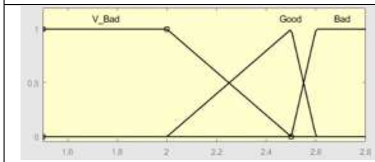
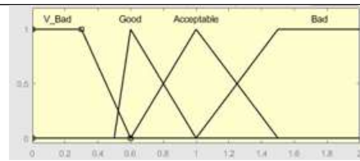
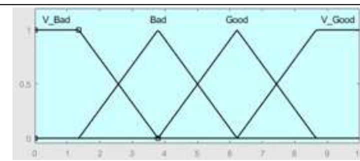
Height	Lateral Separation	Short Vertical marking
		

Table 13.14: Short Vertical Marking Fuzzy Sets.

Short Signs						
Hght	L Sep			Hght	L Sep	
B	B	B		G	G	VG
B	A	B		G	VB	VB
B	G	B		VB	B	B
B	VB	VB		VB	A	B
G	B	B		VB	G	B
G	A	G		VB	VB	VB

Table 13.15: Short Vertical Marking Fuzzy Rules.

Tall vertical marking location.

- Height. Land measure height (m).
- Lateral separation. Land measure between marking and road (m).

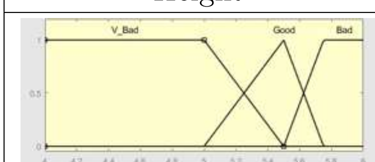
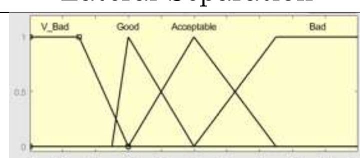
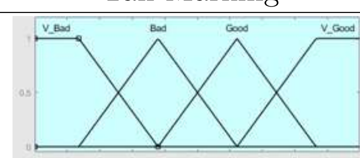
Height	Lateral Separation	Tall Marking
		

Table 13.16: Tall Location Vertical Marking Fuzzy Sets

Tall Location						
Hght	L Sep			Hght	L Sep	
B	B	B		G	G	VG
B	A	B		G	VB	VB
B	G	B		VB	B	VB
B	VB	VB		VB	A	VB
G	B	G		VB	G	VB
G	A	G		VB	VB	VB

Table 13.17: Tall Location Vertical Marking Fuzzy Rules.

Tall vertical marking location.

- Location. Height and lateral separation evaluation.
- Longitudinal distance. Relation between land distance and project distance of mark and point specified.

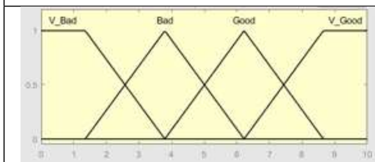
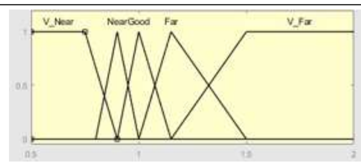
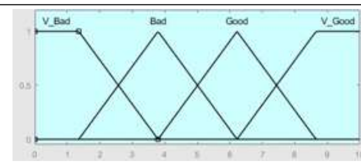
Location	Longitudinal Distance	Vertical Marking
		

Table 13.18: Vertical Marking Fuzzy Sets

Vertical Marking						
Ub	L D			Ub	L D	
VG	VF	B		B	VF	VB
VG	F	G		B	F	B
VG	G	VG		B	G	B
VG	N	G		B	N	B
VG	VN	B		B	VN	VB
G	VF	B		VB	VF	VB
G	F	B		VB	F	VB
G	G	G		VB	G	VB
G	N	B		VB	N	VB
G	VN	B		VB	VN	VB

Table 13.19: Inventory Vertical Marking Fuzzy Rules

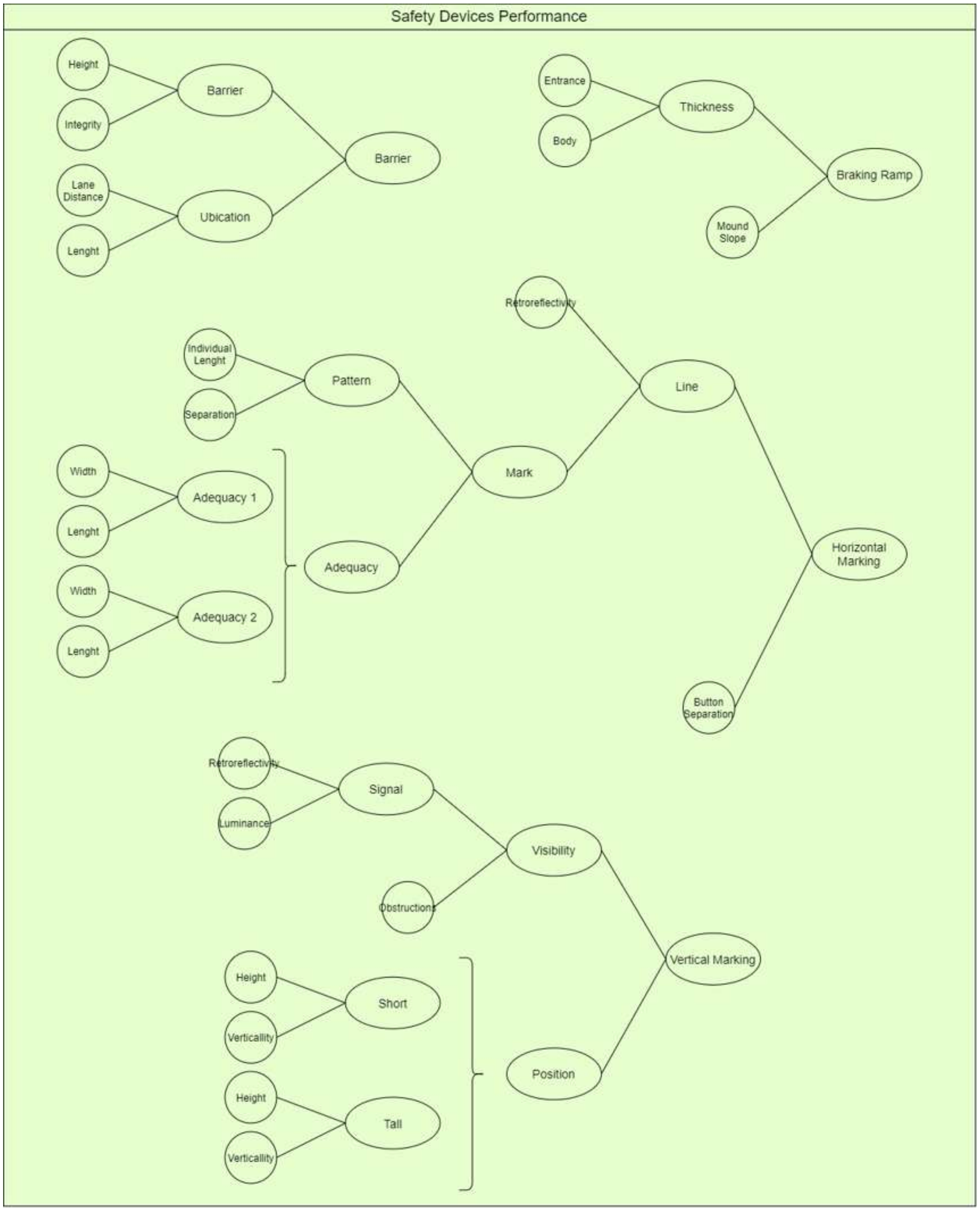


Figure 13.3: Safety Devices Performance Model

Barrier.

- Height. Difference between land height and project height (cm).
- Integrity. Visual evaluation, continuity, terminals, distance between elements...

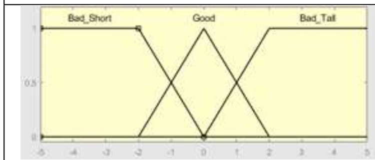
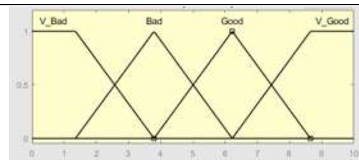
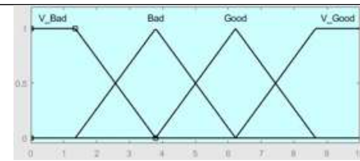
Height	Integrity	Barrier
		

Table 13.20: Barrier Fuzzy Sets

Barrier						
Hgt	Int			Hgt	Int	
B S	VG	B		G	B	B
B S	G	B		G	VB	B
B S	B	VB		B T	VG	G
B S	VB	VB		B T	G	G
G	VG	VG		B T	B	B
G	G	G		B T	VB	VB

Table 13.21: Performance Barrier Fuzzy Rules

Barrier location.

- Lane distance. Land distance between barrier and road lane (m)
- Length. Additional barrier length of object length (m).

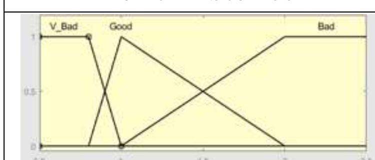
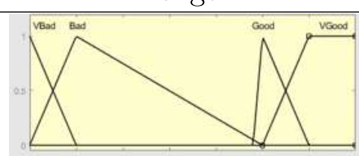
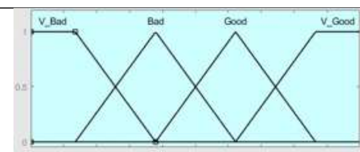
Lane Distance	Length	Location
		

Table 13.22: Barrier Location Fuzzy Sets

Location						
L D	Lng			L D	Lng	
VB	VB	VB		G	G	G
VB	B	VB		G	VG	VG
VB	G	B		B	VB	VB
VB	VG	B		B	B	B
G	VB	VB		B	G	B
G	B	B		B	VG	G

Table 13.23: Barrier Location Fuzzy Rules

Performance barrier.

- Barrier. Height and integrity evaluation.
- Location. Lane distance and barrier length evaluation.

Performance Barrier						
Bar	Loc			Bar	Loc	
VG	VG	VG		B	VG	G
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 13.24: Safety Barrier Fuzzy Rules

Material thickness.

- Entrance. Braking material thickness in entrance (cm)
- Body. Braking material thickness in body (cm)

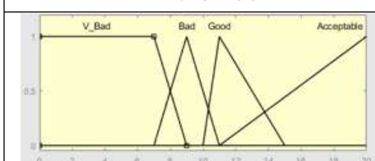
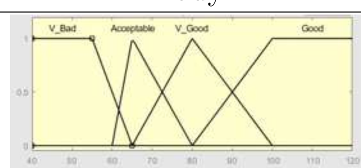
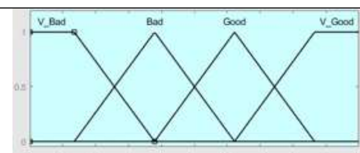
Entrance	Body	Thickness
		

Table 13.25: Braking Ramp Thickness Fuzzy Sets

Material Thickness						
Entrance	Body			Entrance	Body	
A	VG	G		B	VG	B
A	G	G		B	G	B
A	A	G		B	A	B
A	VB	B		B	VB	VB
G	VG	VG		VB	VG	B
G	G	G		VB	G	B
G	A	G		VB	A	B
G	VB	B		VB	VB	VB

Table 13.26: Braking Ramp Thickness Fuzzy Rules

Braking ramp performance.

- Thickness. Entrance and body braking material thickness evaluation.

- Mound Slope. Percentage slope of braking material mounds.

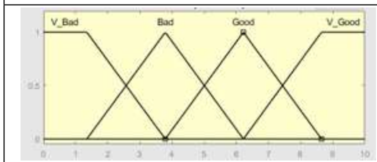
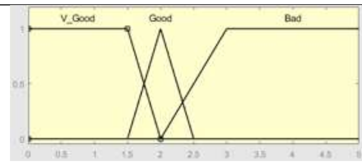
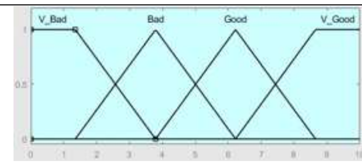
Thickness	Mound Slope	Braking Ramp
		

Table 13.27: Braking Ramp Fuzzy Sets

Performance						
Thickness	Mnd Slp			Thickness	Mnd Slp	
VG	VG	VG		B	VG	G
VG	G	G		B	G	B
VG	B	B		B	B	B
G	VG	VG		VB	VG	B
G	G	G		VB	G	VB
G	B	B		VB	B	VB

Table 13.28: Braking Ramp Fuzzy Rules

Pattern.

- Individual length. Length of elements of discontinuous line (m).
- Separation. Distance between elements of discontinuous line (m).

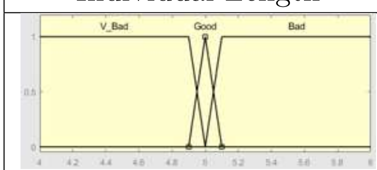
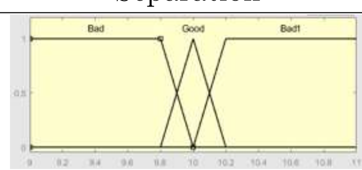
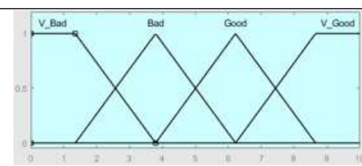
Individual Length	Separation	Pattern
		

Table 13.29: Horizontal Marks Pattern Fuzzy Sets

Pattern		
Individual Lenght	Separation	
B	B	B
B	G	B
B	B1	B
G	B	G
G	G	VG
G	B1	G
VB	B	B
VB	G	B
VB	B1	VB

Table 13.30: Horizontal Marks Pattern Fuzzy Rules.

Adequacy 1. Discontinuous line

- Width. Line width (cm).
- Length. Difference between land length and minimum length (m).

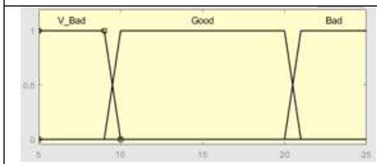
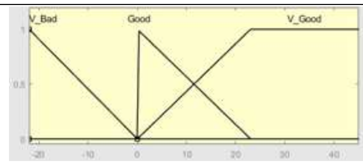
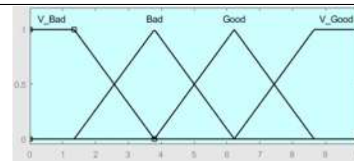
Width	Lenght	Adequacy 1
		

Table 13.31: Horizontal Marks Adequacy 1 Fuzzy Sets

Adequacy 2. Continuous line.

- Width. Line width (cm).
- Length. Difference between land length and minimum length (m).

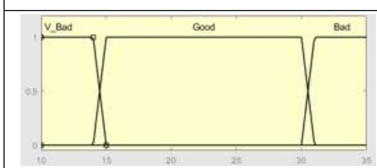
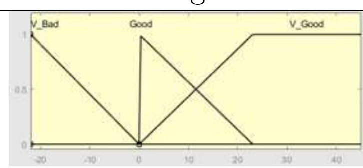
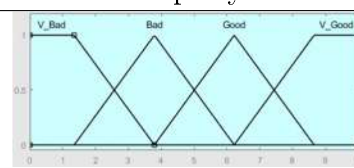
Width	Lenght	Adequacy 2
		

Table 13.32: Horizontal Marks Adequacy 2 Fuzzy Sets

Adequacy		
Width	Length	
VB	VB	VB
VB	G	B
VB	VG	B
G	VB	VB
G	G	G
G	VG	VG
B	VB	VB
B	G	G
B	VG	G

Table 13.33: Horizontal Marks Adequacy Fuzzy Rules

Horizontal Mark.

- Pattern. Individual Length and separation evaluation.
- Adequacy. Width and length evaluation.

Mark						
Pattern	Adqcy			Pattern	Adqcy	
VG	VG	VG		B	VG	B
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	VG		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 13.34: Horizontal Mark

Line.

- Mark. Pattern and adequacy evaluation
- Retroreflectivity. Difference between initial and land measure of line retroreflectivity.

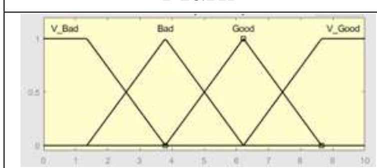
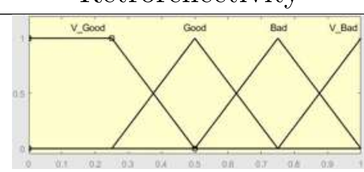
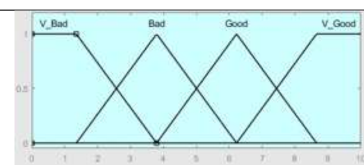
Mark	Retroreflectivity	Line
		

Table 13.35: Horizontal Marks Line Fuzzy Sets

Line						
Retroref	Mark			Retroref	Mark	
VG	VG	VG		B	VG	B
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 13.36: Horizontal Marks Line Fuzzy Rules

Horizontal Marking.

- Line. Retroreflectivity and mark evaluation.
- Button separation. Number of spaces between individual lines in discontinuous line without reflective buttons.

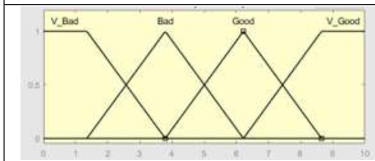
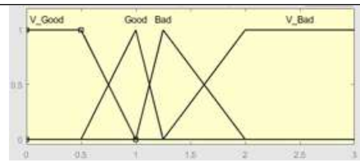
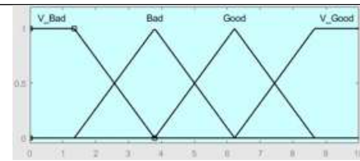
Line	Button Separation	Horizontal Marking
		

Table 13.37: Horizontal Marking Fuzzy Sets

Performance						
Line	Butt			Line	Butt	
B	VG	B		VG	VG	VG
B	G	B		VG	G	VG
B	B	B		VG	B	G
B	VB	VB		VG	VB	B
VB	VG	B		G	VG	VG
VB	G	B		G	G	G
VB	B	VB		G	B	G
VB	VB	VB		G	VB	B

Table 13.38: Horizontal Marking Fuzzy Rules

Vertical Marking Signal.

- Retroreflectivity. Difference between initial and land measure of line retroreflectivity.
- Luminance. Land measure luminance related to maximum value specified by color.

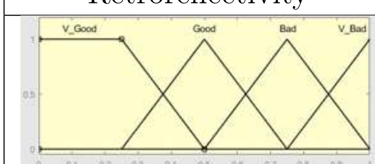
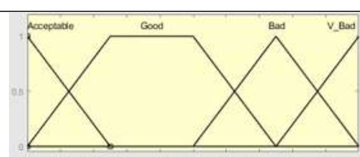
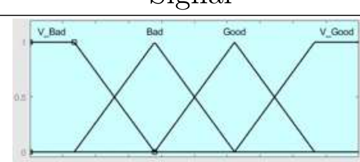
Retroreflectivity	Luminance	Signal
		

Table 13.39: Vertical Marking Signal Fuzzy Sets

Signal						
Ret	Lum			Ret	Lum	
VG	A	G		B	A	B
VG	G	VG		B	G	G
VG	B	G		B	B	B
VG	VB	B		B	VB	VB
G	A	G		VB	A	VB
G	G	G		VB	G	B
G	B	G		VB	B	VB
G	VB	B		VB	VB	VB

Table 13.40: Vertical Marking Signal Fuzzy Sets

Visibility

- Signal. Luminance and retroreflectivity evaluation
- Obstruction. Visual evaluation.

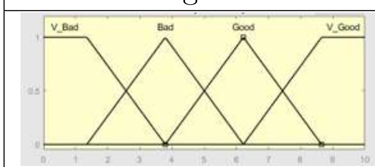
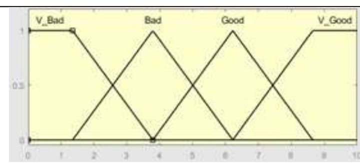
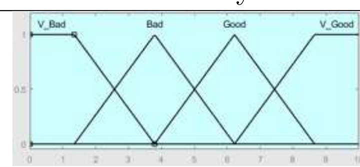
Signal	Obstruction	Visibility
		

Table 13.41: Vertical Marking Visibility Fuzzy Sets

Visibility						
S Vis.	Obst			S Vis.	Obst	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 13.42: Vertical Marking Visibility Fuzzy Rules

Vertical Marking Sign Position.

- Height. Land measure (m).
- Verticality. Grades angle respect horizontal.

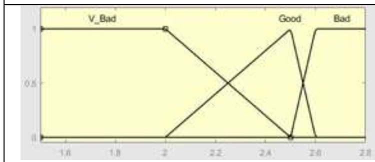
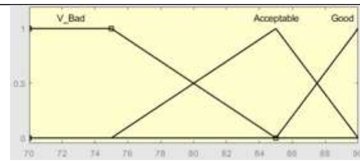
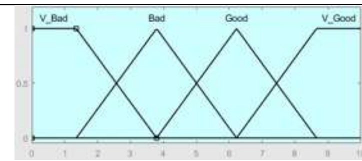
Height	Verticality	Short Position
		

Table 13.43: Vertical Marking Short Position Fuzzy Sets

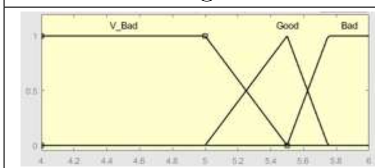
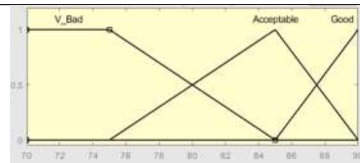
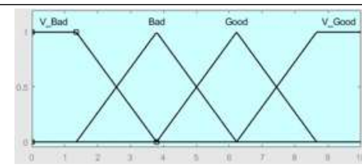
Height	Verticality	Short Position
		

Table 13.44: Vertical Marking Tall Position Fuzzy Sets

Position						
Short				Tall		
Hgh	Vert			Hgh	Vert	
VB	VB	VB		VB	VB	VB
VB	A	B		VB	A	VB
VB	G	B		VB	G	VB
G	VB	B		G	VB	B
G	A	G		G	A	G
G	G	VG		G	G	VG
B	VB	B		B	VB	B
B	A	B		B	A	B
B	G	B		B	G	B

Table 13.45: Vertical Marking Position Fuzzy Rules

Vertical Marking Performance.

- Visibility. Sign and obstruction evaluation.
- Position. Height and verticality evaluation

Vertical Marking Performance						
Vis	Pos			Vis	Pos	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 13.46: Vertical Marking Performance Fuzzy Rules

Chapter 14

Annex G

14.1 Geotechnical Assets Rock Cuttings.

14.1.1 Sedimentary Cutting.

Sedimentary Cutting Inventory.

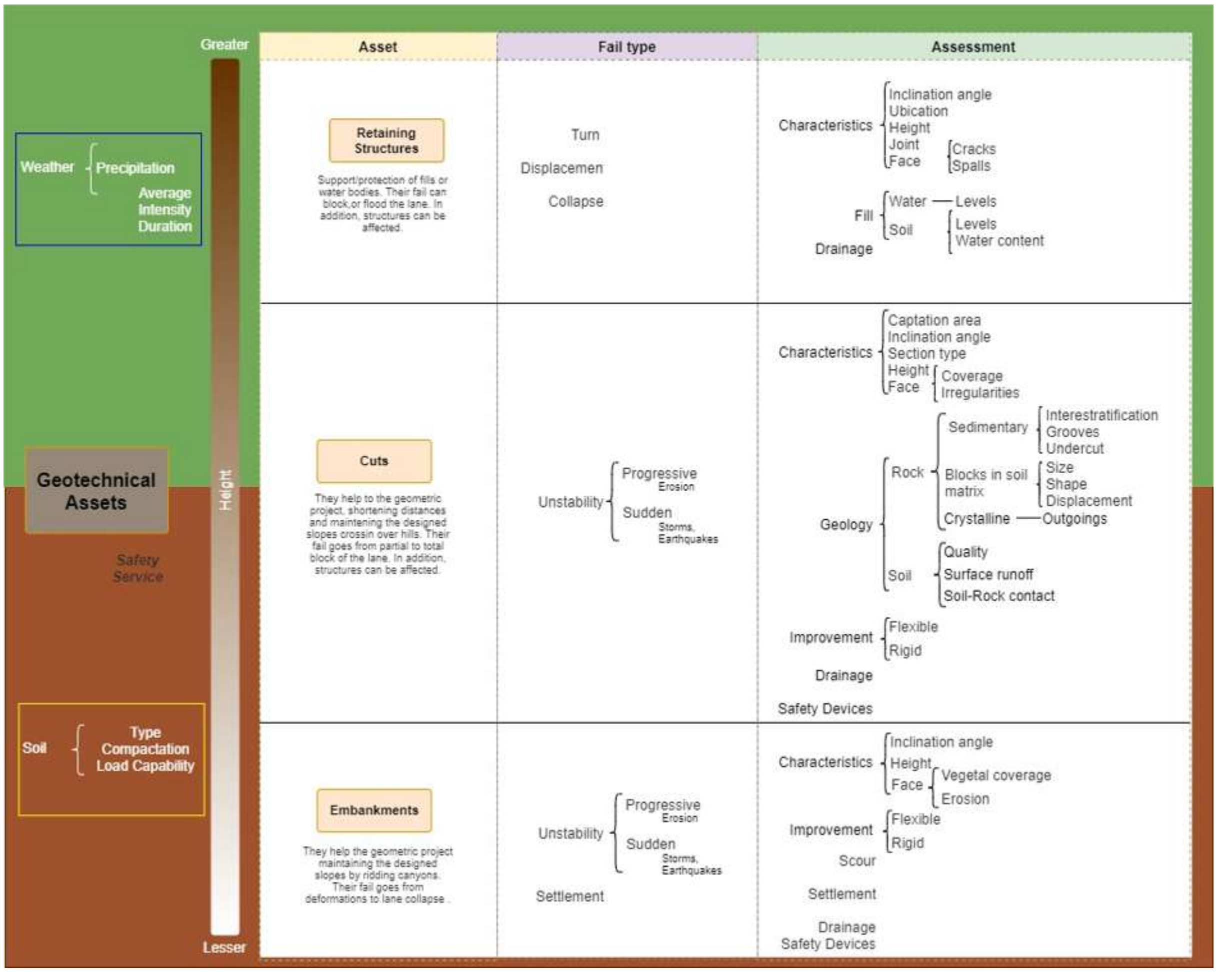


Figure 14.1: Sedimentary Cutting Inventory Model

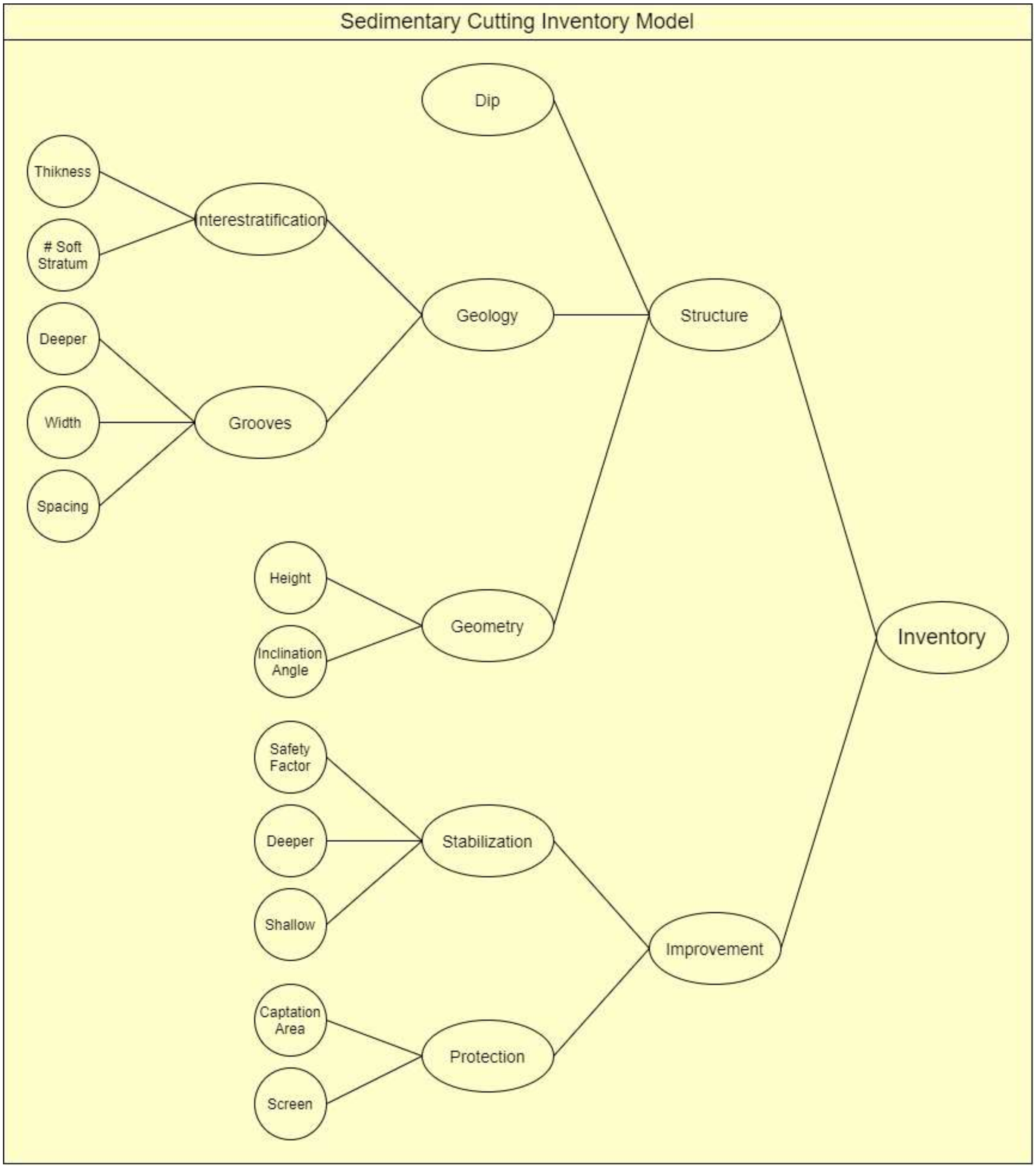


Figure 14.2: Sedimentary Cutting Inventory Model

Inter-stratification.

- Thickness. Land measure (cm)
- Soft stratum. Number of soft stratum in the cutting body

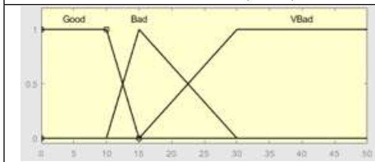
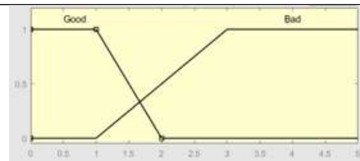
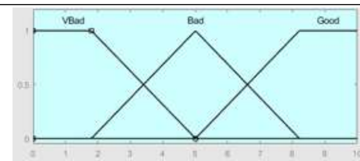
Thickness (cm)	Soft Stratum	Inter-stratification
		

Table 14.1: Inter-stratification Fuzzy Sets

Inter-stratification										
T	S S			T	S S			T	S S	
G	G	G		B	G	B		VB	G	B
G	B	G		B	B	B		VB	B	VB

Table 14.2: Inter-stratification Fuzzy Rules

Grooves.

- Deeper. Land measure (cm)
- Width. Land measure (cm)
- Spacing. Visual evaluation, distance between grooves.

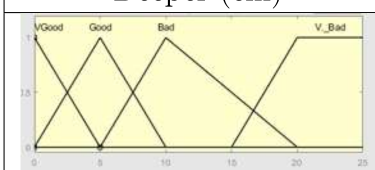
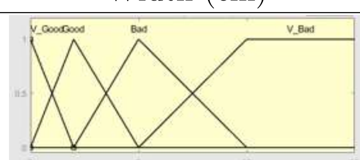
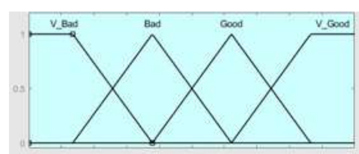
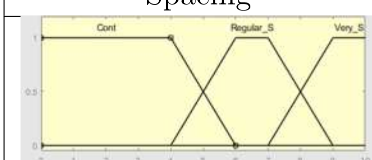
Deeper (cm)	Width (cm)	Grooves
		
Spacing		
		

Table 14.3: Grooves Fuzzy Sets

Grooves														
D	W	S			D	W	S			D	W	S	
VG	VG	VS	VG		G	G	RS	G		B	B	C	B
VG	VG	RS	VG		G	G	C	B		B	VB	VS	B
VG	VG	C	VG		G	B	VS	G		B	VB	RS	B
VG	G	VS	VG		G	B	RS	B		B	VB	C	VB
VG	G	RS	VG		G	B	C	B		VB	VG	VS	VG
VG	G	C	VG		G	VB	VS	B		VB	VG	RS	VG
VG	B	VS	VG		G	VB	RS	B		VB	VG	C	VG
VG	B	RS	VG		G	VB	C	VB		VB	G	VS	B
VG	B	C	VG		B	VG	VS	VG		VB	G	RS	B
VG	VB	VS	VG		B	VG	RS	VG		VB	G	C	VB
VG	VB	RS	VG		B	VG	C	VG		VB	B	VS	B
VG	VB	C	VG		B	G	VS	G		VB	B	RS	B
G	VG	VS	VG		B	G	RS	G		VB	B	C	VB
G	VG	RS	VG		B	G	C	B		VB	VB	VS	VB
G	VG	C	VG		B	B	VS	B		VB	VB	RS	VB
G	G	VS	G		B	B	RS	B		VB	VB	C	VB

Table 14.4: Grooves Fuzzy Rules

Geology.

- Inter-stratification. Thickness and number of soft stratum evaluation.
- Grooves. Deeper, width and spacing evaluation

Geology										
Inter	Groo			Inter	Groo			Inter	Groo	
G	VG	VG		B	G	G		VB	B	B
B	VG	G		VB	G	B		G	VB	B
VB	VG	B		G	B	B		B	VB	VB
G	G	G		B	B	B		VB	VB	VB

Table 14.5: Geology Fuzzy Rule

Geometry.

- Height. Project measure (m).
- Inclination angle. Grades angle of body cutting.

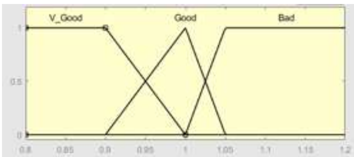
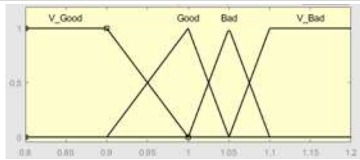
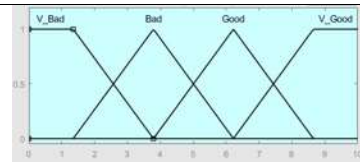
Height (m)	Inclination angle (°)	Geometry
		

Table 14.6: Geometry Fuzzy Sets

Geometry										
H	I A			H	I A			H	I A	
L	G	VG		M	B	B		VH	G	G
L	B	G		H	G	G		VH	B	VB
M	G	VG		H	B	B				

Table 14.7: Geometry Fuzzy functions

Structure.

- Geology. Inter-stratification and grooves evaluation.
- Geometry. Height and inclination angle evaluation.

Structure 1 is used when the cutting dip towards road.
Structure 2 is used when the cutting dip towards land.

Road Direction Dip														
Structure 1														
Gl	Gm			Gl	Gm			Gl	Gm			Gl	Gm	
VG	VG	G		G	VG	G		B	VG	B		VB	VG	VB
VG	G	G		G	G	G		B	G	B		VB	G	VB
VG	B	B		G	B	B		B	B	VB		VB	B	VB
VG	VB	B		G	VB	VB		B	VB	VB		VB	VB	VB

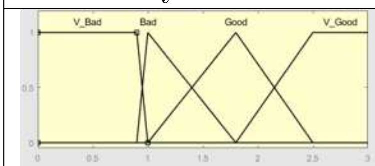
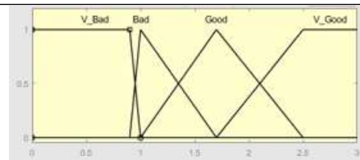
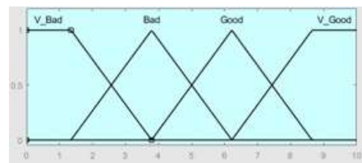
Table 14.8: Structure 1 Fuzzy Rules

Land Direction Dip														
Structure 2														
Gl	Gm			Gl	Gm			Gl	Gm			Gl	Gm	
VG	VG	VG		G	VG	VG		B	VG	G		VB	VG	G
VG	G	VG		G	G	G		B	G	G		VB	G	G
VG	B	G		G	B	G		B	B	G		VB	B	B
VG	VB	B		G	VB	B		B	VB	B		VB	VB	VB

Table 14.9: Structure 2 Fuzzy Rules

Improvement.

- Safety factor 1. Improvement works include deeper and shallow stabilization.
- Safety factor 2. Improvement works include deeper stabilization.
- Safety factor 3. Improvement works include shallow stabilization.
- Safety factor 4. Cutting does not requires the stabilization works.
- Caption area. Percentage between project or land measure related to safety caption area.

<table>
<tr><td>Safety Factor 1</td><td>Safety Factor 2</td><td>Improvement</td></tr>
<tr><td></td><td></td><td rowspan="3"></td></tr>
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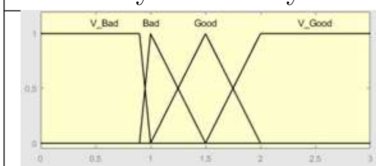
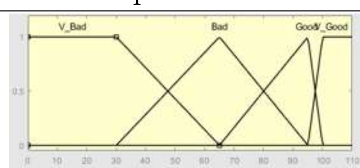
<tr><td></td><td></td></tr>
</table>

Table 14.10: Improvement Fuzzy Sets

Improvement 1-2-3-4											
S F	C A		S F	C A		S F	C A		S F	C A	
VG	VG	VG	G	VG	VG	B	VG	B	VB	VG	B
VG	G	VG	G	G	G	B	G	B	VB	G	VB
VG	B	G	G	B	B	B	B	B	VB	B	VB
VG	VB	B	G	VB	B	B	VB	VB	VB	VB	VB

Table 14.11: Improvement Fuzzy Rules

Inventory.

- Structure. Geology, geometry and dip evaluation.
- Improvement. Stabilization and road protection evaluation.

Inventory											
St	Im		St	Im		St	Im		St	Im	
VG	VG	VG	G	VG	VG	B	VG	G	VB	VG	G
VG	G	VG	G	G	G	B	G	G	VB	G	G
VG	B	G	G	B	B	B	B	B	VB	B	VB
VG	VB	B	G	VB	B	B	VB	VB	VB	VB	VB

Table 14.12: Inventory Fuzzy Rules

Sedimentary Cutting Performance.

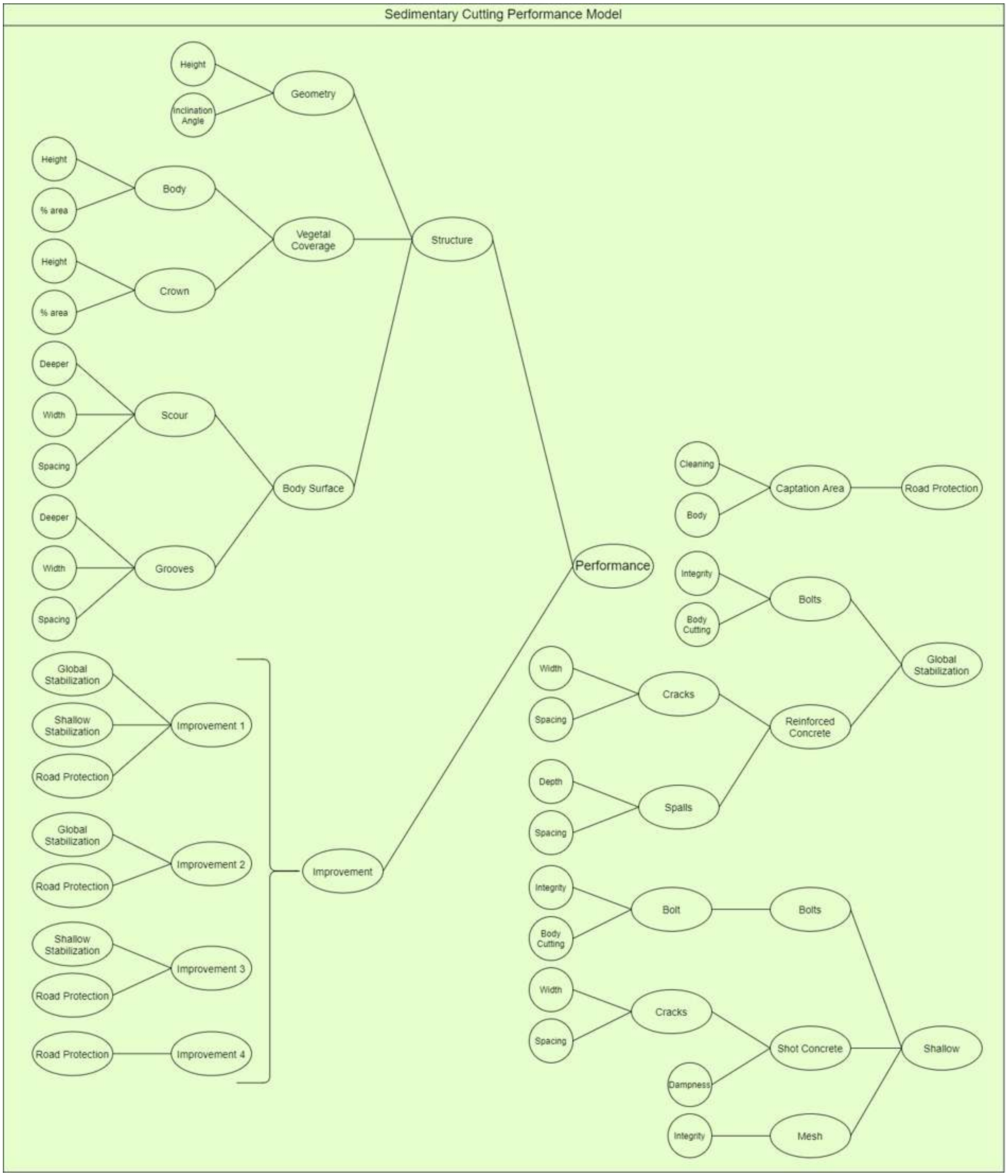


Figure 14.3: Sedimentary Cutting Performance Model

Geometry.

- Height. Land height change related to project or inventory measure.

- Inclination angle. Land change related to project or inventory value.

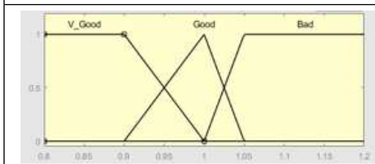
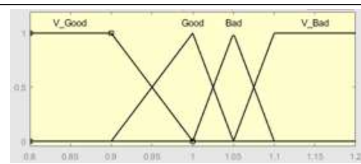
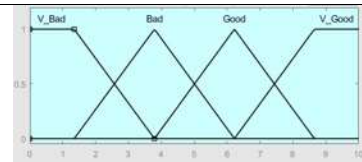
Height	Inclination Angle	Geometry
		

Table 14.13: Performance Geometry Fuzzy Sets

Geometry										
H	I A			H	I A			H	I A	
VG	VG	VG		G	VG	VG		B	VG	G
VG	G	VG		G	G	G		B	G	B
VG	B	G		G	B	B		B	B	VB
VG	VB	B		G	VB	VB		B	VB	VB

Table 14.14: Geometry Fuzzy Rules

Vegetation.

- Height. Average or common vegetation height (m).
- Area. Percentage of total area with vegetation.

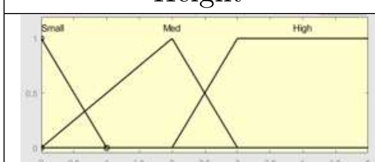
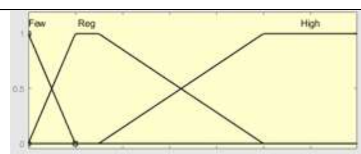
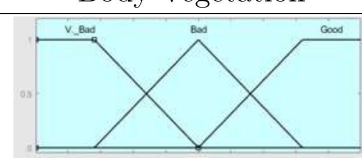
Height	Area	Body Vegetation
		

Table 14.15: Body Vegetation Fuzzy Sets

Body Vegetation										
H	A			H	A			H	A	
S	F	G		M	F	G		H	F	G
S	R	G		M	R	B		H	R	VB
S	H	G		M	H	V.B.		H	H	VB

Table 14.16: Body Vegetation Fuzzy Rules

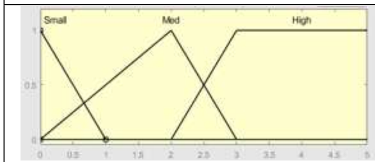
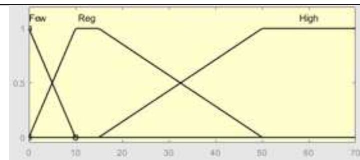
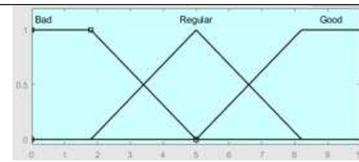
Height	Area	Crown Vegetation
		

Table 14.17: Crown Vegetation Fuzzy Sets

Crown Vegetation		
Height	% area	
S	F	B
S	R	B
S	H	B
M	F	B
M	R	R
M	H	G
H	F	B
H	R	G
H	H	G

Table 14.18: Crown Vegetation Fuzzy Rules

Vegetal Coverage.

- Body Vegetation. Height and area evaluation.
- Crown Vegetation. Height and area evaluation.

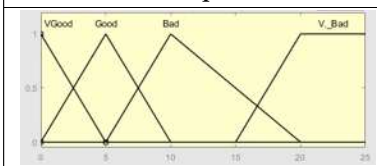
Vegetal Cov		
Body	Crown	
G	G	VG
G	R	G
G	B	B
B	G	B
B	R	B
B	B	VB
VB	G	VB
VB	R	VB
VB	B	VB

Table 14.19: Vegetal Coverage Fuzzy Rules

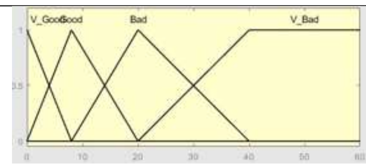
Scour/Grooves.

- Deeper. Land measure (cm).
- Width. Land measure (cm).
- Spacing. Visual evaluation.

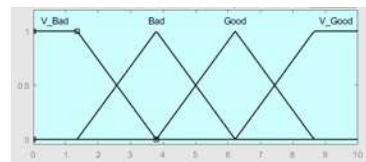
Deeper



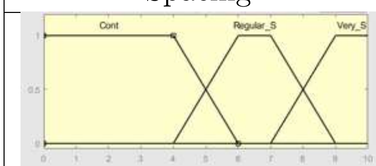
Width Scour



Scour/Grooves



Spacing



Width Grooves

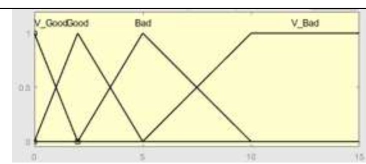


Table 14.20: Scour/Grooves Fuzzy Sets

Scour/Grooves															
Deep	Width	Spac		Deep	Width	Spac		Deep	Width	Spac		Deep	Width	Spac	
VG	VG	VS	VG	G	VG	VS	VG	B	VG	VS	VG	VB	VG	VS	VG
VG	VG	RS	VG	G	VG	RS	VG	B	VG	RS	VG	VB	VG	RS	VG
VG	VG	Cont	VG	G	VG	Cont	VG	B	VG	Cont	VG	VB	VG	Cont	VG
VG	G	VS	VG	G	G	VS	G	B	G	VS	G	VB	G	VS	B
VG	G	RS	VG	G	G	RS	G	B	G	RS	G	VB	G	RS	B
VG	G	Cont	VG	G	G	Cont	B	B	G	Cont	B	VB	G	Cont	VB
VG	B	VS	VG	G	B	VS	G	B	B	VS	B	VB	B	VS	B
VG	B	RS	VG	G	B	RS	B	B	B	RS	B	VB	B	RS	B
VG	B	Cont	VG	G	B	Cont	B	B	B	Cont	B	VB	B	Cont	VB
VG	VB	VS	VG	G	VB	VS	B	B	VB	VS	B	VB	VB	VS	VB
VG	VB	RS	VG	G	VB	RS	B	B	VB	RS	B	VB	VB	RS	VB
VG	VB	Cont	VG	G	VB	Cont	VB	B	VB	Cont	VB	VB	VB	Cont	VB

Table 14.21: Scour and grooves fuzzy rules

Body Surface.

- Scour. Deep, width and spacing evaluation.
- Grooves. Deep, width and spacing evaluation.

Body surface					
Scour	Grooves		Scour	Grooves	
VG	VG	VG	B	VG	B
VG	G	VG	B	G	B
VG	B	B	B	B	B
VG	VB	B	B	VB	VB
G	VG	G	VB	VG	B
G	G	G	VB	G	VB
G	B	B	VB	B	VB
G	VB	B	VB	VB	VB

Table 14.22: Body surface fuzzy rules

Structure.

- Geometry. Height and inclination angle evaluation.
- Body. Grooves and scour evaluation.
- Vegetal coverage. Height and area evaluation.

Structure															
Geom	Body	V Cov		Geom	Body	V Cov		Geom	Body	V Cov		Geom	Body	V Cov	
VG	VG	VG	VG	G	VG	VG	VG	B	VG	VG	G	VB	VG	VG	G
VG	VG	G	VG	G	VG	G	VG	B	VG	G	G	VB	VG	G	B
VG	VG	B	G	G	VG	B	G	B	VG	B	B	VB	VG	B	B
VG	VG	VB	B	G	VG	VB	B	B	VG	VB	B	VB	VG	VB	B
VG	G	VG	G	G	G	VG	G	B	G	VG	G	VB	G	VG	G
VG	G	G	G	G	G	G	G	B	G	G	G	VB	G	G	B
VG	G	B	G	G	G	B	G	B	G	B	B	VB	G	B	B
VG	G	VB	B	G	G	VB	B	B	G	VB	B	VB	G	VB	B
VG	B	VG	B	G	B	VG	B	B	B	VG	B	VB	B	VG	B
VG	B	G	B	G	B	G	B	B	B	G	B	VB	B	G	VB
VG	B	B	B	G	B	B	B	B	B	B	B	VB	B	B	VB
VG	B	VB	B	G	B	VB	B	B	B	VB	B	VB	B	VB	VB
VG	VB	VG	B	G	VB	VG	B	B	VB	VG	B	VB	VB	VG	VB
VG	VB	G	B	G	VB	G	B	B	VB	G	VB	VB	VB	G	VB
VG	VB	B	VB	G	VB	B	VB	B	VB	B	VB	VB	VB	B	VB
VG	VB	VB	VB	G	VB	VB	VB	B	VB	VB	VB	VB	VB	VB	VB

Table 14.23: Structure fuzzy rules

Qualification		Very Good Qualification from 7.4 to 10	Good Qualification from 5 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad qualification from 0 a 2.56
Bolts	Integrity	Head and backing plate are firmely and in very good condition. No or just perceptible deformations, corrosion, or spalls.	Head and backing plate are firmely and in good condition. Minor deformations, corrosion, or spalls.	Head and backing plate are firmely. They are deteriorated. Deformation, corrosion or chipping. Backing plate deformed or section area reduced.	There are not head and/or backing plate. Head or backing plate are not firmely. Head completely deteriorated. Backing plate destroyed or with very significative reduction of section area.
	Body Slope	Surrounding backing plate surface is in very good condition. There is not visible fracturing or undercut.	Surrounding backing plate surface in good condition. Fractures or undercut begins to show, slight fractures are observed.	Surrounding backing plate surface in bad condition. Fractures or undercut width <3mm. There are scour in less of 25% of backing plate perimeter.	Surrounding backing plate surface in very bad condition. Cracking in multiple directions. Cracking width >3mm. Greater of 25% of backing plate perimeter is scoured.
Shot concrete	Infiltration	No visible infiltrations or they are just noticeable.	Focused area with low infiltration.	There is a high infiltration or many small to medium infiltration areas. They are very noticeable.	Infiltration has beed caused shot concret peeled.
Mesh	Integrity	Anchors and mesh body in very good condition. Anchors without corrosion or scour. Body mesh without visible deterioration.	Anchors and mesh body in good condition. Anchors without corrosion or scour. Body mesh with low deterioration (corrosion or focused mesh tears).	Anchors and mesh body in bad condition. Anchors with low to medium corrosion or scour. Body mesh withgeneralized deterioration (corrosion or focused mesh tears).	Anchors and mesh body in very bad condition. Anchors with low to medium corrosion or scour. Body mesh with generalized deterioration (corrosion or big mesh tears).
Road Protection	Caption surface	Cleaning caption surface. There are not fall material or debris accumulation.	Small to medium falling material or debris acumulation in less of 20% of caption surface.	Small to big falling material or debris acumulation in less of 50% of caption surface.	Medium to big falling material or debris acumulation greater to 50% of caption surface.
	Screen	Base and body screen in very good condition. There are not scour, or discontinuities.	Base and screen body in good condition. Low scour. There are not discontinuities. Small screen inclination.	Base and screen body in bad condition. Moderate scour. Small discontinuities. Moderated screen inclinations.	Base and screen body in very bad condition. Big scour surfaces. There are noticeable discontinuities. Big screen inclinations.

Table 14.24: Performance Improvement descriptions

Bolt.

- Integrity. Visual evaluation.
- Body Cutting. Visual evaluation

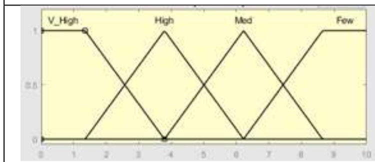
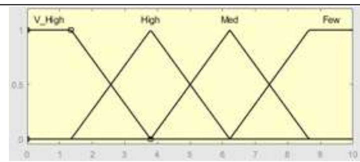
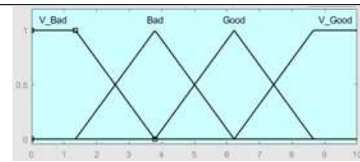
Integrity	Body Cutting	Bolt
		

Table 14.25: Bolt Fuzzy Sets

Bolts						
Integ	B cut			Integ	B cut	
F	F	VG		H	F	G
F	M	G		H	M	VB
F	H	B		H	H	VB
F	VH	VB		H	VH	VB
M	F	G		VH	F	VB
M	M	G		VH	M	VB
M	H	VB		VH	H	VB
M	VH	VB		VH	VH	VB

Table 14.26: Bolt Fuzzy Rules

Cracking/Spalls.

- Spacing. Visual evaluation.
- Width. Land measure (mm)

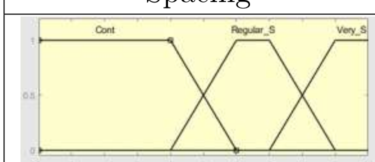
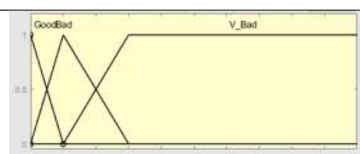
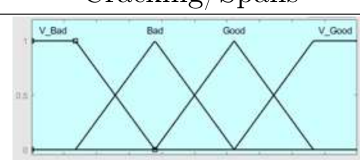
Spacing	Width	Cracking/Spalls
		

Table 14.27: Cracking/Spalls Fuzzy Sets

Cracks				Spalls		
Width	Spacing			Depth	Spacing	
G	VS	VG		G	VS	VG
G	RS	VG		G	RS	VG
G	Cont	G		G	Cont	VG
B	VS	G		B	VS	G
B	RS	B		B	RS	B
B	Cont	B		B	Cont	B
VB	VS	B		VB	VS	B
VB	RS	VB		VB	RS	VB
VB	Cont	VB		VB	Cont	VB

Table 14.28: Cracking and Spalls Fuzzy Rules

Reinforced Concrete.

- Cracking. Width and Spacing evaluation.
- Spalls. Width and Spacing evaluation. Land measure (mm)

Reinforced Concrete						
Crack	Spalls			Crack	Spalls	
VG	VG	VG		B	VG	G
VG	G	G		B	G	B
VG	B	G		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	G		VB	B	B
G	VB	B		VB	VB	VB

Table 14.29: Reinforced concrete Fuzzy Rules

Global Stabilization System.

- Bolts. Integrity and scour evaluation
- Reinforced concrete. Cracking and spalls evaluation.

Global Stabilization						
Bolts	R Conc			Bolts	R Conc	
VG	VG	VG		B	VG	G
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.30: Global stabilization

Shot Concrete.

- Cracking. Width and spacing evaluation.
- Dampness. Visual evaluation.

Shot Concrete						
Cracks	Damp			Cracks	Damp	
VG	VG	VG		B	VG	B
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	VG		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 14.31: Shot concrete

Shallow Stabilization 1.

- Bolts. Integrity and Body Cutting evaluation.
- Shot Concrete. Cracking and dampness evaluation.

Shallow S1						
Bolts	S Conc			Bolts	S Conc	
VG	VG	VG		B	VG	G
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.32: Shallow stabilization 1

Shallow Stabilization 2.

- Bolts. Integrity and Body Cutting evaluation.
- Mesh. Visual evaluation.

Shallow S2						
Bolts	Mesh			Bolts	Mesh	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	G		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	VB
G	B	G		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.33: Shallow Stabilization 2

Improvement 1.

- Global Stabilization.
- Shallow Stabilization.
- Road Protection.

Improvement 1																		
G S	S S	R P			G S	S S	R P			G S	S S	R P			G S	S S	R P	
VG	VG	VG	VG		G	VG	VG	G		B	VG	VG	B		VB	VG	VG	B
VG	VG	G	VG		G	VG	G	G		B	VG	G	B		VB	VG	G	B
VG	VG	B	G		G	VG	B	B		B	VG	B	B		VB	VG	B	VB
VG	VG	VB	B		G	VG	VB	B		B	VG	VB	VB		VB	VG	VB	VB
VG	G	VG	VG		G	G	VG	G		B	G	VG	B		VB	G	VG	B
VG	G	G	G		G	G	G	G		B	G	G	B		VB	G	G	B
VG	G	B	B		G	G	B	B		B	G	B	B		VB	G	B	VB
VG	G	VB	B		G	G	VB	B		B	G	VB	VB		VB	G	VB	VB
VG	B	VG	G		G	B	VG	G		B	B	VG	B		VB	B	VG	B
VG	B	G	G		G	B	G	G		B	B	G	B		VB	B	G	VB
VG	B	B	B		G	B	B	B		B	B	B	B		VB	B	B	VB
VG	B	VB	B		G	B	VB	B		B	B	VB	VB		VB	B	VB	VB
VG	VB	VG	B		G	VB	VG	B		B	VB	VG	B		VB	VB	VG	VB
VG	VB	G	B		G	VB	G	B		B	VB	G	B		VB	VB	G	VB
VG	VB	B	B		G	VB	B	VB		B	VB	B	VB		VB	VB	B	VB
VG	VB	VB	VB		G	VB	VB	VB		B	VB	VB	VB		VB	VB	VB	VB

Table 14.34: Improvement 1.

Improvement 2.

- Global Stabilization.
- Road Protection.

Improvement 2						
G Stab	R Prot			G Stab	R Prot	
VG	VG	VG		B	VG	G
VG	G	VG		B	G	B
VG	B	G		B	B	B
VG	VB	B		B	VB	B
G	VG	G		VB	VG	B
G	G	G		VB	G	VB
G	B	G		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.35: Improvement 2.

Improvement 3.

- Shallow Stabilization.
- Road Protection.

Improvement 3						
S Stab	R Prot			S Stab	R Prot	
VG	VG	VG		B	VG	G
VG	G	VG		B	G	B
VG	B	G		B	B	B
VG	VB	G		B	VB	VB
G	VG	VG		VB	VG	B
G	G	G		VB	G	B
G	B	G		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.36: Improvement 3

Performance.

- Structure. Geometry, body and vegetal coverage evaluation.
- Improvement. Stabilization and Road Protection evaluation.

Performance						
Str	Imp			Str	Imp	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	VG		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.37: Performance Fuzzy Rules

14.1.2 Crystalline Cutting

Crystalline Cutting Inventory

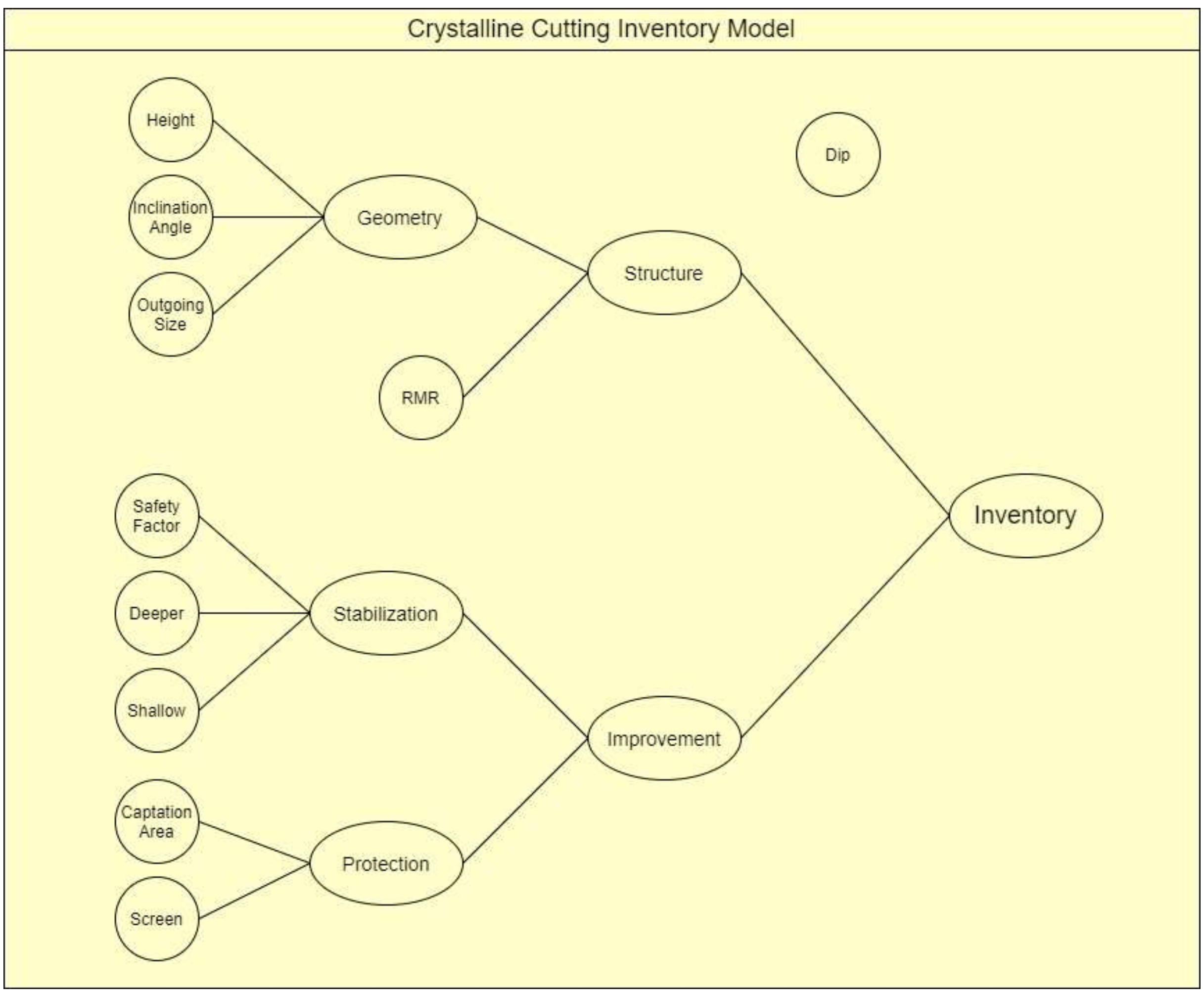


Figure 14.4: Crystalline Cutting Inventory Model

Geometry.

- Height. Project measure (m).
- Inclination Angle. Grades angle measure.
- Outgoing Size. Land measure (m).

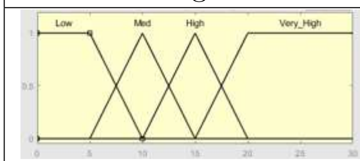
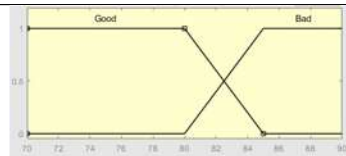
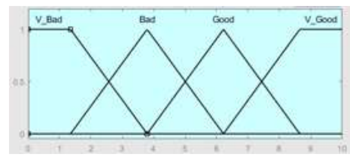
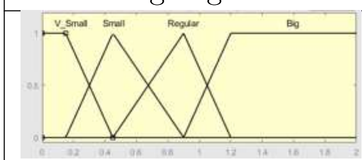
Height	Inclination Angle	Geometry
		
Outgoing Size		
		

Table 14.38: Crystalline Cutting Geometry Fuzzy Sets

Geometry								
Hght	Inc An	O Size			Hght	Inc An	O Size	
L	G	VS	VG		H	G	VS	VG
L	G	S	VG		H	G	S	G
L	G	R	G		H	G	R	G
L	G	B	G		H	G	B	B
L	B	VS	G		H	B	VS	B
L	B	S	G		H	B	S	B
L	B	R	G		H	B	R	B
L	B	B	G		H	B	B	VB
M	G	VS	VG		VH	G	VS	G
M	G	S	G		VH	G	S	B
M	G	R	G		VH	G	R	B
M	G	B	G		VH	G	B	B
M	B	VS	G		VH	B	VS	B
M	B	S	G		VH	B	S	B
M	B	R	G		VH	B	R	VB
M	B	B	G		VH	B	B	VB

Table 14.39: Crystalline Cutting Geometry Fuzzy Rules

Structure.

- Geometry. Height, inclination angle, and outgoing size evaluation.
- RMR. Bieniawski land evaluation.

Structure 1 is used when the cutting dip towards road.
Structure 2 is used when the cutting dip towards land.

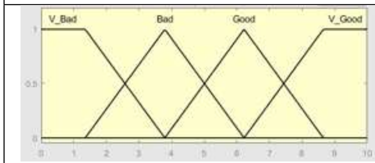
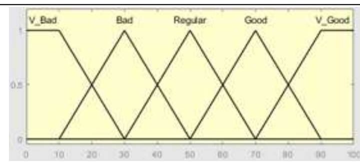
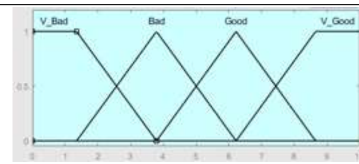
Geometry	RMR	Structure
		

Table 14.40: Crystalline Cutting Structure Fuzzy Sets

Road Direction Dip						
Structure 1						
RMR	Geom			RMR	Geom	
VG	VG	VG		R	B	B
VG	G	G		R	VB	VB
VG	B	G		B	VG	G
VG	VB	B		B	G	B
G	VG	G		B	B	B
G	G	G		B	VB	VB
G	B	B		VB	VG	G
G	VB	B		VB	G	B
R	VG	G		VB	B	VB
R	G	G		VB	VB	VB

Table 14.41: Structure 1 Fuzzy Rules

Land Direction Dip						
Structure 2						
RMR	Geom			RMR	Geom	
VG	VG	VG		R	B	G
VG	G	VG		R	VB	B
VG	B	G		B	VG	G
VG	VB	B		B	G	G
G	VG	VG		B	B	B
G	G	G		B	VB	B
G	B	G		VB	VG	G
G	VB	B		VB	G	B
R	VG	G		VB	B	B
R	G	G		VB	VB	VB

Table 14.42: Structure 2 Fuzzy Rules

Stabilization.
Stabilization fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Road Protection.

Road Protection fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Improvement.
Improvement fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Inventory.
Inventory fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Crystalline Cutting Performance

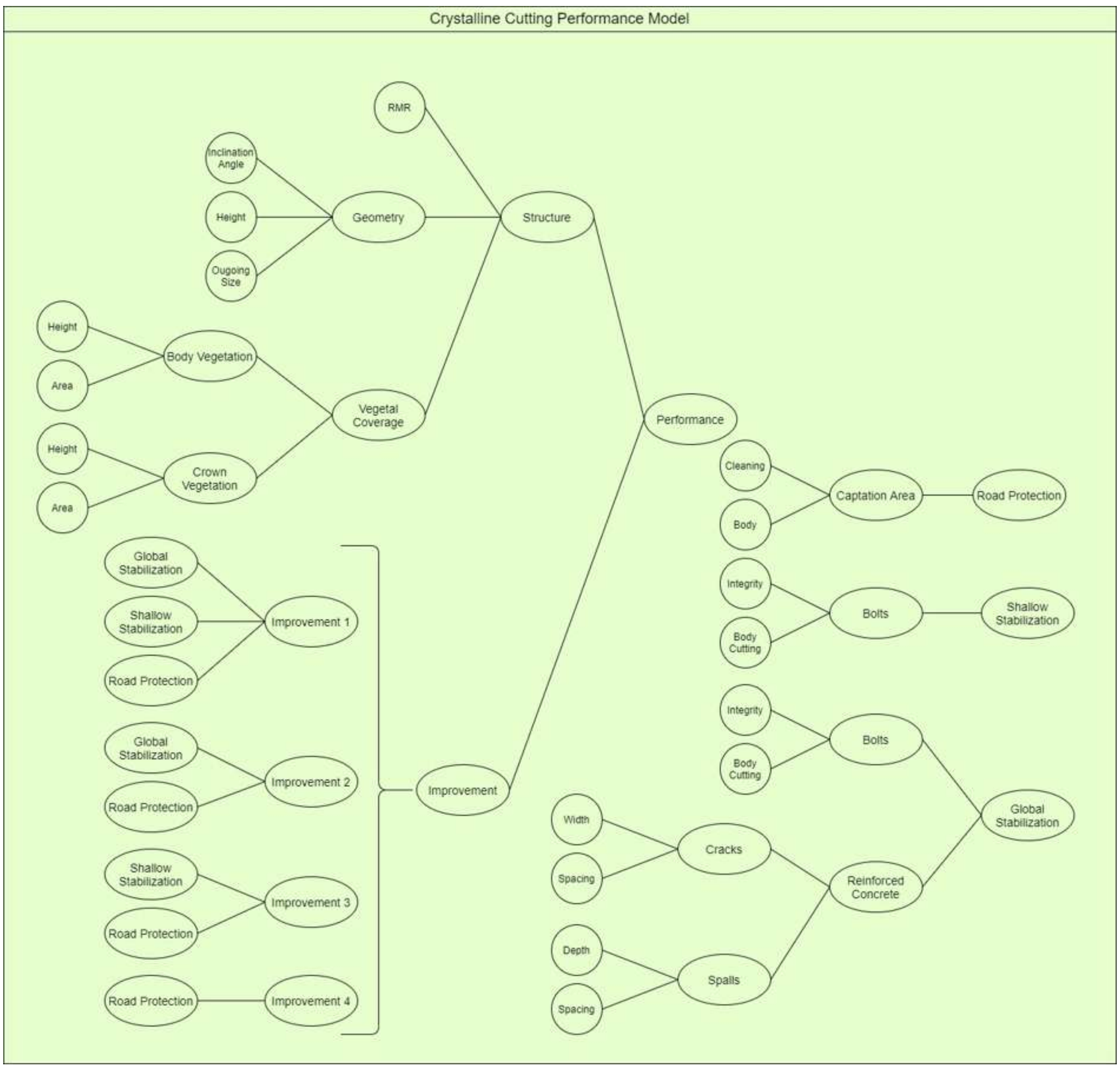


Figure 14.5: Crystalline Cutting Performance Model

Geometry.

- Height. Land height change related to project or inventory measure.
- Inclination angle. Land change related to project or inventory value.
- Outgoing Size. Land measure (m).

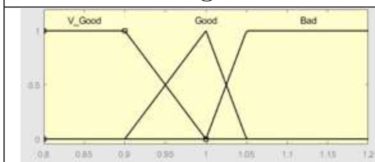
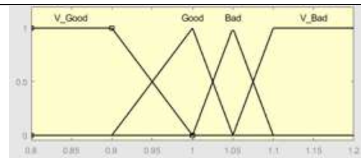
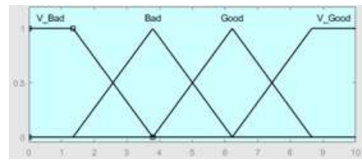
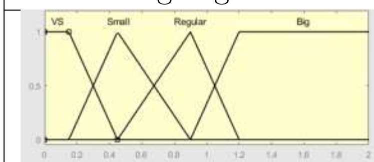
Height	Inclination Angle	Geometry
		
Outgoing Size		
		

Table 14.43: Crystalline Cutting Performance Geometry Fuzzy Sets

Geometry															
Inc An	Hght	O Size		Inc An	Hght	O Size		Inc An	Hght	O Size		Hght	Inc An	O Size	
VG	VG	VS	VG	G	VG	VS	VG	B	VG	VS	G	VB	VG	VS	G
VG	VG	S	VG	G	VG	S	VG	B	VG	S	G	VB	VG	S	G
VG	VG	R	VG	G	VG	R	G	B	VG	R	G	VB	VG	R	B
VG	VG	B	G	G	VG	B	G	B	VG	B	B	VB	VG	B	B
VG	G	VS	VG	G	G	VS	G	B	G	VS	B	VB	G	VS	B
VG	G	S	VG	G	G	S	G	B	G	S	B	VB	G	S	B
VG	G	R	G	G	G	R	G	B	G	R	B	VB	G	R	VB
VG	G	B	G	G	G	B	G	B	G	B	B	VB	G	B	VB
VG	B	VS	G	G	B	VS	B	B	B	VS	B	VB	B	VS	VB
VG	B	S	G	G	B	S	B	B	B	S	B	VB	B	S	VB
VG	B	R	B	G	B	R	B	B	B	R	B	VB	B	R	VB
VG	B	B	B	G	B	B	B	B	B	B	B	VB	B	B	VB

Table 14.44: Crystalline Cutting Performance Geometry Fuzzy Rules

Body Vegetation.
Vegetal coverage sets and fuzzy rules were presented in section Sedimentary Cutting

Crown Vegetation.
Vegetal coverage sets and fuzzy rules were presented in section Sedimentary Cutting

Vegetal Coverage.
Vegetal coverage sets and fuzzy rules were presented in section Sedimentary Cutting

Structure.

- RMR. Bieniawski land evaluation.

- Geometry. Height, inclination angle, and outgoing size evaluation.
- Vegetal Coverage. Height and percentage area evaluation.

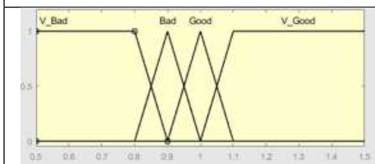
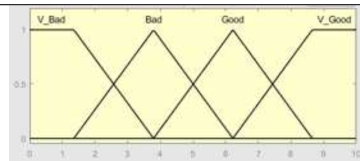
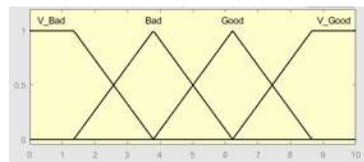
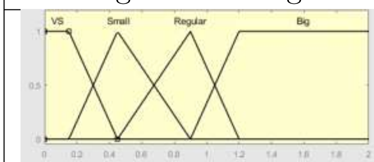
RMR	Geometry	Structure
		
Vegetal Coverage		
		

Table 14.45: Crystalline Cutting Performance Structure Fuzzy Sets

Structure															
Geom	RMR	V Cov		Geom	RMR	V Cov		Geom	RMR	V Cov		Geom	RMR	V Cov	
VG	VG	VG	VG	G	VG	VG	VG	B	VG	VG	G	VB	VG	VG	G
VG	VG	G	VG	G	VG	G	VG	B	VG	G	G	VB	VG	G	B
VG	VG	B	G	G	VG	B	G	B	VG	B	G	VB	VG	B	B
VG	VG	VB	B	G	VG	VB	B	B	VG	VB	B	VB	VG	VB	B
VG	G	VG	VG	G	G	VG	G	B	G	VG	G	VB	G	VG	B
VG	G	G	VG	G	G	G	G	B	G	G	G	VB	G	G	B
VG	G	B	G	G	G	B	G	B	G	B	B	VB	G	B	B
VG	G	VB	B	G	G	VB	B	B	G	VB	B	VB	G	VB	B
VG	B	VG	G	G	B	VG	B	B	B	VG	B	VB	B	VG	B
VG	B	G	G	G	B	G	B	B	B	G	B	VB	B	G	VB
VG	B	B	B	G	B	B	B	B	B	B	B	VB	B	B	VB
VG	B	VB	B	G	B	VB	B	B	B	VB	B	VB	B	VB	VB
VG	VB	VG	B	G	VB	VG	B	B	VB	VG	B	VB	VB	VG	VB
VG	VB	G	B	G	VB	G	B	B	VB	G	VB	VB	VB	G	VB
VG	VB	B	VB	G	VB	B	VB	B	VB	B	VB	VB	VB	B	VB
VG	VB	VB	VB	G	VB	VB	VB	B	VB	VB	VB	VB	VB	VB	VB

Table 14.46: Crystalline Cutting Performance Structure Fuzzy Rules

Caption Area.
Caption Area fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Reinforced concrete.
Cracking, Spalls, and Reinforced Concrete fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Bolt.
Bolt fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Improvement.

Improvement fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Performance.
Performance sets and fuzzy rules were presented in section Sedimentary Cutting.

14.1.3 Rock in Soil Matrix Cutting.

Rock in Soil Matrix Cutting Inventory.

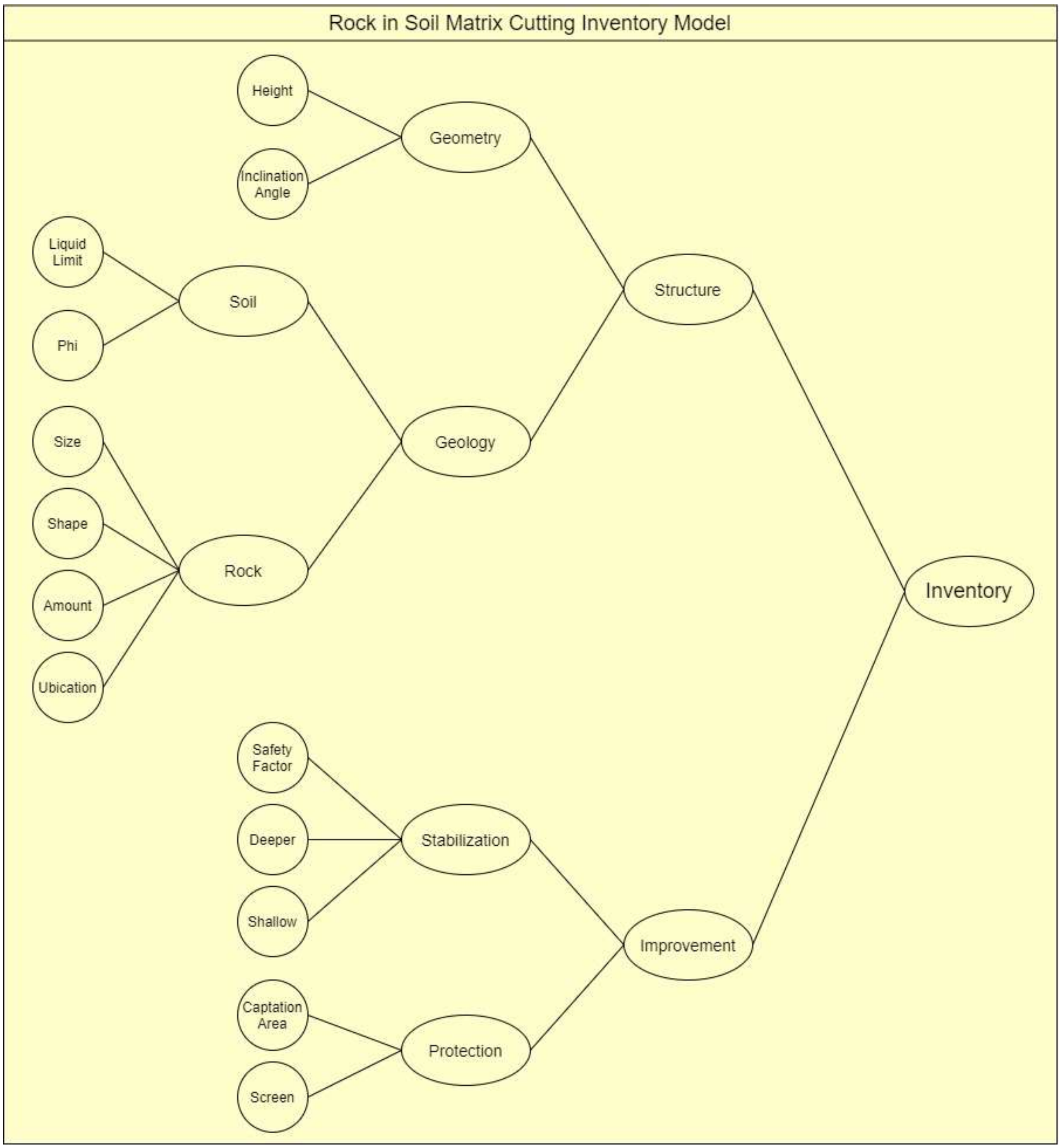


Figure 14.6: Rock in Soil Matrix Cutting Inventory Model

Geometry.

- Height. Project measure (m)
- Inclination Angle. Grades project measure

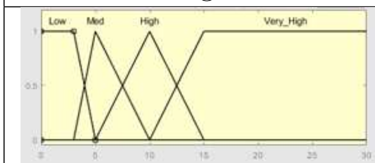
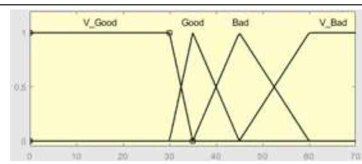
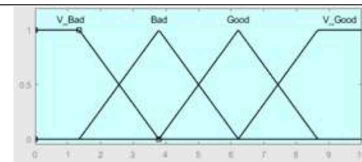
Height	Inclination Angle	Geometry
		

Table 14.47: Rock in Soil Matrix Geometry Inventory Fuzzy Sets

Geometry						
Height	In Ang			Height	In Ang	
L	VG	VG		H	VG	G
L	G	VG		H	G	G
L	B	G		H	B	B
L	VB	B		H	VB	VB
M	VG	VG		VH	VG	G
M	G	G		VH	G	B
M	B	B		VH	B	VB
M	VB	B		VH	VB	VB

Table 14.48: Rock in Soil Matrix Geometry Inventory Fuzzy Rules

Soil.

- Liquid Limit. Geotechnical property cutting soil.
- Phi. Geotechnical property cutting soil.

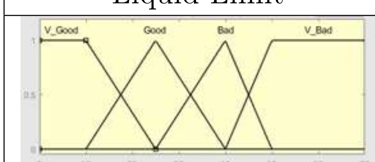
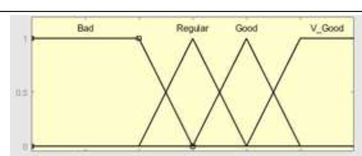
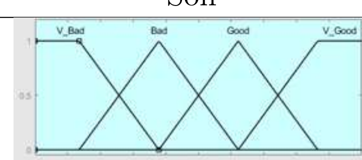
Liquid Limit	Phi	Soil
		

Table 14.49: Rock in Soil Matrix Soil Inventory Fuzzy Sets

Soil						
LL	Phi			LL	Phi	
VG	VG	VG		B	VG	G
VG	G	G		B	G	G
VG	R	G		B	R	B
VG	B	B		B	B	B
G	VG	VG		VB	VG	G
G	G	G		VB	G	B
G	R	G		VB	R	B
G	B	B		VB	B	VB

Table 14.50: Rock in Soil Matrix Soil Inventory Fuzzy Rules

Evaluation	Very Good Qualification from 7.4 to 10	Good Qualification from 5 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad Qualification from 0 to 2.56
Shape	Tabular blocks.	Cubic blocks. Relatively flat.	Cubic and angular blocks.	Round and flat blocks. Or blocks with inclination toward road.
Amount	Individual and isolated blocks.	Dispersed rock blocks.	Rock groups distributed into cutting body.	Rock group distributed into all the cutting body.
Placement	Blocks located in upper third of body cutting.	Blocks located in middle third of body cutting.	Blocks located in lower third of body cutting.	

Table 14.51: Rock shape, amount and placement status description.

Block.

- Size. Diameter land measure (m).
- Shape. Visual evaluation.
- Amount. Visual evaluation.
- Placement. Visual evaluation.

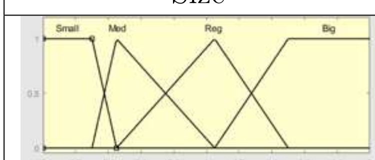
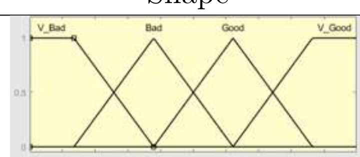
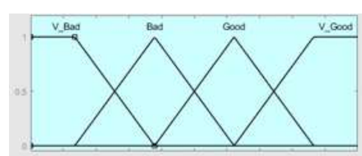
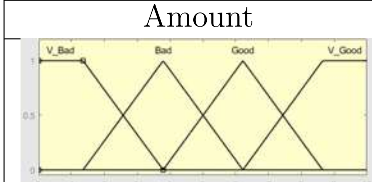
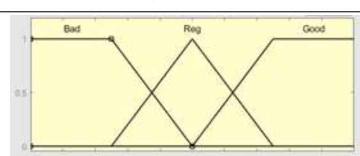
Size	Shape	Block
		
Amount	Placement	
		

Table 14.52: Rock in Soil Matrix Block Inventory Fuzzy Sets

Block																						
Siz	Shp	Amn	Ubi			Siz	Shp	Amn	Ubi			Siz	Shp	Amn	Ubi			Siz	Shp	Amn	Ubi	
S	B	VG	R	G		M	VG	VG	R	VG		R	VG	VG	R	G		B	VG	VG	R	G
S	B	G	R	G		M	VG	G	R	VG		R	VG	G	R	G		B	VG	G	R	G
S	B	B	R	B		M	VG	B	R	VG		R	VG	B	R	G		B	VG	B	R	G
S	B	VB	R	B		M	VG	VB	R	G		R	VG	VB	R	B		B	VG	VB	R	B
S	B	VG	G	G		M	G	VG	R	G		R	G	VG	R	G		B	G	VG	R	G
S	B	G	G	G		M	G	G	R	G		R	G	G	R	G		B	G	G	R	G
S	B	B	G	G		M	G	B	R	G		R	G	B	R	G		B	G	B	R	G
S	B	VB	G	B		M	G	VB	R	B		R	G	VB	R	B		B	G	VB	R	B
S	B	VG	B	B		M	B	VG	R	G		R	B	VG	R	G		B	B	VG	R	B
S	B	G	B	B		M	B	G	R	G		R	B	G	R	G		B	B	G	R	B
S	B	B	B	B		M	B	B	R	B		R	B	B	R	B		B	B	B	R	B
S	B	VB	B	B		M	B	VB	R	B		R	B	VB	R	B		B	B	VB	R	VB
S	G	VG	R	VG		M	VB	VG	R	G		R	VB	VG	R	G		B	VB	VG	R	B
S	G	G	R	VG		M	VB	G	R	B		R	VB	G	R	B		B	VB	G	R	B
S	G	B	R	VG		M	VB	B	R	B		R	VB	B	R	B		B	VB	B	R	VB
S	G	VB	R	G		M	VB	VB	R	B		R	VB	VB	R	B		B	VB	VB	R	VB
S	G	VG	G	VG		M	VG	VG	G	VG		R	VG	VG	G	VG		B	VG	VG	G	VG
S	G	G	G	VG		M	VG	G	G	VG		R	VG	G	G	VG		B	VG	G	G	VG
S	G	B	G	VG		M	VG	B	G	VG		R	VG	B	G	VG		B	VG	B	G	G
S	G	VB	G	VG		M	VG	VB	G	G		R	VG	VB	G	G		B	VG	VB	G	G
S	G	VG	B	G		M	G	VG	G	VG		R	G	VG	G	G		B	G	VG	G	G
S	G	G	B	G		M	G	G	G	VG		R	G	G	G	G		B	G	G	G	G
S	G	B	B	G		M	G	B	G	VG		R	G	B	G	G		B	G	B	G	G
S	G	VB	B	G		M	G	VB	G	G		R	G	VB	G	G		B	G	VB	G	B
S	VB	VG	R	G		M	B	VG	G	G		R	B	VG	G	G		B	B	VG	G	G
S	VB	G	R	B		M	B	G	G	G		R	B	G	G	G		B	B	G	G	B
S	VB	B	R	B		M	B	B	G	B		R	B	B	G	B		B	B	B	G	B
S	VB	VB	R	B		M	B	VB	G	B		R	B	VB	G	B		B	B	VB	G	B
S	VB	VG	G	G		M	VB	VG	G	G		R	VB	VG	G	G		B	VB	VG	G	B
S	VB	G	G	B		M	VB	G	G	B		R	VB	G	G	B		B	VB	G	G	B
S	VB	B	G	B		M	VB	B	G	B		R	VB	B	G	B		B	VB	B	G	VB
S	VB	VB	G	B		M	VB	VB	G	B		R	VB	VB	G	B		B	VB	VB	G	VB
S	VB	VG	B	B		M	VG	VG	B	G		R	VG	VG	B	G		B	VG	VG	B	G
S	VB	G	B	B		M	VG	G	B	G		R	VG	G	B	G		B	VG	G	B	G
S	VB	B	B	B		M	VG	B	B	G		R	VG	B	B	G		B	VG	B	B	G
S	VB	VB	B	B		M	VG	VB	B	G		R	VG	VB	B	B		B	VG	VB	B	B
S	VG	VG	R	VG		M	G	VG	B	G		R	G	VG	B	G		B	G	VG	B	G
S	VG	G	R	VG		M	G	G	B	G		R	G	G	B	G		B	G	G	B	G
S	VG	B	R	VG		M	G	B	B	G		R	G	B	B	G		B	G	B	B	G
S	VG	VB	R	G		M	G	VB	B	B		R	G	VB	B	B		B	G	VB	B	B
S	VG	VG	G	VG		M	B	VG	B	G		R	B	VG	B	G		B	B	VG	B	B
S	VG	G	G	VG		M	B	G	B	B		R	B	G	B	B		B	B	G	B	B
S	VG	B	G	VG		M	B	B	B	B		R	B	B	B	B		B	B	B	B	VB
S	VG	VB	G	VG		M	B	VB	B	B		R	B	VB	B	B		B	B	VB	B	VB
S	VG	VG	B	G		M	VB	VG	B	B		R	VB	VG	B	B		B	VB	VG	B	B
S	VG	G	B	G		M	VB	G	B	B		R	VB	G	B	B		B	VB	G	B	VB
S	VG	B	B	G		M	VB	B	B	B		R	VB	B	B	VB		B	VB	B	B	VB
S	VG	VB	B	G		M	VB	VB	B	VB		R	VB	VB	B	VB		B	VB	VB	B	VB

Table 14.53: Block Fuzzy Rules

Geology.

- Soil. Liquid limit and Phi evaluation.
- Block. Size, shape, amount and placement evaluation.

Geology						
Soil	Block			Soil	Block	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	G		B	B	B
VG	VB	G		B	VB	B
G	VG	VG		VB	VG	B
G	G	G		VB	G	VB
G	B	G		VB	B	VB
G	VB	G		VB	VB	VB

Table 14.54: Geology Fuzzy Rules

Structure.

- Geometry. Height, and inclination angle evaluation.
- Geology. Soil and Block evaluation

Structure						
Geol	Geom			Geol	Geom	
VG	VG	VG		B	VG	G
VG	G	G		B	G	G
VG	B	G		B	B	B
VG	VB	B		B	VB	VB
G	VG	VG		VB	VG	G
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.55: Structure Fuzzy Rules

Stabilization.
Stabilization fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Road Protection.
Road Protection fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Improvement.
Improvement fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Inventory.
Inventory fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Rock in Soil Matrix Cutting Performance.

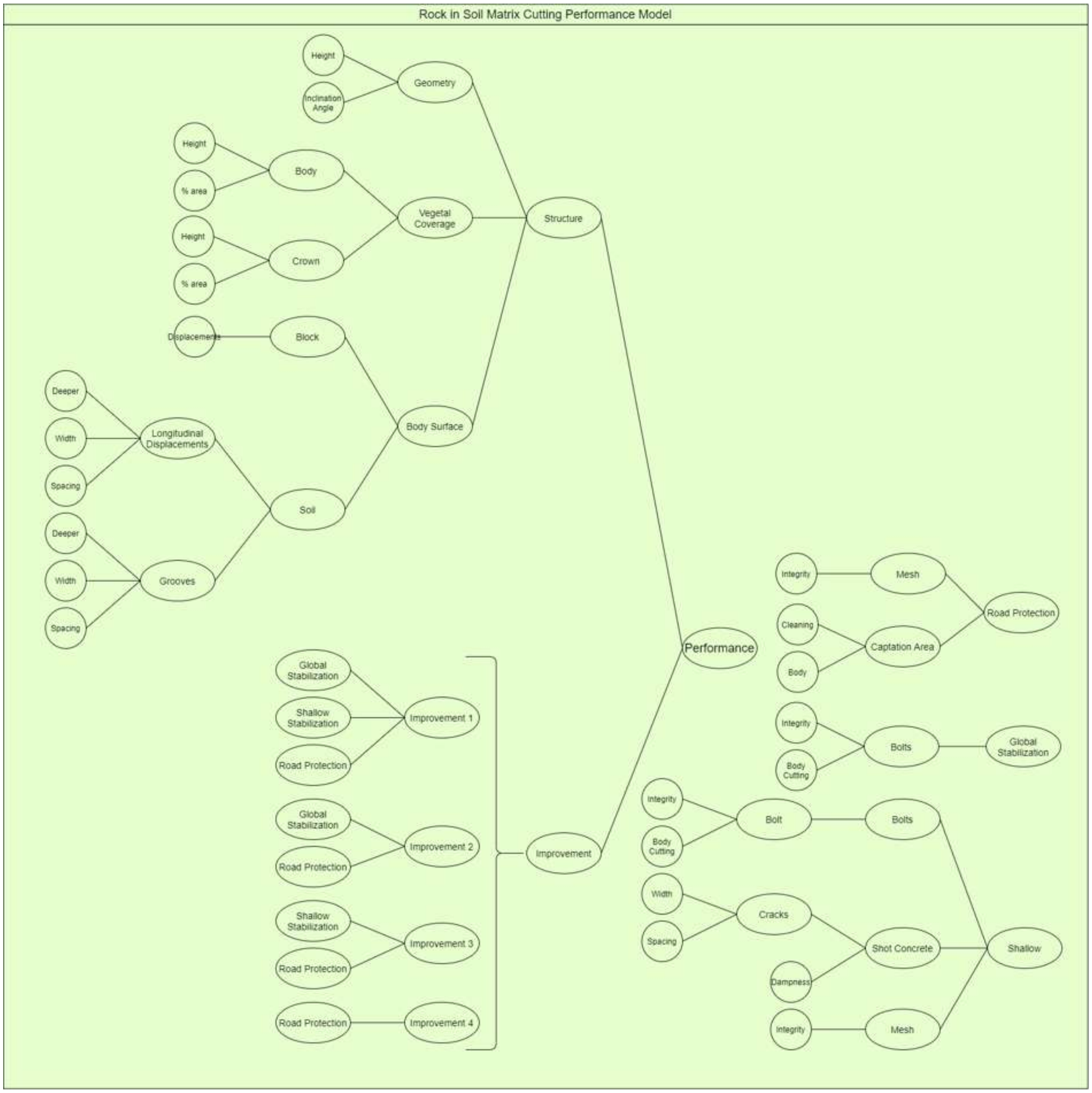


Figure 14.7: Rock in Soil Matrix Cutting Performance Model

Geometry.

Geometry performance fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Body and Crown Vegetation.

- Height. Land average height of vegetation (m).
- Area. Percentage area whit vegetal coverage.

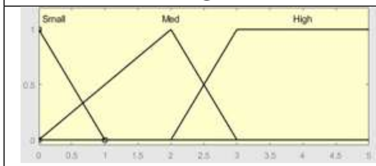
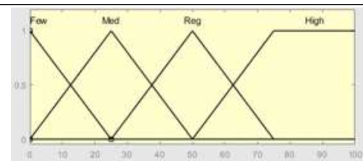
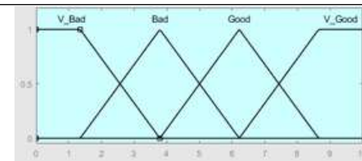
Height	Area	Body Vegetation
		

Table 14.56: Rock in Soil Matrix Performance Body Vegetation Fuzzy Sets

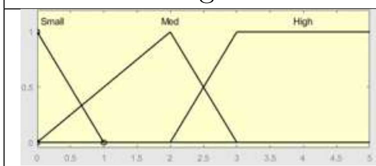
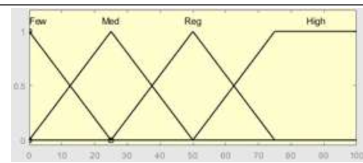
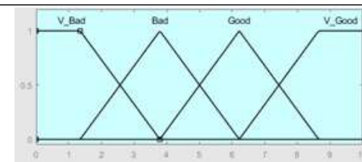
Height	Area	Body Vegetation
		

Table 14.57: Rock in Soil Matrix Performance Crown Vegetation Fuzzy Sets

Body Vegetation				Crown Vegetation		
Height	Area			Height	Area	
S	F	VB		S	F	VB
S	M	VB		S	M	VB
S	R	G		S	R	B
S	H	G		S	H	B
M	F	VB		M	F	VB
M	M	B		M	M	B
M	R	G		M	R	G
M	H	VG		M	H	VG
H	F	B		H	F	B
H	M	G		H	M	G
H	R	VG		H	R	VG
H	H	VG		H	H	VG

Table 14.58: Body and Crown Vegetation Fuzzy Rules

Vegetal Coverage.

- Body Vegetation. Height and area evaluation.
- Crown Vegetation. Height and area evaluation.

Vegetal Coverage					
B Veg	C Veg		B Veg	C Veg	
VG	VG	VG	B	VG	B
VG	G	VG	B	G	B
VG	B	G	B	B	B
VG	VB	B	B	VB	VB
G	VG	G	VB	VG	B
G	G	G	VB	G	B
G	B	B	VB	B	VB
G	VB	B	VB	VB	VB

Table 14.59: Vegetal Coverage Fuzzy Rules

Soil Longitudinal Displacements and Grooves.

- Deeper. Land Measure (cm).
- Width. Land measure (cm).
- Spacing. Visual evaluation.

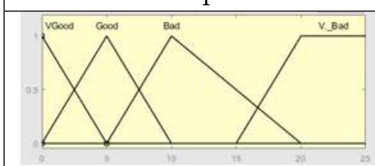
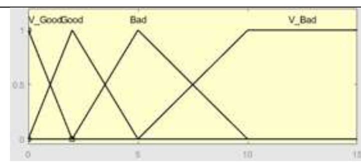
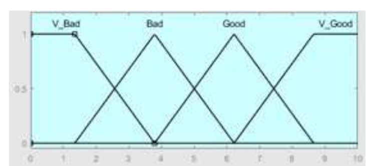
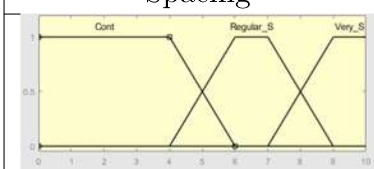
Deeper	Width	L. Displ./Grooves
		
Spacing		
		

Table 14.60: Rock in Soil Matrix Longitudinal Displacements Fuzzy Sets

Longitudinal Disp./Grooves															
Deep	Wid	Spac		Deep	Wid	Spac		Deep	Wid	Spac		Deep	Wid	Spac	
VG	VG	VS	VG	G	VG	VS	VG	B	VG	VS	VG	VB	VG	VS	VG
VG	VG	RS	VG	G	VG	RS	VG	B	VG	RS	VG	VB	VG	RS	VG
VG	VG	C	VG	G	VG	C	VG	B	VG	C	VG	VB	VG	C	VG
VG	G	VS	VG	G	G	VS	G	B	G	VS	G	VB	G	VS	B
VG	G	RS	VG	G	G	RS	G	B	G	RS	G	VB	G	RS	B
VG	G	C	VG	G	G	C	B	B	G	C	B	VB	G	C	VB
VG	B	VS	VG	G	B	VS	G	B	B	VS	B	VB	B	VS	B
VG	B	RS	VG	G	B	RS	B	B	B	RS	B	VB	B	RS	B
VG	B	C	VG	G	B	C	B	B	B	C	B	VB	B	C	VB
VG	VB	VS	VG	G	VB	VS	B	B	VB	VS	B	VB	VB	VS	VB
VG	VB	RS	VG	G	VB	RS	B	B	VB	RS	B	VB	VB	RS	VB
VG	VB	C	VG	G	VB	C	VB	B	VB	C	VB	VB	VB	C	VB

Table 14.61: Longitudinal Displacements and Grooves Fuzzy Rules

Soil.

- Displacement. Deeper, width, and spacing evaluation.
- Grooves. Deeper, width, and spacing evaluation.

Soil						
L Dis	Groo			L Dis	Groo	
VG	VG	VG		B	VG	B
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.62: Soil Fuzzy Rules

Evaluation	Very Good Qualification from 7.4 to 10	Good Qualification from 5 to 7.3	Bad Qualification from 2.57 to 4.99	Very Bad Qualification from 0 to 2.56
Block Displacement	All rock blocks are in their original location.	Some rock blocks have been displaced less of 1 meter from original location. All the rock block displaced are located in the middle or upper third of body cutting.	Some rock blocks have been displaced greater of 1 meter from original location. All the rock block displaced are located in the middle or upper third of body cutting.	Some rock blocks have been displaced greater of 1meter from original location.

Table 14.63: Rock Blocks displacement status descriptions.

Body Surface.

- Soil. Longitudinal displacement and grooves evaluation.
- Block Displacement. Visual evaluation.

Body Surface						
Soil	B Disp			Soil	B Disp	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	B
G	VG	G		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.64: Body Surface Fuzzy Rules

Structure.
Structure fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Bolts.
Bolts fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Mesh.
Mesh fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Cracks.
Cracks fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Shot Concrete.
Shot concrete fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Shallow Stabilization.

- Bolts.
- Shot Concrete.
- Mesh

Shallow stabilization 1				Shallow stabilization 2		
Bolts	S Conc			Bolts	Mesh	
VG	VG	VG		VG	VG	VG
VG	G	G		VG	G	VG
VG	B	B		VG	B	G
VG	VB	B		VG	VB	B
G	VG	G		G	VG	G
G	G	G		G	G	G
G	B	B		G	B	G
G	VB	B		G	VB	B
B	VG	G		B	VG	B
B	G	B		B	G	B
B	B	B		B	B	B
B	VB	VB		B	VB	VB
VB	VG	B		VB	VG	B
VB	G	B		VB	G	VB
VB	B	VB		VB	B	VB
VB	VB	VB		VB	VB	VB

Table 14.65: Structure 1 Fuzzy Rules

Road Protection.
Road protection fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Improvement.
Improvement fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

Performance.
Performance fuzzy sets and fuzzy rules were presented in section Sedimentary Cutting.

14.2 Geotechnical Assets Soil Cutting

Soil Cutting Inventory

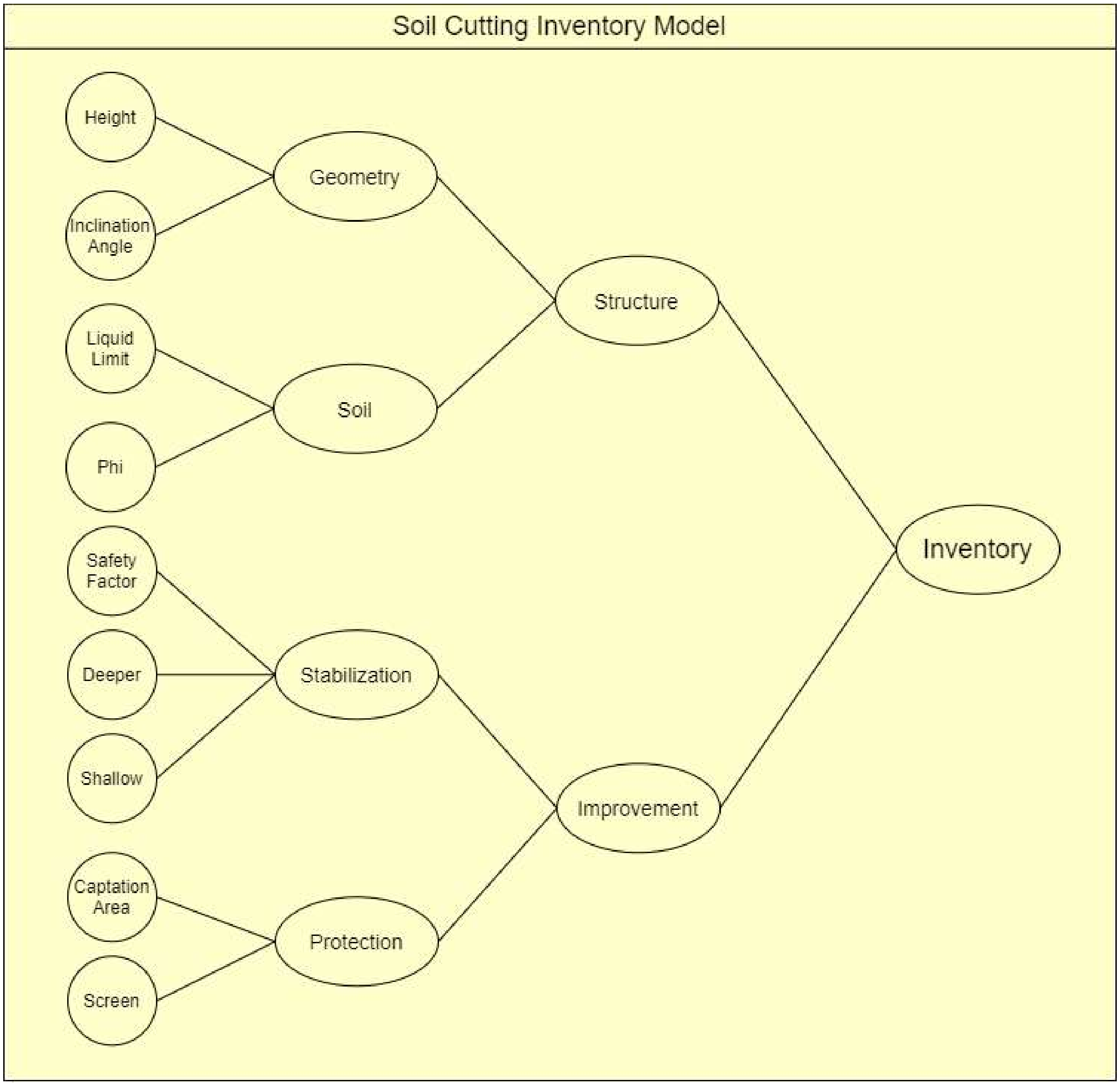


Figure 14.8: Soil Cutting Inventory Model

Geometry.

- Height. Project measure (m)
- Inclination Angle. Grades Angle measure.

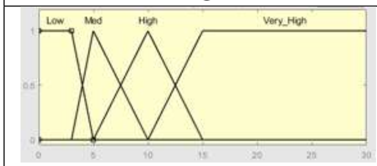
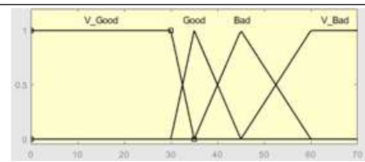
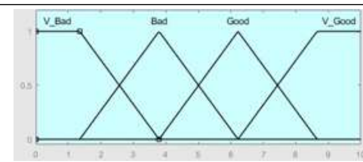
Height	Inclination Angle	Geometry
		

Table 14.66: Soil Cutting Geometry Fuzzy Sets

Geometry						
Height	I Angle			Height	I Angle	
L	VG	VG		H	VG	G
L	G	VG		H	G	G
L	B	G		H	B	B
L	VB	B		H	VB	VB
M	VG	VG		VH	VG	G
M	G	G		VH	G	B
M	B	B		VH	B	VB
M	VB	B		VH	VB	VB

Table 14.67: Fuzzy Rules

Soil.
Soil fuzzy sets and fuzzy rules were presented in section Rock in soil matrix.

Structure						
Soil	Geo			Soil	Geo	
VG	VG	VG		B	VG	G
VG	G	G		B	G	G
VG	B	G		B	B	B
VG	VB	B		B	VB	VB
G	VG	VG		VB	VG	G
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.68: Structure Fuzzy Rules

Stabilization.
Stabilization fuzzy sets and fuzzy rules were presented in section sedimentary cutting.

Road Protection.
Road protection fuzzy sets and fuzzy rules were presented in section sedimentary cutting.

Improvement.
Improvement fuzzy sets and fuzzy rules were presented in section sedimentary cutting.

Inventory.
Inventory fuzzy sets and fuzzy rules were presented in section sedimentary cutting.

Soil Cutting Performance

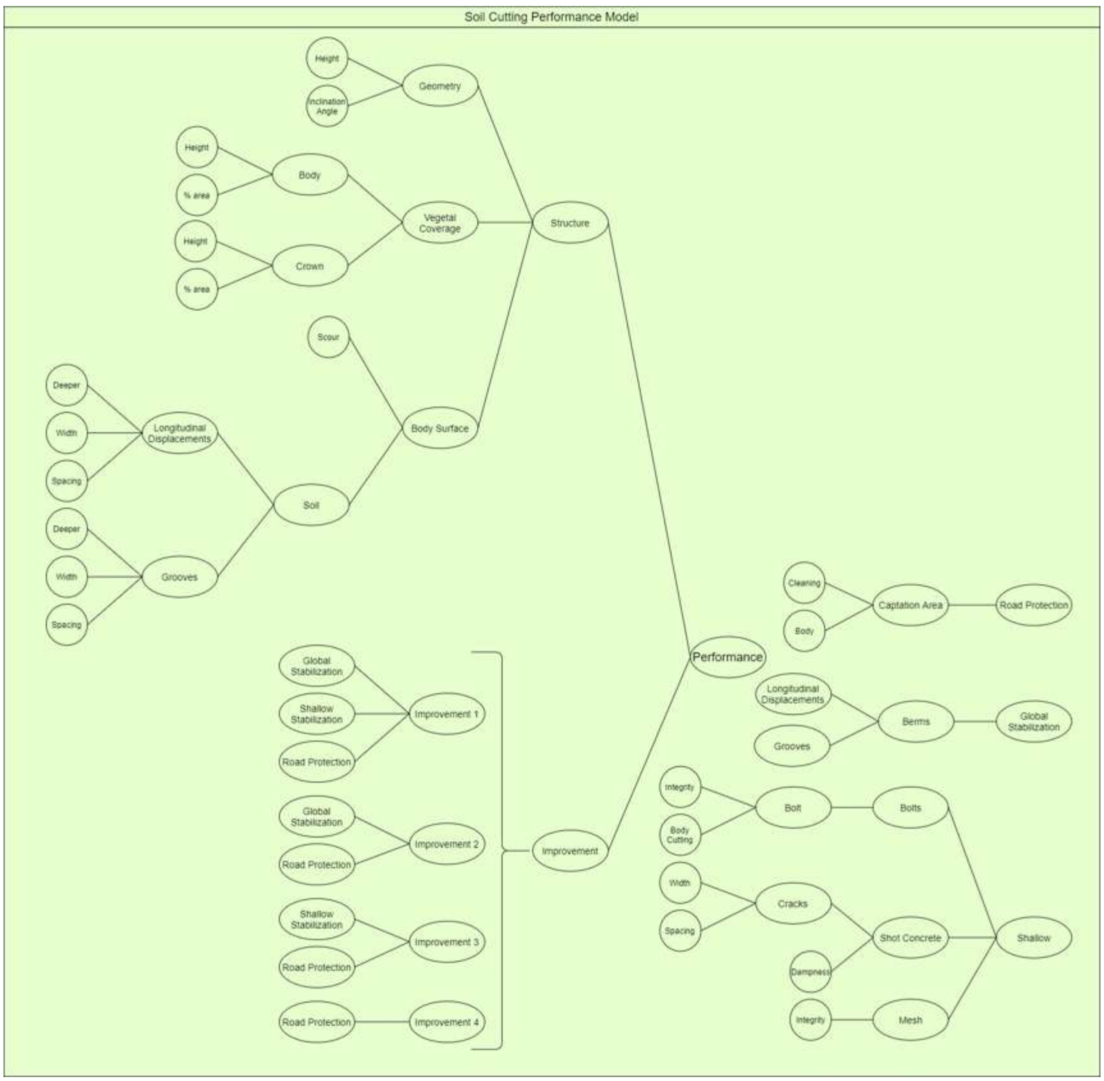


Figure 14.9: Soil Cutting Performance Model

Geometry.

Geometry fuzzy sets and fuzzy rules were presented in section rock in soil matrix cutting.

Body Vegetation

Body vegetation fuzzy sets and fuzzy rules were presented in section rock in soil matrix cutting.

Crown Vegetation

Crown vegetation fuzzy sets and fuzzy rules were presented in section rock in soil matrix cutting.

Vegetal Coverage

Vegetal Coverage fuzzy sets and fuzzy rules were presented in section rock in soil matrix cutting.

Longitudinal Soil Displacement

Longitudinal soil displacement fuzzy sets and fuzzy rules were presented in section rock in soil matrix cutting.

Grooves

Grooves fuzzy sets and fuzzy rules were presented in section rock in soil matrix cutting.

Soil

Soil fuzzy sets and fuzzy rules were presented in section rock in soil matrix cutting.

Body Surface.

- Scour. Visual evaluation
- Soil. Longitudinal displacements and scour evaluation

Body Surface						
Soil	Scour			Soil	Scour	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 14.69: Body Surface Fuzzy Rules

Structure

Structure fuzzy sets and fuzzy rules were presented in section rock in soil matrix cutting.

Berms (Global stabilization).

- Longitudinal soil displacement. Width, deeper and spacing evaluation.
- Grooves. Width, deeper and spacing evaluation.

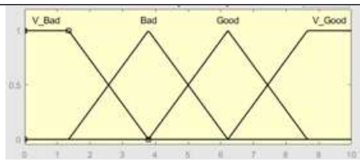
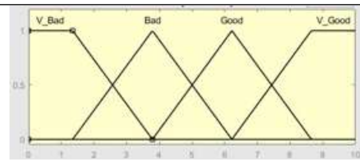
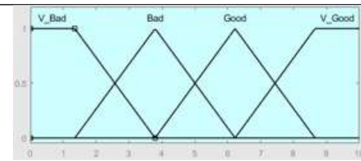
Longitudinal Displacements	Grooves	Berms
		

Table 14.70: Soil Cutting Performance Berms Fuzzy Sets

Berms						
L Dis	Groo			L Dis	Groo	
VG	VG	VG		B	VG	B
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 14.71: Berms Fuzzy Rules

Bolts
Bolts fuzzy sets and fuzzy rules were presented in section sedimentary cutting.

Cracks
Cracks fuzzy sets and fuzzy rules were presented in section sedimentary cutting.

Shot concrete
Shot concrete fuzzy sets and fuzzy rules were presented in section sedimentary cutting.

Shallow stabilization
Shallow stabilization fuzzy sets and fuzzy rules were presented in section rock in soil matrix.

Road Protection
Road protection fuzzy sets and fuzzy rules were presented in section sedimentary cutting.

Improvement

Improvement fuzzy sets and fuzzy rules were presented in section sedimentary cutting.

Performance
Performance fuzzy sets and fuzzy rules were presented in section sedimentary cutting.

Chapter 15

Annex H

15.1 Geotechnical Assets Embankment

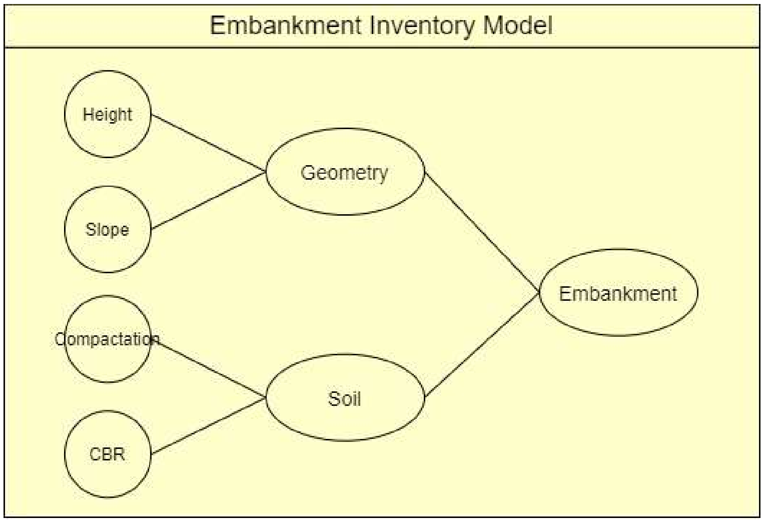


Figure 15.1: Embankment Inventory Model

Geometry.

- Height. Project measure (m)
- Slope. Grades slope project.

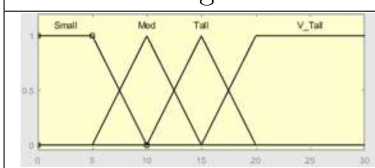
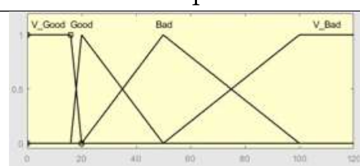
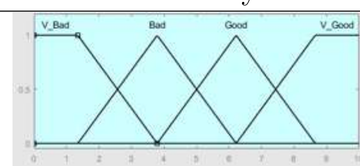
Height	Slope	Geometry
		

Table 15.1: Embankment Geometry Fuzzy Sets

Geometry						
Slope	Height			Slope	Height	
VG	S	VG		B	S	B
VG	M	VG		B	M	B
VG	H	G		B	H	VB
VG	VH	G		B	VH	VB
G	S	VG		VB	S	B
G	M	G		VB	M	VB
G	H	G		VB	H	VB
G	VH	B		VB	VH	VB

Table 15.2: Embankment Geometry Fuzzy Rules

Soil.

- Compaction. Percentage related Maximum AASHTO.
- CBR. Land geotechnical measure

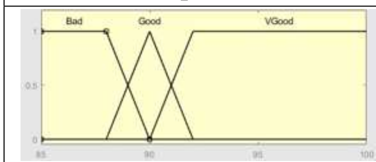
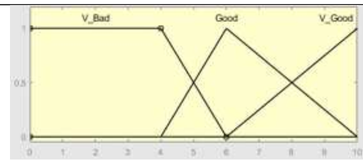
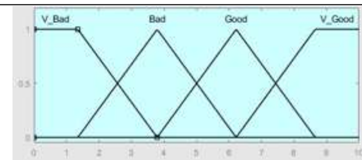
Compaction	CBR	Soil
		

Table 15.3: Embankment Soil Fuzzy Sets

Soil		
Comp	CBR	
VG	VG	VG
VG	G	VG
VG	B	B
G	VG	VG
G	G	G
G	B	B
B	VG	B
B	G	B
B	B	VB

Table 15.4: Soil Fuzzy Rules

Inventory.

- Geometry. Height and inclination angle evaluation.
- Soil. Compaction and CBR evaluation.

Inventory						
Geo	Soil			Geo	Soil	
VG	VG	VG		B	VG	G
VG	G	VG		B	G	B
VG	B	G		B	B	B
VG	VB	B		B	VB	VB
G	VG	VG		VB	VG	B
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 15.5: Fuzzy Rules

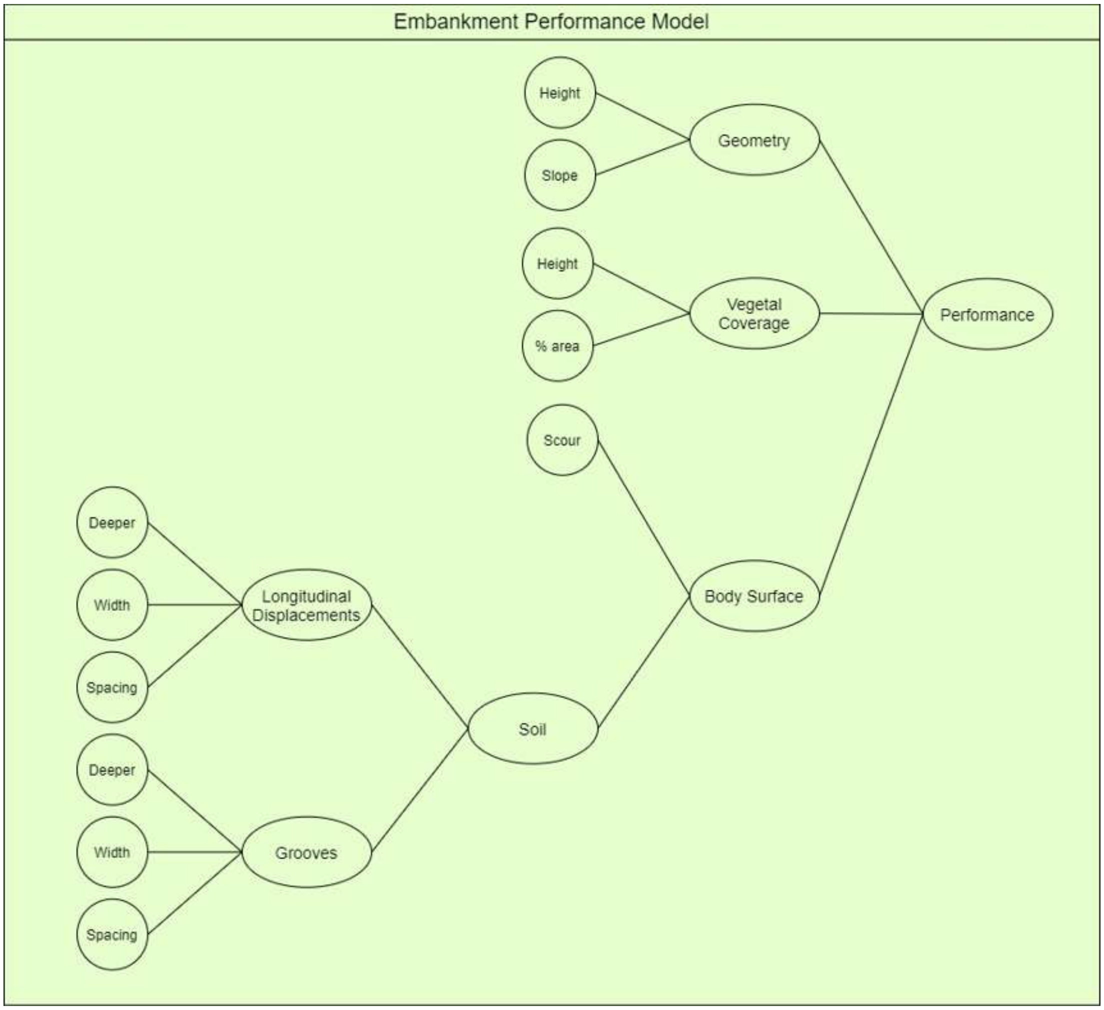


Figure 15.2: Embankment Performance Model

Geometry.

- Height. Land measure related to project or inventory measure.
- Slope. Land measure related to project or inventory measure.

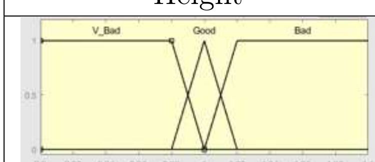
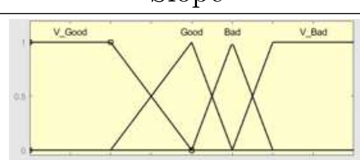
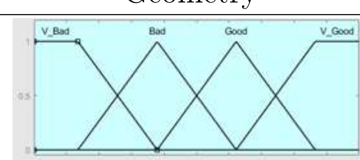
Height	Slope	Geometry
		

Table 15.6: Embankment Performance Geometry Fuzzy Sets

Geometry		
Slope	Height	
VG	VG	VG
VG	G	VG
VG	B	G
G	VG	B
G	G	VG
G	B	G
B	VG	B
B	G	VB
B	B	G
VB	VG	B
VB	G	VB
VB	B	VB

Table 15.7: Fuzzy Rules

Vegetal Coverage.

- Height. Average vegetation height.
- Area. Surface percentage with vegetal coverage.

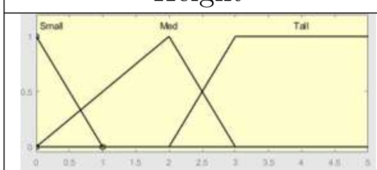
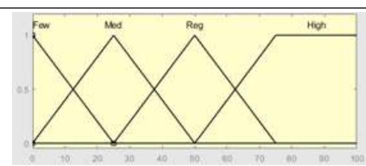
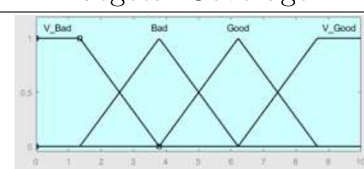
<table>
<tr><th>Height</th><th>Area</th><th>Vegetal Coverage</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 15.8: Embankment Performance Vegetal Coverage Fuzzy Sets

Vegetal Coverage		
Height	Area	
S	F	B
S	M	G
S	R	G
S	H	VG
M	F	B
M	M	G
M	R	G
M	H	B
T	F	B
T	M	B
T	R	VB
T	H	VB

Table 15.9: Vegetal Coverage Fuzzy Rules

Longitudinal Displacements and Grooves.

- Deeper. Land measure (cm)
- Width. Land measure (cm)
- Spacing. Visual evaluation.

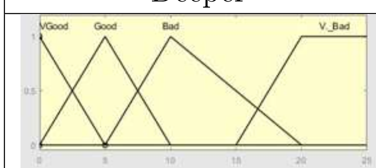
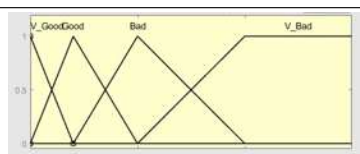
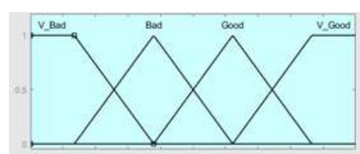
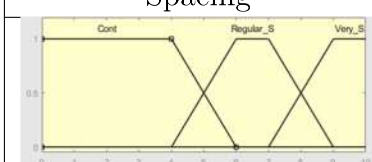
Deeper	Width	Longitudinal Disp/Grooves
		
Spacing		
		

Table 15.10: Longitudinal Displacements and Grooves Fuzzy Sets.

Longitudinal Disp./Grooves															
Deep	Wid	Spac		Deep	Wid	Spac		Deep	Wid	Spac		Deep	Wid	Spac	
VG	VG	VS	VG	G	VG	VS	VG	B	VG	VS	VG	VB	VG	VS	VG
VG	VG	RS	VG	G	VG	RS	VG	B	VG	RS	VG	VB	VG	RS	VG
VG	VG	C	VG	G	VG	C	VG	B	VG	C	VG	VB	VG	C	VG
VG	G	VS	VG	G	G	VS	G	B	G	VS	G	VB	G	VS	B
VG	G	RS	VG	G	G	RS	G	B	G	RS	G	VB	G	RS	B
VG	G	C	VG	G	G	C	B	B	G	C	B	VB	G	C	VB
VG	B	VS	VG	G	B	VS	G	B	B	VS	B	VB	B	VS	B
VG	B	RS	VG	G	B	RS	B	B	B	RS	B	VB	B	RS	B
VG	B	C	VG	G	B	C	B	B	B	C	B	VB	B	C	VB
VG	VB	VS	VG	G	VB	VS	B	B	VB	VS	B	VB	VB	VS	VB
VG	VB	RS	VG	G	VB	RS	B	B	VB	RS	B	VB	VB	RS	VB
VG	VB	C	VG	G	VB	C	VB	B	VB	C	VB	VB	VB	C	VB

Table 15.11: Longitudinal Displacements and Grooves Fuzzy Rules.

Body Surface.

- Scour. Visual evaluation.
- Soil. Longitudinal displacement and grooves evaluation.

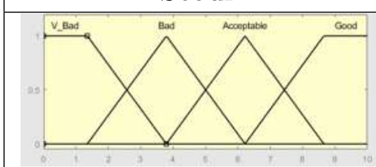
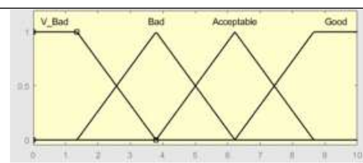
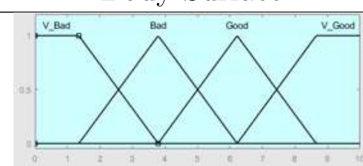
Scour	Soil	Body Surface
		

Table 15.12: Embankment Performance Body Surface Fuzzy Sets

Body Surface					
Body	Scour		Body	Scour	
VG	G	VG	B	G	B
VG	A	G	B	A	B
VG	B	B	B	B	B
VG	VB	B	B	VB	VB
G	G	G	VB	G	VB
G	A	G	VB	A	VB
G	B	B	VB	B	VB
G	VB	B	VB	VB	VB

Table 15.13: Fuzzy Rules

Performance.

- Geometry. Height and slope evaluation.
- Body Surface. Soil deformations and scour evaluation.

- Vegetal Coverage. Height and percentage area with vegetal evaluation.

Performance															
Geo	B Surf	Veg Co		Geo	B Surf	Veg Co		Geo	B Surf	Veg Co		Geo	B Surf	Veg Co	
VG	VG	VG	VG	G	VG	VG	VG	B	VG	VG	G	VB	VG	VG	G
VG	VG	G	VG	G	VG	G	VG	B	VG	G	G	VB	VG	G	B
VG	VG	B	G	G	VG	B	G	B	VG	B	B	VB	VG	B	B
VG	VG	VB	G	G	VG	VB	B	B	VG	VB	B	VB	VG	VB	B
VG	G	VG	VG	G	G	VG	G	B	G	VG	G	VB	G	VG	G
VG	G	G	G	G	G	G	G	B	G	G	G	VB	G	G	B
VG	G	B	G	G	G	B	G	B	G	B	B	VB	G	B	B
VG	G	VB	G	G	G	VB	B	B	G	VB	B	VB	G	VB	B
VG	B	VG	B	G	B	VG	B	B	B	VG	B	VB	B	VG	B
VG	B	G	B	G	B	G	B	B	B	G	B	VB	B	G	VB
VG	B	B	B	G	B	B	B	B	B	B	B	VB	B	B	VB
VG	B	VB	B	G	B	VB	B	B	B	VB	B	VB	B	VB	VB
VG	VB	VG	VB	G	VB	VG	B	B	VB	VG	B	VB	VB	VG	VB
VG	VB	G	VB	G	VB	G	B	B	VB	G	VB	VB	VB	G	VB
VG	VB	B	VB	G	VB	B	VB	B	VB	B	VB	VB	VB	B	VB
VG	VB	VB	VB	G	VB	VB	VB	B	VB	VB	VB	VB	VB	VB	VB

Table 15.14: Fuzzy Rules

Chapter 16

Annex I

16.1 Road Section Evaluation Model

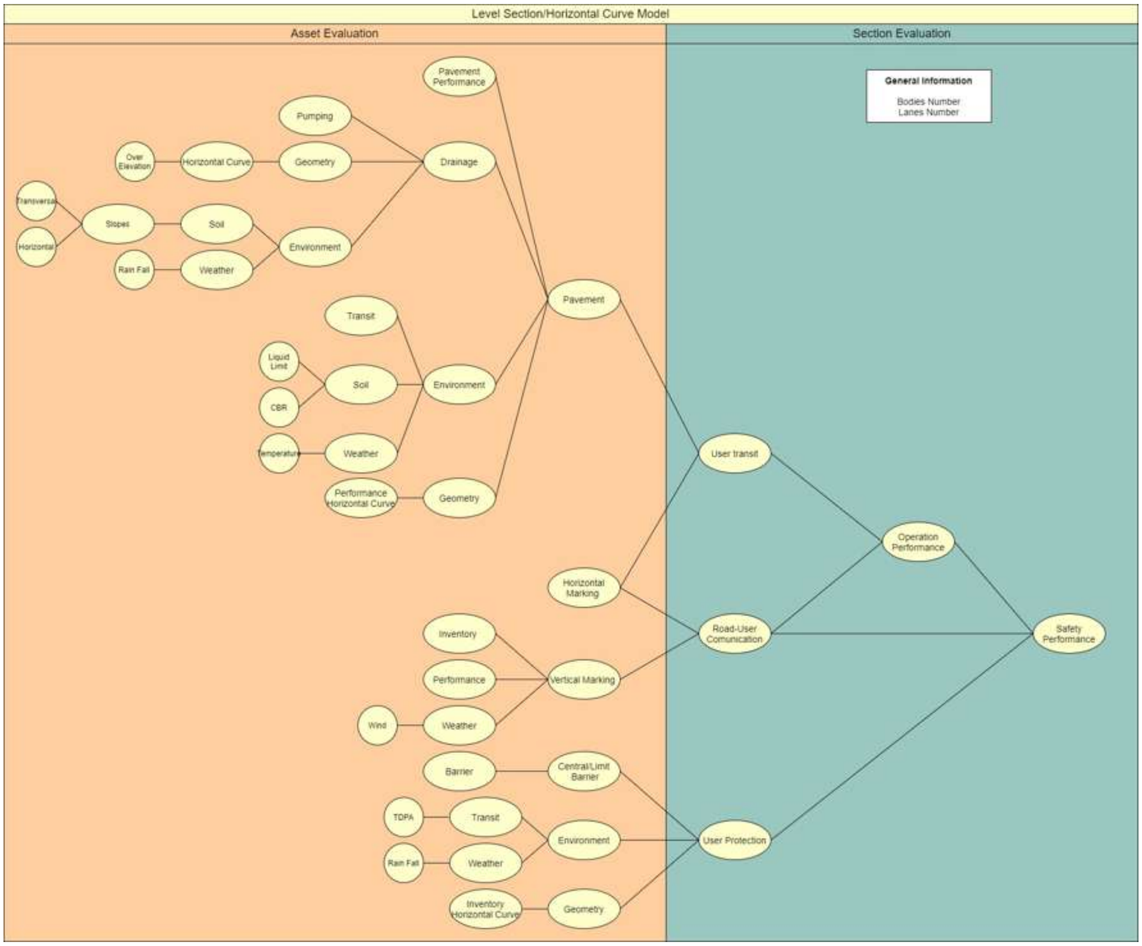


Figure 16.1: Horizontal Curve Level Section Performance evaluation

Pavement Drainage Environment						
Soil	Rain Fall			Soil	Rain Fall	
VG	VG	VG		B	VG	G
VG	G	VG		B	G	B
VG	B	G		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 16.1: Pavement Drainage Environment Fuzzy Rules

Pavement Drainage								
Pump	Ov. Elev.	Environ			Pump	Ov. Elev.	Environ	
VG	VG	VG	VG		B	VG	VG	G
VG	VG	G	VG		B	VG	G	G
VG	VG	B	G		B	VG	B	B
VG	VG	VB	G		B	VG	VB	VB
VG	G	VG	G		B	G	VG	G
VG	G	G	G		B	G	G	G
VG	G	B	G		B	G	B	B
VG	G	VB	G		B	G	VB	VB
VG	B	VG	B		B	B	VG	B
VG	B	G	B		B	B	G	B
VG	B	B	B		B	B	B	B
VG	B	VB	B		B	B	VB	VB
VG	VB	VG	B		B	VB	VG	B
VG	VB	G	B		B	VB	G	VB
VG	VB	B	VB		B	VB	B	VB
VG	VB	VB	VB		B	VB	VB	VB
G	VG	VG	G		VB	VG	VG	B
G	VG	G	G		VB	VG	G	B
G	VG	B	G		VB	VG	B	B
G	VG	VB	G		VB	VG	VB	B
G	G	VG	G		VB	G	VG	B
G	G	G	G		VB	G	G	B
G	G	B	G		VB	G	B	B
G	G	VB	G		VB	G	VB	B
G	B	VG	G		VB	B	VG	B
G	B	G	G		VB	B	G	VB
G	B	B	B		VB	B	B	VB
G	B	VB	B		VB	B	VB	VB
G	VB	VG	B		VB	VB	VG	VB
G	VB	G	B		VB	VB	G	VB
G	VB	B	VB		VB	VB	B	VB
G	VB	VB	VB		VB	VB	VB	VB

Table 16.2: Pavement Drainage Fuzzy Rules

Soil										
LL	CBR			LL	CBR			LL	CBR	
VG	VG	VG		G	VG	VG		B	VG	B
VG	G	VG		G	G	G		B	G	B
VG	R	G		G	R	G		B	R	VB
VG	B	B		G	B	B		B	B	VB
VG	VB	B		G	VB	B		B	VB	VB

Table 16.3: Pavement Environment Soil Fuzzy Rules

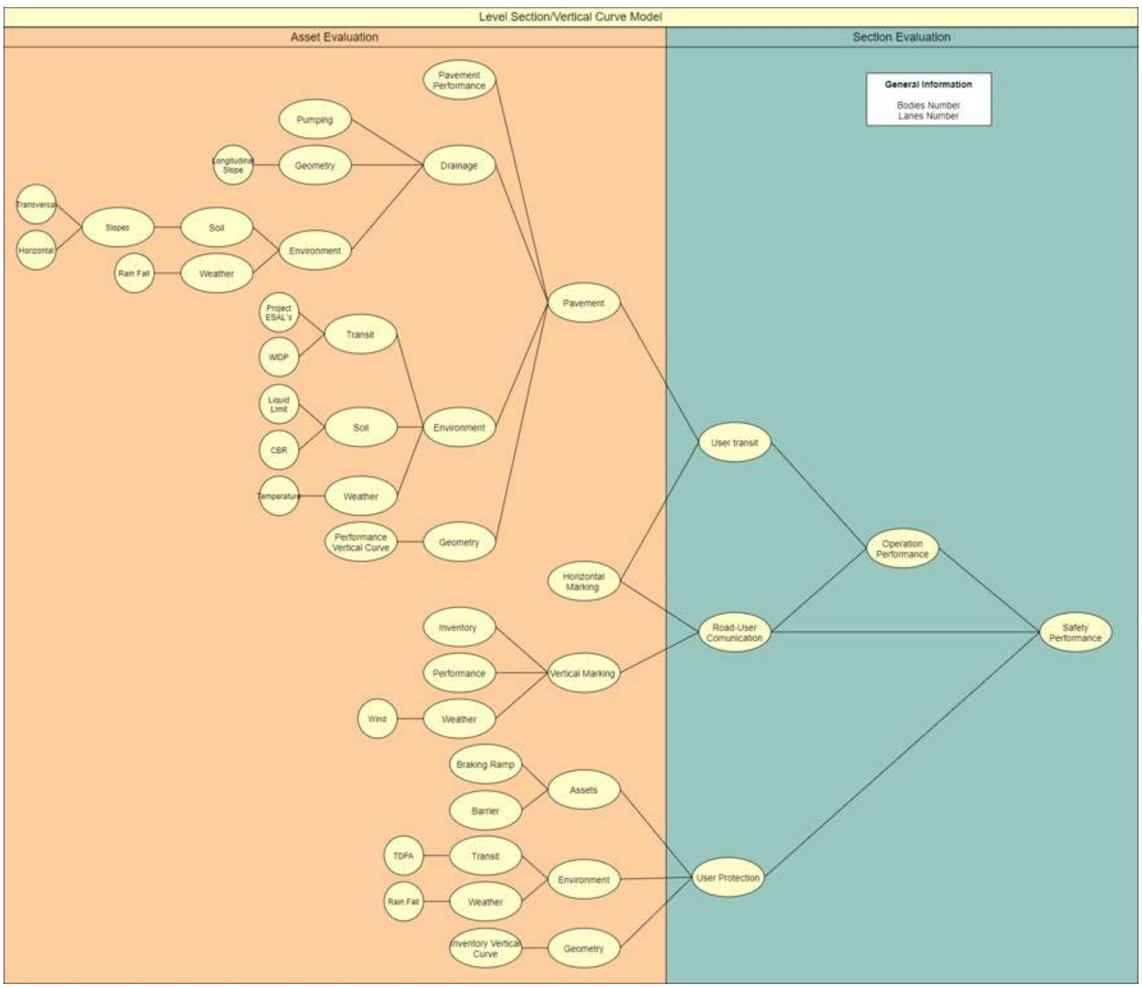


Figure 16.2: Vertical Curve Level Section Performance evaluation

Pavement										
Perf	Drain	H Curve	Environ			Perf	Drain	H Curve	Environ	
VG	VG	VG	VG	VG		VG	B	VG	VG	G
VG	VG	VG	G	VG		VG	B	VG	G	G
VG	VG	VG	B	VG		VG	B	VG	B	G
VG	VG	VG	VB	VG		VG	B	VG	VB	G
VG	VG	G	VG	VG		VG	B	G	VG	G
VG	VG	G	G	VG		VG	B	G	G	G
VG	VG	G	B	VG		VG	B	G	B	G
VG	VG	G	VB	G		VG	B	G	VB	G
VG	VG	B	VG	B		VG	B	B	VG	B
VG	VG	B	G	B		VG	B	B	G	B
VG	VG	B	B	B		VG	B	B	B	B
VG	VG	B	VB	B		VG	B	B	VB	B
VG	VG	VB	VG	VB		VG	B	VB	VG	VB
VG	VG	VB	G	VB		VG	B	VB	G	VB
VG	VG	VB	B	VB		VG	B	VB	B	VB
VG	VG	VB	VB	VB		VG	B	VB	VB	VB
VG	G	VG	VG	VG		VG	VB	VG	VG	B
VG	G	VG	G	VG		VG	VB	VG	G	B
VG	G	VG	B	VG		VG	VB	VG	B	B
VG	G	VG	VB	VG		VG	VB	VG	VB	B
VG	G	G	VG	VG		VG	VB	G	VG	B
VG	G	G	G	G		VG	VB	G	G	B
VG	G	G	B	G		VG	VB	G	B	B
VG	G	G	VB	G		VG	VB	G	VB	B
VG	G	B	VG	B		VG	VB	B	VG	VB
VG	G	B	G	B		VG	VB	B	G	VB
VG	G	B	B	B		VG	VB	B	B	VB
VG	G	B	VB	B		VG	VB	B	VB	VB
VG	G	VB	VG	VB		VG	VB	VB	VG	VB
VG	G	VB	G	VB		VG	VB	VB	G	VB
VG	G	VB	B	VB		VG	VB	VB	B	VB
VG	G	VB	VB	VB		VG	VB	VB	VB	VB

Table 16.4: Pavement Fuzzy Rules. 1)

Pavement										
Perf	Drain	H Curve	Environ			Perf	Drain	H Curve	Environ	
G	VG	VG	VG	G		G	B	VG	VG	G
G	VG	VG	G	G		G	B	VG	G	G
G	VG	VG	B	G		G	B	VG	B	G
G	VG	VG	VB	G		G	B	VG	VB	G
G	VG	G	VG	G		G	B	G	VG	G
G	VG	G	G	G		G	B	G	G	G
G	VG	G	B	G		G	B	G	B	G
G	VG	G	VB	G		G	B	G	VB	G
G	VG	B	VG	B		G	B	B	VG	B
G	VG	B	G	B		G	B	B	G	B
G	VG	B	B	B		G	B	B	B	B
G	VG	B	VB	B		G	B	B	VB	B
G	VG	VB	VG	VB		G	B	VB	VG	VB
G	VG	VB	G	VB		G	B	VB	G	VB
G	VG	VB	B	VB		G	B	VB	B	VB
G	VG	VB	VB	VB		G	B	VB	VB	VB
G	G	VG	VG	G		G	VB	VG	VG	B
G	G	VG	G	G		G	VB	VG	G	B
G	G	VG	B	G		G	VB	VG	B	B
G	G	VG	VB	G		G	VB	VG	VB	B
G	G	G	VG	G		G	VB	G	VG	B
G	G	G	G	G		G	VB	G	G	B
G	G	G	B	G		G	VB	G	B	B
G	G	G	VB	G		G	VB	G	VB	B
G	G	B	VG	B		G	VB	B	VG	VB
G	G	B	G	B		G	VB	B	G	VB
G	G	B	B	B		G	VB	B	B	VB
G	G	B	VB	B		G	VB	B	VB	VB
G	G	VB	VG	VB		G	VB	VB	VG	VB
G	G	VB	G	VB		G	VB	VB	G	VB
G	G	VB	B	VB		G	VB	VB	B	VB
G	G	VB	VB	VB		G	VB	VB	VB	VB

Table 16.5: Pavement Fuzzy Rules. 2)

Pavement										
Perf	Drain	H Curve	Environ			Perf	Drain	H Curve	Environ	
B	VG	VG	VG	B		B	B	VG	VG	B
B	VG	VG	G	B		B	B	VG	G	B
B	VG	VG	B	B		B	B	VG	B	B
B	VG	VG	VB	B		B	B	VG	VB	B
B	VG	G	VG	B		B	B	G	VG	B
B	VG	G	G	B		B	B	G	G	B
B	VG	G	B	B		B	B	G	B	B
B	VG	G	VB	B		B	B	G	VB	B
B	VG	B	VG	B		B	B	B	VG	B
B	VG	B	G	B		B	B	B	G	B
B	VG	B	B	B		B	B	B	B	B
B	VG	B	VB	VB		B	B	B	VB	VB
B	VG	VB	VG	VB		B	B	VB	VG	VB
B	VG	VB	G	VB		B	B	VB	G	VB
B	VG	VB	B	VB		B	B	VB	B	VB
B	VG	VB	VB	VB		B	B	VB	VB	VB
B	G	VG	VG	B		B	VB	VG	VG	VB
B	G	VG	G	B		B	VB	VG	G	VB
B	G	VG	B	B		B	VB	VG	B	VB
B	G	VG	VB	VB		B	VB	VG	VB	VB
B	G	G	VG	B		B	VB	G	VG	VB
B	G	G	G	B		B	VB	G	G	VB
B	G	G	B	B		B	VB	G	B	VB
B	G	G	VB	VB		B	VB	G	VB	VB
B	G	B	VG	B		B	VB	B	VG	VB
B	G	B	G	B		B	VB	B	G	VB
B	G	B	B	B		B	VB	B	B	VB
B	G	B	VB	VB		B	VB	B	VB	VB
B	G	VB	VG	VB		B	VB	VB	VG	VB
B	G	VB	G	VB		B	VB	VB	G	VB
B	G	VB	B	VB		B	VB	VB	B	VB
B	G	VB	VB	VB		B	VB	VB	VB	VB

Table 16.6: Pavement Fuzzy Rules. 3)

Pavement										
Perf	Drain	H Curve	Environ			Perf	Drain	H Curve	Environ	
VB	VG	VG	VG	B		VB	B	VG	VG	VB
VB	VG	VG	G	B		VB	B	VG	G	VB
VB	VG	VG	B	VB		VB	B	VG	B	VB
VB	VG	VG	VB	VB		VB	B	VG	VB	VB
VB	VG	G	VG	B		VB	B	G	VG	VB
VB	VG	G	G	B		VB	B	G	G	VB
VB	VG	G	B	VB		VB	B	G	B	VB
VB	VG	G	VB	VB		VB	B	G	VB	VB
VB	VG	B	VG	B		VB	B	B	VG	VB
VB	VG	B	G	B		VB	B	B	G	VB
VB	VG	B	B	VB		VB	B	B	B	VB
VB	VG	B	VB	VB		VB	B	B	VB	VB
VB	VG	VB	VG	B		VB	B	VB	VG	VB
VB	VG	VB	G	B		VB	B	VB	G	VB
VB	VG	VB	B	VB		VB	B	VB	B	VB
VB	VG	VB	VB	VB		VB	B	VB	VB	VB
VB	G	VG	VG	B		VB	VB	VG	VG	VB
VB	G	VG	G	B		VB	VB	VG	G	VB
VB	G	VG	B	VB		VB	VB	VG	B	VB
VB	G	VG	VB	VB		VB	VB	VG	VB	VB
VB	G	G	VG	B		VB	VB	G	VG	VB
VB	G	G	G	B		VB	VB	G	G	VB
VB	G	G	B	VB		VB	VB	G	B	VB
VB	G	G	VB	VB		VB	VB	G	VB	VB
VB	G	B	VG	B		VB	VB	B	VG	VB
VB	G	B	G	B		VB	VB	B	G	VB
VB	G	B	B	VB		VB	VB	B	B	VB
VB	G	B	VB	VB		VB	VB	B	VB	VB
VB	G	VB	VG	B		VB	VB	VB	VG	VB
VB	G	VB	G	B		VB	VB	VB	G	VB
VB	G	VB	B	VB		VB	VB	VB	B	VB
VB	G	VB	VB	VB		VB	VB	VB	VB	VB

Table 16.7: Pavement Fuzzy Rules. 4)

User Transit						
Assets	H Mark			Assets	H Mark	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	B
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 16.8: User Transit Fuzzy Rules

Vertical Marking								
Inv	Perf	Wind			Inv	Perf	Wind	
VG	VG	VG	VG		B	VG	VG	G
VG	VG	G	VG		B	VG	G	G
VG	VG	B	VG		B	VG	B	B
VG	VG	VB	VG		B	VG	VB	B
VG	G	VG	G		B	G	VG	G
VG	G	G	G		B	G	G	B
VG	G	B	G		B	G	B	B
VG	G	VB	G		B	G	VB	B
VG	B	VG	B		B	B	VG	B
VG	B	G	B		B	B	G	B
VG	B	B	B		B	B	B	B
VG	B	VB	B		B	B	VB	VB
VG	VB	VG	B		B	VB	VG	VB
VG	VB	G	B		B	VB	G	VB
VG	VB	B	VB		B	VB	B	VB
VG	VB	VB	VB		B	VB	VB	VB
G	VG	VG	VG		VB	VG	VG	G
G	VG	G	G		VB	VG	G	G
G	VG	B	G		VB	VG	B	B
G	VG	VB	G		VB	VG	VB	B
G	G	VG	G		VB	G	VG	B
G	G	G	G		VB	G	G	B
G	G	B	G		VB	G	B	B
G	G	VB	G		VB	G	VB	VB
G	B	VG	B		VB	B	VG	VB
G	B	G	B		VB	B	G	VB
G	B	B	B		VB	B	B	VB
G	B	VB	B		VB	B	VB	VB
G	VB	VG	B		VB	VB	VG	VB
G	VB	G	B		VB	VB	G	VB
G	VB	B	VB		VB	VB	B	VB
G	VB	VB	VB		VB	VB	VB	VB

Table 16.9: Vertical Marking Fuzzy Rules

Road-User Comunication						
Horiz	Vert			Horiz	Vert	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	B		B	VB	VB
G	VG	VG		VB	VG	B
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	B		VB	VB	VB

Table 16.10: Road-User Comunication Fuzzy Rules

Operation Performance						
U Transit	R-U Com			U Transit	R-U Com	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	G		B	B	B
VG	VB	B		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	VB
G	B	G		VB	B	VB
G	VB	B		VB	VB	VB

Table 16.11: Operation Performance Fuzzy Rules

Environment						
ESAL´S	R Fall			ESAL´S	R Fall	
L	L	G		M	H	G
L	N	G		M	VH	B
L	M	G		H	L	G
L	H	B		H	N	G
L	VH	B		H	M	B
N	L	VG		H	H	B
N	N	VG		H	VH	VB
N	M	G		VH	L	B
N	H	G		VH	N	B
N	VH	B		VH	M	B
M	L	VG		VH	H	VB
M	N	VG		VH	VH	VB
M	M	G				

Table 16.12: User Protection Environment Fuzzy Rules

User Protection								
Geom	Assets	Environ			Geom	Assets	Environ	
VG	VG	VG	VG		B	VG	VG	G
VG	VG	G	VG		B	VG	G	G
VG	VG	B	VG		B	VG	B	G
VG	VG	VB	G		B	VG	VB	G
VG	G	VG	G		B	G	VG	G
VG	G	G	G		B	G	G	G
VG	G	B	G		B	G	B	B
VG	G	VB	G		B	G	VB	B
VG	B	VG	G		B	B	VG	B
VG	B	G	G		B	B	G	B
VG	B	B	B		B	B	B	B
VG	B	VB	B		B	B	VB	VB
VG	VB	VG	B		B	VB	VG	VB
VG	VB	G	B		B	VB	G	VB
VG	VB	B	VB		B	VB	B	VB
VG	VB	VB	VB		B	VB	VB	VB
G	VG	VG	G		VB	VG	VG	B
G	VG	G	G		VB	VG	G	B
G	VG	B	G		VB	VG	B	B
G	VG	VB	G		VB	VG	VB	B
G	G	VG	G		VB	G	VG	B
G	G	G	G		VB	G	G	B
G	G	B	G		VB	G	B	B
G	G	VB	G		VB	G	VB	B
G	B	VG	B		VB	B	VG	VB
G	B	G	B		VB	B	G	VB
G	B	B	B		VB	B	B	VB
G	B	VB	B		VB	B	VB	VB
G	VB	VG	B		VB	VB	VG	VB
G	VB	G	B		VB	VB	G	VB
G	VB	B	VB		VB	VB	B	VB
G	VB	VB	VB		VB	VB	VB	VB

Table 16.13: User Protection Fuzzy Rules

Safety Performance								
Op Perf	R-U Com	U. Prot.			Op Perf	R-U Com	U. Prot.	
VG	VG	VG	VG		B	VG	VG	B
VG	VG	G	VG		B	VG	G	B
VG	VG	B	G		B	VG	B	B
VG	VG	VB	B		B	VG	VB	VB
VG	G	VG	VG		B	G	VG	B
VG	G	G	VG		B	G	G	B
VG	G	B	B		B	G	B	B
VG	G	VB	B		B	G	VB	VB
VG	B	VG	G		B	B	VG	B
VG	B	G	G		B	B	G	B
VG	B	B	B		B	B	B	B
VG	B	VB	B		B	B	VB	VB
VG	VB	VG	B		B	VB	VG	VB
VG	VB	G	B		B	VB	G	VB
VG	VB	B	VB		B	VB	B	VB
VG	VB	VB	VB		B	VB	VB	VB
G	VG	VG	G		VB	VG	VG	B
G	VG	G	G		VB	VG	G	B
G	VG	B	G		VB	VG	B	VB
G	VG	VB	B		VB	VG	VB	VB
G	G	VG	G		VB	G	VG	B
G	G	G	G		VB	G	G	B
G	G	B	B		VB	G	B	VB
G	G	VB	B		VB	G	VB	VB
G	B	VG	G		VB	B	VG	VB
G	B	G	G		VB	B	G	VB
G	B	B	B		VB	B	B	VB
G	B	VB	VB		VB	B	VB	VB
G	VB	VG	VB		VB	VB	VG	VB
G	VB	G	VB		VB	VB	G	VB
G	VB	B	VB		VB	VB	B	VB
G	VB	VB	VB		VB	VB	VB	VB

Table 16.14: Safety Performance Fuzzy Rules

Assets						
Barrier	B Ramp			Barrier	B Ramp	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 16.15: User Protection Assets Fuzzy Rules

Assets						
Pump	Kerb			Pump	Kerb	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	VG		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 16.16: Pavement Drainage Assets Fuzzy Rules

Assets						
B Chute	Culvert			B Chute	Culvert	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	VG		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 16.17: Embankment Drainage Assets Fuzzy Rules

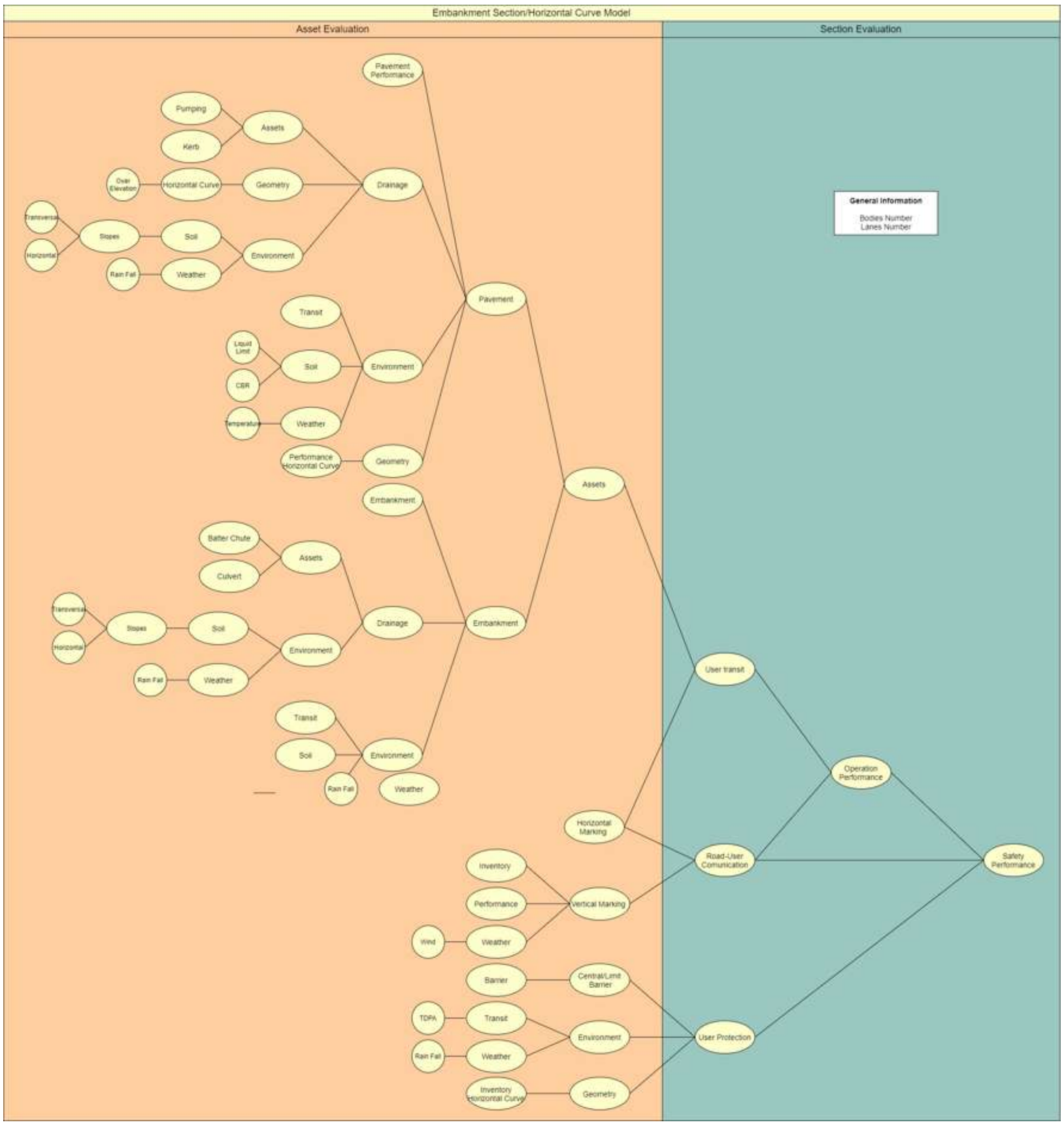


Figure 16.3: Horizontal Curve Embankment Section Performance evaluation

Drainage						
Assets	Environ			Assets	Environ	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	G		B	B	B
VG	VB	G		B	VB	VB
G	VG	G		VB	VG	B
G	G	G		VB	G	VB
G	B	G		VB	B	VB
G	VB	G		VB	VB	VB

Table 16.18: Geotechnical Drainage Fuzzy Rules

Geotechnical Asset								
Asset	Drain	Environ			Asset	Drain	Environ	
VG	VG	VG	VG		B	VG	VG	B
VG	VG	G	VG		B	VG	G	B
VG	VG	B	G		B	VG	B	B
VG	VG	VB	G		B	VG	VB	VB
VG	G	VG	G		B	G	VG	B
VG	G	G	G		B	G	G	B
VG	G	B	G		B	G	B	B
VG	G	VB	G		B	G	VB	VB
VG	B	VG	G		B	B	VG	B
VG	B	G	G		B	B	G	B
VG	B	B	G		B	B	B	B
VG	B	VB	G		B	B	VB	VB
VG	VB	VG	B		B	VB	VG	VB
VG	VB	G	B		B	VB	G	VB
VG	VB	B	B		B	VB	B	VB
VG	VB	VB	B		B	VB	VB	VB
G	VG	VG	G		VB	VG	VG	B
G	VG	G	G		VB	VG	G	B
G	VG	B	G		VB	VG	B	VB
G	VG	VB	G		VB	VG	VB	VB
G	G	VG	G		VB	G	VG	B
G	G	G	G		VB	G	G	VB
G	G	B	G		VB	G	B	VB
G	G	VB	G		VB	G	VB	VB
G	B	VG	G		VB	B	VG	VB
G	B	G	G		VB	B	G	VB
G	B	B	B		VB	B	B	VB
G	B	VB	B		VB	B	VB	VB
G	VB	VG	B		VB	VB	VG	VB
G	VB	G	B		VB	VB	G	VB
G	VB	B	B		VB	VB	B	VB
G	VB	VB	B		VB	VB	VB	VB

Table 16.19: Geotechnical Asset Fuzzy Rules (Embankment, Cutting)

Assets						
Pavement	Geotechnical			Pavement	Geotechnical	
VG	VG	VG		B	VG	B
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 16.20: Assets Fuzzy Rules

Assets						
Pump	Ditch			Pump	Ditch	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	VG		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 16.21: Pavement Drainage Assets Fuzzy Rules

Assets						
C Ditch	B Chute			C Ditch	B Chute	
VG	VG	VG		B	VG	B
VG	G	VG		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	VG		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 16.22: Cutting Drainage Assets Fuzzy Rules

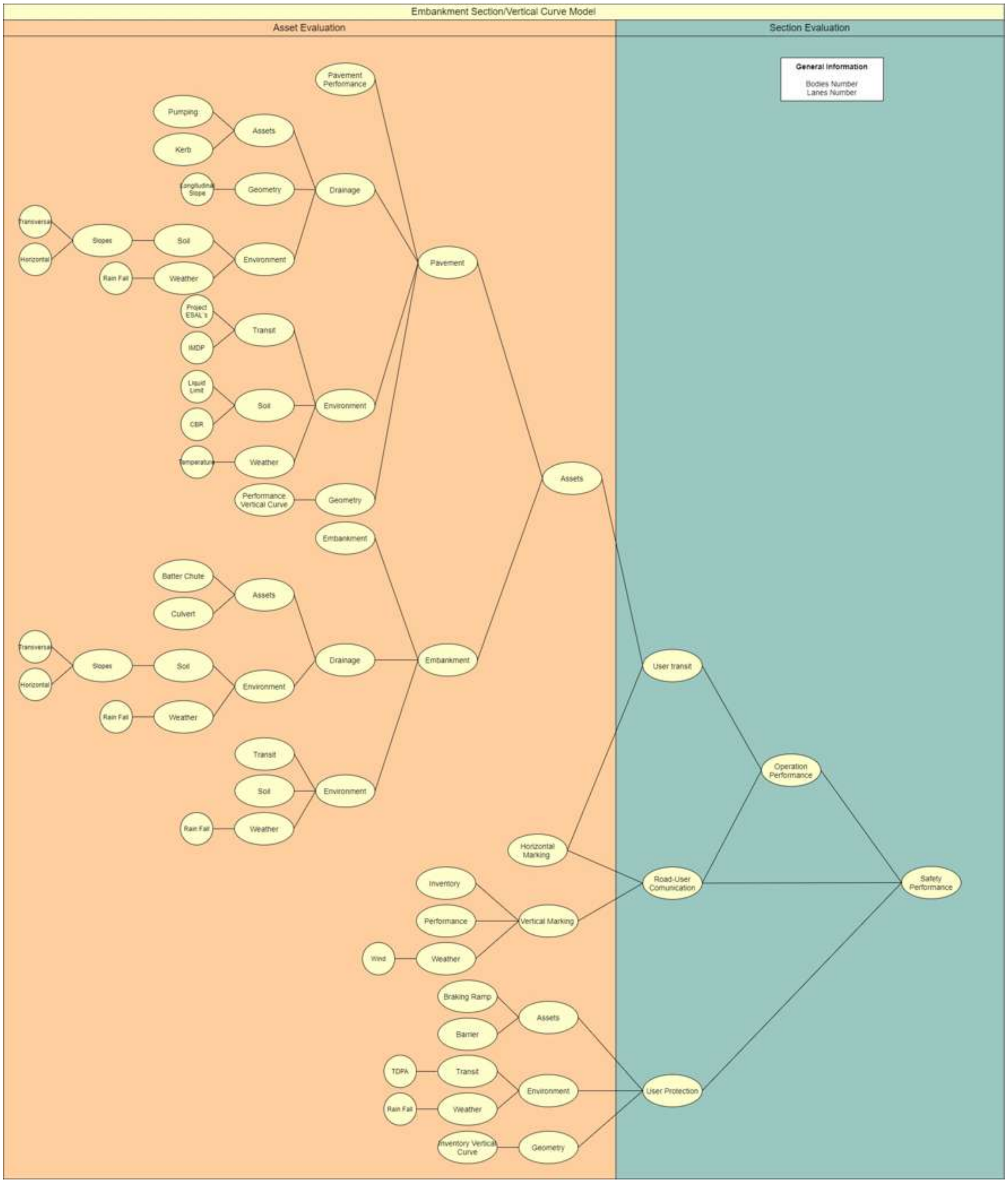


Figure 16.4: Vertical Curve Embankment Section Performance evaluation

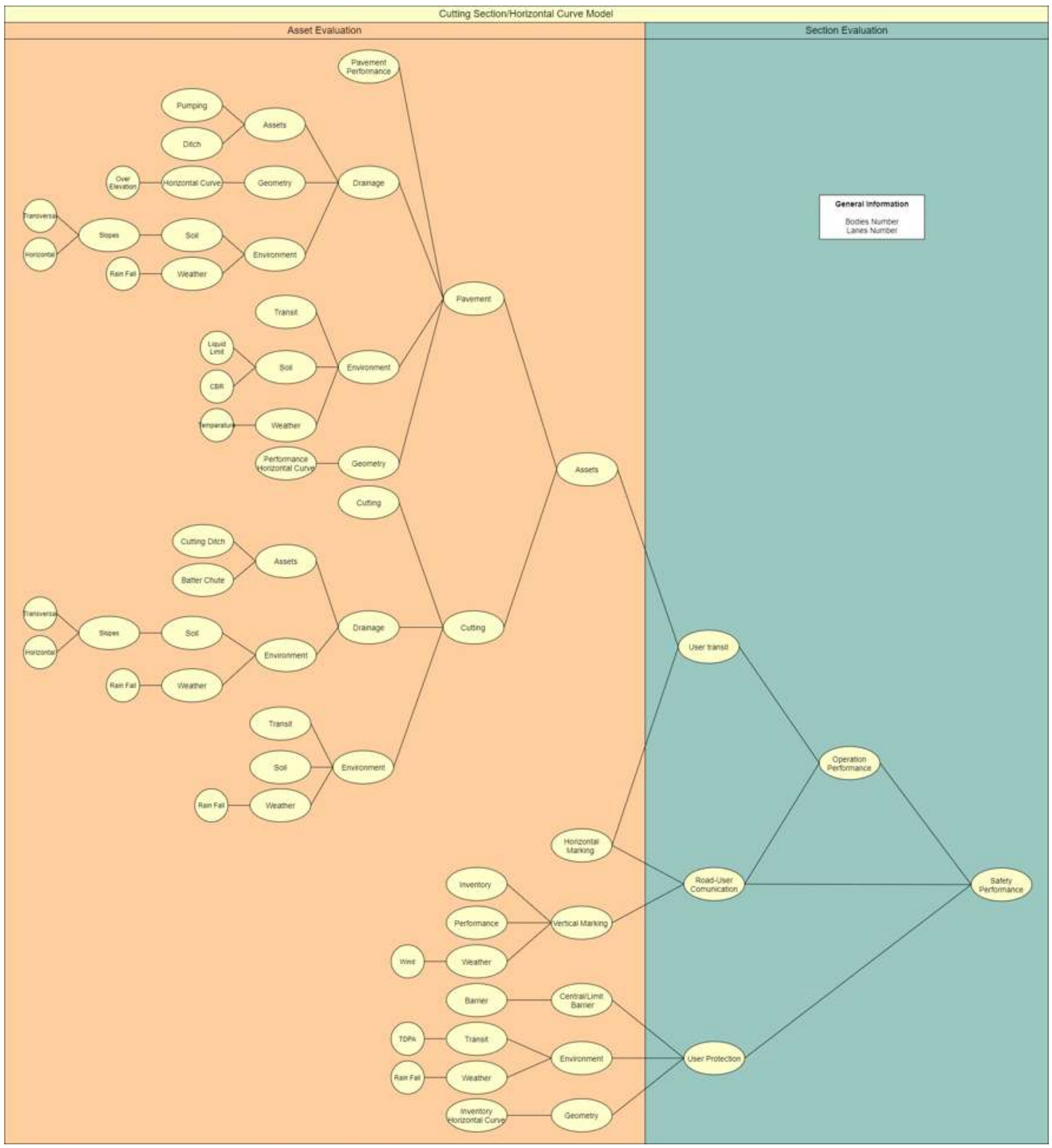


Figure 16.5: Horizontal Curve Cutting Section Performance evaluation

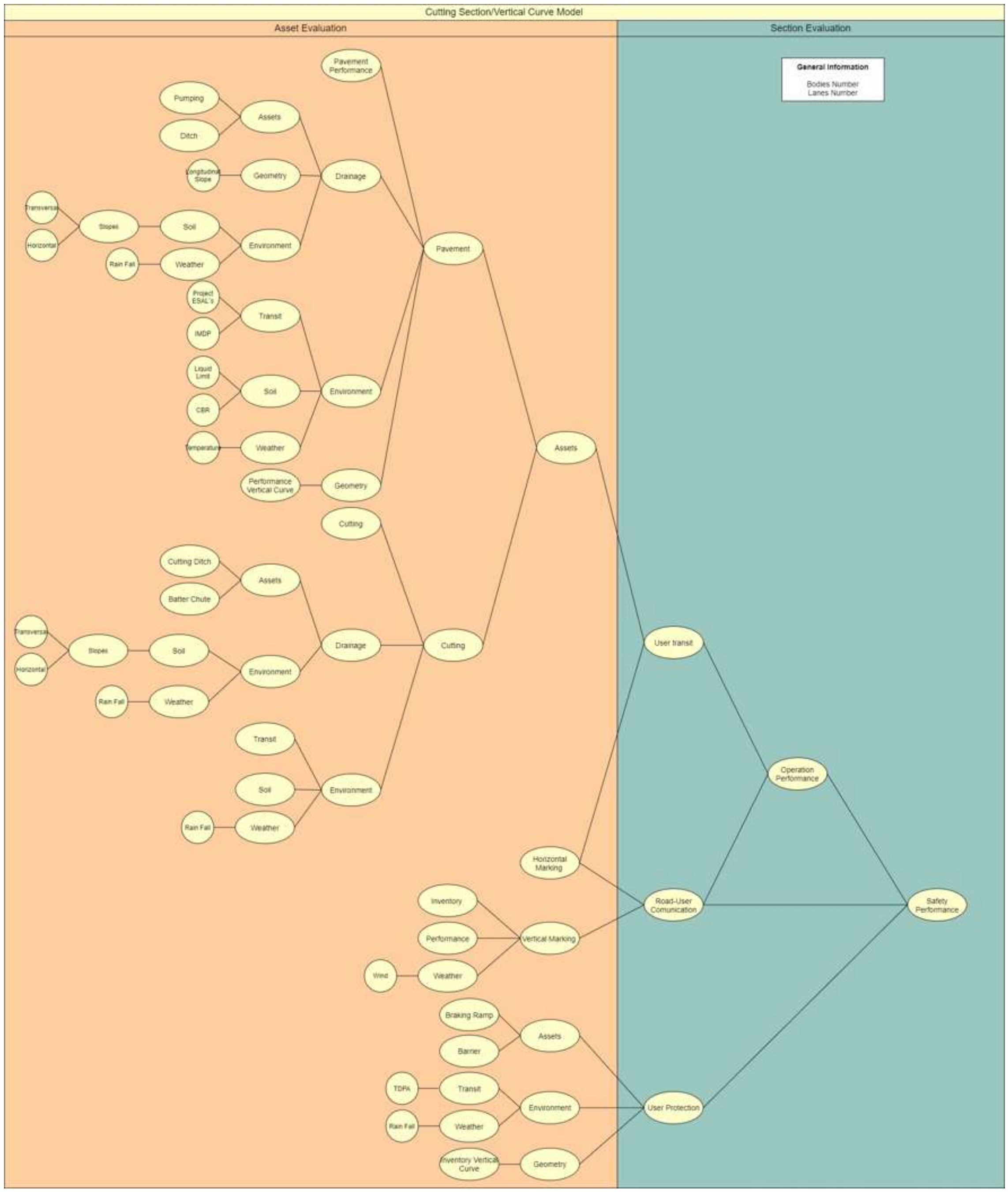


Figure 16.6: Vertical Curve Cutting Section Performance evaluation

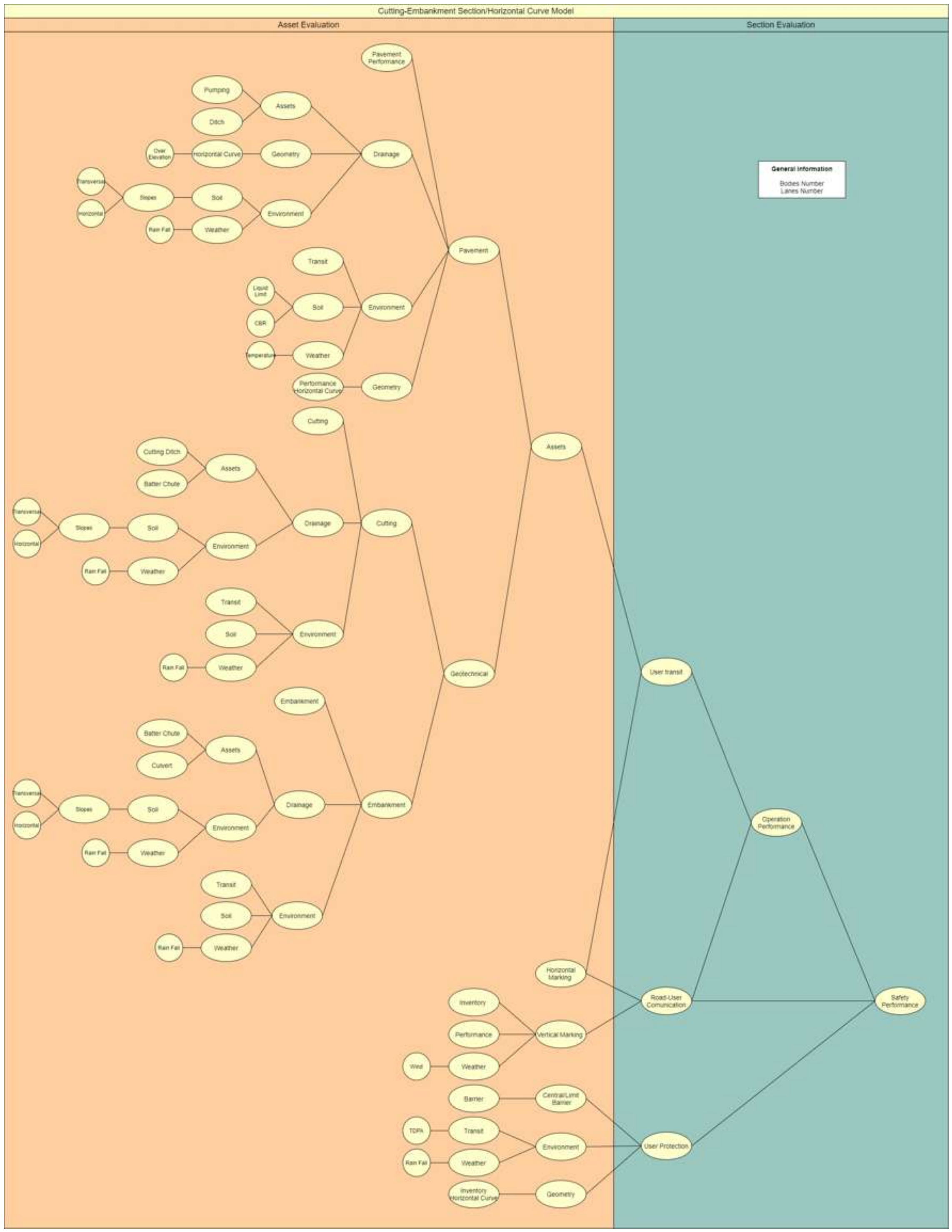


Figure 16.7: Horizontal Curve Cutting/Embankment Section Performance evaluation

Geotechnical Assets						
Embankment	Cutting			Embankment	Cutting	
VG	VG	VG		B	VG	B
VG	G	G		B	G	B
VG	B	B		B	B	B
VG	VB	VB		B	VB	VB
G	VG	G		VB	VG	VB
G	G	G		VB	G	VB
G	B	B		VB	B	VB
G	VB	VB		VB	VB	VB

Table 16.23: Geotechnical Assets Fuzzy Rules

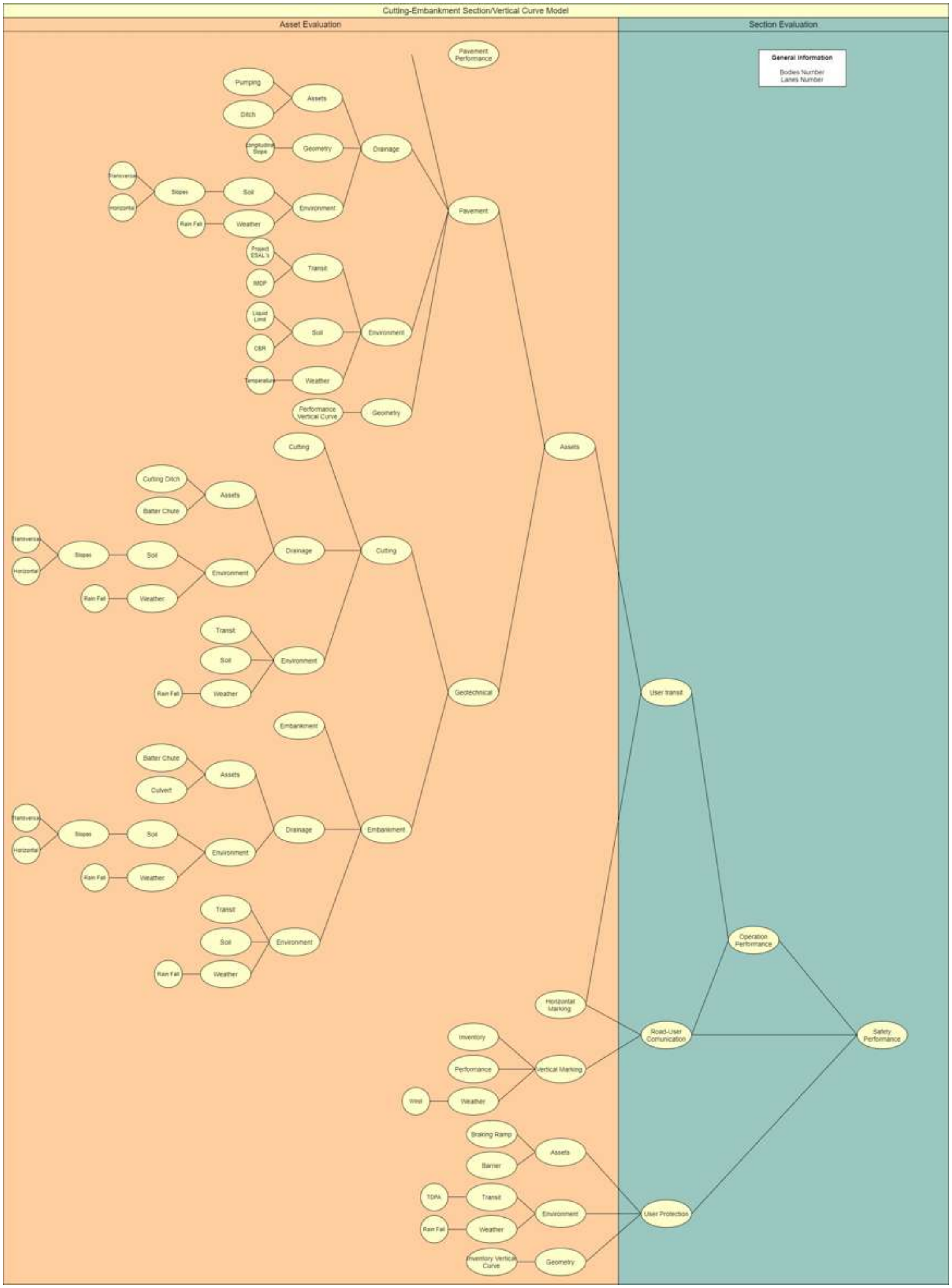


Figure 16.8: Vertical Curve Cutting/Embankment Section Performance evaluation

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