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GI:DRM
Global Initiative on Disaster Risk Management

DISASTER RISK MANAGEMENT IN PUBLIC INVESTMENT IN HIGHWAYS

Why is defining critical projects important for sustainable investment?

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GENERAL INTRODUCTION

The Global Initiative on Disaster Risk Management, a project implemented by the German Development Cooperation (GIZ) and commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ), is supporting international and national, governmental and non-governmental selected stakeholders in their efforts to achieve coherence in terms of planning, implementing and reporting disaster risk management in line with the Sendai Framework for Disaster Risk Management, the Paris Agreement and other international agendas, such as the 2030 Agenda and Habitat III.

The assignment has been commissioned by the GIDRM to assist countries in Latin American and the Caribbean in organizing their infrastructure in terms of disaster risks. The assignment is focusing on the road infrastructure of Chile, Costa Rica and Mexico. In the 2018 DIRCAIBEA meeting (November 2018 in Guatemala) the goal and work plan (framework and work strategy) of the assignment were presented to prepare the soil for more fruitful work during the visits to the different countries. It is worth noting that this assignment is part of the 2030 agenda of the Paris Agreement, the Sendai Framework and Habitat III which all highlight the role of public investment in infrastructure with regard to disaster risk management.

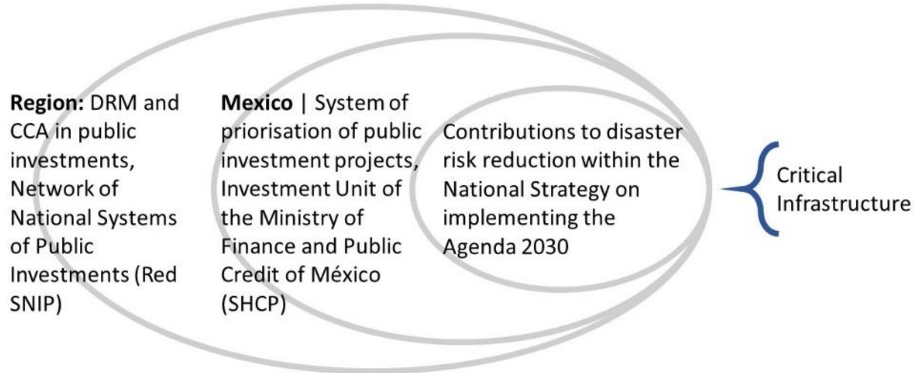
Figure 1: Targets of the Sendai Framework for Disaster Risk Reduction and its Priorities

Figure 2: Sustainable Development Goals and targets of Goal 9 directly related to disaster risk management

It is important to bear in mind that the long-term goal is to have a common Latin American model for disaster risk assessment in critical road infrastructure, thus achieving great synergies between the different countries and enabling easy and accumulative transfer of experiences.

At first sight, materialization of DRM in Latin America and the Caribbean in terms of critical infrastructure is as shown figure 3:

Figure 3: The GIDRM and critical infrastructure in Latin American and the Caribbean



However, in order to achieve these higher goals, it is necessary to understand what critical infrastructure is, how it can be classified as such and how this is related to the concept of disaster risk management. In other words, a proper strategy is to be designed that combines these two concepts (disaster risk and criticality), gives them a logical joint action structure, and, very importantly, that makes sense to all authorities involved in public-investment decision-making.

In this sense the following logical decision structure was designed which applies to any country where the concept of criticality and effectivity in assigning resources is relevant (see figure 4).

Figure 4: Solution strategy. Diagram linking criticality to disaster risk

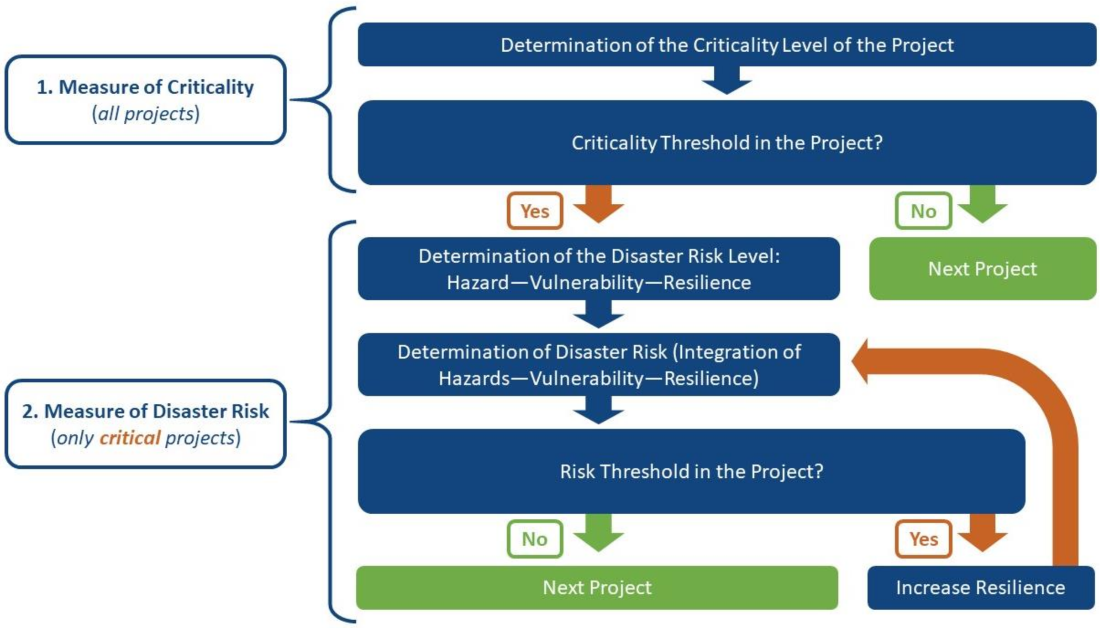


Figure 4 shows the logic behind the strategy. It can be described in three steps:

- First, the idea is to determine what the critical road infrastructures for the country are, from a point of view capable of integrating multiple criteria and based upon absolute proportional metrics to enable a mathematically valid way of analyzing and synthesizing, a reliable measurement ruler and their possible thresholds or acceptable criticality maximum, in view and in the perspective of the different decisionmakers and specialists (multi-purpose vision). All of this is immerged in the multicriteria analysis models, particularly in AHP/ANP (Analytic Hierarchy Process/Analytic Network Process).
- Second, once it has been defined which are the critical highways (critical road infrastructure), the second phase of the solution strategy can commence, which is presented in figure 4 and assesses the level or degree of disaster risk said infrastructure is subject to in terms of its present threats, degree of exposure, vulnerability and response capacities.
- Third, for those infrastructures defined as critical and that are subject to a high risk level (higher than the previously calculated risk acceptability threshold), a mitigation or adjustment of the risk is conducted to improve its capacity (for example: robustness, speed and/or redundancy), in their design stage, construction stage and/or already built stage. This can be done efficiently, meaning, to such point that the gap between the acceptable risk threshold and the calculated risk value, if this exceeds it, can be closed.

This solution scheme or strategy allows for prioritization of those highways that require more or faster attention (efficiency and response speed when assigning resources). This way, investments can be made to overcome the risk gap and place the project below the acceptable risk level or threshold (Project Risk < Acceptable Risk Threshold). Finally, this leads to the execution of investments that are indeed required for the project (not more, not less) in the required timespan.

It is important to keep this strategy in mind throughout the assignment; in fact, it is the reason for the reorientation of the way to face the work initially described in the Conditions. For example, the Bases mention interviews in Chile, Costa Rica and Mexico. However, and in line with the strategy shown in figure 4, it is much more efficient to hold multicriteria and multipurpose workshops to present and improve the criticality measurement model, in order to achieve the 3 central points, in line with the strategy presented.

The three points are the following:

- A clear and transversal definition of the concept of criticality in road infrastructure.
- An assessment model or models representing the criticality defined in the previous points and the most homogeneous (transversal) characteristics as possible for the different countries.
- Criticality metrics (measurement ruler) agreed upon between the different institutions relevant to the road infrastructure problem and assignation of resources of the country.

DEFINITION OF THE OVERALL GOAL

As a starting point of any decision-making process, first an agreement needs to be reached on the overall goal to be achieved. In this case the *goal* is: "To measure the criticality degree of road infrastructure" in order to classify it in comparison to the existing road network.

To achieve this, there should be clarity on the concept of criticality. The UNDRR terminology shows a first approach to the concept of critical infrastructure. In general, critical infrastructure is defined as: "The physical structures, facilities, networks and other assets which provide services that are essential to the social and economic functioning of a community or society.".

Even though that definition of criticality in infrastructure gives an orientation, it is not sufficient for the purposes looked for here and it has to be adjusted to the specific case of road infrastructure. In other words, the central concept of "physical structures for the functioning or essential service to community" needs to be translated to road infrastructure, to then make it operative (obtain an achievement measure).

For this purpose, the central concept used in road environment which is "connectivity" was used. The main goal pursued in road infrastructure is connectivity of the network. This means, keeping the network always connected to be able to deliver the services required for the community.

Based on this, two things can be concluded regarding the main goal. First, the idea of road connectivity should be essential and, second, it should be related to the concepts of physical, functional and community and/or social infrastructure, so as to give an integral answer to the concept of criticality, and, at the same time, remain aligned with the definition given for critical infrastructure in general.

When following this logic, the following can be defined:

GOAL OF THE MODEL: Building a measurement ruler to prioritize routes according to their degree of criticality.

CRITICALITY: any element or situation significantly altering connectivity in the road network.

This way, a critical route can be defined as follows:

CRITICAL ROUTE: a route (or part of it), whose failing potentially seriously affects functional, physical and/or social connectivity of the network.

Therefore, the ultimate purpose of classifying critical highways is:

"Ensuring connectivity in the territory in priority sections in terms of their physical, functional and social infrastructure".

Once the strategy and the general goal have been clearly and measurably defined, workshops were held in the focus countries.

MULTICRITERIA SESSION IN CHILE

Overall goal Chile: Building a criticality model for highways, validating applicability in the context of the Chilean road network and determining the weights of the strategic criteria (1st hierarchy level).

Development

The assignment was carried out in two parts, on November 27th and 30th, 2018. The first meeting took place in the GIZ facilities in Santiago and was attended by specialists from the MOP (Ministry of Public Works), MDS (Ministry of Social Development), SUR (University Residence Service), GIZ and ECLAC (Economic Commission for Latin America and the Caribbean).

On November 30th an additional work session was held in the facilities of the MOP, specifically in the road department. The session aimed at revising the model obtained in the previous session and weighing its strategic criteria.

During the multicriteria session of November 27th, the following tasks were performed to fulfill the indicated goal:

1. Revision of the criticality model goal
2. Identification of assumptions
3. Construction of the proto-model (structure and main criteria)
4. Description/definition of criteria

Below, the main considerations related to the previous tasks are summarized.

1. Revision of the goal

Revising the goal was a difficult task, especially because there was no clarity on what to understand by criticality in highways and, above all, what the model would be used for in the long-term. This caused an important discussion around the purpose of the assignment, in the sense that the concept of criticality in highways should be clarified. Finally, an agreement was reached that the idea of criticality in highways must be closely related to the concept of connectivity, a base concept of the entire road system, as is explained at the end of the introduction chapter.

Based on this, the overall goal and the sentence associated to criticality and was developed and subsequently also used in the discussions in Costa Rica and Mexico. Below, the result is shown regarding the goal and its general explanation.

GOAL OF THE MODEL: Building a measurement ruler to prioritize routes according to their degree of criticality.

CRITICALITY: any element or situation significantly altering connectivity in the road network.

This way, a critical route can be defined as follows:

CRITICAL ROUTE: a route (or part of it) whose failing potentially seriously affects functional, physical and/or social connectivity of the network.

Therefore, the ultimate purpose of determining critical highways is to ensure connectivity on the national territory in priority sections.

The criticality model was given a precise purpose, namely, to be able to classify (in terms of basic measurement) critical structural or secondary routes or highways, in order to be able to define those highways for which it is a priority to perform a disaster risk analysis. It is not possible to perform the analysis for all highways, therefore, the highways identified as critical should be given priority.

The following figure (Figure 5) shows the logic behind the decision process, showing that, in case a highway is critical (high criticality degree), the highway is taken to the stage of assessing the degree of disaster risk it faces.

Figure 5: Decision structure for road infrastructure classification according to its degree of criticality

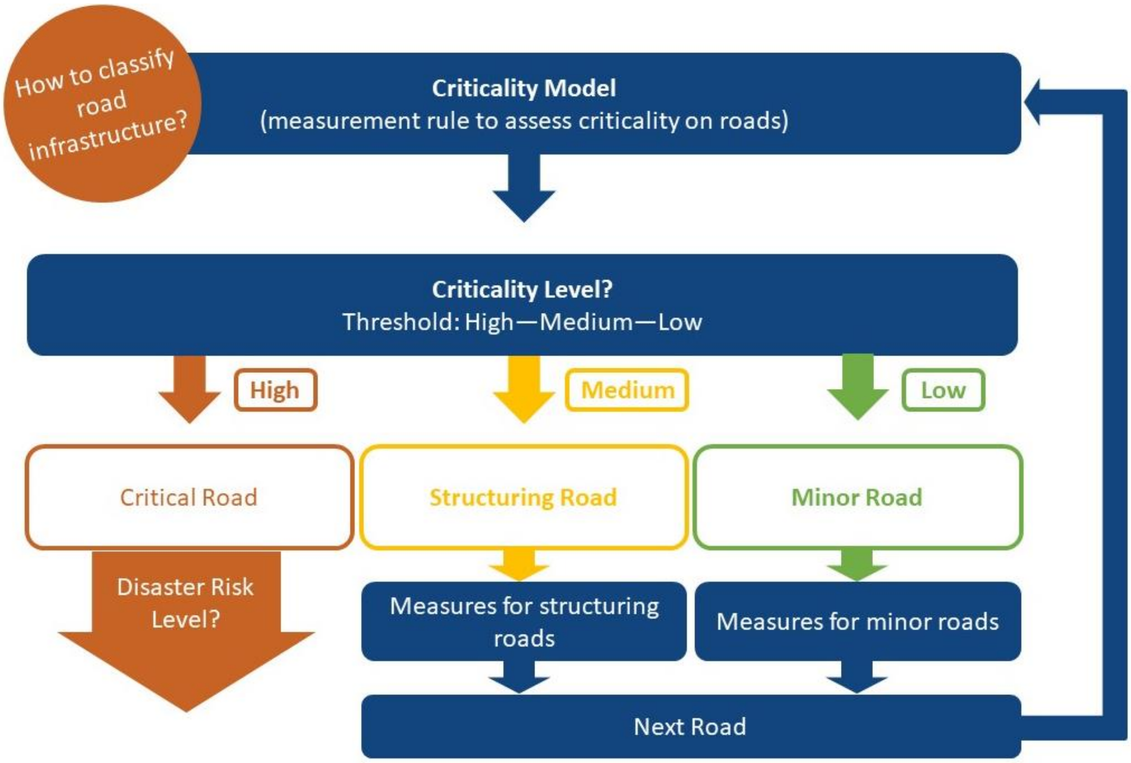
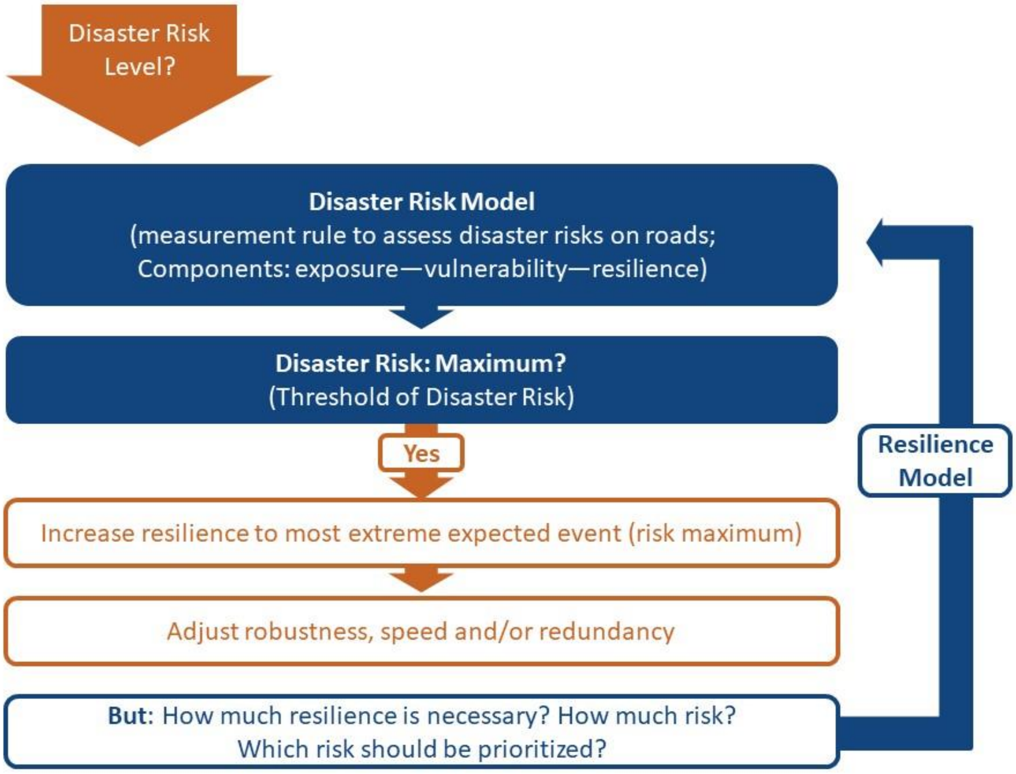


Figure 6 explains the decision logic for those highways that need a disaster risk analysis (critical highways):

Figure 6: Decision structure for road infrastructure classification according to its degree of criticality



Finally, a summary is given of the general strategy built in the sessions as well as office work, which reflects the decision-making logic of the entire process (Figure 4) and that was globally shown in the general introduction.

In simple terms, the way to make the strategy operative shows that, in a first stage, the highway criticality metrics have to be defined. With these metrics, or measurement ruler, all highway projects can be assessed to determine which are critical by comparing them to the criticality threshold (maximum acceptable degree of criticality)[1].

In a second stage, and only for a subset of critical highways, their degree of disaster risk they face in view of their threats, exposure, vulnerabilities and capacities is determined. Finally, for those critical highways with a disaster risk higher than the acceptability threshold[2], their capacities need to be increased to make them more resilient in terms of robustness, speed and/or redundancy until the existing gap is covered. The latter is calculated with the disaster risk determination metrics as the difference between the risk degree of the highway project's (or section according to the scale level the analysis is done with) and the maximum acceptability threshold.

The main advantage of this decision logic or operational scheme (see Figure 4: Solution strategy) is the optimization of the allocation of funds for disaster risks in highways to accelerate recovery of the services and the number of road goods affected, especially those of critical nature.

[1] The criticality threshold or maximum acceptable degree can be calculated with correctly defined absolute proportional metrics.
[2] Idem previous point.

2. Identification of assumptions

The following assumptions associated to the model, indicated with comments, were reviewed and confirmed as valid.

- The regulation in force on route classification and characteristics is applied.
- Highways are regularly submitted to maintenance as defined in the design. In other words, the state of maintenance of a highway or route is not a factor to consider in their criticality determination from connectivity perspective.
- Routes will be assessed not as a whole, but as the sum of "sections or components", which will be submitted to application of the scales associated with the terminal criteria. In the case of Mexico, the measurement unit applies to the section/subsection, which is the unit on which the information record is kept, and which is defined by "origin – destination".

3. Construction of the model (structure and criteria)

The model was built considering that their three branches or main criteria should be: physical criticality, functional criticality and social criticality, since these are the three basic elements or fundamental pillars all road planning should respond to.

4. Description/definition of criteria

Given the duration of the session, no efforts were made to explicitly define the model's criteria. It was agreed to review the final model (once analyzed in Costa Rica and Mexico) with the local team to review and complete the local definitions and weights as a task resulting from this exercise.

Below the criticality proto-model built in Chile is shown.

CRITICALITY MODEL

- ↳ **Goal: Prioritize routes according to their degree of criticality**
  - ↳ Physical Criticality (within and outside of the project) (D: ,431)
    - ↳ Number and capacity of alternative routes (outside of the project)
    - ↳ Arc size (within the project)
    - ↳ Traffic level (within the project)
    - ↳ Type and Number of active highways in the arc (road, bridge, viaduct, tunnel)
      - ↳ Type
      - ↳ Number
    - ↳ Standard (type of road paving or surface) road asset
  - ↳ Functional Criticality (D: ,355)
    - ↳ Access to production system
      - ↳ Local
      - ↳ Regional
      - ↳ National
      - ↳ International
    - ↳ Access to services
      - ↳ Drinking water
      - ↳ Safety (police, fire brigade, shelters)

↳ Health (hospitals, post, emergency center)
↳ Energy
↳ Harbors and airports

↳ Social Criticality (D: ,214)

↳ Degree of isolation

↳ Population characteristics

↳ Education level
↳ Percentage of poverty
↳ Percentage of people with disabilities
↳ Age distribution
↳ Indigenous communities

5. Obtaining the weights of the strategic criteria

The weights of the strategic (physical, functional and social) criteria were obtained by comparing the structure agreed upon to peers. The process was done openly, aspiring to obtain the consensus of all participants, without forming groups per institution.

For the strategic goals, the focus was placed on the priorities suggested ahead and may differ from those applied today. The process was one of great discussion and it was concluded that physical criticality is the most relevant concept to define a route's criticality, because:

- Even though functionality is essential, if we have no infrastructure, we cannot assign it a function.

It was validated that the consistency of the matrix of peer-comparisons was adequate (did not exceed the theoretical acceptability threshold according to the matrix size). In this case consistency was practically 100%.

In summary, the strategic criteria weights of the criticality model for Chile, in principal (and subject to later revision) are given by:

Strategic criterion	Weight
Physical criticality	43.1%
Functional criticality	35.5%
Social criticality	21.4%

Matrix inconsistency = 0.004%

6. Obtaining the measurement ruler

For the national case no global measurement ruler was obtained, since it only got to weighing the strategic criteria and physical, functional and social criticality (1st level criteria).

Conclusions of the visit

The goal of the multicriteria work session in Chile was fundamentally fulfilled. This means, both in terms of building a proto-model that would serve as a starting point for the rest of the countries (Costa Rica and Mexico) and for obtaining the weights of the strategic levels, even though these were only a first approach subject to revision after returning from the field work.

The following steps were established consisting of the revision of the model when returning to Chile, revision of the changes and, above all, the possible improvements carried out in Costa Rica and Mexico in order to perform a future integration of the models of the three countries into a homogenous Latin American model and develop a pilot instance to apply the model by assessing some selected highways and analyze the criticality classification of the associated sections.

MULTICRITERIA SESSION COSTA RICA

Overall goal Costa Rica: Reviewing and improving the proposed criticality model, validating applicability in the context of the Costa Rican road network, determining the weights of the strategic criteria and sub-criteria of each section, in order to obtain the global measurement ruler.

Development

The workshop was held on December 3rd and 4th, in the facilities of the Ministry of Public Works and Transport (MOPT by its acronym in Spanish) of Costa Rica, in the City of San José de Costa Rica, led by the vice-minister of Infrastructure, and with participation of specialists from the ministry, the national road commission and the ministry of planning.

During the session the following tasks were fulfilled to comply with the indicated goal:

1. Revision of the goal
2. Revision of the model (structure and criteria)
3. Description/definition of criteria
4. Identification of assumptions
5. Obtaining weights of strategic criteria
6. Obtaining weights of other criteria
7. Scale proposition for terminal criteria

Below, the main considerations or aspects related to the previous tasks are summarized.

1. Revision of the goal

The goal of the model is expressed as follows: ***Prioritizing (measuring) the routes according to their degree of criticality for the road network.***

In this sense, a critical route is understood to be one whose failing seriously affects connectivity of the network.

The Costa Rican team agreed with the suggested goal, with the clarification that, by regulatory dispositions, the MOPT has competence on the national and international routes and that, therefore, in this case the cantonal (communal) routes remain outside the scope, which are the responsibility of the relevant municipalities. Likewise, the goal was expressed in terms of routes, since the term “road” is not locally representative.

It is worth highlighting that, from theoretical perspective, the suggested model could be applied at municipal level, to classify its cantonal routs and later be consolidated nationwide, should a vision at that scale be required.

It was explicitly agreed not to include references to the use of the route criticality indicator within the context of disaster risk management, since said classification allows for a broader use, open to the nature inherent of the roads, which could be interesting to use in other fields.

2. Revision of the model (structure and criteria)

The proposed model was reviewed in terms of physical, functional and social criticality, and the understanding of the concept was discussed, validating that indeed a discrimination can be made between route criticality levels, sharing experiences to clarify terminologies and points of view.

In said revision the following guiding principles were applied:

- Focusing contributions towards reaching the proposed goal.
- Simplicity: gathering relevant information avoiding excessively detailed aspects which could make the model unnecessarily complex.
- Information availability should not be a restriction. In other words, if a certain concept was considered relevant, the unavailability of information should not lead to “removing” said model criterion.
- Multinationality: flexible vision in recognizing terms/realities, since the model would be applied in different countries.

The main adjustments/clarifications introduced to the model developed in Chile were the following:

- Terminology: ‘Route’ preferred over ‘road’, even when “critical route” is also a denomination of a project planning and follow-up methodology (CPM), but it is understood that in this context its meaning is associated with the criticality of the road.

Physical criticality criteria:

- Length of the section/arch: interest in the measurement associated to the habilitation time and cost. Note: the definition section is preferable over arch, since arch refers to identifiable reference points (cities) at its ends.
- Alternative route: refers to redundancy; what is interesting is the capacity to absorb traffic from the primary road, since it often presents restrictions in terms of the kind of

vehicles it can accept, therefore it is not fully equivalent. What is interesting is the possibility to deviate traffic, even when the associated times are not similar. Seasonal aspects can influence as well (routes not available in winter), but these were not considered.

- A key aspect of the alternative route is the capacity to absorb heavy traffic (4-axis trucks or buses) which, in case it is impossible to continue on the alternative route, may create great congestion.
- Concepts such as: turn radius, design speed or service level were analyzed and discarded.
- Air and maritime connectivity were not considered in the number of alternate routes.
- Topographical characteristics of the arch. Diverse components were reviewed and the following key aspects associated with the criticality slope (vertical curves) and road sinuosity (horizontal curves) were established.

Functional criticality criteria:

- Production system: the production system includes all the country's economic activities, such as tourism, financial services, computer services.
- Services: on many occasions, on the side or under the route there are service facilities (telecommunications, water piping), which means that an interruption of the road signifies an interruption of these services.
- A classification of the highways as international, national, regional and local is available for all routes in the country. A route can belong to only one of these categories.
- Telecommunications initially associated with optic fiber, Internet, considering that, in disaster emergencies, there is satellite phone service. However, given the low availability of this service at national level, the telephone service is kept within telecommunications.
- Ports, airports and intermodal stations also include train and bus stations, where a change from one means of transport to another takes place.
- Public transport as a service is discarded, since, generally, it is associated with all the routes, without adding criticality to the assessment of a section.

Social criticality criteria:

- Isolation: understood in function of the dependence of the population on the route's existence and availability.
- Population characteristics: Discussion on the criticality associated with the most vulnerable populations. Specific concepts are analyzed, and education is discarded because of its homogenous level in the country.
- % of poverty: measured by social development index.
- Influence area: the way to determine it has to be defined, to assure that application is uniform throughout the country.
- Connection routes: increase the criticality because of access to the population.
- Number of intersections with cantonal routes: the higher their number, the higher the criticality of the section.

As a summary of this activity, the work team was in agreement on the developed structure and confirmed that it is viable and they have the information required for the model at the level or scale of "control sections" (concept comparable to section).

3. Description/definition of criteria

No significant time was dedicated to explicitly define the model criteria. It was agreed to send the model to the local team to complete the definitions as a task emanating from this workshop. Nonetheless, precisions were included into the definitions of the criteria within the multicriteria decision model, to retain the main concepts.

4. Identification of Assumptions

The following assumptions were identified:

- The regulation in force on route classification and characteristics is applied.
- Highways are indeed submitted to maintenance as defined in the design. In other words, the state of maintenance of a highway or route is not a factor to consider in their criticality determination from connectivity perspective.
- Routes will finally be assessed not as a whole, but as the sum of "arches", which will be submitted to application of the scales associated with the terminal criteria. In the case of Costa Rica, the measurement unit is called Control Section, which is defined as units of at least 3km long, and on which the MOPT and other entities gather information and resources are assigned.

5. Obtaining weights of the strategic criteria

The weights were obtained by comparing the structure agreed upon to peers. The process was done openly, aspiring to obtain consensus of all participants, without forming groups per institution.

For the strategic goals, the focus was placed on what is desired for the future, not necessarily how things are done today. In this sense, it was estimated that physical criticality is the most relevant concept to define a route's criticality, because it is the indispensable means sustaining the highway's functionality.

In all cases, it was validated that the consistency of the matrix of peer-comparisons was adequate (did not exceed the theoretical acceptability threshold according to the matrix size).

The (consensus) strategic criteria weights for Costa Rica are the following:

Strategic criterion	Weight
Physical criticality	45.0%
Functional criticality	33.4%
Social criticality	21.6%

6. Obtaining weights of sub-criteria

The weights of other criteria were obtained by the same peer-comparison procedure.

The following figure shows the multicriteria decision model (AHP) with its structure and global weights of the variables. It is worth highlighting that these weights were obtained on 03/12 and others on 04/12.

CRITICALITY MEASUREMENT MODEL

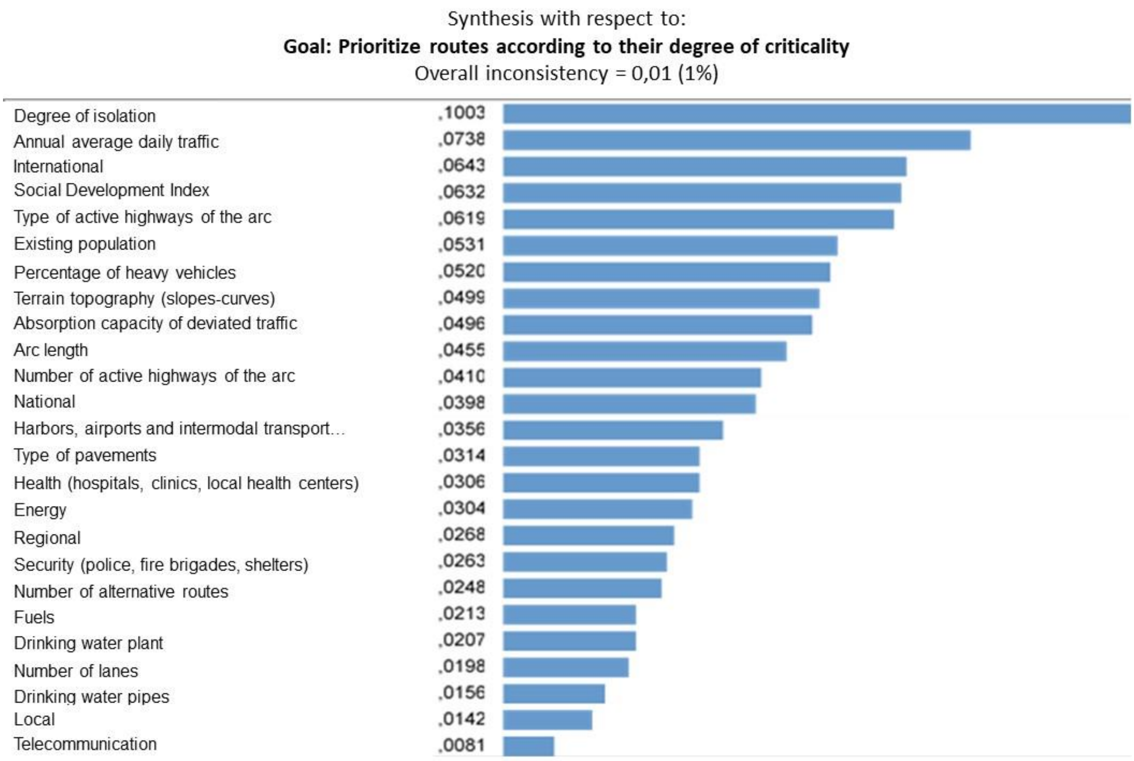
- ↳ **Goal: Prioritize routes according to their degree of criticality**
  - ↳ Physical Criticality (D: ,4498)
    - ↳ Number and capacity of alternative routes (D: ,0745)
      - ↳ Number of alternative routes (D: ,0248)
      - ↳ Absorbing capacity of diverted traffic (D: ,0496)
    - ↳ Arc length (D: ,0455)
    - ↳ Arc transit (D: ,1257)
      - ↳ Annual average daily traffic (D: ,0738)
      - ↳ Percentage of heavy vehicles (D: ,0520)
    - ↳ Type and Number of active highways in the arc (bridge, viaduct, tunnel, holding station) (D: ,1029)
      - ↳ Type of active highways in the arc (D: ,0619)
      - ↳ Number of active highways in the arc (D: ,0410)
    - ↳ Arc standard (D: ,1011)
      - ↳ Type of pavement (D: ,0314)
      - ↳ Number of lanes (D: ,0198)
      - ↳ Terrain topography (slopes-curves) (D: ,0499)
  - ↳ Functional Criticality (D: ,3336)
    - ↳ Access to production system (D: ,1451)
      - ↳ Local (D: ,0142)
      - ↳ Regional (D: ,0268)
      - ↳ National (D: ,0398)
      - ↳ International (D: ,0643)
    - ↳ Essential services facilities in the arc (D: ,1886)
      - ↳ Access to essential services facilities (D: ,1132)
        - ↳ Health (hospitals, clinics, local health center) (D: ,0306)
        - ↳ Safety (police, fire brigade, shelters) (D: ,0263)
        - ↳ Harbors, airports and intermodal transport in the arc (D: ,0356)
        - ↳ Drinking water plant (D: ,0207)
      - ↳ Interruption of services (D: ,0754)
        - ↳ Telecommunication (D: ,0081)
        - ↳ Energy (D: ,0304)
        - ↳ Drinking water pipes (D: ,0156)
        - ↳ Fuels (D: ,0213)
  - ↳ Social Criticality (D: ,2166)
    - ↳ Degree of isolation (D: ,1003)
    - ↳ Social development index (D: ,0632)
    - ↳ Existing population (D: ,0531)

7. Measurement ruler

The measurement ruler says how the global weights of terminal criteria are distributed. Therefore, it indicates how the highway alternatives (sections or arches) will be measured and what criteria will impact most on their final assessment (degree of criticality) and to what extent.

The following figure shows the measurement ruler associated with the previous model.

Note: this ruler was shared with the people in Costa Rica at the end of the second day (session of December 4th).



On the measurement ruler it is easy to observe the following two situations:

1. The ruler is not entirely linear, even though its distribution is relatively uniform.
2. The ruler is composed of a total of 25 terminal criteria, also known as measurement indicators.
3. The joint importance of the first 9 terminal criteria represent 57% of the decision (56.81%), which indicates that these criteria play the most important role. This is in agreement with the statistical fact that they are criteria which represent at least 5% of the model's global weight.

8. Scale proposition for the terminal criteria

Once the measurement ruler had been established, it was agreed to continue with the terminal criteria scales, at least in their descriptive definition and levels. Below, the proposed scales are attached, grouped per physical, functional and social criticality branch.

Physical criticality	
Number of alternative routes	
None	
One	
More than one	
Traffic absorption capacity	
Only light and double-traction vehicles	
Only light vehicles	
All kinds of vehicles	
Length of the arch	
Extreme	> 20 kms
High	10 - 20 kms
Moderate	3 - 10 kms
Low	< 3 kms
AADT	
Strategic	> 25,000 annual daily average vehicles (total, not per lane)
High	Between 2,500 and 25,000
Moderate	Between 500 and 2499
Low	< 500
Percentage of heavy vehicles (trucks and buses)	
High	> 25 % daily average flow
Moderate	Between 10 and 24%
Low	< 10%
Type of road asset of the arch	
Very high	Viaduct or tunnel
High	Bridge (over water flow, above or under) or major sewage (> 6mt)
Medium	Drainage system (minor sewage) and walls
Low	Pavements
Number of road asset of the arch	
Two or more	Two or more assets present in the section/arch
One	One asset
None	No assets

Type of pavement	
Dirt	Dirt section
Gravel	Gravel section
Asphalt or concrete	Asphalt or concrete section
Number of lanes	
One	Section of one lane per side
Two	Section of two lanes per side
More than two	Section of more than two lanes per side
Topography of the terrain	
Extreme	Mountainous and sinuous
High	Straight or wavy mountainous and sinuous
Moderate	Wavy and straight or flat and sinuous
Low	Flat and straight

Functional criticality	
Local	
Yes	Does it belong to the basic access network in the National Transport plan? (2011 - 2035)
No	Does not belong
Regional	
Yes	Does it belong to the regional distributors network in the National Transport Plan? (2011 - 2035)
No	Does not belong
National	
Yes	Does it belong to the territorial integration connector network in the National Transport Plan? (2011 - 2035)
No	Does not belong
International	
Yes	Does it belong to the high capacity network in the National Transport Plan? (2011 - 2035)
No	Does not belong
Health (hospital, clinic, health center)	
None	No presence in this section/arch
One	One in this section/arch

More than one	More than one present in this section/arch
Safety (police, firefighters, shelters)	
None	No presence in this section/arch
One	One in this section/arch
More than one	More than one present in this section/arch
Ports, airports and intermodal services	
None	No presence in this section/arch
One	One in this section/arch
More than one	More than one present in this section/arch
Drinking-water plant	
None	No presence in this section/arch
One	One in this section/arch
More than one	More than one present in this section/arch
Telecommunications	
None	No presence in this section/arch
One	One in this section/arch
More than one	More than one present in this section/arch
Energy	
None	No presence in this section/arch
One	One in this section/arch
More than one	More than one present in this section/arch
Water pipelines	
None	No presence in this section/arch
One	One in this section/arch
More than one	More than one present in this section/arch
Fuel	
None	No presence in this section/arch
One	One in this section/arch
More than one	More than one present in this section/arch

Social criticality
Degree of isolation

High	No other exit route
Moderate	At least one cantonal exit route
Low	At least one other national exit route
Social Development Index (SDI)	
Quintile I	Section belongs to Quintile I
Quintile II	Section belongs to Quintile II
Quintile III	Section belongs to Quintile III
Quintile IV	Section belongs to Quintile IV
Quintile V	Section belongs to Quintile V
Population density	
Quintile I	Section belongs to Quintile I
Quintile II	Section belongs to Quintile II
Quintile III	Section belongs to Quintile III
Quintile IV	Section belongs to Quintile IV
Quintile V	Section belongs to Quintile V

Conclusions of the Costa Rica visit

The goal of the work sessions in Costa Rica were fully achieved thanks to the participation of a motivated team interested in the topics presented.

The participation of the Vice-Minister was a clear sign of the interest in the construction of an index to determine the degree of criticality in highways within disaster risk management, thus recognizing that the resources available do not allow for the incorporation of mitigation measures in all the road infrastructure works and that, therefore, it is necessary to prioritize in terms of their degree of criticality.

Finally, we can mention that the team is competent in their field, very motivated and interested in having access to the final results and willing to participate in any kind of national highway criticality assessment pilot project, starting with the Vice-Minister himself.

REPORT ON THE MULTICRITERIA SESSION IN MEXICO

Overall goal Mexico: Review and improve the proposed criticality model, validating the applicability in the context of the Mexican road network and determining weights of the strategic criteria and their sub-criteria in order to obtain the global measurement ruler.

Development

The workshop took place on December 6th, 2018 in the GIZ facilities in Mexico City and was attended by specialists from the Secretariats of Communications and Transport (SCT) and Finance (SH).

On December 7th an additional work session was held in the facilities of the SCT, in particular in the General Highway Department, in order to share the current work lines in terms of allocating resources and classifying the federal roads and routes in Mexico.

During the multicriteria session on December 6th, the following tasks were performed in order to fulfill the indicated goal:

1. Revision of the goal of the criticality model
2. Identification of assumptions
3. Revision of the model (structure and criteria)
4. Description/definition of criteria
5. Obtaining weights of strategic criteria
6. Obtaining the measurement ruler
7. Revision of scales for terminal criteria

Below, the main considerations associated with the previous tasks are summarized. It should be highlighted that, in this opportunity, the presented model was obtained during the sessions held in Costa Rica. In other words, Mexico started with the model obtained in Costa Rica which is an improved and optimized version of the initial Chilean model.

1. Revision of the goal

The goal of the workshop generated some discussion, in terms of identifying the priority sections of the federal road network in which to incorporate disaster risk management, in order to optimize the allocation of funds for disasters, accelerate the recovery of services and the number of affected road goods. The idea to change the planning or filtering perspective to select disaster mitigation projects generated some uncertainty as to the use of the criticality classification.

This position was marked by the representatives of the Sub-secretariat of Communications and Transport who moved the work session to the following day.

The goal of the suggested model is expressed as followed: ***Prioritizing (measuring) the routes according to their degree of criticality for the road network.***

A critical road is understood to be a road whose failing significantly affects connectivity of the network. Therefore, the purpose of identifying critical highways is to ensure connectivity on the national territory.

The Mexican team validated the suggested goal with the following complementary considerations:

- In agreement about not including references to the context of disaster risk management, because this is a second stage once the highway criticality has been classified (see strategy), the goal should be framed in terms of planning and infrastructure with the Ministry of Finance, who manages the Public Investment System.
- The Secretariat of Telecommunications and Transport has competence over the federal roads only. The roads that are the responsibility of state governments or at rural level are outside this scope. In any case, like in Costa Rica, the suggested model could also be applied at state level, to classify its local routes and then be consolidated nationwide.
- The importance of starting with highways in disaster risk management since they have no insurance coverage, and then extending to other branches. In this sense, it can be applied to the existing network as well as in the creation of new highways, after a disaster risk analysis.
- Criticality is a vision "parallel" to the concept of importance (primary and secondary networks), whose overlap position can be determined after a highway assessment exercise.
- The parameters considered to determine the primary highways include directly affected population, special access points (ports, airports), GDP of the area, etc.

The Mexican highways are classified in three groups: federal (50 thousand kms built), state (150 thousand km built) and rural and connection highways (200 thousand km built).

Federal highways in Mexico, eminently freeways, are classified as follows:

Type of highway	Comments
Primary network (25 thousand kms)	Formed by mainlines (19 thousand kms) and inter-mainlines (6 thousand kms). They do not get into urban areas.
Secondary network (25 thousand kms)	

2. Identification of assumptions

The following assumptions associated to the model, indicated with comments, were reviewed and confirmed as valid.

- The regulation in force on route classification and characteristics is applied.
- Highways are effectively submitted to maintenance as defined in the design. In other words, the state of maintenance of a highway or route is not a factor to consider in their criticality determination from connectivity perspective.
- Routes will be assessed not as a whole, but as the sum of "sections", which will be submitted to application of the scales associated with the terminal criteria. In the case of Mexico, the measurement unit applies to the section/subsection, which is the unit on which the information record is kept, and which is defined by "origin – destination".

3. Revision of the model (structure and criteria)

The suggested model was reviewed according to its physical, functional and social criticality. The understanding of the involved concepts was discussed by sharing experiences to clarify terminology and validating that it would indeed enable the determination of criticality levels between highways.

Said analysis applied the same principles as those applied in Costa Rica:

- Focus on contributions to achieving the proposed goal
- Simplicity
- Availability of information must not be a restriction
- Multinationality

Below, some considerations/explanations/discussions points on the revision of the model are mentioned.

Physical criticality criteria:

- Presence of service points or phytosanitary revision points. A discussion was held on including them in the sense of whether or not they constituted complementary assets (emergency stations, fuel supply, food facilities, rest and sanitary services, truck weighting) and it was decided to exclude them as they are not relevant for the concept of criticality.
- Access to facilities: The criterion of “access to border crossings” (immigration, customs, phytosanitary controls) was added, which are the dry or height ports. The criterion of “access to administrative and financial services” was added too.
- The Spanish term for “water pipeline”, “cañerías de agua” was replaced by “tuberías de agua”.

Functional criticality criteria:

- At state network level, the Secretariat of Transport has no more information on the indicators associated with local characteristics.

Social criticality criteria:

- In Mexico there are several development indexes. The following were addressed: multidimensional poverty index, human development index (of the UNDP), the index of social lag (from the National Assessment Council, Coneval), the margination index, definitely converging by the Multidimensional Poverty Index (MPI), which would be the equivalent for poverty measurement of the IDS indicator suggested in Costa Rica. This index considers the measurement of social shortage in aspects such as education, access to basic services (health, emergency, etc.), access to social security, access to food and aspects of quality and living spaces.
- As for the assessment of poverty, it is measured per section. This makes it compulsory to define, at operational level how to execute it. One option is to interpolate values according to the populations directly connected by the section, or by taking the value for the worst case. The question was raised for internal discussion.

As a summary of this activity, the work team was in agreement on the developed structure and confirmed that its operation is viable in the federal highways since there is information available at the level of section/sub-section to perform an assessment at the required level.

4. Description/definition of criteria

Given the duration of the session, no efforts were made to explicitly define the model's criteria. It was agreed to send the model to the local team to complete the definitions as a task resulting from this exercise. Regardless, precisions were included in the criteria within the multicriteria decision model, in order to retain the main concepts.

5. Obtaining the weights of the strategic criteria

The weights were obtained by comparing the structure agreed upon to peers. The process was done openly, aspiring to obtain the consensus of all participants, without forming groups per institution.

For the strategic goals, the focus was placed on the priorities suggested ahead and may differ from those applied today. The process was one of great discussion and it was concluded that functional criticality is the most relevant concept to define a route's criticality, because:

- It directly serves the route's connectivity goal; in other words, the service is the ultimate purpose of the infrastructure (above the infrastructure itself)
- Functional or operational continuity of the service synthesizes the effect interruptions cause to the production system or services through infrastructure.
- Functionality is the most perceptible point also for the community.

In all cases, it was validated that the consistency of the matrix of peer-comparisons was adequate (did not exceed the theoretical acceptability threshold according to the matrix size).

In summary, the strategic criteria weights of the criticality model for Mexico are given by:

Strategic criterion	Weight
Physical criticality	21.6%
Functional criticality	56.8%
Social criticality	21.6%

6. Obtaining the measurement ruler

The weights of the remaining criteria were obtained by the same procedure. The figure below shows the structure with their associated global weights. It is worth mentioning that in the session on December 6th only the weights of the first, second and third level criteria were reviewed, and for the fourth (last) level the values proposed for Costa Rica were maintained.

The following figure shows the multicriteria decision model (AHP), its criteria, structure and weights of the variables.

Regarding the criterion Access to Production System, the highway classification was reformulated for the highways existing in the federal network: mainlines, inter-mainlines and secondary highways.

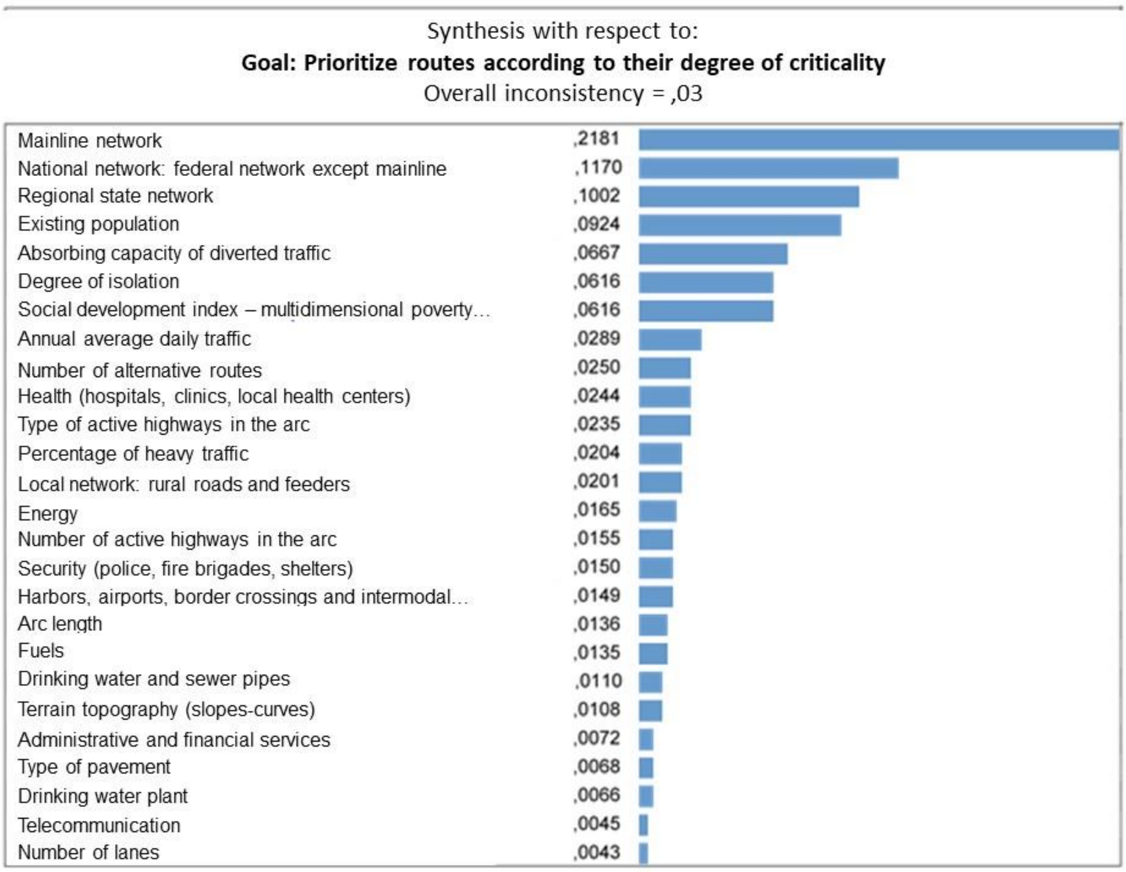
CRITICALITY MODEL

- ↳ **Goal: Prioritize routes according to their degree of criticality**
    - ↳ Physical Criticality (D: ,216)
        - ↳ Number and capacity of alternative routes (D: ,092)
            - ↳ Number of alternative routes (D: ,025)
            - ↳ Absorbing capacity of diverted traffic (D: ,067)
        - ↳ Arc length (D: ,014)
        - ↳ Arc transit (D: ,049)
            - ↳ Annual average daily traffic (D: ,029)
            - ↳ Percentage of heavy vehicles (D: ,020)
        - ↳ Type and Number of active highways in the arc (bridge, viaduct, tunnel) (D: ,039)
            - ↳ Type of active highways in the arc (D: ,023)
            - ↳ Number of active highways in the arc (D: ,016)
        - ↳ Arc standard (D: ,022)
            - ↳ Type of pavement (D: ,007)
            - ↳ Number of lanes (D: ,004)
            - ↳ Terrain topography (slopes-curves) (D: ,011)
    - ↳ Functional Criticality (D: ,569)
        - ↳ Access to production system (D: ,455)
            - ↳ Mainline network (D: ,218)
            - ↳ Local network: local roads and feeders (D: ,020)
            - ↳ Regional state network (D: ,100)
            - ↳ National network: federal network except mainline (D: ,117)
        - ↳ Access to essential service facilities in the area or interruption of those services (D: ,114)
            - ↳ Access to facilities (D: ,068)
                - ↳ Health (hospitals, clinics, local health center) (D: ,024)
                - ↳ Safety (police, fire brigade, shelters) (D: ,015)
                - ↳ Harbors, airports, border crossings and intermodal transport in the arch (D: ,015)
                - ↳ Drinking water plant (D: ,007)
                - ↳ Administrative and financial services (D: ,007)
            - ↳ Interruption of services (D: ,045)
                - ↳ Telecommunication (D: ,004)
                - ↳ Energy (D: ,016)
                - ↳ Drinking water and sewer pipes (D: ,011)
                - ↳ Fuels (D: ,013)
    - ↳ Social Criticability (D: ,216)
        - ↳ Degree of isolation (D: ,062)
        - ↳ Social development index – multidimensional poverty index (D: ,062)
        - ↳ Existing population (D: ,092)

Measurement ruler

The measurement ruler shows the relative importance of the terminal criteria in the criticality assessment and establishes the most determining criteria in the criticality level of the highway sections or arches and to what extent.

The following figure shows the measurement ruler associated with the previous model. This ruler was shared with the participants and the end of the session and validated by the attendants.



In the previous measurement ruler, the following can be observed:

- The ruler is formed by a total of 26 terminal criteria or measurement indicators, and their distribution is clearly not linear (it could, in general, approach an exponential curve with a negative exponent like $x^{(-n)}$). The important thing is that three large zones are highlighted in the graph.
- In the first zone the first 4 terminal criteria can be classified: mainline, regional, state and population network existing in the section, which belong to the functional criticality branch and which represent 52.77% of the criticality decision, which indicates that these are the criteria which mainly determine the criticality of a section.
- Then there is a 2nd zone (intermediate zone) with 3 more terminal criteria: absorption capacity of the alternate highway, degree of isolation of the population and social development index, part of the social criticality branch, which represent 18.99% of the criti-

cality decision. It is worth noting that, if we add these two zones up, over 70% of the decision on highway criticality is obtained covering the 7 criteria which each weigh over 5% of the total.

- Finally, there is a 3rd zone (inferior zone) with 19 indicators (with less than 5% each), which together represent 30% of the total.

7. Revision of scales for the terminal criteria

Once the measurement ruler had been established, the proposed definitions of the scale levels of the terminal criteria were superficially analyzed. Though no explicit modifications were introduced, some scales were detected where the size of Mexico requires to review the proposed definitions based upon the Costa Rican scale. This aspect leads to supposing that, in the general application of the developed model, it is possible that countries should analyze and introduce some adjustments to the scales in terms of volume/size of the road network to be assessed. Below, only the scales are mentioned where the attendants indicated that, in principle, it would be necessary to review the definition of the levels.

Physical criticality	
Number of alternative routes: Could be interesting to differentiate 2 or more than two	
None	There is no alternative route
One	There is at least one alternative route
More than one	There are more than one alternative routes
Length of the section: validate the length of the section	
Extreme	> 20 kms
High	10 - 20 kms
Moderate	3 - 10 kms
Low	< 3 kms
AADT: Average traffic in accordance with the Mexican reality	
Strategic	> 25,000 vehicles annual daily average (total, not per lane)
High	Between 2,500 and 25,000
Moderate	Between 500 and 2499
Low	< 500
Percentage of heavy vehicles (trucks and buses): check Mexican statistics	
High	> 25 % daily average flow
Moderate	entre 10 - 24%
Low	< 10%
Number of lanes: check if it is convenient to separate 2 and more than 2	
One	Section of one lane per side
Two	Section of two lanes per side
More than two	Section with more than two lanes per side

Functional criticality	
Secondary	
Yes	Belongs
No	Does not belong
Inter-mainline	
Yes	Belongs
No	Does not belong
Mainline	
Yes	Belongs
No	Does not belong

Social criticality	
Degree of isolation: modify cantonal and national nomenclature	
High	No other exit route
Moderate	At least one other cantonal exit route
Low	At least one other national exit route
Social Development Index (SDI): check multidimensional poverty index levels	
Quintile I	Section belongs to Quintile I
Quintile II	Section belongs to Quintile II
Quintile III	Section belongs to Quintile III
Quintile IV	Section belongs to Quintile IV
Quintile V	Section belongs to Quintile V
Population density: check index levels in Mexico	
Quintile I	Section belongs to Quintile I
Quintile II	Section belongs to Quintile II
Quintile III	Section belongs to Quintile III
Quintile IV	Section belongs to Quintile IV
Quintile V	Section belongs to Quintile V

Conclusions of the visit

The goal of the multicriteria work session in Chile was fundamentally fulfilled. This means, both in terms of building a proto-model that would serve as a starting point for the rest of the countries (Costa Rica and Mexico) and for obtaining the weights of the strategic levels, even though these were only a first approach subject to revision after returning from the field work.

The goal of the multicriteria work session in Mexico City was fully reached, both in terms of the general model validation (decision structure), the obtainment of the local weights the Mexican reality represents at strategic level and following levels. The final measurement ruler to be used for assessing the sections was validated.

It should be underlined that, at the instigation of the SCT and the SH and with participation of GIZ on Friday December 7th a complementary work session was held on the SCT facilities. During this session, the analysis performed to classify the federal network highways in the primary/secondary levels and then mainline/inter-mainline was presented, and an explanation was given about the imperious need for the SCT for assistance in adjusting and optimizing the existing multicriteria decision model.

The following steps were established: the integration of the models for the 3 countries (Chile, Costa Rica y Mexico) in a Latin American model and the development of a pilot instance for the application of the model, assessing some selected highways and analyzing the criticality classification of the associated sections. Given the specific situation of the change of government in Mexico and the announcements about not building new highways in the new administration, and giving priority to reviewing guidelines, methodologies and processes, an opportunity arises to incorporate new methodologies in the different public administration branches, beyond the revision of legal area.

As for the possibility of a pilot case, this is an agreement that should be established between the GIZ, the Secretariat of Communications and Transport and the Secretariat of Finance. Even though there is a general consensus about the usefulness of the criticality focus in the field of disaster risk management for an optimization of the always scarce resources, this appreciation is not shared at a lower level by the SCT representatives. This can be due to the specific priorities of said secretariat, the lack of communication or visibility of the projects of the disaster risk management area among the attendants or the selection of attendants, with a vision maybe too technical and without direct exposure to issues of disaster risk management.

Finally, it should be underlined that the team is competent in its field, interested in having access to the final study results, but not particularly willing to participate in activities associated to a pilot for federal highway criticality assessment.

As a final conclusion of the entire process of building a highway criticality measurement model for Chile, Costa Rica and Mexico, the well-known fact was confirmed that, the more a decision model matures, the more it gains in conceptualization of the required variables and measurement precision thereof. This is particularly valid in certain complex models like the current one.

This process of gaining quality and representativity of the model can be observed in its whole magnitude to the extent in which the workshops were being held in the different countries, and where the greatest step was made in San José de Costa Rica.