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Climate-resilient roads in Paraguay; Mapping the risks and advising adaptive mitigation measures

Routes résistantes au climat dans le Paraguay: Cartographie des risques et avis sur des mesures d'atténuation adaptées

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ABSTRACT: Transport infrastructure plays a crucial role in growth and development of economies and thriving communities. In Paraguay, the economy depends heavily on (agricultural) export; mainly through road network. Climate-related hazards such as extreme weather threaten the availability of the road infrastructure. Such hazards are expected to increase in the future with changing rainfall amounts and intensities, posing chance of higher frequency for events like precipitation induced floods and landslides. This can have a deleterious effect on transport infrastructure, such as road networks and railways, with large negative economic, social, environmental, and security aftermaths. In this paper, a case study from a World Bank funded pilot project is presented. In this project, Deltares and CSI Ingenieros have been working with the Government of Paraguay (GoP), through its Ministry of Transport and Communications (MOPC), on developing a strategy to assess climate change related risks on the road network and on how improve their resilience. The ROADAPT approach (Roads for today, adapted for tomorrow) was applied for assessing the risk and vulnerability of a part of the road network (pilot study area of over 300 km) and mitigation measures were suggested.

RÉSUMÉ: Les infrastructures de transport joue un rôle crucial dans la croissance et le développement des économies et des sociétés. Au Paraguay, l'économie dépend énormément sur les exports agricoles, notamment à travers le réseau routier. Les aléas climatiques, tel que les conditions météorologiques extrêmes, menacent la disponibilité des infrastructures routières. De tels risques devraient augmenter dans l'avenir avec l'évolution des quantités et de l'intensité des précipitations, laissant entrevoir une fréquence plus élevée d'événements tels que les inondations et les glissements de terrain provoqués par de telles précipitations. Cela peut avoir un effet néfaste sur les infrastructures de transports, telles que les réseaux routiers et les chemins de fer, avec de graves conséquences économiques, sociales, environnementales et sécuritaires. Dans cet article, une étude de cas située dans le contexte d'un projet pilote financé par la Banque Mondiale est présentée. Dans le cadre de ce projet pilote, Deltares et CSI Ingenieros, en collaboration avec le Gouvernement du Paraguay (GoP) et par l'intermédiaire de son Ministère des Transports et de la Communication, ont œuvré à développer une stratégie d'évaluation des risques liés au changement climatique sur le réseau routier et aux moyens d'améliorer sa rési-

lience. L'approche "ROADAPT" (Roads for today, adapted for tomorrow) a été appliquée pour évaluer les risques et la vulnérabilité d'une partie du réseau routier (une zone pilote de plus de 300 km).

Keywords: Resilient infrastructure, ROADAPT, Climate change, Adaptation, Risk Assessment

1 INTRODUCTION

The Transport and Digital Development in the World Bank is working jointly with the Global Facility for Disaster Reduction and Recovery (GFDRR) to support countries in strengthening their capabilities, institutions, instruments and processes to make road networks more resilient to climate conditions and climate change.

According to the World Bank, Climate related hazards remain among the greatest threats to poverty reduction and shared prosperity. These imminent risks can range from heavy precipitation, storms and other extreme weather events, and a single event alone has the ability to turn back the time on decades of progress.

The road sector is particularly susceptible to damage from precipitation and related weather events. Precipitation events can cause flooding and landslides that may disrupt connectivity, and cause significant damage to the road network. . Extremes of temperature can also adversely impact the road surface itself by reducing the overall performance and lifetime and in more serious cases even lead to complete pavement failure and subsequent road closure.

Given the characteristics and conditions of the country of Paraguay, it was selected by the World Bank, for the execution of a pilot study to increase the resilience of the road network.

1.1 Objectives of the pilot study

The objectives of the study were:

1- Elaboration of a methodology for climate change and natural hazard road network vulnerability assessment applicable to the road network in Paraguay.

2- Application of the proposed approach to 3 CREMA corridors with a total length of 318 Km (of the Transport Connectivity project, funded by the World Bank) with GIS maps, and a prioritized action plan of climate resilience measures for the same road network based on a road survey and detailed review of the road engineering designs of selected (vulnerable) assets.

3- Recommendations to enhance the Road Asset Management System with climate change data

2 BACKGROUND

2.1 Paraguay Context

Paraguay is a land-locked country located in South America. According to the International Disaster Database (EM-DAT), Paraguay has been historically exposed to floods, droughts, epidemics, storms, and forest fires. The type of extreme event that has hit Paraguay with the highest frequency in the last 25 years is floods (39.3%). Floods have also caused the highest mortality (40.1%) of all other types of hazards. Flooding and El Nino events show a strong correlation.

The most important recent flooding events in Paraguay can be linked to the El Niño and La Niña events of 1982-1983 and 1997-1998 as well as the 2015–2016 event. These events are characterized by the changes in rainfall- and temperature regime. The consequences of El Niño 2015-2016 amounted to about US$50 million for rehabilitation and reconstruction of road infrastructure and about US$200 million for reha-

bilitation and reconstruction under the Ministry of Public Works and Communications (MOPC)

2.2 Paraguay Road Network

Paraguay's road network length is estimated at 100,000 km, of which only 32,208 km are classified and fall under the Ministry of Public Works and Communications' (MOPC) administration. Most of the road network is concentrated in the southeast of the country, in general, and particularly the paved network. The North West (Chaco), with 3% of the total population, lacks adequate connectivity with the rest of the country and the neighbouring countries.

2.3 Project area

The project focussed on over 300 km of roads, distributed over 3 corridors/routes. In Table 1, the routes and their lengths are described and in Figure 1, the layout is presented.

Table 1. Description of the routes, which are focus of this study

Corridor	Route	Segment	Length
1	1	San Juan Bautista – Encarnación	174,0 km
8	8	Carayao – Tacuara	67,2 km
	3	Tacuara – Calle 6000	12,0 km
	3	Tacuara – San Estanislao	4,9 km
10	10	Mbutuy – Yasy Cañy	70,6 km

A site survey during the project (June 2017) indicated some of the current locations where climate threats play a role. Figure 2 shows an example of such locations and the encountered problems. The issues detected during the site visit were; areas affected by erosion within the embankments and below the lanes due to rainwater drainage problems, eroded embankments due to creek flooding, billboards destroyed by strong winds, and reduced/loss of visibility due to the intentional burning of vegetation in the road berms/ verges.

Figure 1: Layout of the project routes 1, 8, and 10 (highlighted in blue).

Figure 2: Sample of Survey images along Route 8.

3 CLIMATE CHANGE RISK ASSESSMENT & ADAPTATION METHOD

3.1 The ROADAPT method

In this study, the ROADAPT guidelines/methodology (Bles 2016) were used to assess the climate change risk and adaptation measures. The ROADAPT guidelines cover:

A. Guidelines on the use of climate data for the current and future climate

B. Guidelines on the application of a QuickScan on climate change risks for roads

C. Guidelines on how to perform a detailed vulnerability assessment

D. Guidelines on how to perform a socio economic impact assessment

E. Guidelines on how to select an adaptation strategy

These guidelines deal with the way road authorities could adapt their road network and assets to the effects of climate change. It is the extreme weather that affects the road infrastructure and the level of service offered to their users, and climate change may result in changed frequencies of extreme weather. It is important to have an overview of how the weather can threaten road infrastructure and/or road users. Within the ROADAPT guidelines such an overview has been developed as a starting point for all risk and vulnerability studies to the effects of extreme weather on roads.

The elements of the ROADAPT method that were in this project consisted of:

- QuickScan for risk assessment.
- Detailed Vulnerability Assessment (as required) – to determine vulnerable locations.
- Guidelines on Adaptation.

In the next sections, these elements will be discussed in more detail with examples from the study location.

4 CURRENT AND FUTURE CLIMATE

4.1 Current climate in Paraguay

According to the World weather and climate information, the climate of Paraguay can be considered as sub-tropical. Paraguay has a rainy season from October to April. Average annual rainfall is about 1,000 mm in the Asunción area, about 1500 mm in the forest eastern regions, and about 800 mm in the Chaco.

The weather in Paraguay, as in many other areas in the world, is strongly influenced by El Niño (EN) events El Niño events occur irregularly at intervals of 2-7 years, although the average is about once every 3-4 years. During El Niño events, wind circulation, air temperature, and precipitation patterns change resulting in a direct impact on weather around the world.

More specifically, events such as El Niño have a major impact for Paraguay on average rainfall values. Figure 3, shows the relationship between El Niño and regional precipitation patterns.

The amount of precipitation varies in Paraguay according to location, monthly accumulated precipitation amounts for the Asuncion area in Paraguay may vary between 42 mm in July to 158mm in January, according to (UNdata, http://data.un.org).

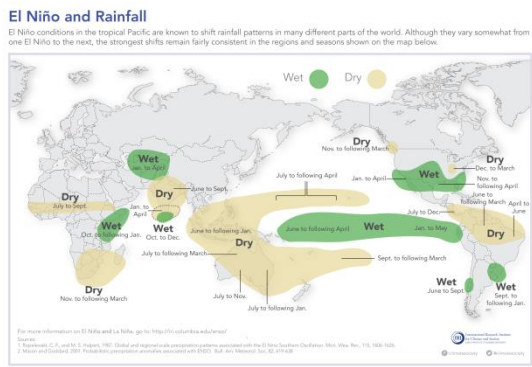

Figure 3: What Changes in Rainfall are Typical during El Niño? (International Federation of Red Cross and Red Crescent Societies: Forecasts in Context)

The average annual temperature in Paraguay varies between 21°C in the south-east and 25°C in the Chaco area. The summer period in Paraguay has high average monthly temperatures with average maximum between 30°C and 33°C. Winters are temperate and dry with average monthly temperatures between 13°C and 21°C.

4.2 Future climate in Paraguay

Climate change may be defined as: any systematic change in the long-term statistics of climate elements (such as temperature, rainfall, or winds) sustained over several decades or longer. According to IPCC (Intergovernmental Panel on Climate Change), climate change may be due to natural external forcings, such as changes in solar emission or slow changes in the earth's orbital elements; natural internal processes of the climate system; or anthropogenic forcing.

Given the impact of El Nino on Paraguay and more specifically the roads in Paraguay, it is important to understand how these phenomena may be affected. Literature on this subject seems divided: according to (e.g. Cho 2017) and (Collins 2010), science is inconclusive as to if global warming influences/ intensifies El Nino. However (Cai 2014) presents climate modelling evidence for a doubling in the occurrences in the future in response to greenhouse warming.

From the predictions based on available climate change scenarios and models (e.g. Barcena 2014), it is expected that the average annual temperature will increase gradually over time. In 2050, the average annual temperature may have risen by approximately 1.0°C. In 2100, the temperature rise maybe 2.0-4.0°C, depending on emission scenarios. Regarding precipitation, monthly accumulated precipitation for the Asuncion area may vary between 42mm and 158mm, depending on the time of the year. The average annual precipitation may increase slightly, depending on RCP (Representative Concentration Pathways) scenario. However this increase is most prominent towards the end of this century and little to no increase of the average is expected before 2060-2070.

Based on the increase of the average annual temperature, a 7% increase per degree ºC may be expected for short, extreme precipitation events, which form the basis of the design philosophy of road culverts. For short intense precipitation events in the project area the amount of rainfall may increase up to 5–9% in 2050 and 15.0–26% in 2100, depending on RCP emission scenario.

5 VULNERABILITY ASSESSMENT

5.1 High-risk threats

To identify the high-risk threats along the routes of the study area and gather local expert information, a workshop was organized at an early stage of the project with experts from the various stakeholders. During this meeting, a list of threats was established that are relevant to the CREMA corridors. The likelihood and impact of the threats were estimated by scoring for the current situation. This was done for both roads of high and low importance. The class boundaries (i.e. what constitutes a score of 1, 2, 3 or 4) for both likelihood and impact were discussed prior to scoring. The various scores were determined by calculating the averages of the provided scores of the experts.

The results of the scoring session are given in the risk matrix below (Figure 4). On the horizontal axis the likelihood classes are plotted, whereas the vertical axis shows the impact classes. In Figure 4, each and every circle represents a scored threat. The number in the circles in the matrix correspond to the threat identification numbers as used during the workshop (e.g. 1 refers to Flooding of road surface (assuming no traffic is possible)).

Note that the addition of a letter next to the number in the circle corresponds to the importance of a road section (where ‘a’ = road of low importance and ‘c’ = road of high im-

portance). The importance class of the road sections were discussed during the workshop and later determined in a socio-economic analysis.

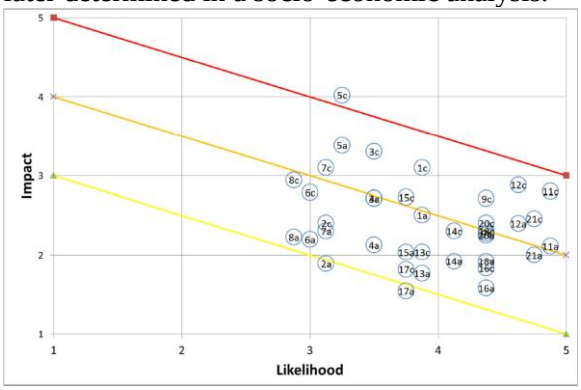

Figure 4: Risk matrix indicating threats (numbered circles) for the current situation.

The yellow, orange and red lines in the risk matrix are only indications and serve mainly to prioritize between the various threats i.e. the high risk threats are those in the top right corner.

5.2 Future developments

To determine how the risk of the threats changes in time, we looked at how the likelihood changes over time as a function of climate change. Note that in theory, also the impact may change for example as a result of changing socio-economic growth patterns possibly leading to changes in the relative importance of the roads in the future. During the study there was no indication/evidence that this is the case.

For precipitation related threats, a likelihood function can be determined by plotting the mean values for the return period as a function of the likelihood classes and then fitting a function to the resulting curve. Using the resulting likelihood function, the actual return period can be determined of the average likelihood scores of the threat under consideration. From the return period and using current Intensity-Duration-Frequency (IDF) curves for the project area, rain fall intensity can be determined for the considered threat. For future projections, the future IDF curves could be used and with use of duration and rainfall intensity from the previous step, a new return period can be estimated. The new estimated return periods are then used to update the classes as described in Figure 4. For most of the identified threats, the likelihood score has increased and the general trend is increase of the threat in the future.

5.3 Risk assessment and vulnerability maps

In order to determine which locations are relatively most vulnerable (e.g. more likely to be affected) for the identified high-risk threats, a vulnerability assessment was conducted using the methodology and ROADAPT guidelines. Vulnerability maps were produced for the following three threats:

- Flooding due to overflow of rivers and canals.
- Overloading of hydraulic systems crossing the road.
- Erosion of road embankment due to water runoff.

For every threat, vulnerability factors were identified, numbered and then classified from 1, indicating low vulnerability, to 3, indicating high vulnerability. The vulnerability factors represent characteristics of either the surroundings of the road or of the road itself, that influence the possibility of the threat occurring. As such, the resulting vulnerability maps are an integration of all relevant vulnerability factors. They provide insight into the relative likelihood of a threat occurring i.e. a high vulnerability index score equals an elevated likelihood of the threat occurring.

To give an example, vulnerability factors for ‘Flooding due to overflowing of rivers and creeks’ are; road elevation (relative to nearby river), proximity to the river/canal, and location in the flood plain. One of the resulting maps for a part of route 1 is shown in Figure 5. The results are given as a vulnerability index, which is a relative index score. A higher vulnerability in-

dex score indicates a higher vulnerability for this threat.

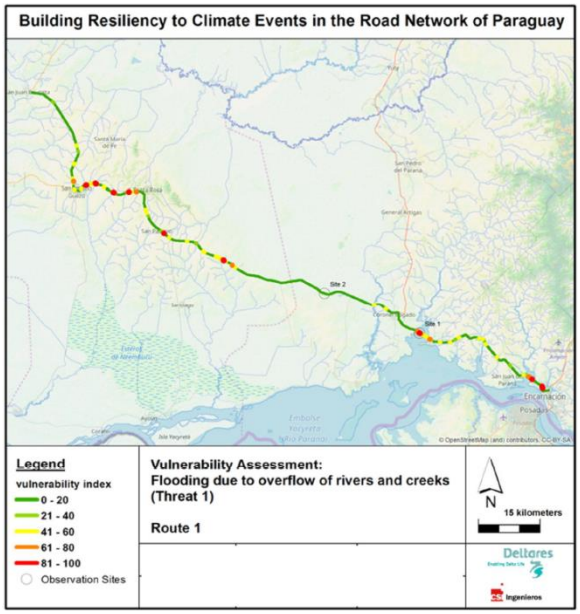

Figure 5: Vulnerability assessment of threat 1: 'Flooding due to overflow of rivers and creeks' done for the southern road sections (route 1).

6 MITIGATION AND ADAPTATION

6.1 Mitigation

Once the high risk threats have been determined, mitigating measures were identified and implemented. Planning for, and reducing the impact of, a disaster is called disaster management. It often consists of a 'before the event' part, 'during the event' part and an 'after the event' part. This is summarized in the Disaster cycle (Figure 6).

Which measures make the most sense to take, depends on how effective they are and how expensive they are. The relationship between cost and effectiveness may be determined in a Cost-Effectiveness Analysis (CEA). The CEA is made for a long list of selected measures. After the selection of the measures, a scoring exercise was done based on expert judgement of CSI and Deltares, in which the effectiveness of a generic measure was assessed for a particular threat.

Figure 6: Steps in the disaster cycle

The effectiveness is given as a percentage of the total threat being treated i.e. an effectiveness of 100% implies that once the measure has been taken, the risk is completely reduced. The effectiveness for a specific threat was consequently combined with an estimated cost of the measure. The cost effectiveness is determined by dividing the cost of the measure with the effectiveness.

The costs for the measure were transformed into an annual cost in the form of an annuity, based on the technical life span of the measure and an estimated interest rate of 5% and including the estimated annual costs for operation and maintenance. To give an example, for the case of flooding due to overflowing of rivers and creeks, results indicated that taking measures that fall in the 'protection' side of the disaster cycle for this threat, e.g. embankment elevation, building floodwalls, rebuilding of roads on safer ground, although being very effective, have a relatively bad CEA score due to the high costs involved. As a result, the first steps that may be taken fall on the 'recovery' side of the disaster cycle i.e. 'response and recovery'.

6.2 Adaptation

For a selected number of locations/sites, detailed review has been done in order to better assess

the vulnerability, and when possible review the design. For these locations, adaptive measures were suggested using the Dynamic Adaptive Policy Pathways (DAPP) approach indicatively.

The DAPP approach aims to support the development of an adaptive plan that is able to deal with conditions of deep uncertainties, such as climate change. An adaptive plan specifies actions to be taken immediately, to be prepared for the near futures and actions to be taken now to keep options open to adapt if needed in the future. Adaptation Tipping Points (ATP) are a key concept in DAPP. An adaptation tipping point specifies the conditions under which the status quo, a mitigating measure or a combination of measures will fail. An adaptation tipping point is reached when the magnitude of external change is such that a measure no longer can meet its objectives, and new measures are needed to achieve the objectives. The timing of an adaptation tipping point (the sell-by year of actions) is climate scenario dependent. However, due to lack of data, ATP's were only given as an indication and the DAPP diagrams developed primarily for discussion purposes.

To give an example, embankment erosion due to water run-off along the surface was identified at one of the sites and adaptation measures were advised. A DAPP diagram was made for this threat/site to graphically indicate possible measures and how these may be implemented as a function of time. The results are illustrated in Figure 7.

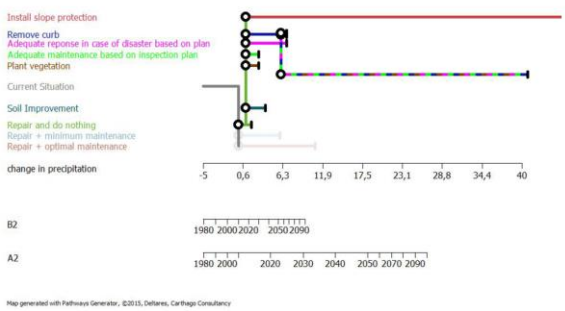

Figure 7: DAPP for an embankment erosion due to water run-off.

7 CONCLUSIONS

In this paper, results from a World Bank pilot project regarding building resiliency to climate events in the road network of Paraguay are presented and discussed. The work included, among others, risk due to climate change and vulnerability assessment and mapping, socio-economic analysis, mitigation and adaption measures, and recommendations for contracts of new roads or maintenance contracts for existing roads.

8 ACKNOWLEDGEMENTS

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