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ANALYSIS OF QUALITY CONTROL PLANS FOR BRIDGE OVER THE RIVER MAZA JUGLA ACCORING TO COST TU 1406 METHODOLOGY

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Abstract. Bridges are one of the most expensive elements of the road network, and therefore in the bridge management process, it is very important to make the most technically efficient and cost-effective decisions about planned actions such as maintenance, rehabilitation and reconstruction works. Decisions have to be based both on the current situation and possible future options and alternatives.
The European Cooperation in Science and Technology (COST) during the action TU 1406 "Quality specifications for roadway bridges, standardization at a European level (BridgeSpecs)" in the period from 2014 to 2019 has developed the framework for the development of bridge Quality Control Plans (QCP) including the system of data collection, data processing and outcomes.
This article analyses and compares different Quality Control Plans developed according to COST TU 1406 methodology for the existing bridge over the river Maza Jugla, located on regional road P10 at km 34.80 in Latvia.

Keywords: bridge, bridge stock, inventory, inspection, maintenance, condition, load model

1. Introduction

The European Cooperation in Science and Technology (COST) during the action TU 1406 "Quality specifications for roadway bridges, standardization at a European level (BridgeSpecs)" in the period from 2014 to 2019 has developed the framework for the development of bridge Quality Control Plans (QCP) including the system of data collection, data processing and outcomes.
Based on action workgroup technical reports and offered methodology two possible QCP for roadway bridge over the river Maza Jugla in Latvia are made. As the overall technical condition of the bridge is poor and it is planned to rehabilitate bridge in coming years, one of main outcomes of this article is to compare the strategy selected by State Limited Liability Company "Latvian State Roads" to rehabilitate bridge now versus the option "to do nothing" and reconstruct bridge when it becomes unusable. The preparation process of case study is done according to the scheme (Figure 3.1) described in WG4 Technical report "Preparation of case study" with the following main steps:

- Data collection of existing structure,
- Technical condition assessment and evaluation of performance indicators (PI) and key performance indicators (KPI),
- Material testing – carbonisation depth,
- Development of different QCP and their comparison.

Data used for case study is obtained from bridge inspection in 2020 and bridge management system LatBrutus of SLLC "Latvian State Roads".

2. General data of bridge

2.1 Basic information

The bridge over the river Maza Jugla is located in the Latvian regional road network on regional road P10 Incukalns-Ropazi-Ikskile at kilometre 34.80 (see Figure 1 and Figure 2). As the bridge is located in the urban area Tinuzi, the allowed driving speed is 50 km/h. According to last traffic data from 2019 the traffic intensity is 1677 cars per day including 11% of heavy traffic. According to data of Latvian bridge management system LatBrutus the bridge condition is evaluated as "Very poor condition".

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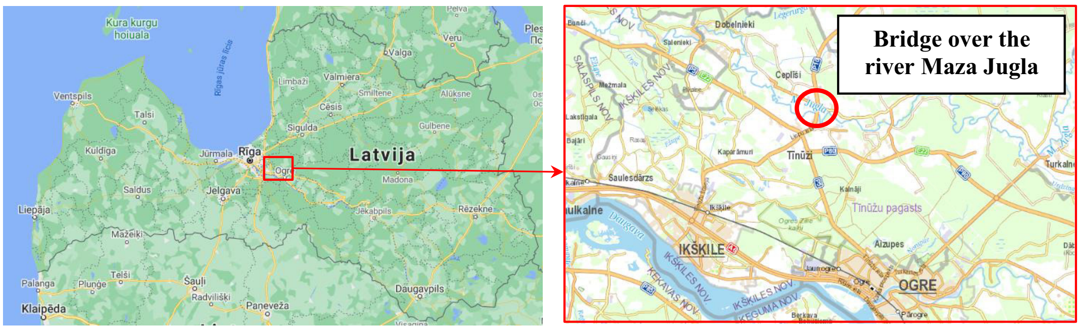


Figure 1. Location of the bridge

Figure 2. Bridge overview

2.2 Bridge structural elements and equipment

New bridge superstructure over the river Maza Jugla was built in 1962 on the existing cast-in-situ reinforced concrete abutments built in 1948. Bridge superstructure is made of four continuous reinforced concrete cast-in-situ cantilever beams with scheme 7.65+20.30+7.65m. Main beams are connected with cast-in-situ cross beams. The bridge is designed according to Soviet traffic loads N-13 and special vehicle loads NG-60. The original bridge design documentation is shown in Figure 3. In cross section the superstructure has two pedestrian sidewalks with corresponding width of 0.85m and carriageway with the total width of two lanes of 7.0 m.

Bridge substructure was constructed in 1948. The piers are massive cast-in-situ reinforced concrete supports based on solid rock. Main dimensions of piers are 9.61 x 1.22 metres. One pier has rigid steel bearings, but the another - reinforced concrete roller bearings. In the upstream side there are ice cutters in the form of a triangle.

The bridge is equipped with two reinforced concrete sidewalks, stone masonry slope covering, steel railings and steel drainage tubes. There are no special deformation joints as the bridge is designed with semi-integral superstructure. In both ends of superstructure there are saw cuts in asphalt pavement. Road accesses and superstructure itself is paved with asphalt. The bridge is equipped with galvanized steel road signs.

2.3 Load capacity

Bridge load bearing capacity is recalculated due to bridge special inspection caried out in 2020. Bridge bearing capacity is appropriate to load model of everyday traffic flow LM3 (52 tons) used in Latvia. The summary of bearing capacity recalculation results is shown in Table 1.

Table 1. Load bearing capacity calculation summary

Most laoded beam	Section	Force	Characteristic					Design	Section resistance R_d	R_d/E_d
			Dead weight				Live Load			
			G1	G2	G3	$G_{k.sum}$	LM3 (52t)	Max. Design value G_d.+$Q_{d.}$		
	1-1	M, km*m	345,9	268,6	193,1	807,6	973,7	2318	2330	1,01
	3-3	M, km*m	392,9	450,3	359	1202,2	937,2	2790	3025	1,08
	1-1	V, KN	110	141	112,5	363,5	163	683	800	1,17
	3-3	V, KN	150,5	160,5	126,3	437,3	161	770	947	1,23

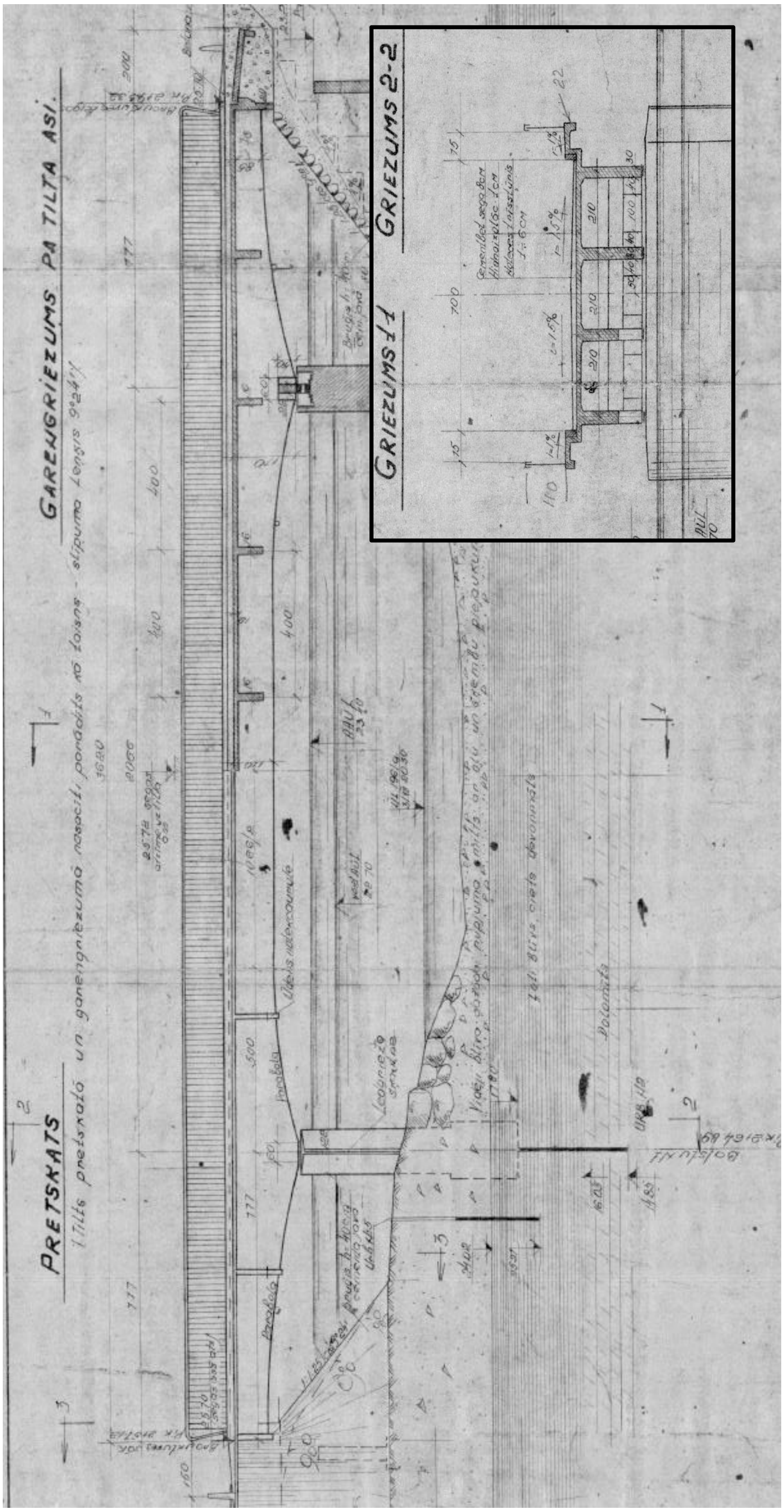


Figure 3. Original drawing of bridge over the river Maza Jugla

3. Technical condition

Technical condition of the bridge is evaluated based on existing bridge inspection data and visual inspection done by trained engineers. The results of technical condition data are processed according to WG3 framework ontology as shown in Figure 4 and summarized in Table 2 according to WG3 offered methodology. Damage process and performance indicators are selected from WG3 report, but derivation of KPI's is done based on engineering judgement. Observed defects of structural and non-structural elements are presented and described in Figure 5.

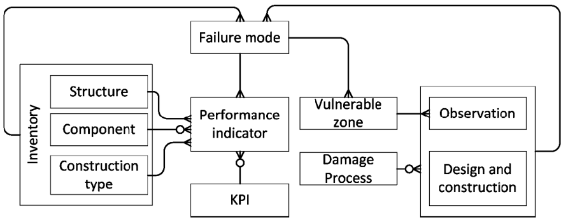
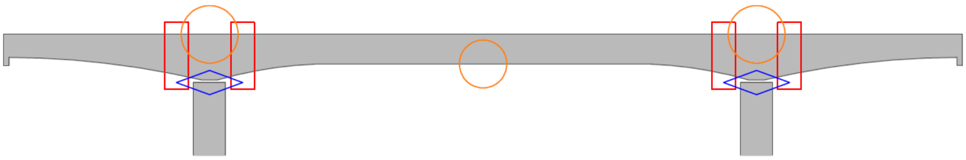


Figure 4. Framework ontology (WG3 report) [3]

In Table 2 damage processes are related to vulnerable bridge zones, as well. Vulnerable bridge zones are defined according to WG3 offered methodology. Vulnerable zones are presented in Figure 5.



Labels:

Orange circle – High moment zones (sagging and hogging),

Red rectangle – High shear region,

Blues diamonds – High compression zone, supporting zone

Figure 5. Vulnerable zones

Fig.6-1. Pavement, sidewalks and railings

Fig.6-2. Saw cut in asphalt pavement

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Fig.6-3. Middle span


Fig.6-4. Pier overview


Fig.6-5. RC plate between main beams


Fig.6-6. Integral end abutment


Fig.6-7. Main beam side surface


Fig.6-8. Main beam bearing area


Fig.6-9. Drainage tubes


Fig.6-10. Abutment top part

Figure 6. Overview of bridge main defects

Table 2. Overview of bridge main defects and vulnerable zones

Structure	Group	Element / Material	Observations			Damage process	Vulnerable zone	Failure mode	Primary KPI	Evaluation	KPI value	
			Damage	Closer specifications								
				QYT	Location						R	S
Coninious multiple span semi-integral beams	Structural elements	Main Beams / RC	concrete spalling, reinforcement corrosion	15%	side beams, outer side surface	corrosion, deterioration	HS, HMS, HMH	Bending and shear failure mode	Reliability (R)	2	4	4
			concrete spalling, reinforcement corrosion	100%	side beams, next to drainage pipes	corrosion, leakage	HS, HMS, HMH	Bending and shear failure mode	Reliability (R)	4		
			longitudinal cracks, concrete delamination	50%	side beams at supports	corrosion, deterioration, freeze-thaw	Bearing area	Shear failure mode	Reliability (R)	3		
			concrete spalling, reinforcement corrosion	15%	plate between main beams	corrosion, deterioration	collaboration	Local bending failure mode	Reliability (R)	2		
			micro cracks, concrete spalling	10%	all beam surface	corrosion, deterioration	-	Bending and shear failure mode	Reliability (R)	2		
		Cross beams / RC	small cracks, concrete spalling	10%	all beam surface	corrosion, deterioration	collaboration	-	Reliability (R)	1		
		Water proofing / bitumen layer	Efflarosence	90%	all below sidewalks	leakage	-	-	symptom	4		
		Bearings / RC roller	to much deformations	100%	all bearings	incorrect instalation	Bearing area	Compresion failure mode	Reliability (R)	2		
			small cracks, concrete spalling	10%	all bearings	corrosion, deterioration	Bearing area	Compresion failure mode	Reliability (R)	2		
		Integral end abutment / RC	small cracks, concrete spalling, reinf. corrosion	50%	bottom part	corrosion, deterioration, humidity	-		Reliability (R)	2		
		Abutment / RC	micro cracks, concrete spalling	50%	all abutment surface	corrosion, deterioration	High compression area	Compresion failure mode	Reliability (R)	2		
			grafiti	50%	long side surfaces	-	High compression area	-	Reliability (R)	1		
			Efflarosence	50%	short side top part	leakage	High compression area	Compresion failure mode	Reliability (R)	2		
	Equipment	Expansion joint (saw cut in asphalt) / bitumen	cracks next to cut, delamination	40%	all lenght	weak foundation, aging of material	-	driving comfort	Safety (S)	2		
		Drainage system / steel tubes	corrosion, loss of section, too short pipes	100%	all pipes	corrosion, inappropriate design solution	HMS	Bending failure mode	Safety (S) / Reliability (R)	3 /3		
		Overlay / asphalt pavement	ceacks	10%	near saw cuts, near center line	aging of material	-	driving comfort	Safety (S)	1		
		Railings / painted steel	flaking, deformations	100%	all surface	corrosion	-	falling from the bridge	Safety (S)	3		
		Sidewalks / RC	spalling, reinforcement corrosion, deformations	100%	surface	abrasion, freeze-thaw, corrosion, aging	-	walking comfort	Safety (S)	4		
			leakage	100%	under sidewalks	leakage	HMS, HS	Bending and share failure modes	Reliability (R)	2		
		Slope covering / stones	washout, vegetation	100%	minor washouts, overall vegetation	subsidence	-	Global stability failure mode	Safety (S)	1		
		Road signs / galvanized steel	no damage	-	-	-	-	driving safety	Safety (S)	1		

4. Material testing – carbonation depth

Carbonation is the reaction of carbon dioxide in the environment with the calcium hydroxide in the cement paste. Carbonation depth is the layer of concrete that is carbonated at its surface. The carbonation involves a decrease of pH in the pore solution which leads into steel depassivation, i.e. carbonation-induced corrosion. Therefore it corresponds to the diagnostic performance indicator whose corresponding performance goal is not reaching the rebar front (concrete cover). As the indicator is already systematically used in quality control checks and related decision-making, it is found already at the operational level (Indicator Readiness level, IRL=9) [8].
Within the scope of carbonation depth testing 35 carbonation tests at different places on the bridge were made. Test points were selected to cover bridge structural and non-structural elements as well as to obtain as extensive overview on the overall bridge carbonisation process as possible. The overview of carbonation test process, measures performed for Beam S1, B1 and carbonisation test results is shown in Figures 7 and 8 and in Table 3.
Carbonation test results show that there is significant scattering of results. It is observed that concrete material structure has major influence on carbonation depth. As bridge beams were cast-in-situ more than 60 years ago it was observed that beam high webs in bottom are poorly compacted, therefore carbonation depth is much higher than in shallow elements.


Figure 7. Carbonation tests

Right – set of tests for beam (S1, B4), west plane, location 2

Left – location 2-1, carbonation depth 5-10mm

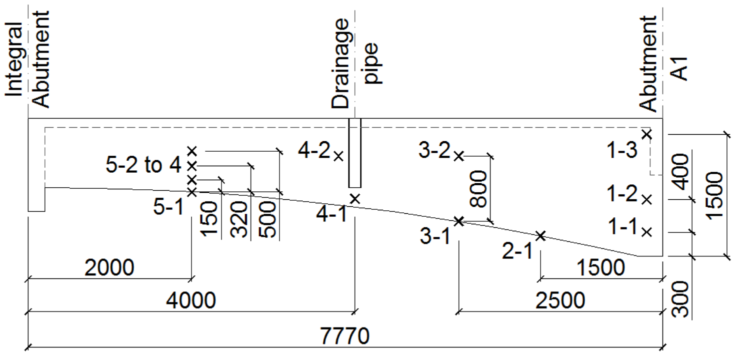

Figure 8. Performed carbonisation depth measures for Beam (S1, B1), east plane

Table 3. Overview of carbonation test results

Element	Location	Carbonisation depth (mm)	Material structure	Notes
Abutment, A1	upstrems, middle	10-15	solid structure	
Abutment, A1	upstrems, top	10-15	weak structure	very detoriated concrete, cracks, efflarocence
Beam (S1, B1), East plane	1-1	5-10	solid structure	
	1-2	>50	porous structure	
	1-3	5-10	solid structure	
	2-1	>50	porous structure	reached reinforcement
	3-1	>50	porous structure	reached reinforcement
	3-2	5	solid structure	
	4-1	>50	porous structure	Under drainage pipe, often wet conditions
	4-2	5	solid structure	next to drainage pipe
	5-1	>50	porous structure	reached reinforcement
	5-2	10-15	solid structure	
	5-3	5	solid structure	
	5-4	5	solid structure	
Beam (S1, B1), West plane	1-1	>50	porous structure	detached concrete cover, reached reinforcement
	1-2	5	solid structure	
	1-3	5	solid structure	
	1-4	>50	porous structure	
	1-5	>50	porous structure	
Beam (S1, B2), East plane	1-1	15-20	solid structure	
	1-2	5-10	solid structure	
	1-3	>50	porous structure	
	1-4	>50	porous structure	
Beam (S1, B4), West plane	1-1	5-10	solid structure	
	1-2	20	solid structure	
	1-3	<5	solid structure	
	1-4	5-10	solid structure	
	2-1	5-10	solid structure	
	2-2	15	solid structure	
	2-3	>50	porous structure	
Cross beam	between S1-S2, above A1	>50	porous structure	
Plate between main beams	between S1-S2	0-5	solid structure	
Integral abutment	middle, between S1-S2	0-5	solid structure	
	West side S1, B4	0-5	solid structure	under sidewalk
	West side S1, B4	0-5	solid structure	under sky

5. Quality control plans

To compare possible bridge management actions the following two possible scenarios were developed and compared: Reference scenario and Preventative scenario. Scenarios were compared on time basis where the bridge is reconstructed after its life-time ends according to Reference scenario.

Reference scenario or case "do noting" considers the lack of any repairs. It is assumed that bridge structural elements could deteriorate at a level when the bridge may not further perform as it is expected – mainly assumed as the lack of bearing capacity. Based on carbonation depth measurements and expert judgement this level is assumed as 30 years. In Reference scenario it should be accepted that the overall bridge condition until bridge replacement will be poor, including low values of Availability and Safety. According to actual new bridge construction prices in Latvia, it is assumed that a new bridge could be built approximately for one million Euros. Figure 9 shows the results in terms of Availability, Costs, Reliability and Safety for the Reference scenario.

Preventative scenario considers major rehabilitation immediately and periodical set of interventions later during life cycle to prevent further development of defects and overall damage to the structure [5]. According to actual bridge rehabilitation prices in Latvia it is assumed that the whole bridge rehabilitation costs approximately 320 thousand Euros. It should be noted that in Preventative scenario close to the year 35 the replacement of bridge water insulation layer and some equipment (parapets, safety barriers, expansion joints) should be planned very likely. Figure 10 shows the results in terms of Availability, Costs, Reliability and Safety for the Preventative scenario.

In both scenarios its assumed that daily maintenance of road including bridge deck is performed, but it is not taken into account in quality control plans.

Figure 11 shows a comparison of two considered scenarios in terms of "spider" diagram.

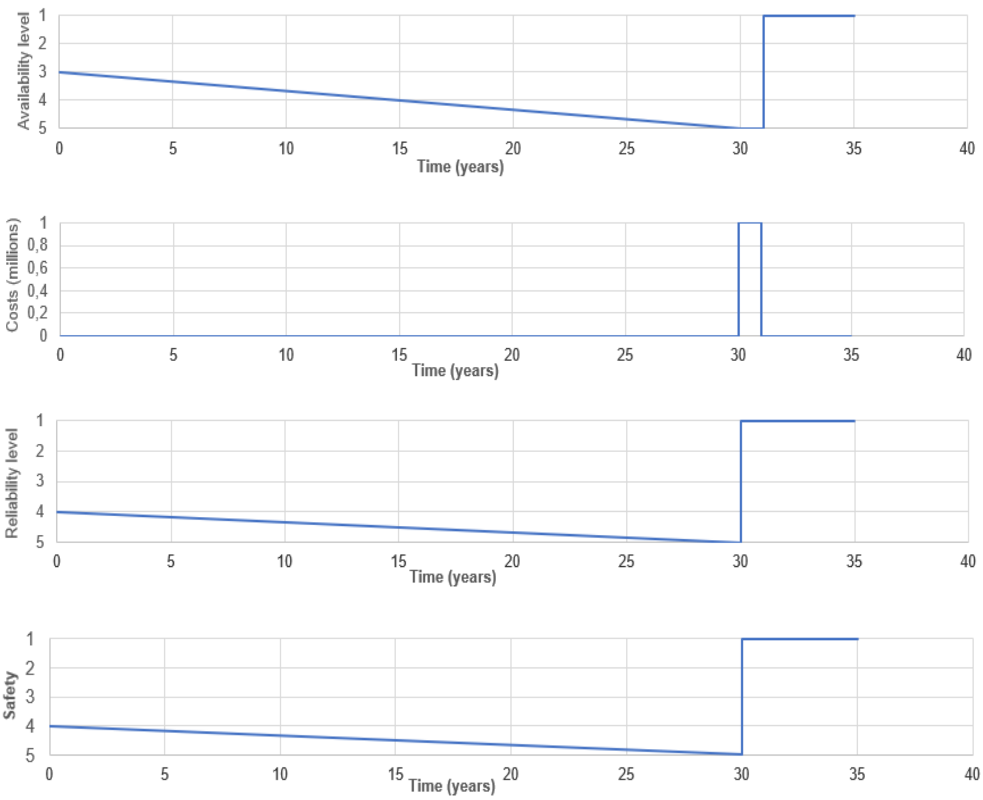

Figure 9. Preventative scenario

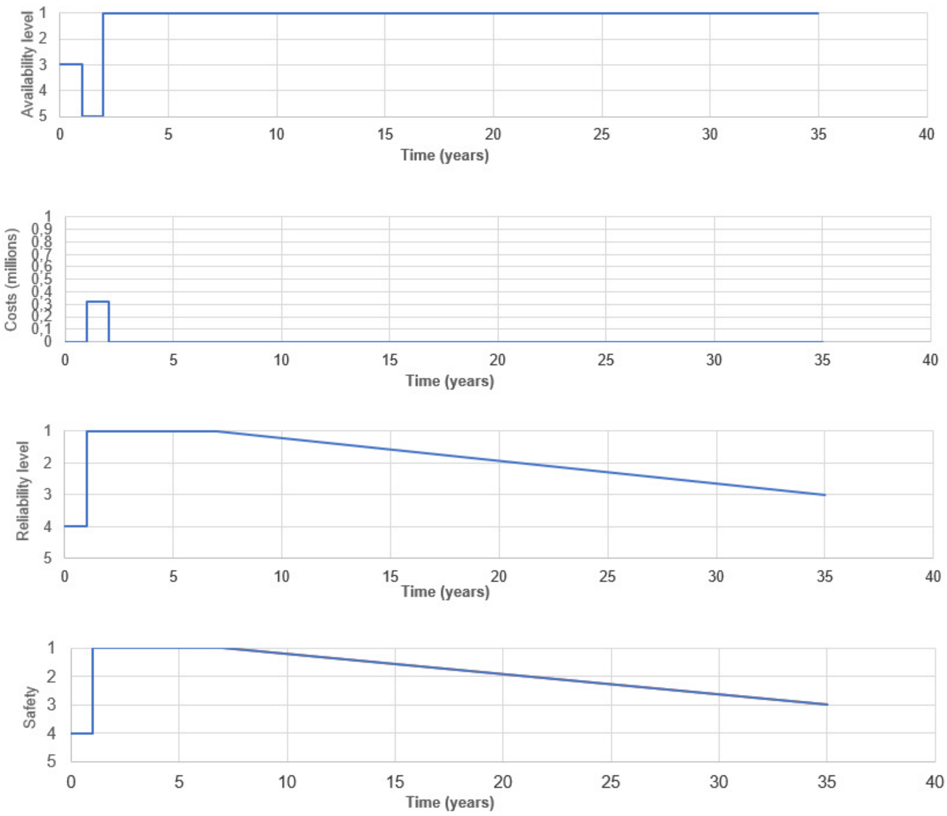

Figure 10. Reference scenario (‘’do nothing’’ case)

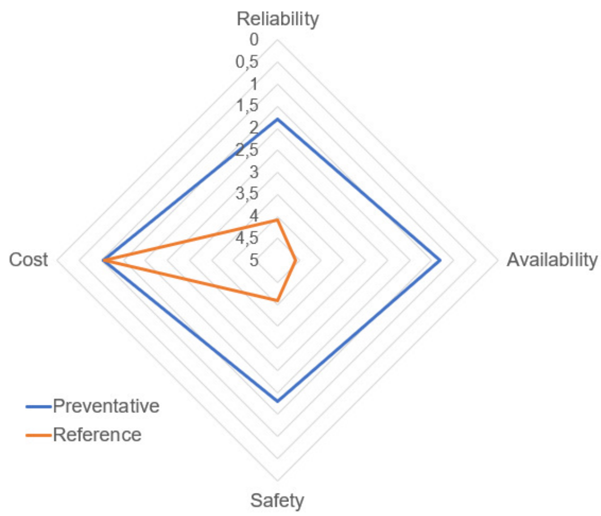

Figure11. Overview of bridge main defects

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6. Conclusions and Suggestions

1. According to the analysis it may be concluded that Preventative scenario is more advantageous than Reference scenario. Though the overall costs are quite similar, other performance indicators are at much higher level.
2. The obtained results from the comparison of quality control plans coincide with the plans of SLLC "Latvian State Roads" to perform bridge rehabilitation.
3. For more accurate bridge life-time modelling the deterioration models based on carbonation measurements such as model described COST Action TU 1406 "Report of the Innovation Subgroup" should be used. To obtain more accurate model more data such as chloride content should be added.
4. It may be concluded that carbonation depth measurements made for this specific bridge may not be used to develop any overall bridge deterioration model because of significant data scattering.

7. Bibliography

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