COST ACTION TU1406

QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

TU1406 WG4 Final report Appendix A16

Bridge Case study

Stone Arch bridge in Viana do Castelo district, Portugal

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1. GENERAL DATA OF THE BRIDGE

Quintão bridge is a roadway stone arch bridge located at km 011 + 524 of EN303 close to Viana do Castelo. The bridge dates back to 1900 (Infraestruturas de Portugal, 2006) and its typology consists of a structural system based on a single stone masonry arch supported by two abutments (Figure 1), which is very common in the European roadway network particularly in Portugal.

The QC evaluation is performed by considering the bridge data recorded in 2008 and 2014. Several minor interventions are referred to be performed in the bridge although only evidences of regular maintenance are documented and perceptible. After that, in 2018, a rehabilitation intervention was performed in the bridge, comprising the deck widening with a concrete slab to its actual width (Infraestruturas de Portugal, 2013), amending its original structural system.

The original structure consists of a single segmental arch with a clear span of about 6 m and a rise of 1 m supported in two abutments with about 3.6 m between their base level and the base of the arch. The arch has regular voussoirs of 0.5 m thick, in granite stone masonry with mortared joints. The bridge has a straight longitudinal profile of about 15.1 m long, and wide ranging from 6.2 m in the arch zone and 6.6 m in the abutment zones. Four gravity walls with variable length, ranging from 9.5 to 25 m long, extend beyond the abutments sustaining the embankments.

a)  b) 

Figure 1 Quintão bridge
a) side view and b) deck view, (Infraestruturas de Portugal, 2014).

The most obvious vulnerable zones for this type of structures are the arch barrel, the spandrel walls and the abutments.

Two regular inspections were carried in 2008 and 2014 (Infraestruturas de Portugal, 2008) (Infraestruturas de Portugal, 2014). According to the Portuguese bridge rating system SGOA, the global condition score assigned by the bridge inspectors in both inspections (in 2008 and 2014, before rehabilitation) was three (zero to five rating scale, where the zero denotes the best condition and five the worst condition) (Freire & Amado, 2015).

2. INSPECTION OF QUINTÃO BRIDGE CARRIED OUT IN 2008

According to the observations made in 2008, two types of defects can be differentiated: the defects related to environmental, physical and chemical actions and the defects related to mechanical actions. Based on the information documented in both reports, the bridge's condition has not worsened.

The first type of defects, is present more broadly in the structure, being generally independent of the structural behaviour, involving problems associated with the presence of water, biological pollution and erosion as shown in Figure 2. It was observed that in general the bridge facing stones have vegetation, moss and lichens, efflorescence and water flowing resulting from insufficient maintenance and inadequacy of the drainage system as shown in Figure 3. Other more localized damages can also be noted from the report, namely lack of stone blocks and lack of mortar in the joints.

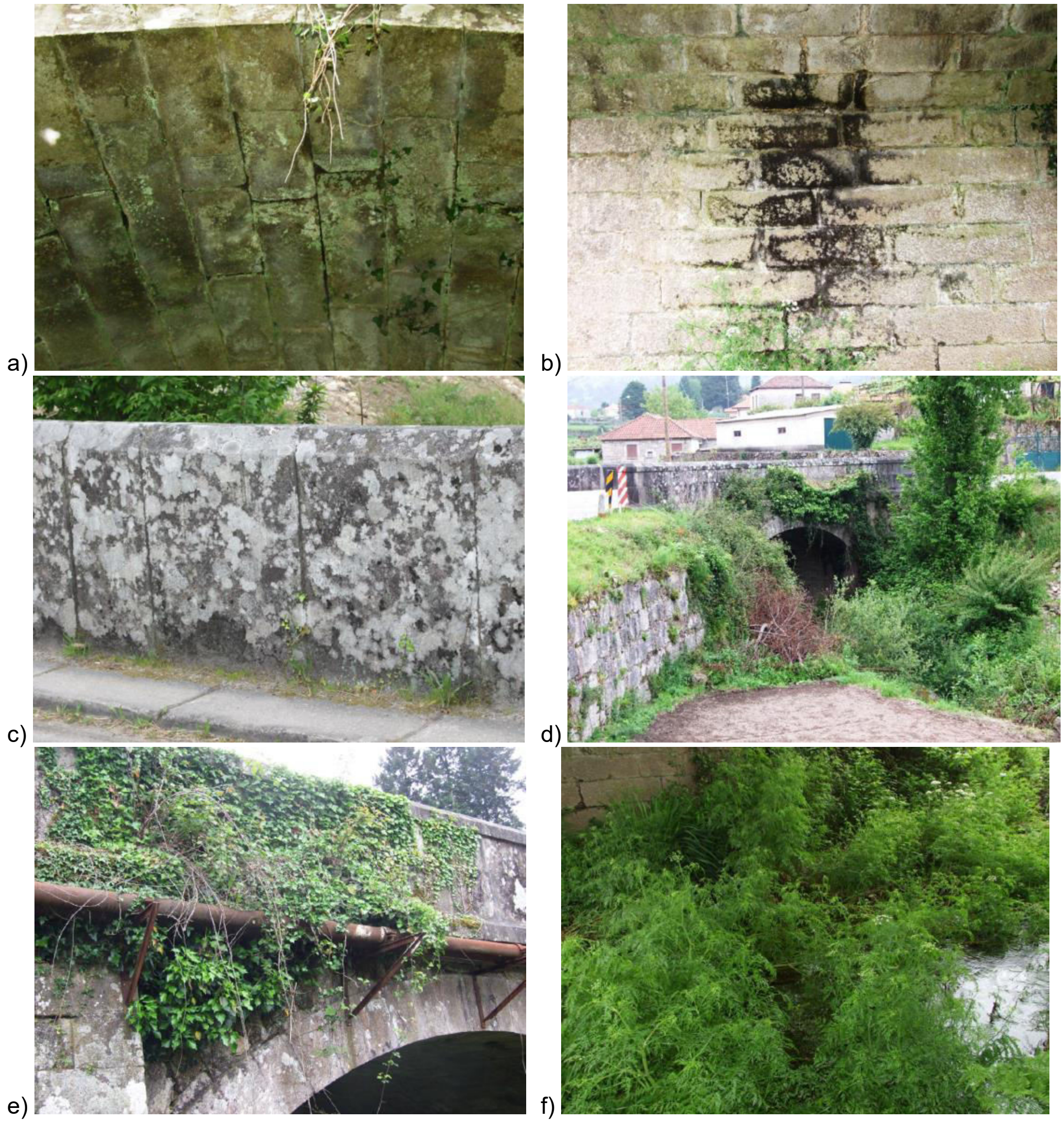


Figure 2- 2008 inspection. Defects - environmental, physical and chemical actions, (Infraestruturas de Portugal, 2008)

a) Water flowing, efflorescence and vegetation, on the arch intrados; b) Black films, moss and lichens, on the intrados of the abutment zone; c) moss and lichens, on the side guards; d) Vegetation, on the bridge south face; e) Vegetation, on the bridge north face; f) Vegetation, on the riverbed

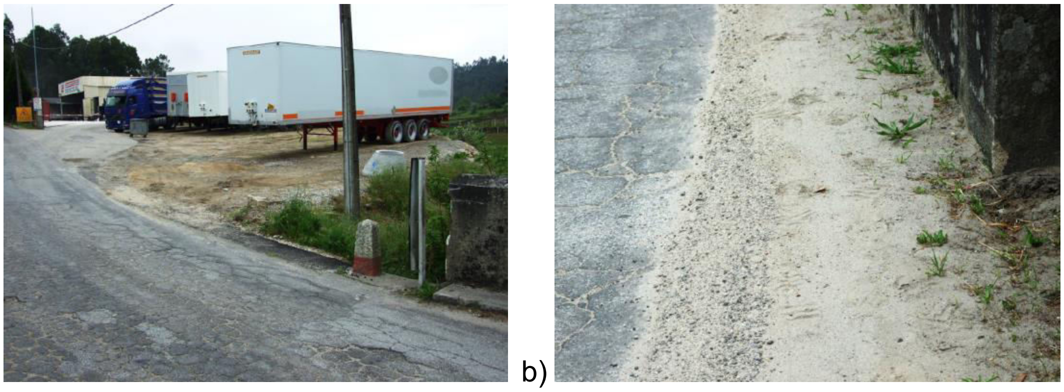

a) b)

Figure 3 Inadequacy of the drainage system at the deck level, (Infraestruturas de Portugal, 2008)
a) Slope conditions direct rainwater to the bridge; b) debris accumulation

The defects related to mechanical actions are in a form of cracks, crushed stones and deformations resulting from undesired settlements and excessive loading. There are noteworthy problems such as: (i) longitudinal cracking in the arch intrados beneath the spandrel walls, (ii) joint opening in the central zone of the arch intrados, (iii) block fracture in the arch crown, (iv) block fracture and crushing in the abutment and arch intrados zones, (v) cracking at the joints on the interface between the mortar and blocks or within the mortar and (vi) joint opening. In Figure 4 examples of the mentioned defects are shown.

Figure 4 Defects associated with mechanical actions, (Infraestruturas de Portugal, 2008)
a) Longitudinal crack in the arch intrados; b) joint opening in the central zone of the arch intrados; c) block fracture in the arch crown; d) block fracture and crushing in the abutment; e) cracking at the joints, block fracture and crushing in the in the abutment zone of the arch.

Apart from the previous observations on the principal structural components of the bridge, from which the inspectors identified the evidence of lack of maintenance, poor quality of the stone, stress concentration and construction defects, other observations regarding non-structural elements as pavement and sidewalks are also mentioned in the inspection report, highlighting safety (life and limb) concerns.

3. INSPECTION OF QUINTÃO BRIDGE CARRIED OUT IN 2014

According to the information documented in both inspection reports (2008 and 2014), most of the defects observed in 2008 were also reported in 2014, without worsening of the defects neither of the condition rating assigned. Examples of the defects observed in 2014 related to environmental, physical and chemical actions are shown in Figure 5 where a similar condition can be identified when compared with the observations shown in Figure 5. Figure 6 shows the defects related to mechanical actions were the same defects reported in 2008 (see Figure 7) can be observed, namely the longitudinal cracking in the arch intrados. Block fracture and crushing in the abutment and arch cannot be observed due to the presence of vegetation in the affected zone. Minor interventions were carried out comprising vegetation removal and asphaltic repaving.

a) b) c) d) e) f)

Figure 5 - 2014 inspection. Defects - environmental, physical and chemical actions, (Infraestruturas de Portugal, 2014)

a) Water flowing, efflorescence and vegetation, on the arch intrados; b) black films, moss and lichens, on the intrados of the abutment zone; c) moss and lichens, on the side guards; d) vegetation, on the bridge south face; e) Vegetation, on the bridge north face; f) Vegetation, on the surrounding area

a) b) c) d)

Figure 6 – 2014 inspection. Defects associated with mechanical actions, (Infraestruturas de Portugal, 2008) a) Longitudinal crack in the arch intrados; b) joint opening in the central zone of the arch intrados; c) block fracture and crushing in the abutment; d) cracking at the joints, block fracture and crushing in the in the arch intrados.

a) b)

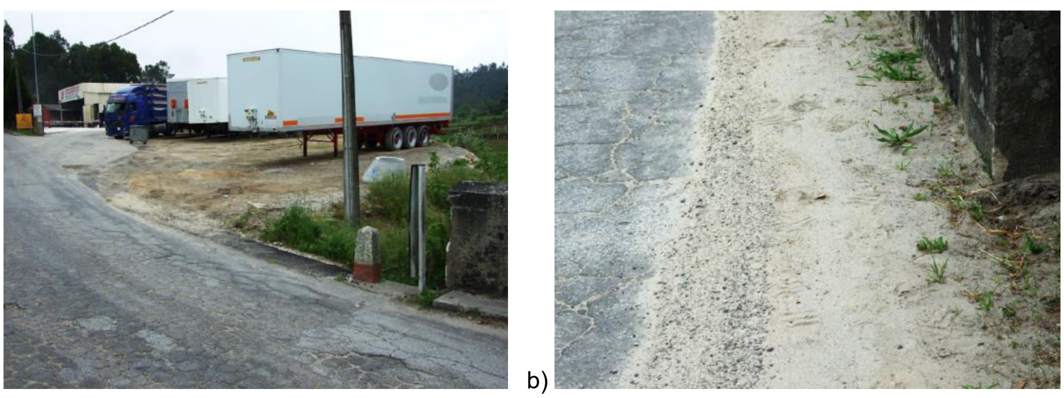


Figure 7 Inadequacy of the drainage system at the deck level, (Infraestruturas de Portugal, 2008) a) Slope conditions direct rainwater to the bridge; b) debris accumulation

In Table 1 a reinterpretation of the data collected in the 2014 inspection is proposed, according to the WG3 methodology. When no correlation is suggested between Observations and Failure Modes, one can consider that the related observations are not yet affecting the performance of the bridge but only pointing to the existence of a certain Damage Process.

Table 1 Qualitative evaluation of Quintão bridge (related to the inspection performed in 2014.)

Structure	Group	Element/ material	Observations			Vulnerable zone	Failure mode	Primary KPI	Element evaluation	Performance value	
			Damage	**Closer specifications**	**Damage process**					**Reliability**	**Safety**
Stone Masonry Arch Bridge	**Structural elements**	Arch	Cracks	Joint opening in the arch longitudinal direction beneath the spandrels	Overloading / Changing geotechnical properties	Arch intrados	Transverse behaviour	(R)	4	**4**	**4**
			Cracks	Joint opening in the arch intrados	Overloading / Changing geotechnical properties	Arch intrados	Longitudinal behaviour/ Arch decompression	(R)	4		
			Rupture	Block fracture	Overloading / Changing geotechnical properties	Arch intrados	Longitudinal behaviour/ Excessive compression	(R)	4		
			Crushing	Crushed stones	Overloading / Changing geotechnical properties	Arch intrados	Longitudinal behaviour/ Excessive compression	(R)	4		
			Deteriorated mortar joints	Lack of mortar	Abrasion/ Erosion	Arch intrados	-	(R)	3		
			Vegetation	-	Biological growth	Arch intrados	-	symptom	-		
			Wet spots	-	Hydraulic inadequacy	Arch intrados	-	symptom	-		
			Efflorescence	-	Water penetrability	Arch intrados	-	symptom	-		
		Spandrel walls	Deteriorated mortar joints	Lack of mortar	Abrasion/ Erosion	Spandrel walls – all	-	symptom	-		
			Vegetation	-	Biological growth	Spandrel walls – all	-	symptom	-		
			Wet spots	-	Hydraulic inadequacy	Spandrel walls – all	-	symptom	-		
		Abutments	Cracks	Cracks at the joints in the intrados zone of the abutment	Soil failure/ Overloading	Abutment-north	Excessive compression	(R)	3		
			Rupture	Block fracture	Soil failure/ Overloading	Abutment-north	Excessive compression	(R)	3		
			Deteriorated mortar joints	Lack of mortar	Abrasion/ Erosion	Abutments – all	-	symptom	-		
			Vegetation	-	Biological growth	Abutments – all	-	symptom	-		
			Wet spots	-	Hydraulic inadequacy	Abutments – all	-	symptom	-		

	Equipment	Sidewalks	Debris accumulation	-	Contaminatio n	-	-	(S)	1		
			Inadequate geometry	Insufficient width	Related with design and construction	-	-	(S)	4		
		Pavemen t	Cracks	-	Abrasion/ Erosion	-	-	(S)	3		

4. KEY PERFORMANCE INDICATORS AND QC PLAN

Regarding experience and the reliability index (β) for such type of bridges, it is assumed for the virgin state that β equals 5.2 for a reference period of one year. Although the bridge was not designed with the notion of design working life, it seems appropriate to assume at least 100 years, given its longevity. Considering the inspection performed in 2014 and relaying on expert judgement, a qualitative assessment of resistance reduction based on observed damages is estimated at approx. 20%. The influence of resistance reduction on reliability is given in Figure 8. This chart was plotted for the present case study adopting a ratio of the live/dead load of 0.05. For the estimated reduction, the related KPI(R)=3. Considering the condition of the bridge, a reassessment and possible intervention should be planed, which corresponds to the action that had been pointed out in the bridge inspection report.

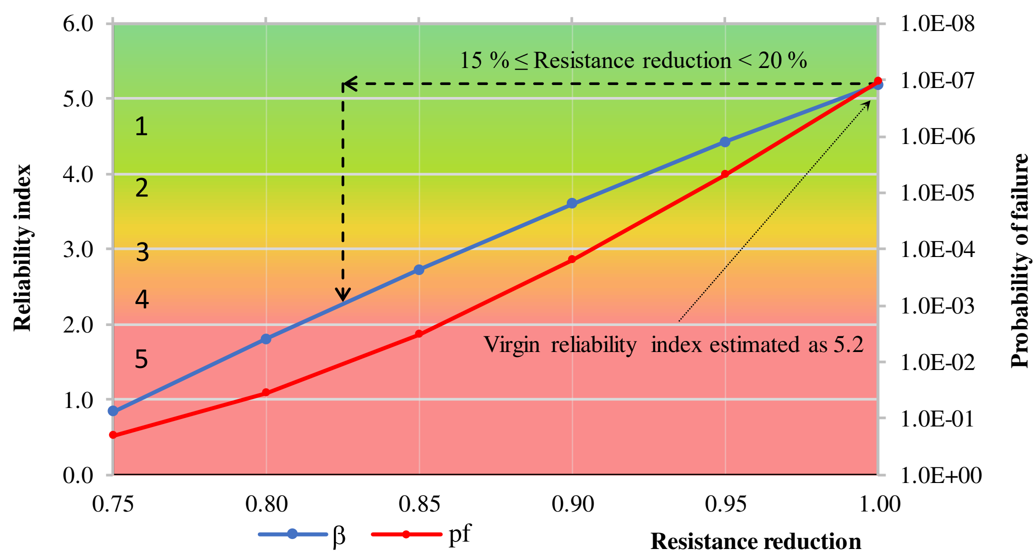
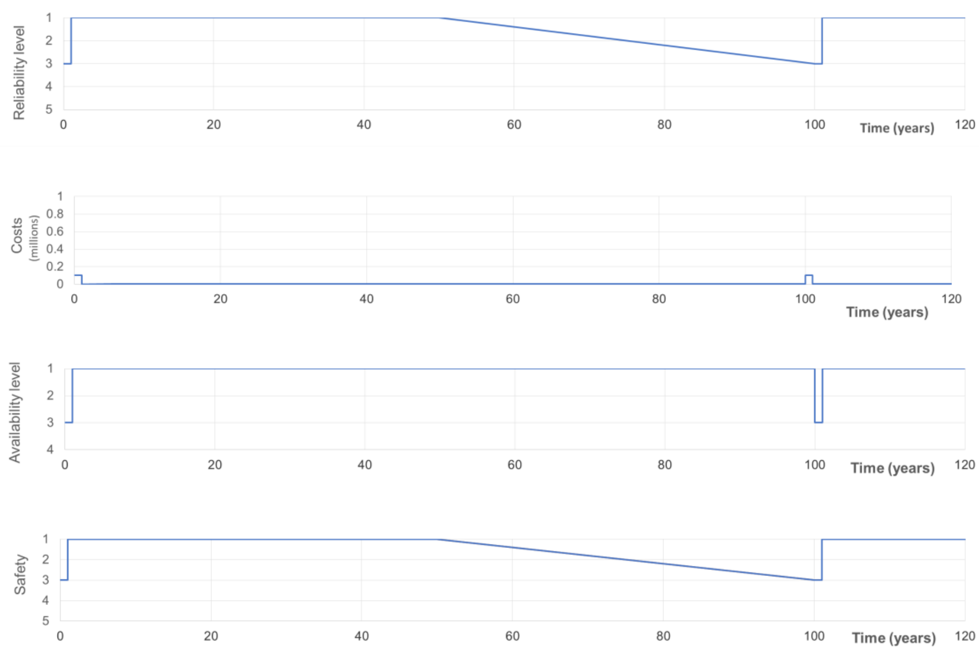


Figure 8 Influence of a resistance reduction on reliability index & probability of failure

Regarding the KPI of Safety (S the observations regarding insufficient width of the sidewalks (inadequate geometry) justify the grade 4 (Table 1), as it is likely that a person could get injured and the intervention shall be performed shortly after inspection. The damages observed in the arch intrados and its interaction with the spandrel walls, considered as vulnerable zones, point to possible failures modes in the transverse plane of the spandrels. Remaining service life was not directly accessed, but this entity is correlated with the rating system used for the inspections (SGOA). The assigned rating of four (the SGOA scale) is defined by the BMS as correlated with a qualitatively estimated remaining service life (understood as a threshold for serviceability) of five years. Here the two maintenance scenarios were compared (Figure 9). The reference maintenance scenario i.e. the "do-nothing" scenario comprise full bridge repair at year 5 and 104 (i.e. when the bridge reaches reliability level five). The preventative scenario implies immediate rehabilitation intervention on a bridge. The maintenance costs were roughly estimated (Economy) and the Availability is established on the network level in a scale from one to four.

a) Reference scenario



b) Preventative scenario

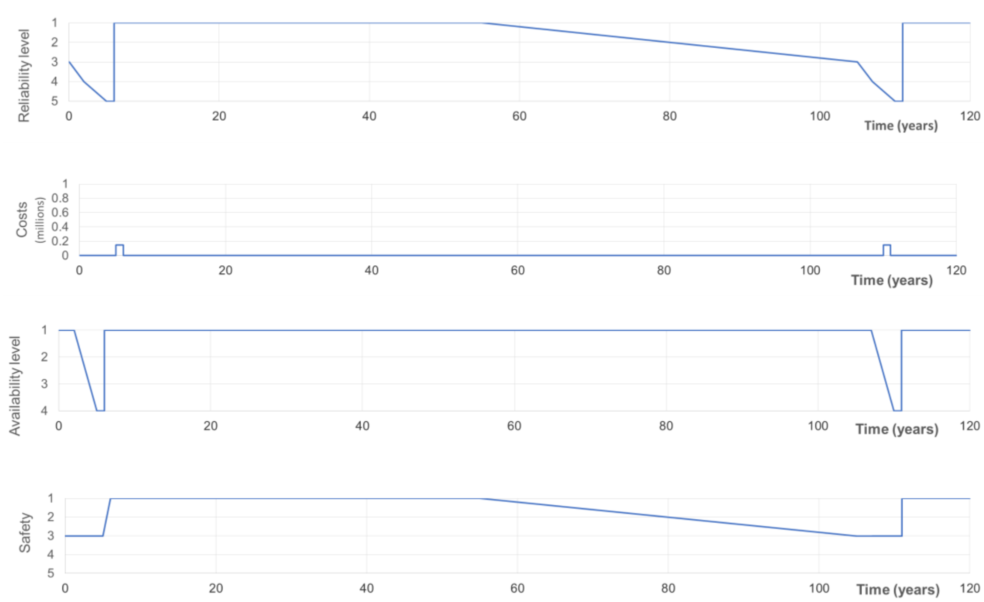


Figure 9 Comparison of KPI's for two maintenance scenarios for the Quintão bridge.

After the normalization of the KPIs, the net present KPI in a form of the spider diagram is presented in Figure 10.

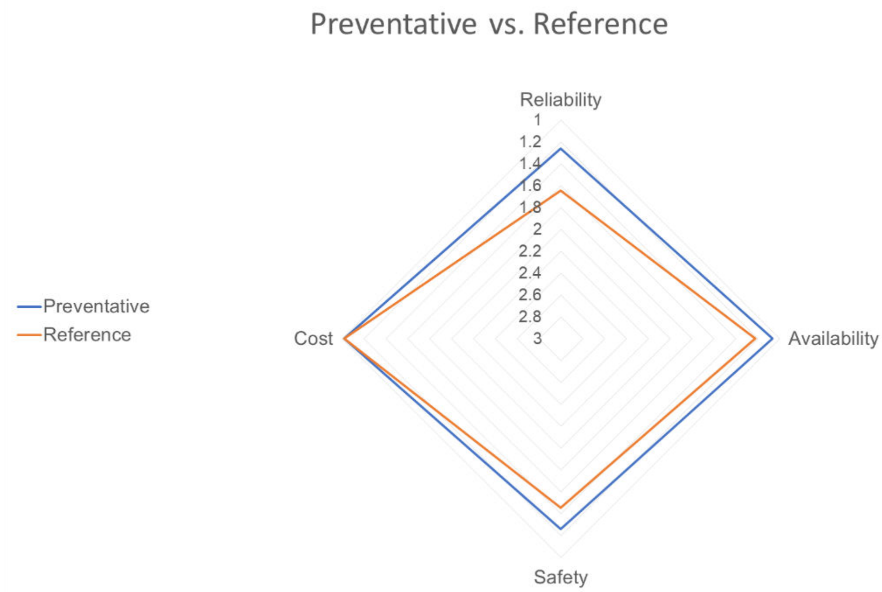


Figure 10 Comparison of net present KPI's for two maintenance scenarios.

5. REFERENCES

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