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LIFECYCLE COST CONSIDERATIONS OF COMPUTER BASED LEVEL CROSSING PROTECTION SYSTEMS

Dejan LUTOVAC[1][0009-0004-2073-6530]
Ana LUTOVAC[2]

Abstract *– This paper deals with the lifetime cost of various computer-based level crossing (CBL-xing) protection system. During the several decades of application CBL-xings protection systems have been following and unseeing the technological advances related to the electronic and computer based hardware. As a result, they use different hardware with various generation of processors and consequently, have various reliability characteristics. All CBL-xing systems have to have very high safety integrity level (SIL) in accordance with CENELEC standards. Usually SIL4 is required. Mostly they have two times two (fail-safe) architecture of the central control computer and a high degree of modularity to allow for the scalability and ability to equip all range of various applications. During the evolution of CBL-xing systems their control modules have experienced higher degree of integration and hence, contributed to minimise design, installation and testing time. Also, the technology advances are used for the realization of all CBL-xings modules, hence contributing to their increased reliability. The MTBF values of the modules of nowadays CBL-xing systems are significantly higher if compared with the MTBF values of some other systems that are realised in earlier time. Although all CBL-xings are mostly comparable from the safety point of view, they may significantly differ from the reliability point of view. The safety characteristics of a CBL-xing are usually required, considered and evaluated at the purchase time, but reliability requirements are often omitted. This approach can cause significant hidden costs during the long lifetime of a CBL-xing. The purpose of this paper is to show how much a CBL-xing system really cost during its lifetime and to demonstrate advantages of high reliable and low power consumption CBL-xings. Savings related to amount of spare parts, maintenance expenses and traffic delays, as well as electricity consumption costs during the 20 years of lifetime of a CBL-xing, are considered and highlighted.*

Keywords - computer-based level crossings, reliability, maintenance, traffic delays, electricity consumption cost, lifecycle cost.

1. INTRODUCTION

The latest CENELEC standards for railway applications have introduced the concept of the life cycle of a CBL-xing protection system [4]. The life of a CBL-xing system after commissioning is regarded from an exploitative point of view. Hence, beside the safety, a significant amount of attention is given to the reliability, availability and maintainability that are of paramount importance for the users. This simply recognises the weight that the *Railway Authorities* - RA put on maintenance issues nowadays.

Tendering processes for signalling products in general, including CBL-xings, for the selection of successful tenderers in the past, only had the technical compliance with the technical requirements and the price. The price has mostly covered the complete realisation of a CBL-xing, as a onetime cost. The cost for a certain quantity of spare parts was also considered by a tender in some cases. But, the complete maintenance cost during its life (usually 20 years) has not been considered in any tender's requirements nor as an award criteria. The reliability and consequently the availability of a CBL-xing system practically determine the lifetime maintenance expenses and have a significant impact on traffic disturbance and traffic delays. The maintenance expenses, disregarding the cost of spare parts, include expenses of the maintenance personnel involved. Potential losses due to traffic delays caused by the failed equipment during the lifespan have also not been considered as one of the winning criteria in any tendering process.

The purpose of this paper is to highlight the significance and value of the total exploitation

[1]Signalling & Control d.o.o., Belgrade, Serbia, sigcon@verat.net.
[2]Software Engineering, School of Electrical Engineering, University of Belgrade, Serbia, alutovac01@gmail.com.

expenses of a CBL-xing protection system. Maintenance expenses and traffic delay losses, during the lifetime of a CBL-xing, will be considered in order to show the advantages of CBL-xing systems with higher reliability and higher availability. The practical example of the relevant expenses will be given using simplified calculations applied to various versions of CBL-xing systems, classified by different reliability features. The comparison between different CBL-xing systems, in the aforementioned context, will be shown below and the advantages of the CBL-xing systems with a higher reliability will be highlighted.

2. TYPICAL CBL-XING APPLICATION

The typical track layout of a CBL-xing system for for a single track application is shown in Figure 1.

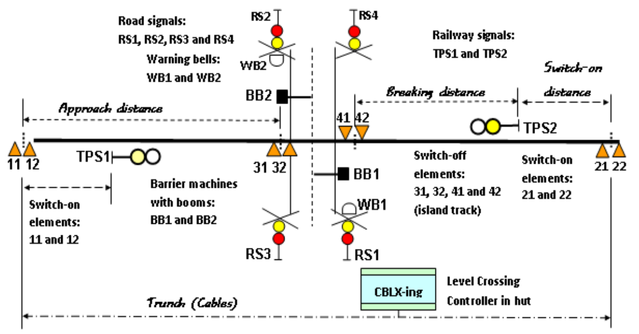

Fig.1. Typical track layout of a CBL-xing system

CBL-xing contains inside and outside equipment. Inside equipment is realised in the controlling cabinet, which is placed at the hut near the crossing. It contains a power supply and the level crossing controller. The controller is responsible for the safety of the system. Therefore, its CPU is realised as a 2 out of 2 (2oo2) system (duplicated for safety).

Road related outside equipment is practically independent of the number of tracks and consists of: boom barriers with booms (BB1 and BB2), road protection signals (RS1, RS2, RS3 and RS4) and warning bells (WB1 and WB2). Road signals are realised as a road traffic lights (semaphores) with LED light modules.

Railway related outside equipment is track and traffic direction dependent and for one bi-directional track usually consists of: train protection signals (TPS1 and TPS2), two pairs of switch-on elements (11/12 and 21/22) and two pairs of switch-off elements (31/32 and 41/42). Power supply usually contains two identical parts (PS1 and PS2). Switch-on (11/12, 21/22) and switch-off (31/32 and 41/42) elements are duplicated for the availability. Also, the road signals (RS1/RS3, RS2/RS4) are duplicated for the availability. In addition, road signals use LED light modules instead of classical signal bulbs to significantly increase reliability. MTBF of road signal LED modules is over 5 years, instead of 600h for the bulbs. Similar situation is with the train protection signals (TPS1 and TPS2), which also use rail LED lights modules with the life expectancy over 10 years.

All modules are of a CBL-xing system are removable, plug in modules, that enable easier and faster replacement (first line maintenance) and significantly reduces MTTR on sight, contributing to the higher availability of the entire system.

3. RAMS FEATURES OF CBL-XINGS

A CBL-xing is a scalable system. It can be used for various track layouts. The size and capacity of a CBL-xing will mostly depend on the number of railway tracks over the road and a place of the crossing (open line or railway station area). Typical application, presented on Figure 1, will be used to show the principle of the MTBF calculation and availability considerations for a CBL-xing system and to highlight the influence of reliability of particular subsystem and parts to the reliability of the entire system. Reliability of a CBL-xing system, for the same application, is mainly dependent on the technology used and producer's concept related to the number and quality (reliability) of the containing parts of the system.

Central 2oo2 computer with its digital inputs and outputs - DIOs is usually highly reliable. It is expected that this part of the system has the same life expectancy as required for the entire system (usually 20 years). As a result, the most producers do not use redundancy for the availability for the CPU 2oo2 computer and its DIOs.

Parts of a CBL-xing that have lower reliability are duplicated for availability, and a failure in one of their channels will not affect the availability of the system as a whole. Although their duplication contributes to a decrease in reliability of the system, the advantages related to availability have prevailing. As the maintenance repair time in very short (for example, 4h) the probability of having a second failure of the remaining redundant element leading to the interruption of the work is very small.

As a result, from the availability point of view, the most critical parts are the parts realised as a single elements with the lowest reliability.

4. TYPICAL CBL-XING ARCHITECTURE

For the calculation of the practical reliability and availability values of a CBL-xing system, we will use an example of a CBL-xing for typical application from Fig.1. The simplified architecture of a CBL-xing system, for typical application from Fig.1, is shown in Figure 2, with MTBF data of the most relevant parts.

The MTBF values for batteries (maintenance free), road signal LED modules, rail signal LED modules, boom barriers with booms and LPM – lighting protection modules are close to the realistic as given by their producers and rounded for easier calculation. The average values of MTBF of all other electronic equipment are also rounded (MTBF=: 250.000h / 500.000h / 1.000.000h / 1,500.000h / 2.000.000h) in relation to the technology used at the time of realisation (marked respectively as Type: A /B / C / D / HR) in order to make the calculation easier and to demonstrate a general approach.

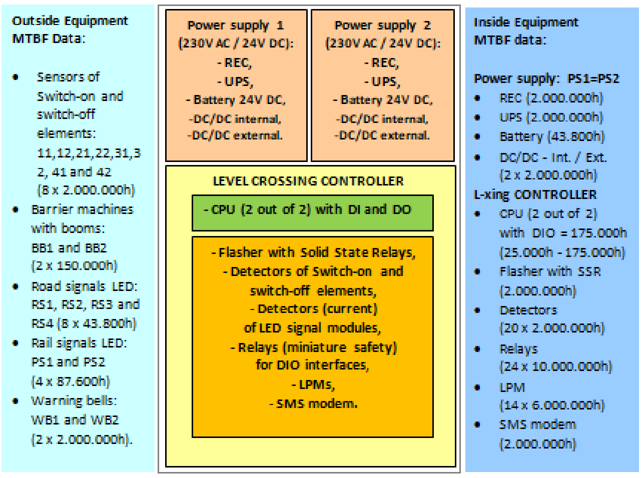

Fig.2. CBL-xing architecture with MTBF data

5. CBL-XING RAMS CALCULATION

Earlier developed processor boards based on 16-bit processors have, in general, the MTBF of about 50.000h (marked as Type A). Type B is related to next generation 80286 CPU boards (MTBF=100.000h). Type C covers 80386 CPU boards (MTBF=150.000h). Type D represents recent CBL-xings (due to the very long implementation time of new computer base technology into the safety related signalling products) based on 80486 CPUs and more advanced processors and architectures including RISC processors for safety applications (MTBF=200.000h) [3].

During the last decade we have experienced new *Commercial-off-the-shelf* - **COTS** controllers, which are used for the realisation of *High Reliable CBL-xings* - **HR CBL-xings**. COTS controllers are comprised of standard components and can therefore be produced, sold, and operated at significantly lower cost. They have a very high reliability (For Type HR MTBF is about 350.000h) and they are approved as SIL 4 for railway application in accordance with CENELEC standards [2].

CPU 2oo2 and DIOs are comparable from the MTBF point of view (usually realised as two units). Hence, we will assume that all DIOs have the same MTBF as CPU 2oo2 and complete CPU (2 out of 2) with DIOs will have a half of MTBF of CPU 2oo2.

In accordance with previous considerations the reliability of the complete CBL-xing system can be expressed via MTBF of its parts. Here, we will use the MTBF data, which are related to the all parts of the CBL-xing of Type HR, as shown in Figure 1.

Number of failures - Failure rate and MTBF of the power supply are:

$$\lambda(PS)=\lambda(PS1)+\lambda(PS2)=2*\lambda(PS1)=2*[\lambda(REC)+\lambda(UPS)+\lambda(Bat.)+2*\lambda(DC/DC)]=\mathbf{4.97E\text{-}05/h}.$$

$$MTBF(PS)=1/\lambda(PS)=\mathbf{20.136h}.$$

Failure rates and MTBF of the CPU 2oo2+DIO are:

$$\lambda(CPU+DIO)=\mathbf{5{,}71E\text{-}06/h}.$$

$$MTBF(CPU+DIO)=1/\lambda(CPU+DIO)=\mathbf{175.000h}.$$

Failure rates and MTBF of the remaining L-xing controller parts are:

$$\lambda(L\text{-}xing\ CP)=\lambda(Flesher)+\lambda(Detectors)+\lambda(Relays)+\lambda(Modem)=\mathbf{1{,}57E\text{-}05/h}.$$

$$MTBF(L\text{-}xing\ CP)=1/\lambda(L\text{-}xing\ CP)=\mathbf{63.559h}.$$

Failure rates and MTBF of the complete L-xing controller are:

$$\lambda(LXC)=\lambda(CPU+DIO)+\lambda(L\text{-}xing\ CP)=\mathbf{2{,}14E\text{-}05/h}.$$

$$MTBF(LXC)=1/\lambda(LXC)=\mathbf{46.625h}.$$

As a result failure rate and MTBF of the Inside Equipment are:

$$\lambda(IE)=\lambda(PS)+\lambda(LXC)=\mathbf{7{,}11E\text{-}05/h}.$$

$$MTBF(IE)=1/\lambda(IE)=\mathbf{14.063h}.$$

Failure rate and MTBF of the Outside Equipment are:

$$\lambda(OE)=\lambda(Switches)+\lambda(BBs)+\lambda(RS)+\lambda(TPS)+\lambda(WB)=\mathbf{2.47E\text{-}04/h}.$$

$$MTBF(OE)=1/\lambda(OE)=\mathbf{4.054h}.$$

Finally, failure rate and MTBF of the CBL-xing are:

$$\lambda(CBL\text{-}xing)=\lambda(IE)+\lambda(OE)=\mathbf{3{,}18E\text{-}04/h}.$$

$$MTBF(CBL\text{-}xing)=1/\lambda(CBL\text{-}xing)=\mathbf{3.147h}.$$

In accordance with the above example, it is possible to calculate simplified or precise MTBF of a CBL-xings for various applications depending on the availability of the accurate MTBF data for all parts.

6. RAMS DIFERENCES OF CBL-XINGS

During the course of 40 years of being applied, various CBL-xing systems have been developed [1]. During the last several years, some RA have been requesting the submission of MTBF data within the tenders. The RAMS numerical characteristics of a CBL-xing are mandatory by CANELEC standards in the aim to demonstrate an appropriate safety integrity level. Hence, the RA will be able to compare the MTBF data of various CBL-xing systems during the tendering phase. The following analyses can serve as an example of determining which CBL-xing system will prove to be the cheapest during its lifespan.

In the aim to compare CBL-xing systems we would have to compare their architecture and determine the MTBF values of their parts that are generally not publicly known. But, the MTBF of the processor boards (CPUs) can be approximately determined based on the level of technology and type of processors used [2]. It is reasonable to assume that the DIOs and the other electronic parts of the system also follow MTBF rates of the CPU technology at the time of system development. Hence, the MTBF characteristics of a CBL-xing system can be determined by analogy to the here presented calculation example for a CBL-xing. In accordance with the above mentioned considerations, various generations of CBL-xing systems and their MTBF values are compared and shown in Table 1. Table 2 presents the number of failures, i.e. required quantity of spare parts, for the analyzed CBL-xing systems, for the lifetime of 20 years.

Tab.1. MTBF of CBL-xing systems and its parts

TYPE	CBLXing Total	CPU + DIO	Controller Parts	Controller Total	Power Supply	Outside Equipm.
	MTBF [h]	MTBF [h]	MTBF [h]	MTBF [h]	MTBF [h]	MTBF [h]
A	2,032	25,000	10,784	7,534	12,876	3,551
B	2,551	50,000	20,520	14,549	16,217	3,822
C	2,895	75,000	37,406	24,958	18,635	3,974
D	3,042	100,000	51,546	34,014	19,610	4,027
HR	3,147	175,000	63,559	46,625	20,136	4,054

From the presented results we can conclude that influence of the reliability of the outside equipment and power supply is practically the most important. Also, the reliability of the remaining controller parts under the control of CPU makes more influence to the MTBF of CBL-xings then the safety CPUs with DIOs.

Tab.2. Number of failures of the CBL-xing systems

TYPE	CBLXing Total	CPU + DIO	Controller Parts	Controller Total	Power Supply	Outside Equipm.
	Failures	Failures	Failures	Failures	Failures	Failures
A	86.21	7.01	16.25	23.25	13.61	49.34
B	68.69	3.50	8.54	12.04	10.80	45.84
C	60.51	2.34	4.68	7.02	9.40	44.09
D	57.59	1.75	3.40	5.15	8.93	43.50
HR	55.67	1.00	2.76	3.76	8.70	43.21

With the goal of estimating the value of the spare parts and maintenance repair time (MTTR of 4h), we can assume that the electronic modules of all analyzed systems have the same price of EUR 3.500, except the CPU and DIOs that have the same price of EUR 35.000 and a maintenance hour price of EUR 250.

The duration of traffic delays, during the lifetime is proportional to the number of faults and MTTR. Failures of the parts have different influences on the availability of the system. The most critical are non-redundant parts with the low MTBF rate (like batteries and road signal LED modules). The accurate analyzes of the elements, which are critical in terms of traffic disruption, depend on the topology of a L-xing and the operational constrains. Therefore, for the further analyses we can assume that only 25% of failed parts will create traffic delays. We can also assume that the duration of a traffic delay will be ½ of the maintenance time required to clear a fault of the part that is responsible for the traffic delay. This way, the total traffic delay time will be 12,5% of the total maintenance time for the lifetime of an L-xing. Losses related to the traffic delays are dependent on the importance of the line. Traffic delay hours are differently rated for various RA (countries). For calculation purposes we will assume that the losses are around EUR 15.000 per 1h of traffic delays. Then, the total lifetime expenses (in EUR) for the analyzed CBL-xing systems, including spare parts, maintenance time and traffic delays, are presented in Table 3.

Total power consumption of CBL-xings varies (from 250W to 1.500W), influencing their lifetime expenses. Lower electricity consumption cost should also be an advantage in the evaluation of tenders.

Tab.3. The lifetime expenses of CBL-xing sysstems.

TYPE	CBLXing Total	CPU + DIO	Controller Parts	Controller Total	Power Supply	Outside Equipm.	MTTF 4h / failure	TD 0,5h / failure
	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR
A	1,255,215	245,280	56,864	302,144	47,622	172,704	86,205	646,540
B	934,599	122,640	29,883	152,523	37,811	160,440	68,685	515,140
C	799,695	81,760	16,393	98,153	32,906	154,308	60,509	453,820
D	746,259	61,320	11,896	73,216	31,270	152,264	57,589	431,920
HR	699,541	35,000	9,648	44,648	30,453	151,242	55,670	417,528

7. CONCLUSIONS

The total initial investment cost for a CBL-xing in the past can be estimates in range of EUR 350.000. It is visible that the lifetime cost of the older generations of CBL-xings is few times higher. Also, the lifetime cost represents a significant amount in comparison to the initial investment cost. The consideration above justifies a need to include the reliability characteristics of a CBL-xing system in the tenders in order to select the best bidder.

The analyses presented in this paper can be used as a guide to determine the real expenses of an L-xing system during its lifetime. The RA can conduct more accurate analyses with the real parameters. As a result, they will be able to select the most economical system for the expected lifetime, rather than the system that is seemingly the cheapest when only the cost up to (and including) the commissioning phase is taken into consideration.

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