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PRETHODNO SAOPŠTENJE

RELIABILITY AND AVAILABILITY OF BELGRADE TRAM ROLLING STOCK

POUZDANOST I RASPOLOŽIVOST BEOGRADSKOG TRAMVAJSKOG SAOBRAĆAJA

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REZIME

Tramvajski saobraćaj ima važno mesto u sistemu javnog gradskog prevoza u Beogradu. Međutim, zbog veoma nepovoljne starosne strukture, lošeg stanja tramvajskih pruga i infrastrukture, kao i sistema održavanja koji zahteva značajno unapređenje, tramvaji su u izuzetno lošem stanju, tako da se onemogućava zadovoljenje prevoznih zahteva, kako danas tako i u budućnosti. Iz tog razloga, a prema trenutnom stanju i budućim potrebama, grad Beograd planira revitalizaciju, rehabilitaciju i modernizaciju ovog vida prevoza. Samim tim bilo je veoma značajno da se mogućnosti obnove i modernizacije analiziraju kroz opsežnu studiju. U ovom radu, koji je proistekao iz pomenute studije, prikazano je stanje postojećeg tramvajskog voznog parka grada Beograda. Posebna pažnja posvećena je pouzdanosti i raspoloživosti voznih sredstava jer je to od najvećeg značaja za definisanje tehničkog nivoa potencijalne modernizacije, odnosno tehničkih i eksploatacionih karakteristika novih tramvaja koje mogu biti predmet potencijalne nabavke.

Ključne reči: *šinsko vozilo, tramvaj, pouzdanost, raspoloživost*

ABSTRACT

The tram traffic has important place and good perspektive in Belgrade public transportation sistem. However, because of unfavorably tram ageing structure, poor condition of rails as well as complete rail infrastructure and maintenance system that requires meaningful improvement, Belgrade trams are in very unsatisfactory shape which disables fulfillment of transport requirements even today and especially in the future. Therefore, according to the curent state and to the future needs, city of Belgrade planns revitalization, rehabilitation and modernisation of this form of transportation. Because of all above said it was important to analyze possibilities for renewal and modernization through serious feasibility study. This paper shows results of the existing Belgrade tram rolling stock condition analysis. Special attention was given to the reliability and availability of tram rolling stock as a foundation for defining technical level of the potential modernization as well as technical and exploitation characteristics of new tram cars that could be purchased in the next period.

Key words: *rail vehicle, tram, reliability, availability*

INTRODUCTION

Within the general urban plan of Belgrade, it is intended that, by the year 2021, there should be a new solution based on three kinds of rail transit: city and suburban rail, LRT system of great capacity and tram. [2]. About 550 million people are transported every year by Belgrade public transport, with the annual mobility of 450 drives per resident. In the total number of passengers carried, the bus transportation participates with 75%, trams and trolleybuses with around 22% and the rail with up to 3%. Concerning that around 18% of total number of passengers carried use trams for transport, this kind of transit is very important and has a good perspective in Belgrade public transportation system. Current situation is not well and that is the main reason why City of Belgrade is planning revitalization, rehabilitation and modernization of this kind of transit. European Bank for Reconstruction and Development (EBRD) and European Investment Bank (EIB) also supports this large, expensive and long-term work. These banks are willing to finance the projects, which would result in transportation infrastructure improvement,

particularly in public transport and with emphases to modernization of actual tram rolling stock.

Before realization, in order to provide its success, it was necessary to analyze possibilities, contents, volume and justification of this renewal. For that reason it was necessary to carry on serious analysis of possibilities for renewal and improvement of tram rolling stock and Traffic Secretariat of Belgrade City Management has accredited the realization of study "The Cost-benefit analysis of tram rolling stock" [1] to the Institute for Research and Design in Economy and Faculty of Mechanical Engineering in Belgrade.

One of the major parts of mentioned study was the analysis of actual condition of tram rolling stock of Belgrade Public Transport Company. Special attention was dedicated to its reliability and availability as a basis for defining a technical level of modernization of actual vehicles as well as for defining operating performance of new trams that could be provided in the future. The results of this analysis are shown in this paper.

CONDITION OF TRAM ROLLING STOCK

The structure and the age

The Public Transportation of Belgrade owns 222 trams and 21 trailers, which makes the total of 243 vehicles. The structure of the tram rolling stock, according to the manufacturer and the type is as follows:

Table 1. The structure of tram rolling stock

Manufacturer	Type	Tram number
CKD	KT-4 M YUB	20
	KT-4 YUB M modernized	30
	KT-4 YUB overhauled	35
	KT-4 YUB unoverhauled	109
	T4	1
DÜWAG	BE 4/4	1
	BE 4/6	26
	Trailers	21
Total		243

Data presented in Table 1 shows that Belgrade Public Transport Company use trams produced by Czech company CKD, which were purchased as newones in a period from 1980 till 1998 and used DÜWAG trams that were procured as donation from Switzerland.

Figure 1 shows age structure of CKD trams and it can be seen that the most of those trams (90 trams) were purchased in the period 1981-1983.

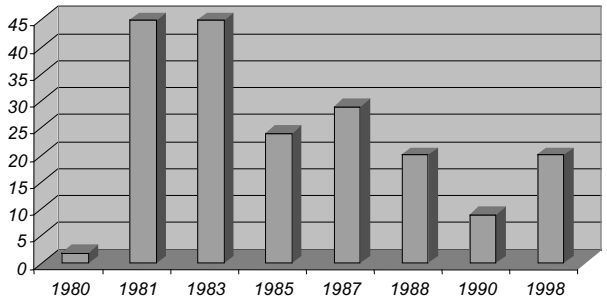

Figure 1 Age structure according to the year of entering the service

These 194 trams have traveled the distance of 174.698.097 km, which is 900.505.6 km per vehicle. The average age of the trams, from the aspect of the exploitation period, is 19.26 years, or more precisely 20 years.

As much as 60% of these trams have been in use for the past 20 years, whereas overhaul was performed on the total of 65 trams, taking into account the 30 trams that were overhauled and modernized in Goša-Inekon cooperation. The remaining 35 trams were independently overhauled by Goša, MIN, Šinvoz and Želvoz. A more precise distribution of trams according to the exploitation period is presented by figure 2.

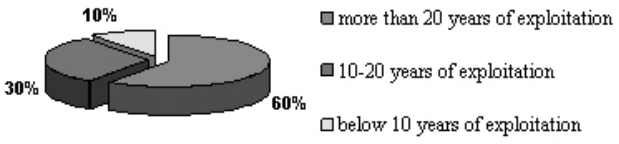

Figure 2. Tram exploitation period

Figure 3 shows the structure of tram rolling stock for DÜWAG trams and one CKD tram of type T4. The type T4 tram was classified together with DÜWAG trams, since it entered service in Belgrade in 2003, and since it arrived in Belgrade together

with the other trams in this group as used, and as a donation of west European countries. When these trams are classified according to the manufacture date, we get the following age structure:

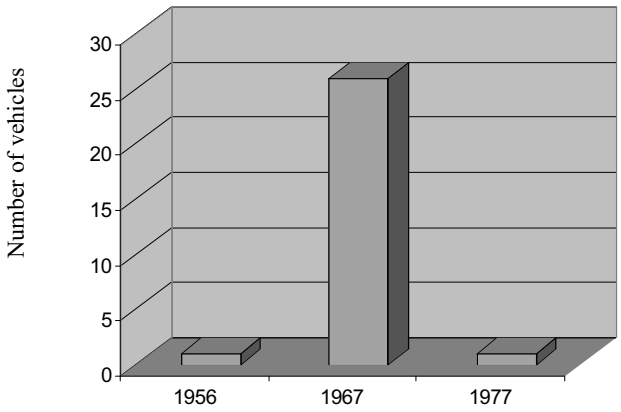

Figure 3. Age structure of Düwag trams (by year of production)

These 27 trams have traveled the distance of 2.341.845 km (from the date of entering the service in Belgrade), or 86.735 km per vehicle. The average age of these trams is 37,62 years.

The next figure shows the structure of tram trailers manufactured by DÜWAG. These trailers were delivered together with the trams of the same manufacturer, as used and as the donation of west European countries. When classified according to the manufacture date, we get the following age structure, presented by figure 4.

These trailers have crossed the distance of precisely 1.878.625 km (from the date of entering the service in Belgrade), or 89.458,33 km per vehicle. The average age of these trailers is 52 years.

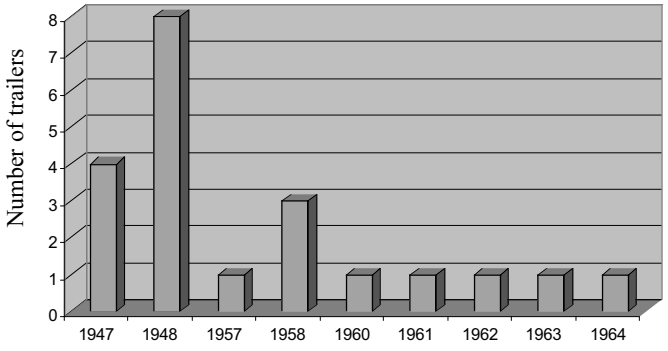

Figure 4. Age structure of Düwag trailers (by the year of production)

RELIABILITY AND AVAILABILITY OF ACTUAL TRAM ROLLING STOCK

The reliability and availability of the existing tram rolling stock have been analyzed on the basis of the data that were obtained from Belgrade Public Transport Company. On the basis of the provided data, we were to establish the characteristics of reliability and availability of the tram rolling stock and at the same time aspiring to achieve another two goals:

– Establishing the difference in reliability and availability of different vehicle groups within the rolling stock, formed by the type and the level of modernization (table 2). The analysis was to show the differences in reliability and availability which justify the higher level modernization, with high reliability values of individual tram subsystems.

– Getting an answer to the question which of the subsystems, devices and equipment in the selected tram groups have the biggest number of failures in previous exploitation. A failure analysis was performed (table 3), the aim of which was to point to the most unreliable subsystems and the need for their reconstruction, that is modernization.

The results of the carried out analyses of reliability and availability are shown in table 2, containing the data for the years 2003. and 2004, that refer to: the average number of trams and the total number of days in and out of service, the total mileage and the total number of failures per year. At the end of the table we can see the total number of failures on 100.000 km, as the reliability value, as well as the figure representing the operational availability on the basis of the total number of days out of service, which comprises the delay time due to preventive and corrective maintenance, together with the logistic and the administrative delay time. As previously stated, the analysis was performed for specially formed tram groups, namely:

– a group of relatively new trams KT-4M YUB with a continual drive regulation, released in traffic in 1998,

– a group of KT-4 YUBM trams, modernized by INEKON and GOŠA, again with a continual drive regulation, released in traffic in the period 2002-2003,

– a group of KT-4 YUB trams, overhauled in our country (GOŠA, MIN, ŽELVOZ and ŠINVOZ), and released in traffic after the overhaul in the period from 1991 till today,

– a group of unoverhauled KT4-YUB trams, released in traffic in the period 1980-1991 and,

– and DÜWAG trams, released in traffic in our country in the period 2001-2003.

Table 2. Reliability and availability of Belgrade Public Transport Company tram rolling stock

Year	Number of trams on average		number of days in total		mileage	Number of failures in total	number of failures on 100.000 km	availability
	in service	out of service	in service	out of service				
1	2	3	4	5	6	7	8	9
New trams KT-4M YUB, garage number: 401 -420 (20 vehicles)								
2003	17,08	2,92	5.661	1.639	435.164	203	46,65	0,78
2004	18	2	6.452	848	442.488	238	54,01	0,88
Modernized trams KT-4 YUBM, INEKON-GOŠA (30 vehicles)								
2003	16	14	4.156	6.794	896.803	713	79,50	0,38
2004	25	5	7.887	3.063	1.627.949	1.152	70,76	0,72
Overhauled trams KT-4 YUB, GOŠA, MIN, ŽELVOZ, ŠINVOZ (35 vehicles)								
2003	32,75	1,25	9.221	3.189	1.638.922	5.368	327,53	0,74
2004	30,5	3,5	9.209	3.201	1.677.332	4.106	244,79	0,74
Unoverhauled trams KT -4 YUB (109 vehicles)								
2003	95,83	14,17	28.676	11.474	5.166.279	16.418	317,79	0,71
2004	89,83	20,17	27.145	13.005	5.125.208	12.438	242,68	0,68
DÜWAG trams (27 vehicles)								
2003	20,42	6,58	6.328	3.527	786.135	693	88,15	0,64
2004	24,58	2,42	7.734	2.121	1.022.889	745	72,83	0,78

Table 3. Number of failures per 100.000 km of individual subsystems, devices and equipment in 2003/2004 [3]

KT-4M YUB		Modernized KT-4 YUBM		Overhauled KT-4 YUB		Unoverhauled KT-4 YUB		DÜWAG		Year	
2003	2004	2003	2004	2003	2004	2003	2004	2003	2004		
0,23	0,23	0,45	0,49	4,03	2,74	5,01	4,23	0,61	1,78	1	Bogie
4,60	7,46	16,50	14,13	70,29	27,38	54,88	35,17	0,13	0,59	2	Cardan brake
0,23	0,46	1,23	1,04	4,21	2,03	4,28	2,44	1,27	1,08	3	Rail brake
5,39	11,30	31,44	25,82	44,73	48,82	42,45	37,40	22,02	16,87	4	Doors
0	0,23	0,11	0,18	3,72	2,45	3,83	2,42	2,29	1,17	5	Lighting
0,23	0,68	0,22	0,68	8,60	5,12	8,19	6,23	1,66	0,88	6	Heating
0	0	0,22	1,04	6,18	5,72	4,70	6,87	1,62	1,47	7	Equipment in the driver's cabin a
0,23	0	0,78	0,37	2,01	1,13	1,91	1,17	2,64	0,78	8	Sand distributors
0	0	0	0,49	0,85	0,89	1,22	0,82	0,61	0,89	9	Platform
5,37	3,82	3,88	2,85	7,38	8,74	9,02	8,67	14,88	8,89	10	Pantograph
0,23	0,45	0,33	0,18	1,71	0,95	1,72	1,17	0,13	0,10	11	Coupling
18,15	16,86	12,80	13,45	54,73	46,87	53,08	45,20	9,67	7,04	12	Regulation of traction drive
2,07	2,49	1,67	1,87	10,03	7,21	10,41	8,46	3,05	3,13	13	Electric brake, overcurrent protection and spotting
0,69	0,45	0,45	0	0,79	2,21	1,83	1,66	0	0	14	Motor generator
1,38	1,36	0,11	0,06	0,46	0,72	0,39	0,80	0	0	15	Motor fan
1,38	2,03	0,68	1,29	0	0	0,74	0,22	0,13	0,10	16	Diagnostic system
4,83	3,16	7,36	4,16	16,13	15,08	15,58	12,58	4,59	8,41	17	Electrical fittings
0,23	0,80	0,11	0,18	0,31	0,54	0,12	0,86	0,26	0,38	18	Accumulator battery
0	0,80	0,33	0,55	0,12	0,40	0,41	0,70	1,14	0,38	19	Other (electric works)
1,38	1,38	1,34	1,84	4,46	3,22	5,69	3,49	9,64	7,63	20	Other (locksmith works)
0	0	0	0	0	0	0	0	11,32	9,61	21	(Air-operated equipment)
46,86	54,01	79,50	70,78	327,53	244,79	317,79	240,88	88,15	72,83	22	TOTAL

Table 4. Number of tram withdrawals from service in the period October 2004 - March 2005

Month	October 2004	November 2004	December 2004	January 2005	February 2005	March 2005	Average per month
Number of withdrawals	1118	1368	1481	1407	1516	1506	1399

In the performed reliability analyses, it was adopted that the failure cause was the tram defectiveness, which resulted in its withdrawal from service or taking to the depot. For that reason it was very interesting to examine number of trams withdrawal per month in a period from October 2004 till March 2005, which is shown in table 4 from which we can conclude that the average number of tram withdrawals from traffic on monthly bases is 1399. It is a rather large number of withdrawals, which is disturbing and indicative from the aspect of failures, that is reliability and availability of tram vehicles. [5]

The results of reliability and availability calculations show quite low reliability values. In other words, we could freely say that there are quite a large number of failures on 100.000 km of distance. The groups of unoverhauled and overhauled unmodernized trams experienced over 300 failures on 100.000 km. One can easily notice the significant differences in the reliability of the new trams KT-4M YUB and modernized trams KT-4 YUBM, relative to the other tram groups of the same type (table 3, figure 5). The biggest difference in reliability is noticed between the new and the overhauled trams (54,01 relative to 244,79 failures on 100.000 km of distance in 2004), which is a logical result showing the impact of the modern tram design (especially modern drive regulation) on the reliability level. Furthermore, it justifies the introduction of modern, continual drive regulation, with the purpose of decreasing the number of failures. It is interesting to note that, in both of the observed years, the overhauled, unmodernized trams show somewhat decreased reliability as compared to the unoverhauled trams (244,79 relative to 242,68 failures on 100.000 km of distance in 2004).

A more thorough analysis of availability calculation results could show and prove the impact of maintenance process characteristics on availability. However, even from the obtained data (table 3, figure 6), we can see that the more reliable technical systems do not require extensive maintenance, and therefore the availability of the new trams is significantly larger that the availability of the other defined tram groups (0,88 relative to 0,68 in 2004).

The analysis of reliability and availability calculation results over the years, shows that they significantly change, although the observed period is only two years long. The reasons are different, one of the most important being an applied maintenance system. A very good example are the modernized trams KT-4 YUBM, the reliability of which considerably increased in just one year whereas the availability

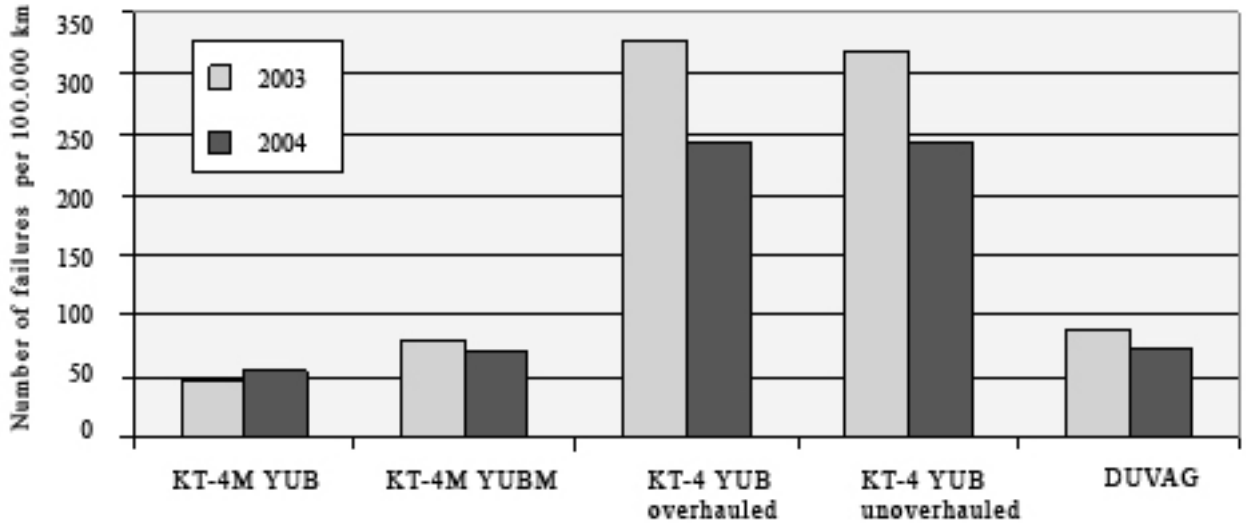

Figure 5. Number of tram failures per 100.000 km in 2003 and 2004 [4]

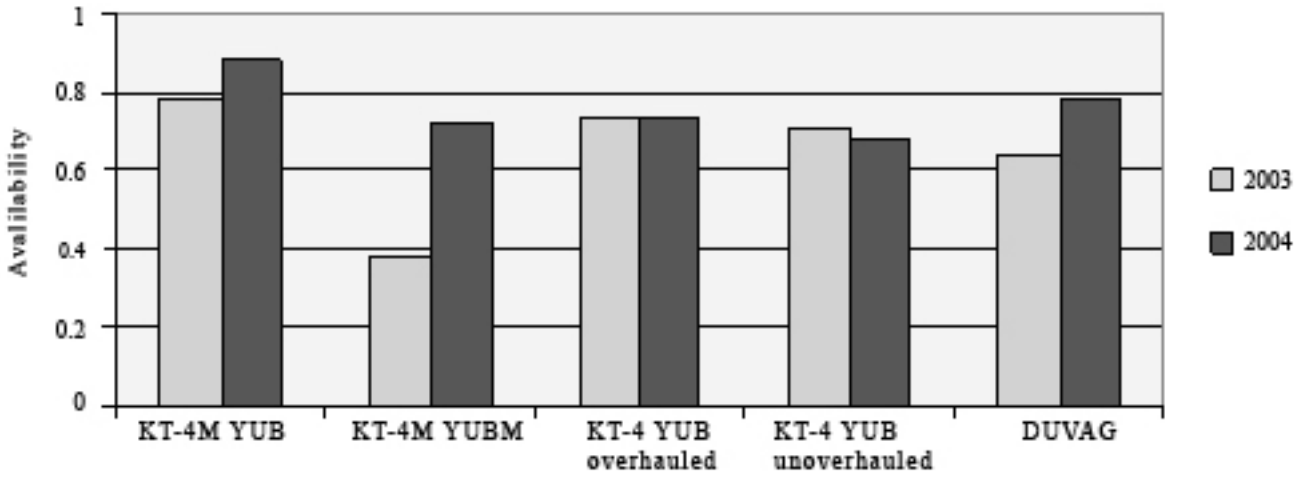

Figure 6. Availability of trams in 2003 and 2004 [4]

showed even better results (from 0,38 in 2003. to 0,72 in 2004). This demonstrates, first of all, the influence of prototype development completion during the exploitation (subsequent reconstructions and corrections of the observed shortcomings - in the period of modernized trams release in traffic, some of the failures, instead of being eliminated on the line, were eliminated in the depot with the necessary supervision of modernization executors), and consequently, of the maintenance system improvement. On the other hand, the enhancement of maintenance efficiency also affected the increase of DÜWAG trams reliability and availability.

The results of failure occurrence frequency analysis for individual subsystems, devices and tram equipment are presented in table 2, for the years 2003. and 2004. According to the table results, the subsystems, devices and the equipment with the highest number of failures, belonging to the overhauled, unmodernized and unoverhauled KT4-YUB trams, are: electric brake, overcurrent protection and spotting (34,3% of the total number of failures in 2004), cardan brake (24,1%), main drive regulation (22%), doors (17,4%) and the electrical fittings (6,4%). Those are the subsystems, devices and the equipment, most of which were reconstructed over the previous overhauls and modernizations.

Due to the achieved improvements, above all in the drive regulation subsystem, the number of failures in individual subsystems, devices and equipment of KT-4M YUB trams and the modernized KT-4 YUBM trams, differs from the number of failures of the overhauled, unmodernized and unoverhauled trams. Namely, the most frequent were: door failures (33,3% of failures in 2004), main drive regulation failures (21%), cardan brake failures (18,3%), electrical fittings failures (9,5%) and pantograph failures (6,4%). It should be noted, though, that in the case of KT-4 YUBM tram, as independently observed, the main drive regulation is still in the top of the list of potential failure sources.

With DÜWAG trams, the doors are the subsystem with the biggest number of failures in 2004 (26,1%), followed by: the pantograph (16,9%), the air-operated equipment (12,8%), the main drive regulation (11%) and the electrical fittings (5,2%).

The analysis of structural change of the most frequent failure modes over the years, shows that this structure in 2004. didn't significantly change relative to 2003. (the first five subsystems with the highest number of failures are the same).

The carried out reliability and availability analysis of the existing rolling stock of Belgrade Public Transport Company clearly points to the directions of its modernization in future, and it can also serve as a basis for defining the technical requirements concerning the acquisition of new trams.

CONCLUSION

Taking into account, the aims placed afore analysis of the reliability and availability of Belgrade tram rolling stock and based on accomplished results following conclusions could be made:

– The results clearly indicate significantly higher levels of reliability of so-called new KT-4M YUB

and modernized KT-4 YUBM trams (both tram groups have continual drive regulation) relative to overhauled and unoverhauled trams KT-4 YUB. In accordance to other observed groups, the availability levels are significantly higher only at KT-4M YUB tram. Lower availability of modernized tram KT-4 YUBM certainly is a result of unrealized prototype development, so after process of removing noticed defects it could be expected that this group of trams is going to have much higher level of availability. Altogether, the accomplished results validate the modernization of existent trams, especially when embedment of continual drive regulation is in question.

– High level of modernization, apropos the modernization of all basic subsystems with the most frequent failures (door failures, main drive regulation failures, cardan brake failures) will contribute to the growth of reliability of trams. Introduction of the modern maintenance technologies will influence the operating availability at the same way. So, the reliability and availability analysis shows that modernization which level is higher than level of previous repairs will significantly contribute to the higher values of the reliability and availability.

– The analysis that was taken also confirmed the influence of maintenance quality to the availability. The examples are DÜWAG trams whose availability shows growth in 2004 (0,78) in relation to 2003 (0,64) due to better training of maintenance team. The situation with so-called new trams KT-4M YUB is similar. Their availability has shown growth to 0,88 in year 2004 (in relation to 0,78 in year 2003), although the total reliability in that period was somewhat reduced, apropos number of failures per 100.000 km decreased from 46,65 in year 2003 to 54,01 in year 2004.

The bad condition of trams makes acquiring of transport requirements very difficult. A low reliability and availability values of tram rolling stock does not leave the possibility that this situation, without radical changes, can be improved. Therefore, Belgrade City Management is planning the revitalization, rehabilitation and modernization of this kind of transport.

For the purpose of renewal and development of tram rolling stock Belgrade Public Transport Company is going to insist on increase of reliability and availability until their satisfactory values are accomplished. In addition, Belgrade Public Transport Company will invest in maintenance system that could make those attributes permanent.

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