SYNTHESIS STUDY ON THE OPERATIONAL RELIABILITY OF AN URBAN TRANSPORT SYSTEM USING ELECTRICALLY DRIVEN TRAMS

Ioan FELEA[*], **István CSUZI**[**], **Călin SECUI**[*], **Gabriel BENDEA**[*]
[*]University of Oradea
[**]Oradea Public Transport Company, (OTL S.A.)

Abstract - The paper is structured in five parts. The first part is a brief presentation of the structure and the functioning of the urban transport systems using electrically driven trams (EUTS), based on which, the equivalent reliability diagrams of these systems are presented. Further on, based on the analysis of operational reliability, one can identify and there are defined the time characteristics and the transport capacity of EUTS. In the third part there are defined and analytically determined the safety and the availability of EUTS. The paper also contains results of a comprehensive study of case on EUTS from Oradea, results on which one can calculate, in the end, the availability indicators of the system. The last part of the paper contains the results and conclusions of the carried out analysis.

Key words: operational reliability, electric traction, indicators, trams.

1. INTRODUCTION

Applying the concept of sustainable development [1] is one of the most important priorities of modern society. In this context, in large urban areas, urban transport of people - in all its aspects - is a priority area of great importance and implications. Outstanding contribution to transport in general, especially of urban public transport (UPT), environmental pollution, especially of the atmosphere by greenhouse gases is well known [2]. Sharpening pollution in big cities is a major problem, which may decide even the fate of transport strategies, implicitly the UPT. In these circumstances, in the perspective of sustainable development, it is essential that local city fathers to consider:

- Priority development of UPT, which will reduce car traffic with all their implications;
- The developing, especially of the urban public transport with electric traction, the transport system that does not pollute, is relatively quiet and increases the safety in circulation.

Specific problems of urban public transport systems are largely reflected in the literature. Much of the work aimed at the UPT systems performance measured by efficiency, service quality and environmental impact. In [3] one can identify the factors that influence the demand for UPT insisting mainly on service quality, and in [4] a methodology for development is proposed and exemplified to elaborate the quality studies of the UPT system. Detailed methodology for assessing the quality of transport service is in [5], applying decisive impact factors such as availability, comfort and convenience. Availability of transport is exanimate in terms of service frequency and service coverage zone. One analyzed the comfort and convenience level for an UPT system using busses. The effectiveness of a specific UPT system is analyzed in [6,7]. Thus, in [6] the effectiveness of the UPT systems of 12 cities from Europe are analyzed, and 7 from Brazil. Based on these results the authors conclude for the UPT systems efficiency of only nine cities in Europe and one in Brazil, the inefficiency is due mainly to social interference. Using recorded data from 15 European UPT systems in [7] one aims to answer three questions identifying the essential performance of transport systems: the impact of design methodology, the impact of organization and the UPT system performance.

This paper is part of the concerns mentioned above, but stands firmly by these, being dedicated to determine the availability of an urban public transport system using electrically driven trams (EUTS) and to exemplify how to illustrate the evaluation of a specific EUTS.

2. SHORT PRESENTATION OF EUTS

EUTS functional aspect can be regarded and treated as a result of the interconnection of three subsystems (Fig.1), [8,9].

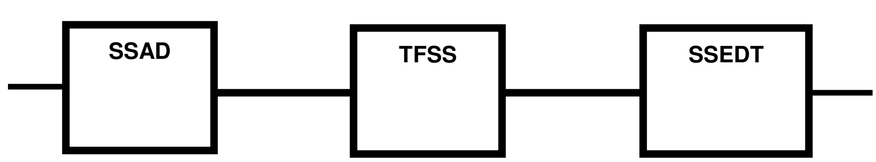

Fig. 1 - Structural block diagram of EUTS

Where:
SSAD - subsystem of electrical values adaptation of the electro-energetic system level (EES), the electrically driven trams (EDT) need;
TFSS - transfer subsystem (distribution) of electric energy (EE) between SSAD and EDT, including: bars of recovery stations (RS) and DC power supply grid from RS, including sections of the injection (SI), the contact sections (CS) and rails (R);
SSEDT- subsystem of powered trams covering the entire vehicle, actuators, with the transfer of EE (pantograph), with speed control equipment (controller, inverter, converter), with own facilities (lighting, thermal comfort) and other specific equipment and facilities.

UPT using EDT in Oradea started in 1906. EUTS of Oradea, operated by SC "Oradea Local Transport SA" (OTL), has the following features:

- Double rail length divided into five zones (Fig. 2): 39.86 km.
- The installed capacity in the five recovery substations: 5550 kVA.
- The total EDT: 73 of which, for maximum carrying capacity is required 44 pieces.
- Types of EDT used:
  → Produced by TATRA (Czech Republic), with DC motors without energy recovery, type KT4D (20 pieces) and T4D + B4D (43 pieces) in circulation, and two pieces of T4D processed for snow cleaning, as so in circulation a total of: 20 + 43 = 63 pieces
  → Produced by SIEMENS (Austria) 151 ULF (Ultra Low Floor): 10 pieces.

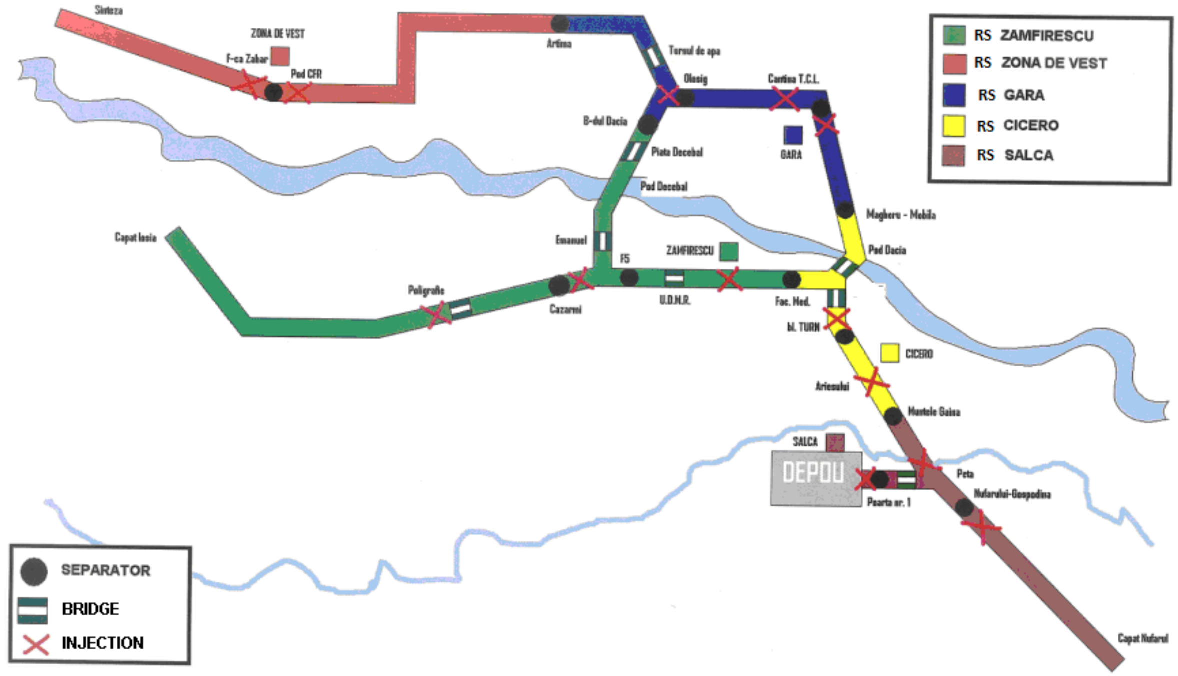

Fig. 2 – The zoning of TFSS at OTL

→ Average number of passengers served daily: 22,761.

- Average distance travelled 2,405,000 km a year;
- Average daily consumption of EE: 8759.8 MWh;
- Average cost per passenger and km EE: 0.055 LEI / passenger x km = 0.012 Euro/passenger x km;
- Average cost of operation: 22,715 thousand lei;
- Average profitability index: 1,128.

3. THE STUDYS OBJECTIVE AND WORKING METHOD

Operational reliability is determined in actual operating conditions [10,11,12,13]. In some cases, such as those of EUTS specific power equipment, laboratory testing and tracking are wasteful exploitation that remain the only source of information on reliability. Information on equipment reliability is useful both for users (maintenance optimization) and for producers (the purpose of corrections in design and manufacture).
The study has as main objective:

- Determine of EUTS equipment and installations operational reliability (OR);
- Hierarchy of equipment and facilities according to their reliability;

- Identify causes and typical modes of failure;
- Determining values for basic indicators of reliability;
- Identify laws that shape the distribution of random variables "for proper functioning time" and "for maintenance".

The applied working methodology was that, typical for such studies [7,8,9] and is based on careful monitoring of operational behaviour of the equipment, recording and event characterization, processing and interpretation of results. At OTL - EUTS, events recorded after equipment failure and during daily maintenance activities (DM), technical maintenance (TM) and prophylactic measurements.

Maintenance and operation staff of EUTS recorded in the books and records specific events, set in the OTL. Going through these documents held, first, information of interest to characterize EUTS - OR components in tables with the following structure [9]:

Table 1. – Synoptic events recorded EUTS components

Nr. crt.	Component of EUTS structure	Date and time of the produced event	Event description [fault element, fault method, causes]	Type and work sheet number	Maintenance time [minutes]
1	2	3	4	5	6
1	·		·		·
2	·		·		·

Systematization array of events was recorded on the three subsystems of EUTS: SSAD, TFSS and SSEDT. Please note that the number of events recorded with reference to SSAD and TFSS components is much lower than for SSEDT, where the level of information details is greater. This situation derives from the legal provisions [9], which are more stringent on monitoring the operation of EDT. Since January 2011, for an analysis of the maintenance of EDT, the internal decision OTL was to increase the detail of the EDT operation behaviour records, realizing, in addition to card occurrences (Table 1) and monthly summary, the following documents:

- Report maintenance activities;
- Synoptic situation of repeated failure for EDT;
- States for EDT;
- Failure for EDT;

In [9] one can find examples of summary tables above documents, which are intermediate between the books and records established and operating maintenance, charts and indicators that has been obtained by statistical processing of events based on statistical data recorded in the [2005 - 2010] period and the first half of 2011 for EDT.

Assessment results are presented in the following levels:

- Interpretation of data concerning events;
- Distribution of random variables and fundamental indicators of reliability of EDT;
- Global indicators of reliability of EDT.

4. STATISTICAL DATA INTERPRETATION ON RECORDED EVENTS AT OTL UTSUEDT.

Results were obtained by processing primary information is presented successively, with reference to three of EUTS - SS.

4.1. Results obtained on SSAD level

SSAD components are subject to the preventive maintenance (PM) works (technical revision) at intervals of about six months. From existing records in the OTL results a few unwanted events, followed by corrective maintenance work on the elements of SSAD structure. Summary of events is shown in table 2.

Tabel 2 – Summary of events followed by corrective maintenance (CM) on SSAD components

Nr. Crt.	The name of the unwanted event	YEAR/ Number of events [$\upsilon(T_A)$]					
		2006	2007	2008	2009	2010	TOTAL on 5 years
1.	Shutdown due to overload or wagon fault	57	65	52	43	922	1139
2.	Lack of communication (computer modem)	24	35	17	14	166	256
3.	No voltage supply of the NES (6kV)	7	18	16	13	11	65
4.	Switch coil lock	14	7	6	3	-	30
5.	Injection Cable Fault	5	7	3	1	7	23
6.	Advanced wear of switch contacts	4	5	4	2	-	16
7.	Diode protection burnout	4	-	4	2	1	11
8.	Switch coil burnout	3	1	2	2	-	8
9.	Pierced diode	-	-	2	2	-	4

For comparison, the number of occurrences of lack of power supply in the national energetic system (NES) "unwanted event is given in table 2, which estimates the level of safety associated with the NES on the connection points of the five RS. Number of events recorded and incomplete information on the characterization of events allows us to make a more complete statistical processing, to determine OR indicators such as total length of defects during the analysis [$\beta(T_A)$], the average time of proper operation [MTBF], average corrective maintenance time [MTCM(MTTR)], λ, μ.

4.2. Results obtained on TFSS level

TFSS components are very important both for security and availability EUTS, especially since there are no reservations in this subsystem. Therefore, TFSS components are subject to rigorous periodic inspections. In [9] provides detailed results of deep checks on the roadworthiness of TFSS. Statistically speaking, the main synthesis of unwanted events at EUTS rail structure (RS) for the 2006-2010 period are presented in table 3.

Table 3. Unwanted events at EUTS rail structure at OTL

Nr. crt.	The name of the unwanted event	YEAR				
		2006	2007	2008	2009	2010
1.	Rail crossings faults (wear, tear, expansion)	205	230	215	220	159
2.	Rail Fractures (joints coupons, coupling different track)	395	380	175	162	155
3.	Switch crossing faults (mobile arms, connection bars, bolts, springs)	55	70	73	67	39
4.	Over widening (track changed, weakened grip)	7	9	4	6	6
5.	TOTAL [$\upsilon(T_A)$]	662	689	467	455	359

4.3. Results obtained on SSEDT level

SSEDT is equipped with a high degree of reservation. However, EDT actions are subject to systematic and targeted PM, based on strict rules [15,16,17]. Database events recorded with reference to SSEDT is much wider than the other two EUTS-SS of OTL and contains findings during the CM and the PM. Results are presented both separately and compared, on all EDT types. In tables 4 to 6 one can find the main components of EDT which recorded undesirable events (faults) in the 2005-2010 period.

Table 4. - List of components with the highest number of defects [$\upsilon(T_A)$] for T4D - EDT type

Nr.crt.	Subsystem or component	YEAR						TOTAL
		2005	2006	2007	2008	2009	2010	
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**
1.	Electric cables	21	61	25	29	22	12	**170**
2.	Solenoids	32	49	52	46	41	22	**242**
3.	Validators	21	130	42	15	45	11	**264**
4.	Oil pumps	40	55	49	77	81	30	**332**
5.	Motor	25	126	55	70	51	38	**365**
6.	Caseing screws	35	89	64	102	77	3	**370**
7.	Pantographs	67	119	111	93	47	20	**457**
8.	Chassis/bogie	80	104	197	85	10	10	**486**
9.	Contactors/contacts	64	133	230	64	58	65	**614**
10.	Accelerator	127	88	246	105	94	40	**700**
11.	Lighting/signallings	54	225	47	271	263	24	**884**
12.	Doors	40	46	71	536	343	17	**1053**
13.	Breaking Systems	620	969	871	286	209	320	**3275**
14.	Others	795	812	1357	1198	1056	320	**5538**
15.	**TOTAL per year** [$\upsilon(T_A)$]	**2021**	**3006**	**3417**	**2977**	**2397**	**932**	**14750**

Table 5. List of components with the highest number of defects [$\upsilon(T_A)$] for kT4D - EDT type

Nr	Subsystem or component	YEAR						TOTAL
		2005	2006	2007	2008	2009	2010	
1.	Oil pump	25	5	1	13	9	1	**54**
2.	Validator	10	17	8	11	9	2	**57**
3.	Electric cables	20	43	12	26	15	4	**120**
4.	Motor	35	14	27	49	24	12	**161**
5.	Pantographs	25	26	40	45	21	13	**170**
6.	Solenoid	30	38	44	66	20	10	**208**
7.	Chassis/bogie	46	51	68	53	39	30	**287**
8.	Contactors/contacts	72	89	112	52	28	25	**378**
9.	Accelerator	70	74	146	75	45	11	**421**
10.	Caseing screw	72	92	143	86	47	8	**448**
11.	Doors	20	35	29	233	136	6	**459**
12.	Lighting/signallings	45	112	47	111	151	44	**510**
13.	Breaking Systems	192	247	249	96	47	104	**935**
14.	Others	423	563	736	615	299	74	**2710**
15.	**TOTAL per year** [$\upsilon(T_A)$]	**1085**	**1406**	**1662**	**1531**	**890**	**344**	**6918**

Tabel 6. - List of components with the highest number of defects [$\upsilon(T_A)$] for ULF - EDT type

Nr.crt.	Subsystem or component	YEAR			TOTAL
		2008	2009	2010	
1.	**2.**	**3.**	**4.**	**5.**	**6.**
1.	Motor	0	0	1	**1**
2.	Pantographs	0	0	4	**4**
3.	Contactors/contacts	0	2	3	**5**
4.	Chassis/bogie	0	0	6	**6**
5.	Electric cables	0	2	5	**7**
6.	Caseing screw	0	1	7	**8**
7.	Solenoid	0	0	10	**10**
8.	Accelerator	0	3	10	**13**
9.	Validator	3	5	7	**15**
10.	Lighting/signallings	2	1	19	**22**
11.	Breaking Systems	4	3	20	**27**
12.	Doors	6	4	22	**32**
13.	Others	26	128	132	**286**
14.	**TOTAL per year** [$\upsilon(T_A)$]	**41**	**149**	**246**	**436**

Fig. 3 shows a comparison of the variable values for the most vulnerable components of the three EDT types[$\upsilon(T_A)$].

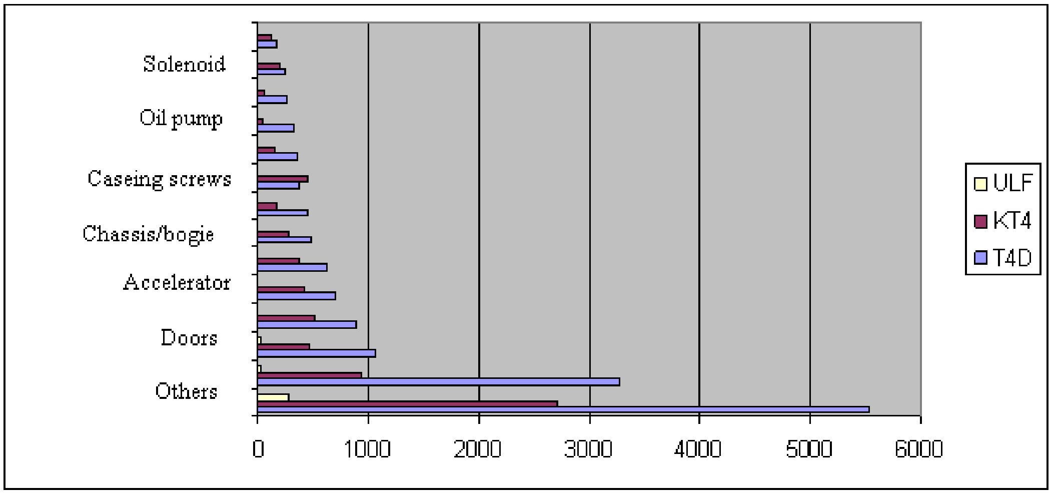

Fig. 3. – Values of [$\upsilon(T_A)$] variable during the analysis time on EDT components

For comparative analysis of EDT, for each EDT type, one calculated the "number of relative fails" indicator for the studied period:

$$\nu_r(T_A) = \frac{\nu(T_A)}{n} \quad (1)$$

n – the number of a certain type of EDT
Results are presented in table 7:

Table 7. – Annual relative number of fails on EDT types

EDT Type	Nr.EDT [n]	Year	Fails per year [$\upsilon(T_A)$]	Relative Fails [$\upsilon_r(T_A)$]
1	**2**	**3**	**4**	**5**
ULF	5	2008	39	7.8
ULF	10	2009	149	14.9
ULF	10	2010	59	5.9
Average/year	8.33		82.33	9.53
KT4D	25	2005	1085	43.4
KT4D	24	2006	1416	59
KT4D	25	2007	1662	66.48
KT4D	30	2008	1511	50.36
KT4D	21	2009	867	41.28
KT4D	20	2010	344	24.57
Average/year	23.83		1147.5	47.51
T4D	44	2005	2021	45.93
T4D	44	2006	3006	68.32
T4D	45	2007	3417	75.93
T4D	42	2008	2898	69
T4D	45	2009	2452	54.48
T4D	43	2010	932	20.71
Average/year	43.83		2379.33	55.72

In Fig.4 and 5, three types of EDT evolutions are compared during the analysis of the "number of relative fails" indicator [$\upsilon_r(T_A)$].

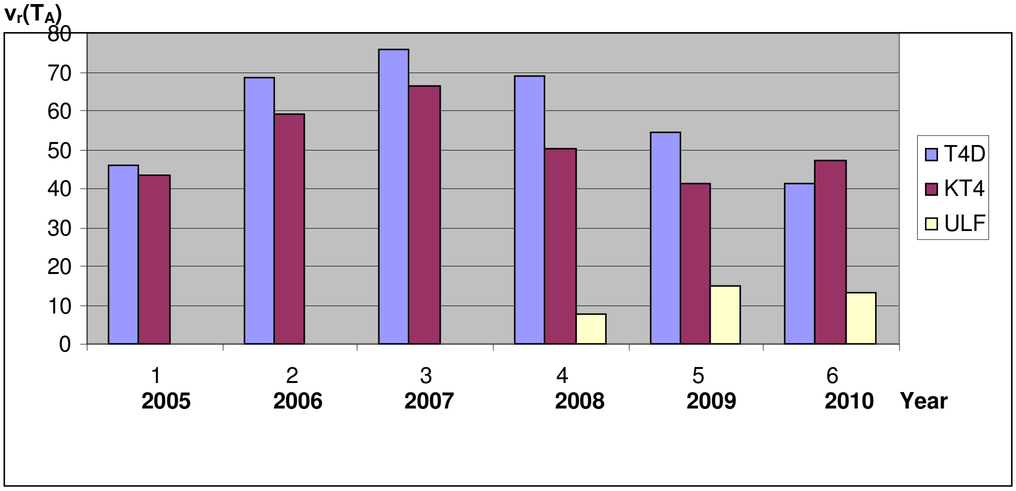

Fig. 4 – The evolution of $\upsilon_r(T_A)$ indicator for EDT of TL

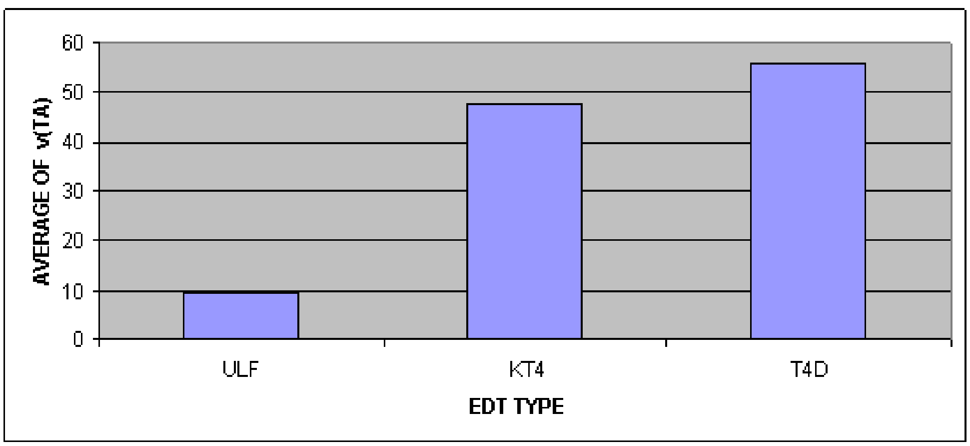

Fig. 5 – The comparison of average values of fails / year $v_r(T_A)$ for EDT of OTL

5. IDENTIFICATION OF DISTRIBUTION LAWS OF RANDOM VARIABLES THAT CHARACTERIZE THE OPERATIONAL RELIABILITY OF EUTS

Based on detailed EDT records, variation form strings of random variables (RV) can be made:

- Good operation time (T_F)
- Corrective maintenance time (T_{CM})
- Preventive maintenance time (T_{PM}).

T_{PM} variable is, in fact, a quasi-random one. Variation strings were calculated for all EDT types, and they are fully given in [9]. Processing of the 9 sets of values by running the program FRVA [18,19], we obtain parameter values of the tested theoretical distribution functions (E, W, N) and maximum deviation values from the empirical distribution [D_{max}], in table 8.

Table 8. – Parameter values of the tested theoretical tested distributions referring on RV specific to EDT of OTL

EDT Type	Distribution function		T_F (R)		T_{CM}(CM)		T_{PM}(PM)	
			Parameter values	D_{max}	Parameter values	D_{max}	Parameter values	D_{max}
T4D	Exponential		λ =0.037	0.097	μ_{CM} =0.067	0.152	μ_{PM} =0.134	0.43
	Weibull	η	23.897	0.075	1.578	0.102	2.885	0.114
		β	1.157		14.164		1.075	
	Normal	m	24.428	35.136	13.319	0.269	3.161	0.41
		σ	35.136		19.68		13.82	
KT4D	Exponential		λ =0.031	0.109	μ_{CM} =0.058	0.202	μ_{PM} =0.325	0.154
	Weibull	η	33.29	0.076	13.587	0.105	2.522	0.102
		β	1.194		1.332		1.223	
	Normal	m	32.045	0.184	13.473	0.304	2.628	0.335
		σ	35.393		24.281		5.573	
ULF	Exponential		λ =0.002	0.486	μ_{CM} =0.255	0.291	μ_{PM} =0.119	0.212
	Weibull	η	143.233	0.101	9.305	0.164	2.484	0.151
		β	0.964		1.431		1.052	
	Normal	m	163.702	0.422	8.455	0.212	2.628	0.335
		σ	810.104		8.065		5.573	

Where the units of measuring are: (λ, μ) - [h^{-1}] ; η – [h]; m – [h] ; σ – [h]

Given the D_{max} values, one recommends the following distribution functions for modelling the reliability and maintainability of EDT:

a.) For KT4D type of EDT:

- Random T_F variable:

$$R(t) = e^{-\left(\frac{t}{33.3}\right)^{1.19}} \quad (2)$$

- Random T_{CM} variable:

$$M_{CM}(t_{CM}) = 1 - e^{-\left(\frac{t_{CM}}{13.59}\right)^{1.33}} \quad (3)$$

Random T_{PM} variable:

$$M_{PM}(t_{PM}) = 1 - e^{-\left(\frac{t_{PM}}{2.52}\right)^{1.22}} \quad (4)$$

b.) For T4D+B4D type of EDT:

- Random T_F variable:

$$R(t) = e^{-\left(\frac{t}{23.9}\right)^{1.16}} \quad (5)$$

- Random T_{CM} variable:

$$M_{CM}(t_{CM}) = 1 - e^{-\left(\frac{t_{CM}}{14.16}\right)^{1.58}} \quad (6)$$

- Random T_{PM} variable:

$$M_{PM}(t_{PM}) = 1 - e^{-\left(\frac{t_{PM}}{2.89}\right)^{1.08}} \quad (7)$$

c.) For ULF type of EDT:

- Random T_F variable:

$$R(t) = e^{-\left(\frac{t}{143.2}\right)^{0.96}} \quad (8)$$

- Random T_{CM} variable:

$$M_{CM}(t_{CM}) = 1 - e^{-\left(\frac{t_{CM}}{9.31}\right)^{1.43}} \quad (9)$$

- Random T_{PM} variable:

$$M_{PM}(t_{PM}) = 1 - e^{-\left(\frac{t_{PM}}{2.48}\right)^{1.05}} \quad (10)$$

Values of fundamental reliability indicators for EDT are presented in table 9.

Table 9. – Values of fundamental reliability indicators for EDT of OTL

EDT Type	**MTBF [hours]**	**MTCM (MTTR) [hours]**	**MTPM [hours]**	**λ [h⁻¹]**	**μ_{CM} [h^{-1}]**	**μ_{PM} [h^{-1}]**
KT4D	32.3	17.24	3.08	0.031	0.058	0.325
T4D+B4D	27.03	14.93	7.46	0.037	0.067	0.143
ULF	500	3.92	8.4	0.002	0.255	0.119

5. CONCLUSIONS

Database operational reliability of the components of OTL - EUTS structure is consistent with respect to EDT and inconsistent with respect to components of SSAD and TFSS structure. The data was organized and completed substantially in the last two years.

Analysis of operational reliability, on the extended five years [2006 ÷ 2010], reflects the following hierarchy of events with the greatest impact on the SSAD structures unavailability of OTL - UTSUEDT:

→ Shutdown due to overload or wagon fault;
→ Lack of communication (computer modem);
→ No voltage supply of the NES (6kV);
→ Switch coil lock;
→ Injection Cable Fault.

The operational reliability analyzes of TFSS networks of OTL - EUTS made for a period of 5 years [2006 ÷ 2010], reflect the following hierarchy of events with the greatest impact on availability of this subsystem:

→ Rail Fractures (joints coupons, coupling different track);
→ Over widening (track changed, weakened grip);
→ Rail crossings faults (wear, tear, expansion);
→ Switch crossing faults (mobile arms, connection bars, bolts, springs).

From the database established for EDT at OTL, during the six years [2005 ÷ 2010], one obtained the following hierarchy of components in terms of impact on EDT operational reliability:

- EDT type T4D + B4D: braking system, lighting system / signal, doors, screw housing and accelerator;
- EDT type KT4D: brakes, doors, lighting / signalling, accelerator and contactors / contacts;
- EDT type ULF: type doors, brake systems, lighting / signalling, validation and acceleration system.

Summary of events registered at OTL database reflects the following increases in the relative number of falls (number of falls / number of copies in use) over 6 years [2005 ÷ 2010] on the endowment EDT of OTL

- for type T4D and KT4D of EDT increased from [2005 ÷ 2008] and decreases in [2008 ÷ 2010] period;
- for type ULF of EDT increased in 2009 and decreased in 2010 compared to 2009;
- the 3 types of EDT of OTL administration, rank in the terms of average value ν_r indicator (relative number of defects per year) as follows: T4D (55.7), KT4D (47.5); ULF (9.5).

Database on the events recorded in the OTL EDT is suitable to statistical analysis of identifying laws that reflect the true empiric distributions of random variables. Application of statistical processing model using the FRVA computer program, concluded that for the three types of EDT and with reference to the three random variables (T_F, T_{CM}, T_{PM}), Weibull distribution law most closely reflects the empirical distribution. The value obtained for the parameter β of the random variable T_F distribution law, reflects the fact that during the analysis, reliability improves for ULF type of EDT compared to the other two types of EDT (KT4D and T4D) which are worse.

The values for EDT fundamental reliability indicators of OTL reflect the followings:

- The reliability of EDT type ULF is much higher than the level of reliability of EDT type kT4D and T4D that have similar values for MTBF indicator;
- Time spent on preventive maintenance for EDT type ULF is greater than EDT type T4D and much higher than type KT4D;
- Corrective maintenance time for EDT type T4D and kT4D is much higher than EDT type ULF;
- CM time for old EDT (KT4D and T4D) is more than PM time of these EDT types; for EDT type ULF this is vice versa.

REFERENCES

[1] ***: *Strategy of sustainable development for EU, Bruxelles*, 10117/06;
[2]***: *Politics of energy for EU*, Phare RO 0006/18.02.2003;
[3] Paulley N. – *The demand for public transport: the effects of fares, quality of service, income and car ownership,* Elsevier Ltd, 2006
[4] L Dell'ollio, A. Ibeas, P. Cecin, *The quality of services desired by transport users*, Elsevier Ltd, 2010
[5] P. Yaliniz, S. Bilgic, Y. Vitosoglu, C. Turan, Evaluation of urban public transportation efficiency in Kutahya, Turkey;
[6] B.R. Sampanio, O.L. Neto, Y. Sampanio, Efficiency analyzes of public transport systems. Lessons for institutional planning, Elsevier Ltd, 2008;
[7] M.G. Karlaftis, D. Tsamboulas, Efficiency measurement in public transport: Are findings specification sensitive? Elsevier Ltd, 2011;

[8] Felea I. - *Reliability in electro-energetics,* Bucureşti, 1996;
[9] Csuzi I., *"Contributions to evaluating and optimizing the energetic and availability performance of the urban electrical traction system ", Thesis for PhD,* University of Oradea, 2011
[10] Birolini A., - *Quality and Reliability of Technical Systems*, Springer–Verlag, Berlin, 1994*;*
[11] O'Connor, P., - *Practical Reliability Engineering*, Editura John Wiley & Sons, England, 1991;
[12] Felea I, Coroiu N., - *Fiabilitatea şi mentenanţa echipamentelor electrice, Editura Tehnică Bucureşti, 2001;*
[13] Ivas D., Munteanu F., - *Fiabilitate, mentenanţă, disponibilitate, performabilitate în hidroenergetică*, Editura Prisma, Râmnicu Vâlcea 2000;
[14] Nitu V.I., - *Fiabilitatea instalaţiilor energetice – Culegere de problema pentru energeticieni,* Ed.Tehnică, Bucuresti 1979;
[15]***: SR EN 50119-2001, *Railway aplications.Fixed instalations.Electric traction overhead contact lines*;
[16]***: *Service guide for tram SiemensULF151,* Oradea 2008;
[17]*** *Documentation of tram Tatra T4D+B4D,* Praga,1974;
[18] Felea I. Secui C., - *Algoritm si program pentru stabilirea functiilor de distributie ale variabilelor aleatoare*, Lucrarile conferintei de electroenergetica, Timisoara,1994;
[19] Felea I., Secui C, Dzitac S., - *Indrumar de aplicatii in fiabilitate,* Editura Universitatii din Oradea, 2008