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MODELING DATA ANALYSIS OF THE SPECIAL INSTALLATION OPERATING WITH EQUIPPING THE FIRE ENGINES

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În articol sunt modelate valorile provenite din exploatarea instalaţiilor speciale care echipează autospecialele de intervenţie ale pompierilor, în programul Mathcad, prin metoda celor mai mici pătrate pentru repartiţia exponenţial negativă şi printr-o metodă originală pentru determinarea repartiţiei Weibull şi Poisson.

In this paper, data obtained from exploitation of special devices mounted on fire engine vehicles are modeled using the MathCAD code. The least square method for the exponential distribution and an original method for determining the Weibull and Poisson distributions are used.

Key words: reliability, fire engines, operating data, density function**.**

1. Introduction

In the reliability theory, fire engines represent a complex system with many structural sub-systems that function mainly in series, wherefore any component failure will stop the fire truck from working.

These devices are complex and are comprised of gas engine (with thermodynamic and mechanical elements), hydraulic installation (hydrodynamic and mechanical elements) and polyphaze fluids with different foam concentrations. Such aspects make the system properties to vary greatly. The interference of many science domains (thermodynamic, mechanic, hydrodynamic and dynamical polyphaze fluids) requires a different approach when studying reliability issues. When using fire trucks, it is necessary to collect data which allow a detailed analysis of the failure and the failure rate, keeping in mind the different time conditions, weather, environment and fire truck maintenance.

Because most reliability studies treat the electric and automation components, and because the information regarding the mechanical and hydraulics components is scarce, the authors adapted the analysis models from the electrical components to the hydraulics components.

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2. Statistical processing of operating data

It is commonly known among practicians that the problem of choosing a statistical model represents, from a statistical point of view, a problem of linking an empirical repartition – given by experiment – to a theoretical repartition chosen as model.

In the case of corrective maintenance the unavailability time data for type A fire trucks have been introduced in Excel, ordered by time of failure occurrence (fig. 1). Horizontal lines have been drawn to determine the density function of unavailability time data, based on statistical methods, especially the Bendat & Piersol model presented in [1].

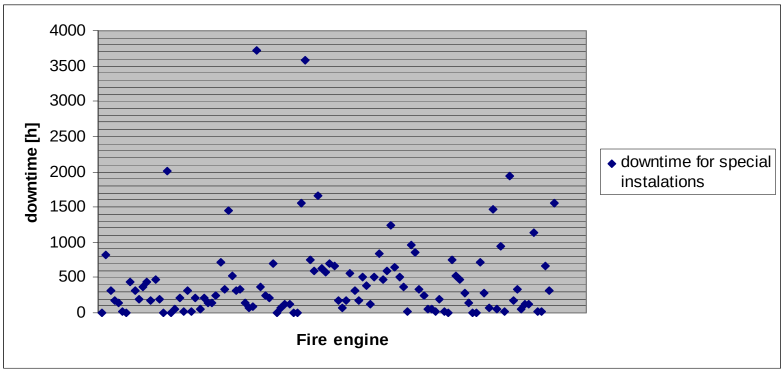

Fig. 1 – Representation of unavailability time data for special installation

Operating data from table 1, for the special installations that equip the fire trucks, has been processed, taking in consideration the belt size of 200 hours, the middle of every interval, the appearance frequency and the relative frequency [1].

It is easy to notice on the figure the two abnormal values which were eliminated because they did not represent the statistical population.

Table 1

Operating data acquired for special installations

Nr.	Interval	Middle of interval	Frequency	Relative frequency
1	0 – 200	100	45	45/105
2	200 – 400	300	23	23/105
3	400 – 600	500	12	12/105
4	600 – 800	700	11	11/105
5	800 – 1000	900	6	6/105
6	1000 – 1200	1100	1	1/105
7	1200 – 1400	1300	2	2/105
8	1400 – 1600	1500	2	2/105
9	1600 – 1800	1700	1	1/105
10	1800 – 2000	1900	2	2/105
Total	0 – 2000	-	105	1.00

The next chart represents the density function of unavailability time data for each analyzed interval, to better observe the shape of the distribution for these values.

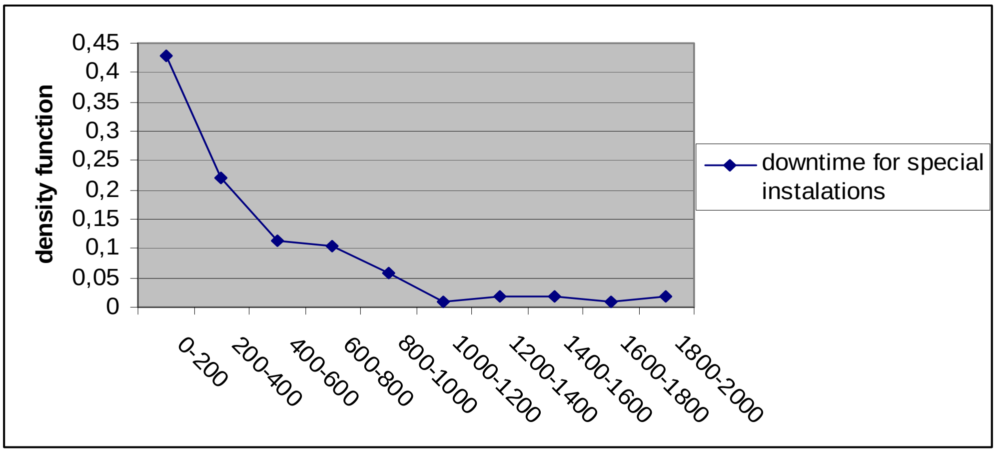

Fig. 2 – The density function of unavailability time data for special installation

3. The use of the least squares method

The values for the density function of unavailability time data was modeled using the MathCAD software, and the exponential, Weibull and Poisson distribution models.

For determinating the statistical repartitions, the analyzed interval is narrowed more than 1000 times, the mathematical functions corresponding to the analyzed models were determined, the function that best fits the analyzed data was chosen and in the end the identified function was transformed in the original function characterizing the failure process.

$$ORIGIN := 1$$

$$x := (0.1 \quad 0.3 \quad 0.5 \quad 0.7 \quad 0.9 \quad 1.1 \quad 1.3 \quad 1.5 \quad 1.7 \quad 1.9)^T$$

$$y := \left(\frac{45}{105} \quad \frac{23}{105} \quad \frac{12}{105} \quad \frac{11}{105} \quad \frac{6}{105} \quad \frac{1}{105} \quad \frac{2}{105} \quad \frac{2}{105} \quad \frac{1}{105} \quad \frac{2}{105}\right)^T$$

$$v := (0.1 \quad 0.3 \quad 0.5 \quad 0.7 \quad 0.9 \quad 1.1 \quad 1.3 \quad 1.5 \quad 1.7 \quad 1.9)^T$$

$$l(x) := l\operatorname{int}erp(x, y, v)$$

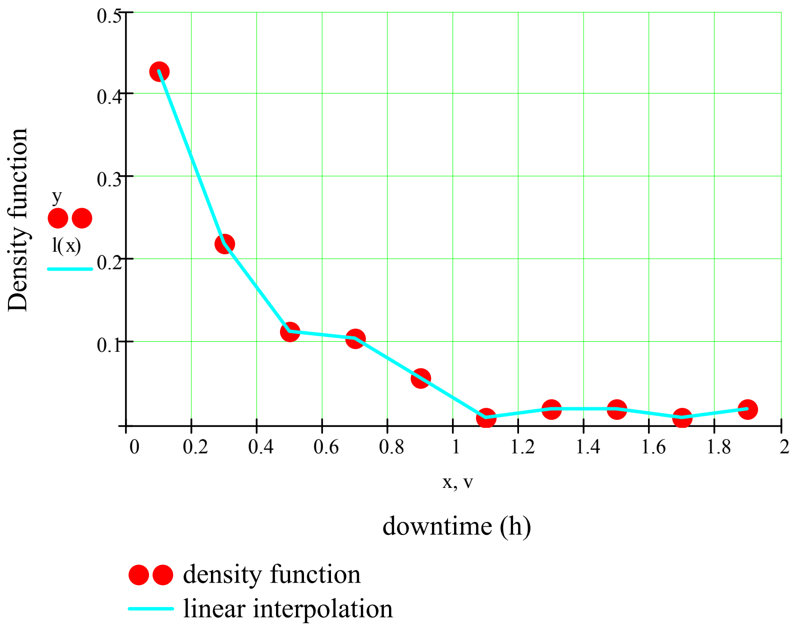

Fig. 3 – The density function of unavailability time data for special installation

$$A := \begin{bmatrix} \sum_{i=1}^{10} (x_i)^2 & \sum_{i=1}^{10} x_i \\ \sum_{i=1}^{10} x_i & 10 \end{bmatrix} \qquad B := \begin{bmatrix} \sum_{i=1}^{10} (x_i \cdot \ln(y_i)) \\ \sum_{i=1}^{10} \ln(y_i) \end{bmatrix}$$

$$A^{-1} \cdot B = \begin{pmatrix} -1{,}995 \\ -1{,}089 \end{pmatrix}$$

By applying the least square method for the exponential function f(u) = exp (a·u + b) and solving the equation system, we obtain the values of the coefficients: a = 1.995 şi b = 1.089:

$$f(u) = \exp(-1.995 \cdot u - 1.089) \tag{1}$$

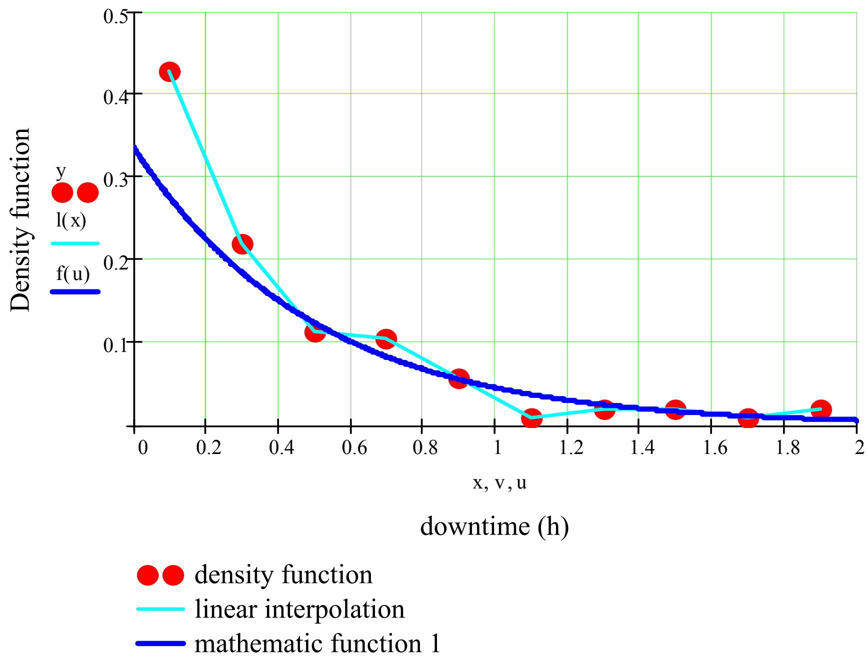

Fig. 4 – Density function modeling of unavailability time data using the least squares method

Analyzing the chart from fig. 4, we can observe that the mathematical function f(u) = exp (a·u + b) does not model all the operating data values; we proceed to identify another exponential function of the following shape g(u) = exp (a·u^2 + b u +c).

$$C := \begin{bmatrix} \sum_{i=1}^{10}(x_i)^4 & \sum_{i=1}^{10}(x_i)^3 & \sum_{i=1}^{10}(x_i)^2 \\ \sum_{i=1}^{10}(x_i)^3 & \sum_{i=1}^{10}(x_i)^2 & \sum_{i=1}^{10}x_i \\ \sum_{i=1}^{10}(x_i)^2 & \sum_{i=1}^{10}x_i & 10 \end{bmatrix} \qquad D := \begin{bmatrix} \sum_{i=1}^{10} -\left[(x_i)^2 \cdot \ln(y_i)\right] \\ \sum_{i=1}^{10} -(x_i \cdot \ln(y_i)) \\ \sum_{i=1}^{10} -\ln(y_i) \end{bmatrix}$$

$$C^{-1} \cdot D = \begin{pmatrix} -1.293 \\ 4.581 \\ 0.223 \end{pmatrix}$$

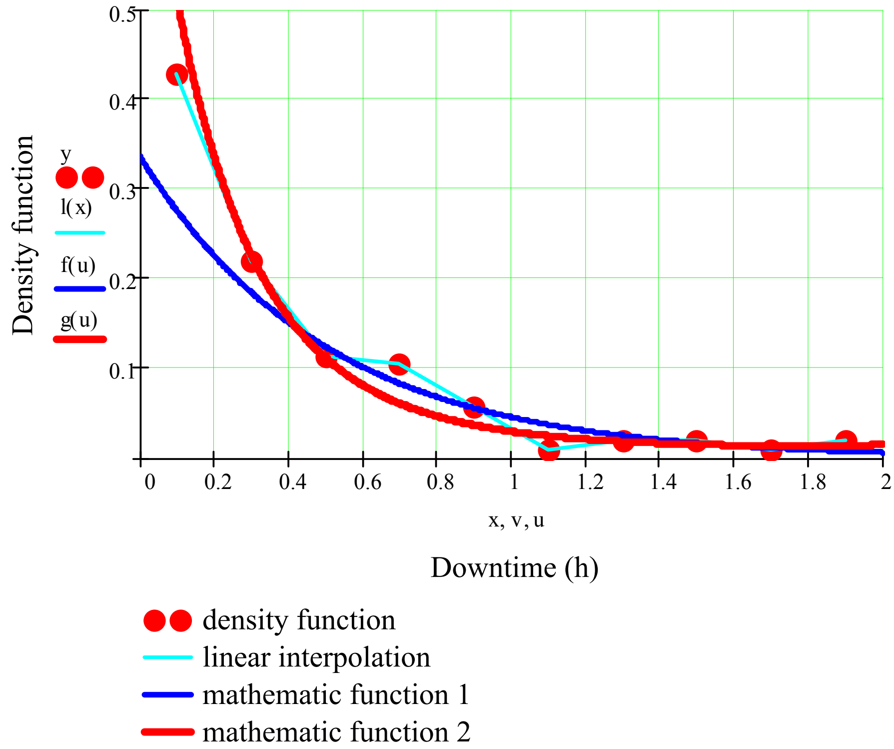

Fig. 5 – Density function modeling of unavailability time data using the least squares method

Solving the system of equation the following values for the coefficients of the function g(u) are obtained: a = -1.293; b = 4.581 and c = 0.223; and the seeked function will have the form:

$$g(u) := \exp\left[-\left(-1.293 \cdot u^2 + 4.581 \cdot u + 0.223\right)\right] \quad (2)$$

4. Analysis model for the Weibull repartition

The random variable **z** is characterized by the Weibull repartition with the β as shape parameter and η as scale parameter.

The Weibull repartition model is analyzed: after choosing the value for β parameter and considering that for every analyzed interval, the failures are modeled after a Weibull process with a specific zeta, we determine the zeta value specific to each process using the root operator. The mean η value for the whole process that characterizes the process of the fire truck failure is determined, and the repartition obtained with this parameter will characterize or not the failure process.

$$w(z) := \frac{0.5}{\eta}\cdot\left(\frac{0.1}{\eta}\right)^{-0.5}\cdot e^{-\left(\frac{0.1}{\eta}\right)^{0.5}} - \frac{45}{105} \qquad \eta := 10$$

$$root(w(\eta),\eta) = 11.274 \qquad \eta_1 := root(w(\eta),\eta)$$

…

$$w(z) := \frac{0.5}{\eta}\cdot\left(\frac{1.9}{\eta}\right)^{-0.5}\cdot e^{-\left(\frac{1.9}{\eta}\right)^{0.5}} - \frac{2}{105} \qquad \eta := 10$$

$$root(w(\eta),\eta) = 310.111 \qquad \eta_{10} := root(w(\eta),\eta)$$

We obtain β = 0.5, and η = 19

$$w(z) := \frac{0.5}{\eta}\cdot\left(\frac{z}{\eta}\right)^{-0.5}\cdot e^{-\left(\frac{z}{\eta}\right)^{0.5}} \tag{3}$$

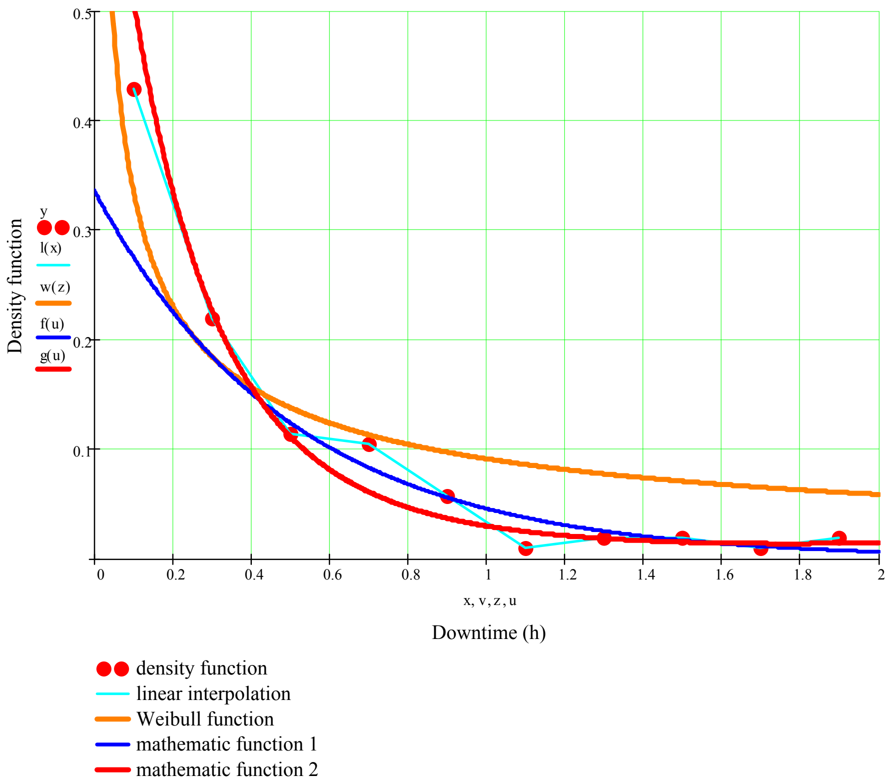

Fig. 6 – Density function modeling of unavailability time data – Weibull repartition

5. Analysis model for the Poisson repartition

The random variable **x** fits the Poisson distribution with λ parameter, if it can take any negative integer value, the literature assigns each process that characterizes abrupt failures to the Poisson distribution.

We analyze the Poisson repartition model considering, for each analyzed interval, that failures are modeled after a Poisson process with a specific λ; we determine each λ for each process with the root operator. We determine λ for the entire process that characterizes the failure of special installation of fire trucks as the mean weighted value, and the Poisson repartition with this parameter will or will not characterize the failure process.

We model the density function of the unavailability time data using the Poisson distribution.

$$p(\lambda) := e^{-\lambda} \cdot \frac{\lambda^2}{2!} - \frac{45}{105} \qquad \lambda := -1 \qquad root(p(\lambda), \lambda) = -0.664$$

$$\lambda_1 := root(p(\lambda), \lambda)$$

$$p(\lambda) := e^{-\lambda} \cdot \frac{\lambda^2}{2!} - \frac{23}{105} \qquad \lambda := -1 \qquad root(p(\lambda), \lambda) = -1.139$$

$$\lambda_2 := root(p(\lambda), \lambda)$$

...

$$\lambda = -1.409$$

$$s := (2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12 \quad 14 \quad 16 \quad 18 \quad 20)$$

$$p(s) := e^{-\lambda} \cdot \frac{\lambda^s}{s!} \tag{4}$$

$$p(s) := (p(2) \quad p(4) \quad p(6) \quad p(8) \quad p(10) \quad p(12) \quad p(14) \quad p(16) \quad p(18) \quad p(20))$$

$$s := (2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12 \quad 14 \quad 16 \quad 18 \quad 20)^T$$

$$y := \left(\frac{45}{105} \quad \frac{23}{105} \quad \frac{12}{105} \quad \frac{11}{105} \quad \frac{6}{105} \quad \frac{1}{105} \quad \frac{2}{105} \quad \frac{2}{105} \quad \frac{1}{105} \quad \frac{2}{105}\right)^T$$

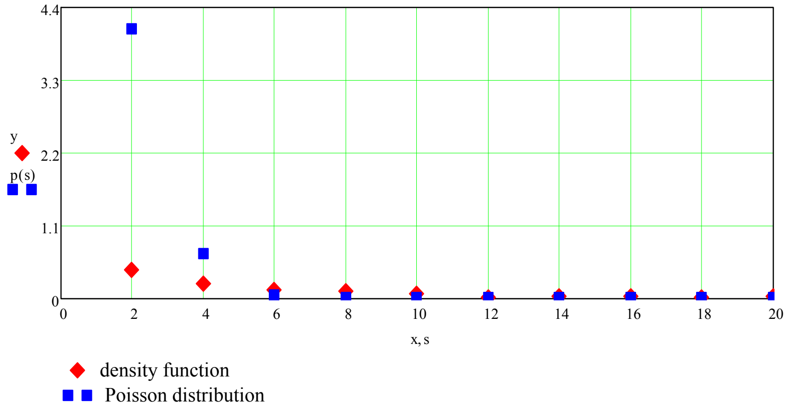

Fig. 7 – Modeling the density repartition of unavailability time data using the Poisson repartition

It is easy to observe in the above chart that the Poisson distribution dos not fit the operating data values for the special installation of fire engine.

6. Determination of the original function. Calculation of the reliability parameters

By analyzing the above methods and the representing charts, we can conclude that the mathematical function that best models the experimental data values for the special installation looks like:

$$g(t) := \exp\left[-\left(-1.293 \cdot 1000^{-2} \cdot t^2 + 4.581 \cdot 1000^{-1} \cdot t + 0.223\right)\right] \quad (5)$$

Reliability parameters specific for maintainability are: g(t)–maintainability function, μ (t) – rate of restorability and MTR – mean time to repair.

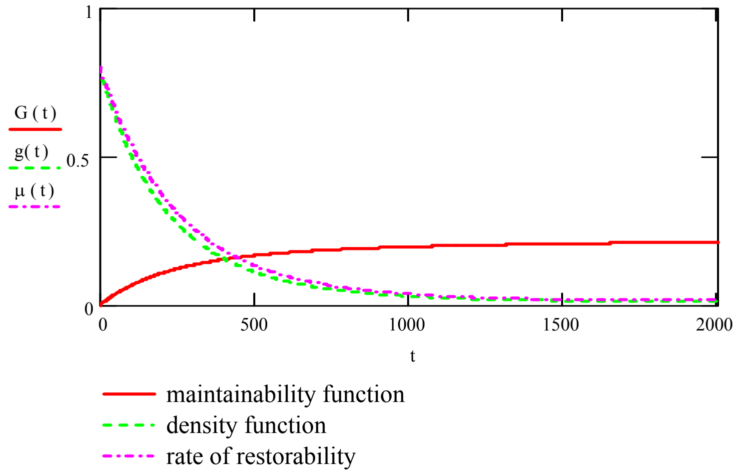

Fig. 8 – Reliability parameters characterizing g(t)

$$G(t) := \int_0^t g(t) \cdot 10^{-3}\, dt \tag{6}$$

$$\mu(t) := \frac{g(t)}{1 - G(t)} \qquad \mu(t) := \frac{\beta}{\eta} \cdot \left(\frac{t \cdot 10^{-3}}{\eta} \right)^{\beta - 1} \tag{7}$$

$$MTR := \int_0^{2000} t \cdot g(t) \cdot 10^{-3}\, dt \qquad MTR = 74.025 \tag{8}$$

6. Conclusions

It is very important to know all the reliability parameters of fire trucks in order to avoid the situation that these equipments fail during the short time they operate.Based on this theoretical and experimental study, new scientifically based data will be available for making new technical specifications.

The models presented for determinating the Weibull and the Poisson distributions are contributions of the authors applying these methods in statistics they brings a modest contribution to the development of this field.

Because the mean time of repair is 74 hours, we can conclude that a fire truck will be unavailable on an average time of three days, if the malfunction occurs at the special installation.

Differences up to 100 hours that appear are due to logistics maintenance management which includes: the short supply of spare parts, mechanic availability and their performances and, last but not least, general repair execution planning, taking into account current repairs.

R E F E R E N C E S

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