Maintenance Operating System Uncertainties Approached through Neutrosophic Theory

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Abstract-This study introduces the concept of uncertainty analysis of Neutrosophic Theory in the sphere of Maintenance Operating System (MOS). The aim of this study is to underline the importance of uncertainties solving in Manitenance Operating System. In maintenance process appear ambiguous states that can't be assimilated neither true, nor false, meaning that the threshold state is a neutral one, being defined as fault in most of cases. In this regard, this uncertainty making decision process can be associated as functioning according to rules of Neutrosophy, and can be evaluated using elements of Neutrosophic Structures, Pareto Charts, maintenance metrics. Identification of uncertainties and study of their impact on maintenance, making the right decision, is the main focus of this paper.

The study is useful for business area, especially manufacturing lines endowed with complex equipment and facilities, also for researchers interested to make improvements for maintenance procedures.

Keywords-uncertainty; neutrosophic theory; constraints; throughput to potential; uncertainty making decision;

I. INTRODUCTION

All advanced systems depend on having a foundation of Maintenance Operating Systems (MOS) in place, even if the owners will not admit that.

A method to improve efficiency and to decrease the downtime in manufacturing process is a goal for everybody.

An efficient maintenance offers a stable manufacturing process assuring reliability of the system.

Vision for MOS is a standardized, proactive and disciplined operating system that engages all team members to maintain the integrity and availability of equipment, facilities and processes.

Desired outcomes mean to engage stakeholders in the development and implementation of a standard MOS that ensures world class manufacturing Throughput to Potential (TTP) of plant facilities and equipment. Uncertainty represents an unsolved situation; it defines a fuzziness state [5].

The aim of this study is to identify uncertainties of MOS that definitely decrease efficiency of the system, to evaluate them through Neutrosophic Theory[1] (NT) and to show the potentiality of the method for uncertainties solving.

The paper is structured as follows: Section 2 briefly describes the preview works related to Neutrosophic Theory, Section 3 discusses about MOS and uncertainties, Section 4 presents some results and statistics interpretation and finally, Section 5 depicts conclusions and directions for future work.

II. PREVIEW WORKS

In this section will be presented some pragmatic areas where neutrosophy is suitable and the basic concept of neutrosophic theory.

Neutrosophy is an available method for uncertainties investigation for any complex manufacturing line that involves advanced technology, many parameters and metrics. It can be applied to evaluate the uncertainty level, to analyze it [8].

Logistics is the field of study focused on the design, control, and implementation of the efficient flow and storage of goods and services. Because of numerous other related information from the point of origin to the point of final consumption with the aim to satisfy the requirements of its existing and prospective customers, the system can generate a lot of uncertainty [1].

A sample of using neutrosophic decision making model on manufacturing line as used for selection quality clay-brick for construction is developed and denoted to be suitable.

[1] Neutrosophic Theory, initiated by Florentin Smarandache, professor at New Mexico University, în 90s with wide applicability în sciences, Smarandache, F. (2005).*A Unifying Field in Logics: NeutrosophicLogic,Neutrosophy, Neutrosophic Set, Neutrosophic Probability and Statistics*, American Research Press, Rehoboth.

Neutrosophy set is a tool that can deal with indeterminacy and inconsistent data [13].

According to the neutrosophy theory, the neutral (uncertainty) instances can be analyzed and accordingly, reduced. There are some spectacular results of applying neutrosophy in practical application such as artificial intelligence [3].

Extending these results, neutrosophy theory can be applied for solving uncertainty also on other domains such as Robotics, where are confirmed results of neutrosophics logics applied to make decisions when appear situations of uncertainty [10],[11].

The real-time adaptive networked control of rescue robots is another project that used neutrosophic logic to control the robot movement in a surface with uncertainties for it [12].

Neutrosophy analyzes, evaluates and interprets uncertainties. The specialty literature denotes that Zadeh introduced the degree of membership/truth (t), so the rest would be (1-t) equal to f, their sum being 1, and he defined the fuzzy set in 1965 [6]. Further, Atanassov improved Zadeh's theory by introducing the degree of nonmembership/falsehood (f) and defining the intuitionist fuzzy set [7].

As novelty to previous theory, Smarandache introduced and defined explicitly the degree of indeterminacy/neutrality (i) as independent component. In any field of knowledge, each structure is composed of two parts: a space, and a set of axioms (or laws) acting (governing) on it. If the space, or at least one of its axioms (laws), has some indeterminacy of the form (t, i, f) ≠ (1, 0, 0), that structure is a (t, i, f) -Neutrosophic Structure [4].

III. MAINTENANCE OPERATING SYSTEM

Maintenance definition according to Business Dictionary, represents activities required or undertaken to conserve as nearly, and as long as possible the original condition of an asset or resource while compensating for normal wear and tear [2].

Without any operating system, a management system, some metrics to measure the progress, you are trying to build a foundation on the sand.

In maintenance process also intervene some uncertainties regarding failures involving equipment efficiency, process flow (bottlenecks on production line, constraints), operators skills, spare parts management, manufacturing line potential, etc. All of them decrease somehow the manufacturing process, directly or indirectly the efficiency of production flow. It is a challenge with the seconds of cycle time of product manufacturing, with maintenance concept of preventive, predictive or corrective, with people training, equipment spare parts or maintenance costs reducing [9].

Nowadays, when manufacturing processes are very complex, involving a lot of different types of machines and equipment, in which the product in fact, is an intricate one, maintenance is deployed as a system subordinated to manufacturing process. The main principles of maintenance are: safety and quality always in top; using data to make decisions; using standardized tools, practices, procedures; applying prevention through a continuously improvement process; optimization of the resources; maintaining the integrity of the equipment; maximize throughput of installed equipment and facilities to its potential, such as shown in Fig. 1.

There are 3 major inputs that generate faults or uncertainties:

- *People:* poor training, lack of versatility, missing technically competent, poor communication;

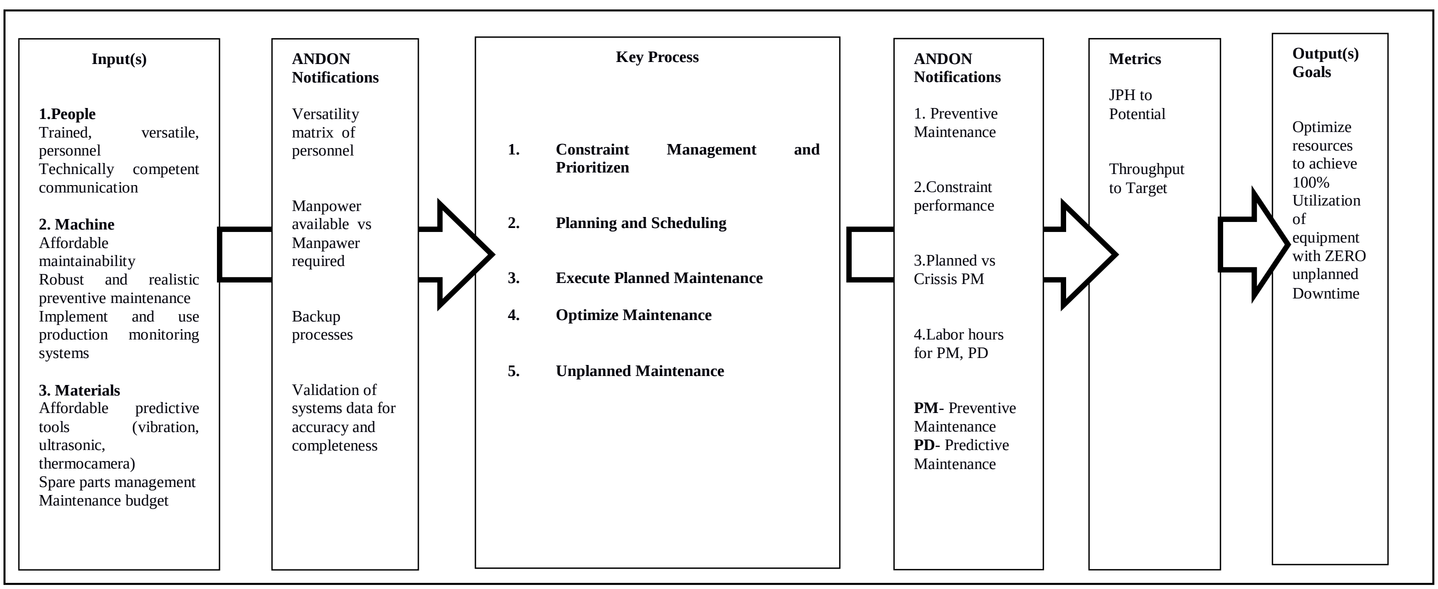


Fig. 1. The structure and elements of MOS

- *Machine*: not affordable maintainability, not realistic preventive maintenance, not existing production monitoring system, not applicable predictive maintenance (thermo camera, ultrasonic, vibration);
- *Materials*: spare parts control with errors, nonstandardization of spare parts, not affordable predictive tools, small maintenance budget .

There are Key Process to control the threats of input: constraint management, planning and scheduling the maintenance, optimize maintenance, do unplanned maintenance.

The efficiency of maintenance is revealed by metrics such as JPH (Job Per Hour) and TTP (Throughput to Potential).

The goal of each system is ZERO defects, meaning no downtime on manufacturing process, an idealistic situation.

According to our goal, we proposed to analyze the faults that generate downtime of the system. The faults are revealed on TTP, a metric that shows the potentiality of manufacturing line to produce parts to high capacity related to engineering capacity. There are 3 zones of TTP that can be interpreted according to an established level (designed) L = 100% :

$$TTP < L - 2.5\% \quad - \quad \text{red zone;} \tag{1}$$

$$L - 2.5\% <= TTP < L - 0.5\% \quad - \quad \text{yellow zone;} \tag{2}$$

$$TTP >= L - 0.5\% \quad - \quad \text{green zone;} \tag{3}$$

Daily collected data shows the status of manufacturing lines, emphasizing the constraints and bottle-necks, such as in Fig. 2.

TTP is a maintenance metric that emphasizes the line balancing from cycle time point of view. This means that within manufacturing line the stations have different cycle time to perform a product, according to the assigned operations. The stations with cycle time at the highest limit are called "constraints" and they can supply "bottle-necks" on manufacturing process.

According to these data it can be analyzed monthly productivity trend related to occurred faults, as in Fig. 3. The graphic underlines the evolution of TTP for constraints stations monthly, weekly for the previous month and daily for the current month.

Evaluating and analyzing the faults, they can be grouped such as: people training (operator lack skill), low communication level, missing spare parts, equipment obsolete level part, equipment parameters out of range, operating error, logistic error (wrong part supply)… Each fault type is generator of uncertainty, and involves uncertainty making decision process.

To evaluate correctly the fault rate we will make it in step 1, Pareto analysis for the most frequent faults group, as in Fig. 4.

Looking into Pareto Charts we see that "operator lack skill" induces a percentage of 25% relative frequency. Interpreting this data, we can say that reducing the rate of this item, it can be also reduced the fault rate of whole system. Operator lack skill involves confusion and uncertainty in faults solving making decision.

THROUGHPUT TO POTENTIAL

Dates	Area	JPH Data Collection Point (Departmental Constraint)	Shift Pattern	Production Time [min/day]	Daily Required Volume [units/day]	Takttime (actual line cycle time) [sec]	JPH Maximum Capacity/ Volume [JPH]	JPD	JPH Net Required (daily required volume) [JPH]	Overspeed [%]	ERR - Engineered Run Rate (Body only) [JPH]	Monthly Data: JPH Net Required compared to JPH Maximum [%]	Total units built during DAY [units]	Total hours run during DAY [hours]	Daily JPH [JPH]	Monthly JHP compared to JPH Maximum [%]	Remark (issue and action plan)
				A	B	C	D = (A/(C/60))/(A/60)	X=D*K	E = B/(A/60)	F = D/E-1		G = E/D	J	K	L = J/K	M = L/D	
	Framing	SF1	5*7.4	444	295	85	42,4	326	39,9	6,2%	41,0	94,1%	315	7,7	40,9	96,6%	
	Framing	SF2	5*7.4	444	295	85	42,4	326	39,9	6,2%	41,0	94,1%	315	7,7	40,9	96,6%	
	Framing	SF3	5*7.4	444	295	85	42,4	326	39,9	6,2%	41,0	94,1%	317	7,7	41,2	97,2%	
	Underbody	SU1	5*7.4	444	350	48	75,0	555	47,3	58,6%	75,0	63,1%	283	7,4	38,2	[illegible]	
	Underbody	SU2	5*7.4	444	350	48	75,0	555	47,3	58,6%	75,0	63,1%	276	7,4	37,3	49,7%	
	Underbody	SU3	5*7.4	444	350	48	75,0	555	47,3	58,6%	75,0	63,1%	295	7,4	39,9	53,2%	
	Underbody	SU4	5*7.4	444	350	70	51,4	381	47,3	8,7%	51,4	92,0%	259	7,4	35,0	68,1%	
	Underbody	SU5	6 * 7.4	444	230	70	51,4	381	31,1	65,5%	51,4	60,4%	258	7,4	34,9	67,8%	
	Underbody	SU6	5*7.4	444	350	70	51,4	381	47,3	8,7%	51,4	92,0%	258	7,4	34,9	[illegible]	Sealer pump fault 60min
	Underbody	SU7	5*7.4	444	350	70	51,4	381	47,3	8,7%	51,4	92,0%	255	7,4	34,5	[illegible]	
	BodySide	SB1	5*7.4	444	295	86	41,9	310	39,9	5,0%	41,0	95,2%	294	7,4	39,7	94,9%	
	BodySide	SB2	5*7.4	444	295	86	41,9	310	39,9	5,0%	41,0	95,2%	297	7,4	40,1	95,9%	
	BodySide	SB3	5*7.4	444	295	83	43,4	321	39,9	8,8%	41,0	91,9%	305	7,4	41,2	95,0%	
	BodySide	SB4	5*7.4	444	295	83	43,4	321	39,9	8,8%	41,0	91,9%	307	7,4	41,5	95,6%	
	Hanging	SH1	5*7.4	444	330	78	46,2	342	44,6	3,5%	41,0	96,6%	329	7,4	44,5	96,3%	
	Closure	SC1	5*7.4	444	190	127	28,3	215	25,7	10,4%	28,3	90,8%	202	7,6	26,6	93,8%	
	Closure	SC2	5*7.4	444	190	127	28,3	213	25,7	10,4%	28,3	90,8%	205	7,5	27,3	96,4%	
	Closure	SC3	5*7.4	444	200	124	29,0	218	27,0	7,4%	28,3	93,1%	205	7,5	27,3	94,1%	

Fig. 2. Throughput to Potential

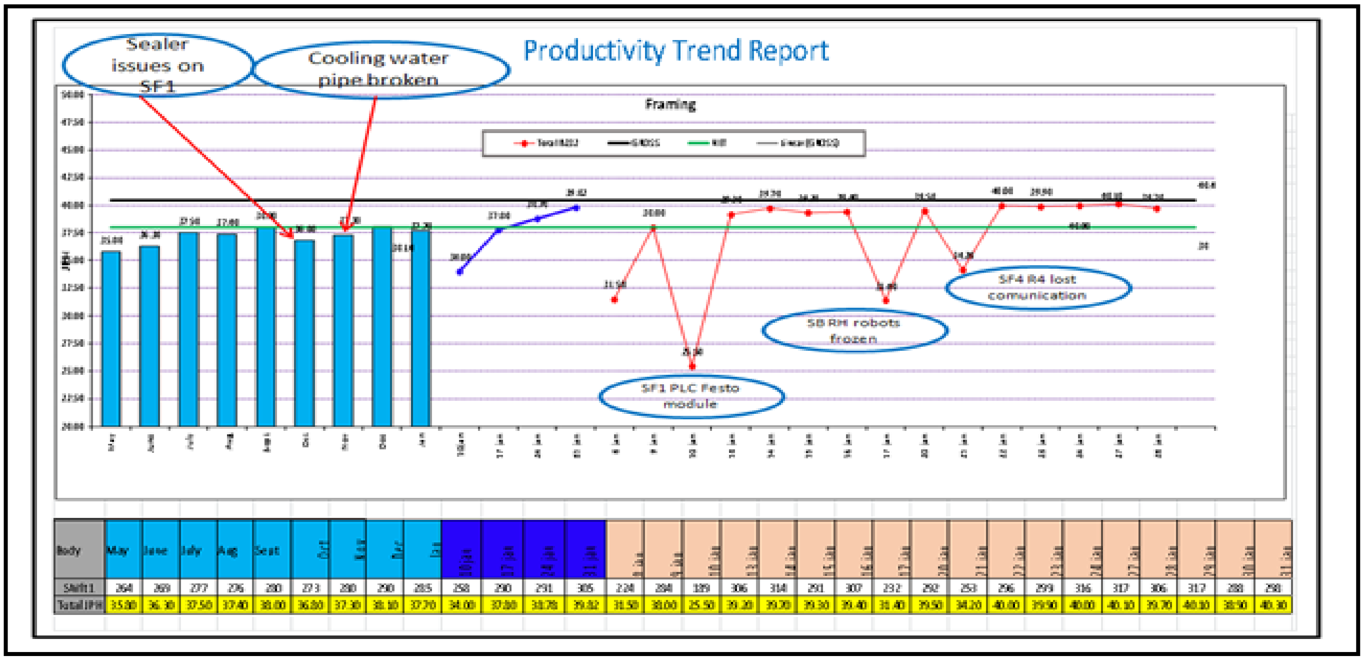
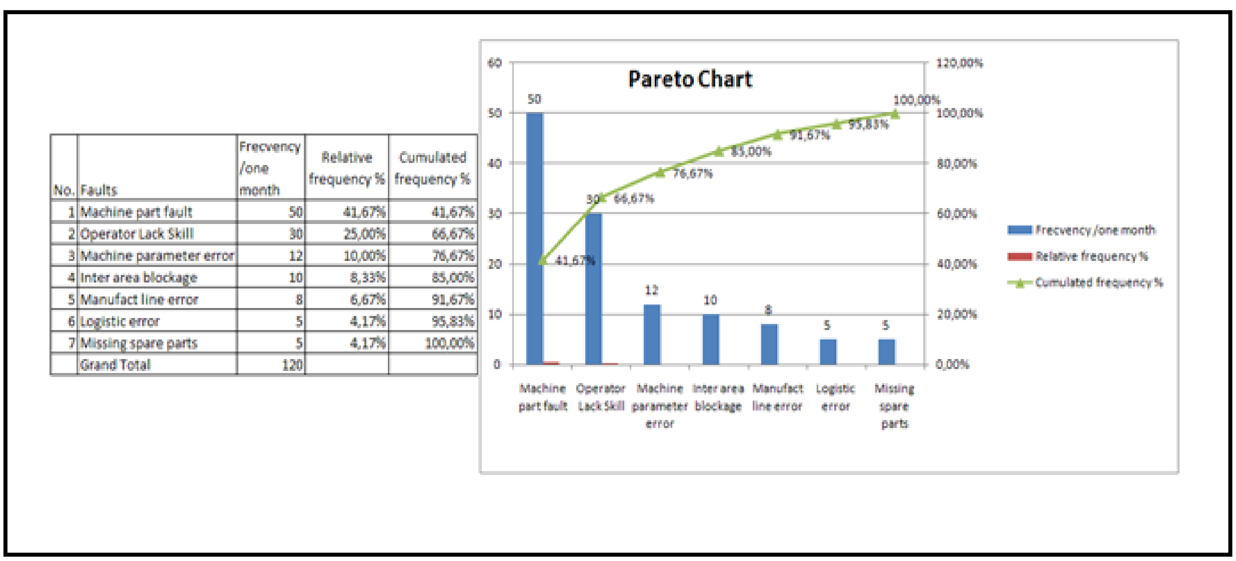


Fig. 3. Evolution in time of TTP

Increasing versatility of maintenance operators, it will cover the solving of wide area of faults making decision, such as quick intervention to equipment, right selection of part replacement, right selection of damaged equipment, avoiding inter-areas blockages, and so on. This is an important moment to make the right decision regarding to choose the appropriate truth degree membership (acceptance), indeterminacy degree membership and falsity degree membership (reject).



No.	Faults	Frecvency /one month	Relative frequency %	Cumulated frequency %
1	Machine part fault	50	41,67%	41,67%
2	Operator Lack Skill	30	25,00%	66,67%
3	Machine parameter error	12	10,00%	76,67%
4	Inter area blockage	10	8,33%	85,00%
5	Manufact line error	8	6,67%	91,67%
6	Logistic error	5	4,17%	95,83%
7	Missing spare parts	5	4,17%	100,00%
	Grand Total	120		

Fig. 4. Pareto Chart Analysis - step 1

To apply the neutrosophic method we have to define the space and the set of axioms for occurred uncertainties. Each operator has skills in different level of specialty knowledge in order to solve a maintenance fault.

To evaluate the level of uncertainty it is important to establish each level of uncertainty related to make the right decision, as is shown in Fig. 5.

The space is represented by operators and the set of axioms, by the skill level of fault solving for each operator. In Fig. 6 is shown the set of axioms for each operator, so we have a (T, I, F), as follows:

a_{11} - operator 1/skill 1
a_{12} - operator 1/skill 2 …

a_{15} - operator 1/ skill 5 and so on to
…
a_{55} - operator 5/ skill 5.

In this context, we can establish the whole space of states True, Indeterminacy, False (T, I, F), and the value of the space. In Fig.6, are presented the spaces and sets of axioms for 5 operators such as a_{ij} (T, I, F).

A complete cycle time to produce a part consists of a sum of specific times, such as: cycle time (effectively), starvation, blockage, wait for auxiliary parts, wait for attention, repair in progress, break, set-up, tool change, no communication. Uncertainties are focused on “wait for attention” when operator is confronted with confusion and ambiguous states, the moment of fault making a decision. The situation is eased byan IT application that monitors and handles the states of equipment in detail, and guides the operator to make more accurate the fault location.

TABLE 1
LEVEL OF UNDERTERMINACY

No.	#L	Level of uncertainty	State		
			T	I	F
1	L1	Solve the fault JIT (Just In Time)	1	0	0
2	L2	Solve the fault + Δt	<1	<0,5	<0,2
3	L3	Solve the fault with help from other operator	<0,5	<0,5<1	<1
4	L4	Nonsolving the fault by operator	0	0	1
5	L5	Nonsolving the fault, nobody in place	0	1	1

Fig. 5. Establishing the neutrosophic uncertainties

STEP 1

	S_1				S_2				S_3				S_4				S_5		
	T_1	I_1	F_1		T_2	I_2	F_2		T_3	I_3	F_3		T_4	I_4	F_4		T_5	I_5	F_5
a_{11}	1	0	0	a_{12}	0,25	0,8	0,5	a_{13}	0,3	0,6	0,3	a_{14}	0	0,9	1	a_{15}	0,9	0,1	0,1
a_{21}	0	0	1	a_{22}	0,9	0,2	0,3	a_{23}	1	0	0	a_{24}	1	0	0	a_{25}	0,3	0,8	0,4
a_{31}	0,2	0,4	0,8	a_{32}	1	0	0	a_{33}	0,4	0,8	0,6	a_{34}	0,2	0,8	0,8	a_{35}	1	0	0
a_{41}	1	0	0	a_{42}	0,6	0,5	0,7	a_{43}	1	0	0	a_{44}	1	0	0	a_{45}	0,1	0,9	0,6
a_{51}	0,7	0,4	0,4	a_{52}	1	0	0	a_{53}	1	0	0	a_{54}	0,4	0,7	0,9	a_{55}	1	0	0

a_{ij} operator - space
S_i skill to solve a fault - set of axioms

Fig. 6. Relation operator/skill - step 1

IV. RESULTS AND STATISTICS

In these conditions we got a realistic distribution of uncertainties regarding solving faults on the manufacturing line. For the step 2, it was applied training for operators in 5 major types of faults (equipment), as a consequence, the level of solving faults increased and uncertainties degree, decreased. So, we obtained the distribution of states as in Fig. 7.

Evaluating the faults occurred during a month, after applying training courses for operators, by ParetoCharts, we got the data shown in Fig. 8.

The number of solved faults decreased from 120 to 54, related to all types of faults.

The goal of MOS aspirs to an intelligent maintenance system, to achieve and sustain zero breakdown. This is the futere of maintenance, equipment, machines and systems to achieve highest performance including also self maintenance capabilities. The operator is a risk factor in this system that has to be taken into consideration. Such a goal can be achieved transforming raw data to valuable information regarding current and future condition and request of the asset.

STEP 2

	S_1				S_2				S_3				S_4				S_5		
	T_1	I_1	F_1		T_2	I_2	F_2		T_3	I_3	F_3		T_4	I_4	F_4		T_5	I_5	F_5
a_{11}	1	0	0	a_{12}	0,9	0,1	0,1	a_{13}	0,8	0,4	0,3	a_{14}	0	0,9	1	a_{15}	1	0	0
a_{21}	0,8	0,4	0,3	a_{22}	1	0	0	a_{23}	1	0	0	a_{24}	1	0	0	a_{25}	0,6	0,6	0,3
a_{31}	0,6	0,4	0,4	a_{32}	1	0	0	a_{33}	0,6	0,5	0,4	a_{34}	0,5	0,6	0,6	a_{35}	1	0	0
a_{41}	1	0	0	a_{42}	0,9	0,2	0,1	a_{43}	1	0	0	a_{44}	1	0	0	a_{45}	0,6	0,5	0,6
a_{51}	1	0	0	a_{52}	1	0	0	a_{53}	1	0	0	a_{54}	0,7	0,5	0,5	a_{55}	1	0	0

a_{ij} **operator**
S_i **skill to solve a fault**

Fig. 7. Relation operator/skill – step 2, after training

No.	Faults	Frecvency /one month	Relative frequency %	Cumulated frequency %
1	Machine part fault	21	38,89%	38,89%
2	Operator Lack Skill	8	14,81%	53,70%
3	Manufact line error	8	14,81%	68,52%
4	Inter area blockage	7	12,96%	81,48%
5	Logistic error	5	9,26%	90,74%
6	Machine parameter error	3	5,56%	96,30%
7	Missing spare parts	2	3,70%	100,00%
	Grand Total	54		

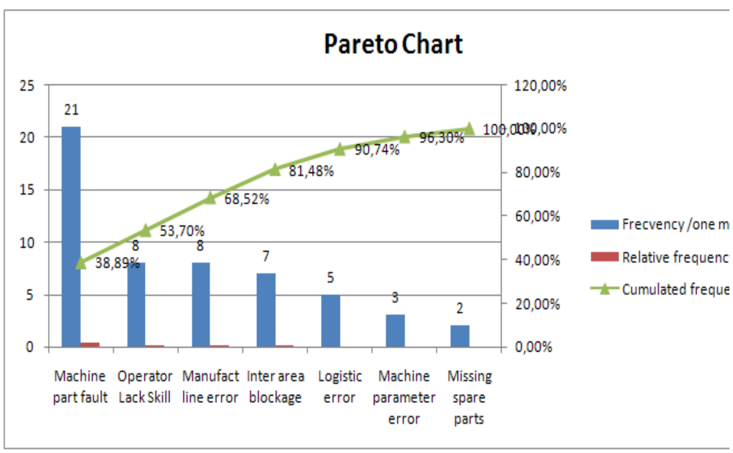


Fig 8. Pareto Chart Analysis - step 2

V. CONCLUSIONS AND FUTURE WORK

The presented work in this study is a step towards developing a procedure available to uncertainties emerging in maintenance process of the complex manufacturing lines. Identification, evaluation, proceeding of the specified uncertainties of suggested metrics are incentive and supporting. It is helpful for MOS analysis, to be sustained by IT application monitoring equipment function, classifying faults, downtime calculus, revealing the reliability of the system. It is a real potentiality to make a decision for uncertainties degree towards.

Solving the uncertainties through mentioned method, classifying them into faults (false) or solving state (true), increases the efficiency of the process.

Analyzing the results, we observed that applying NT it can be emphasized the states of neutrality, ambiguously, uncertainty whereby we can act to transform them into stable status, true or false. Finding this applicability in Business, we can get through the next step, to design an algorithm the more inclusive, that reduce the time to make decision regarding the involved status and to decrease the downtime of equipment.

The science of prognostics is based on the analysis of failure modes, detection of early signs of wear and aging, also fault conditions. Uncertainties, as we have seen in above example, are a source of failure. In this regard, we consider that it is a good opportunity to apply the Neutrosophic Theory to evaluate, analyse and make the right decision solving faults in maintenance process.

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