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SIMULATION OF FEEDING OF MACHINE TOOLS USING ROBOT ARMS

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Abstract: *At a time when there is a lot of talk about the efficiency of using artificial intelligence in industry, this paper wants to present a case study, starting from an automated machine tool servicing cell proposed by the Fanuc company. I studied the efficiency of such cells creating a simulation of the help of Petri nets to see what operations need to be replaced and how we can automate the area more efficiently so that we can make production more efficient regardless of the social crises that are or will come. The pandemic period gave us an impetus in this regard, and the crises on the labour market urge us to find solutions so that production does not suffer and thus, social problems do not intensify.*

Key words: *artificial intelligence, robotics, graphs, economic efficiency.*

1. INTRODUCTION

A topic that exploded in a pandemic context, the artificial intelligence (AI), is not just a trendy topic but a reliable tool with variable applicability in the industrial field.

The artificial intelligence is more than ChatGPT or DALL-E, it is a completion of efforts to increase the production efficiency in factories implementing the "Industry 4.0" principles. [8]

With the avalanche of crises that are demanding humanity, finding solutions to increase and make production more efficient regardless of the size of human capital, has become imminent.

Productivity is a measure of production efficiency that can be thought systemically and is based on the values of input and output parameters. (fig.1) [13]

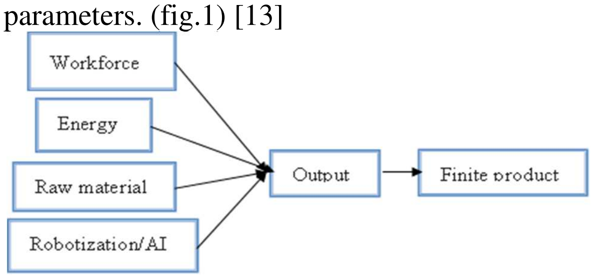

Fig.1. Productivity viewed systemically

We know from the basic economics that the productivity index is an important indicator that measures output respect to inputs.

Since the labour force is getting harder and harder to find every year, the degree of robotization and the use of artificial intelligence also get into the current productivity equation.

The artificial intelligence is a generic term that defines the ability of a machine to imitate human functions such as reasoning, learning, planning and creativity.

The companies prefer to replace the human force with intelligent machines, due to the expenses they have with the operators: for their continuous improvement, vacations, sick leaves, unforeseen events, lack of loyalty to the workplace, salaries, etc., expenses which will be reduced by replacing them with an intelligent mechanism that has no claims.

Economic growth is dependent on two factors:

- The increasing of mass of the labour force
- Increasing productivity

The imbalance produced by one of the factors leads to an economic decline with social implications. So, if labour shortages slow down productivity, AI intervention is needed to maintain the same level of growth.

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The statistics of industrial dynamics presents us some eloquent data in the sense of desire to implement AI in industry. Such an example would be the North American companies that in 2022 ordered more than 44,000 robots excluding autonomous mobile robots or collaborative robotic arms, 11% more than in 2021. [1]

The industrial production is the biggest consumer of AI, 93% of the leaders saying their organizations use AI at least moderately. [1].

The COVID-19 pandemic has raised a number of issues that have increased manufacturers' interest in AI applications.

The Google Trends chart below highlights the willingness of manufacturers to implement artificial intelligence to replace staff shortages.[2] (fig.2)

Fig.2 The evolution of AI in industry according to the Google Trends chart [2]

2. ARTIFICIAL INTELLIGENCE IN POWERING MACHINE TOOLS

2.1. Logical diagram of the robotic line

In the industrial area, the robotic handling applications take the first place. The robots used are usually robots with 6 axes and a precision of 0.01 – 0.2 mm, with working radii between 300 and 3000 mm and with speeds that can reach 6000 mm/sec. [3]

The FANUC company has implemented in a factory of a manufacturer of components for the automotive industry in the European Union, a robotic service cell for the CNCs processing some axes from the steering box, [3]

Starting from this information, we performed the simulation of the cell with the help of Petri Nets, also making changes to the initial proposal of those from FANUC.

The steering system is the most sensitive interface between the driver and the vehicle, the degree of manoeuvrability of the vehicle depends on it. [18]

There are 4 constructive types of steering boxes [18]:

- Rack and pinion steering boxes
- Compact steering boxes
- Electrohydraulic steering boxes
- ZF servotronic

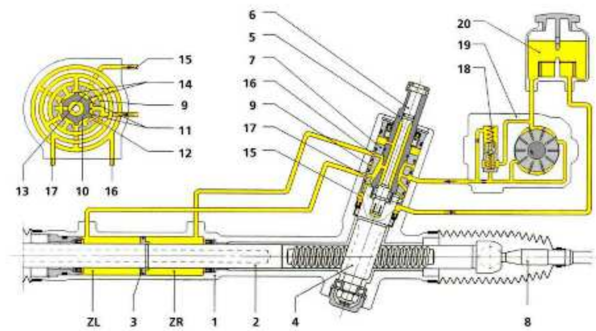


Fig.3. The steering system [18]

The composition of the steering system includes (fig. 3) [18]:

1. Case
2. Rack
3. Pinion
4. Piston
5. Valve rotor
6. Torsion bar
7. Valve bearing
8. Tie rod
9. Oil supply of the radial grooves
10. Oil supply to the grooves
11. Edge of oil supply
12. Axial grooves
13. Oil return from grooves
14. The edge of the oil return channel from the grooves
15. Oil return chamber
16. Radial grooves
17. Radial grooves
18. Pressure relief valve and flow limitation
19. Power steering pump
20. Reservoir for the hydraulic fluid of the cylinders.

The raw parts, including the axis (fig. 3) which is part of the steering box, are formed by steel forging. [18]

The line consists of 4 distinct cells interconnected by a transport system with profiled belt conveyors that allows the parts to be separated and aligned when moving between cells. (Fig. 4): [18]

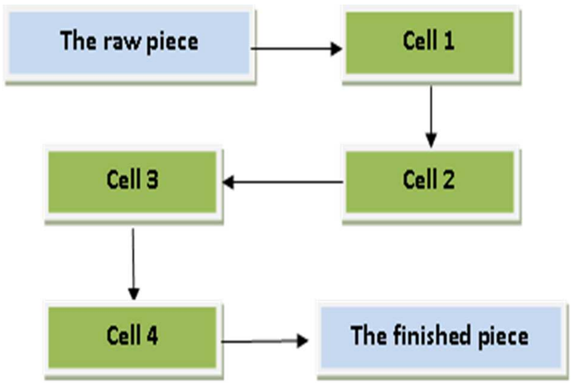


Fig.4. Robotic line diagram

To structure the robotic line and understand the sequence of events that take place along it, the flow can be pencilled in the form of a logical diagram called a graph. [15]

We can define a graph as the geometric representation formed by lines, positions and transitions of some mathematical models or tasks.[11]

The cells are interconnected by a profiled belt conveyor transport system that allows parts to be separated and aligned as they move between cells.

The layout of robotic and automated manufacturing cells had as a central piece a robot to serve a CNC (Fig.5). It is desirable to choose a gripper with two pairs of jaws, to make the operations at the CNC level more efficient. [14]

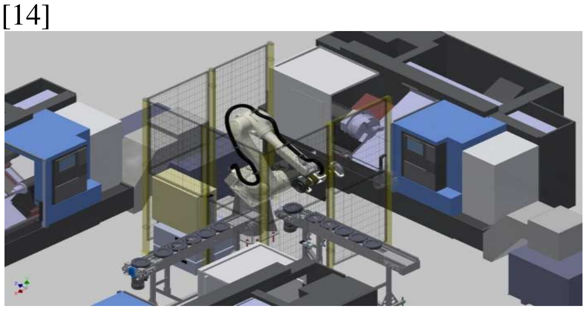


Fig.5. Robot serving a CNC [5]

Thus, one pair of jaws will extract the workpiece from the chuck and the second pair will feed the raw part, so that the robot's movements are more efficient. (Fig.6, 7)[16]

Fig.6. CNC feeding with robot equipped with 2 pairs of jaws [6]

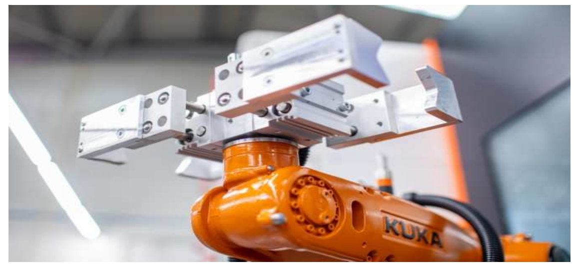


Fig.7. The robot gripper feeding the CNC [7]

The proposed processing centres to be part of the automated cells operate 7 days a week, 24 hours a day. [9]

The robot and the conveyor belts communicate with each other to give an appropriate rhythm to the flow.

The robot-belt operation principle is as follows: a robot takes the raw parts one by one from the feeding conveyor belt and feeds them into the CNC. The optical system, positioned above the belt, communicates to the robot where the raw parts are to be taken by the robot and which are the free places to put the parts extracted by the robot from the CNC. [7]

2.1.1. Cell I

The raw part, coming from the casting, enters in the first cell (fig. 8) with the help of the conveyor belt, which consists of a numerically controlled machine served by a 6-axis robot, equipped with a double pneumatic gripper.

Each side of the gripper has two specially profiled fingers.

The products are introduced into the cell by means of a conveyor with a guide slot and a lateral centring pneumatic piston, with the role of facilitating the picking up of the piece from a fixed point. (Fig. 9)

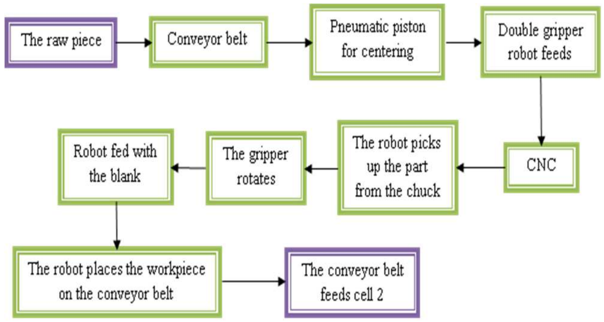


Fig.8 Flow cell I

Fig.9. Conveyor belt feeding Cell 1[3]

After the takeover, the robot releases the previous part with the free gripper from the machine chuck and then places the blank in its place. (Fig. 10)

The processed part is deposited on the exit conveyor, at a fixed point, in an area controlled by a set of sensors, and the robot then resumes the cycle.

Fig.10. FANUC robot [3]

2.1.2. Cell II

The next cell - cell 2 (fig.12) has a similar structure to the first. We have a CNC for additional processing of the part (shaft from the steering box). This cell consists of a robot that feeds a CNC for processing the shaft and a dimensional control machine with LVDT sensors with the role of checking the correctness of the mechanical processing of the piece.

LVDT (Fig.11) is an electromagnetic device with the role of reading and converting signals.

The LVDT automation applications use hermetically sealed dimensional calibration probes [20]

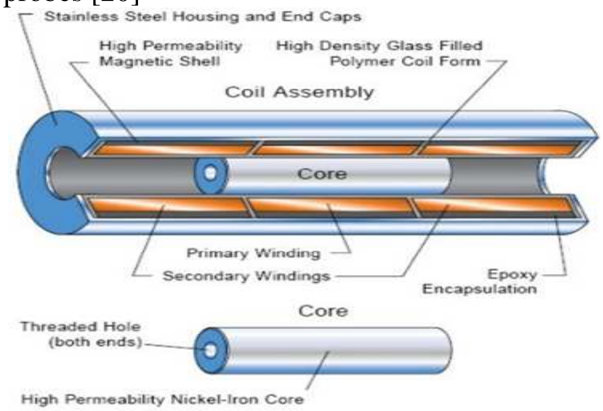


Fig.11. Sensor LVDT [19]

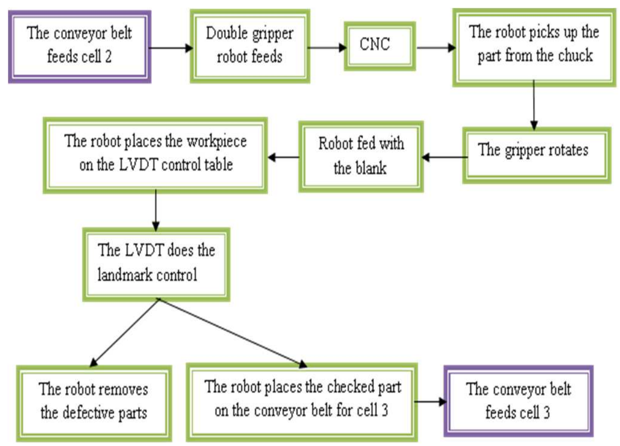


Fig.12. Flow cell II

The comparison is made by the PLC with a series of control data. In case of deviation, the part is declared defective, in which case the robot deposits it in a scrap box.

The detection of a machining error has the effect of sending correction commands to the CNC in order to adjust the position of the machining heads relative to the virtual spindle axis.

If the part matches dimensionally, it is automatically deposited on the conveyor belt to cell 3.

2.1.3. Cell III

In cell 3 (fig.13), we have a robot that serves 2 CNC machines that perform the same operations. Like the parts machined in cell 2, the parts are dimensionally controlled and the scraps are selected from the best ones.

2.1.4. Cell IV

In the last cell, cell IV (fig. 14), the robot feeds the CNC that makes the rack area of the axle in the steering box.

At the entrance to the cell, a machine with 2 positions is required to centre pieces to bring them to a predefined angular position. [3]

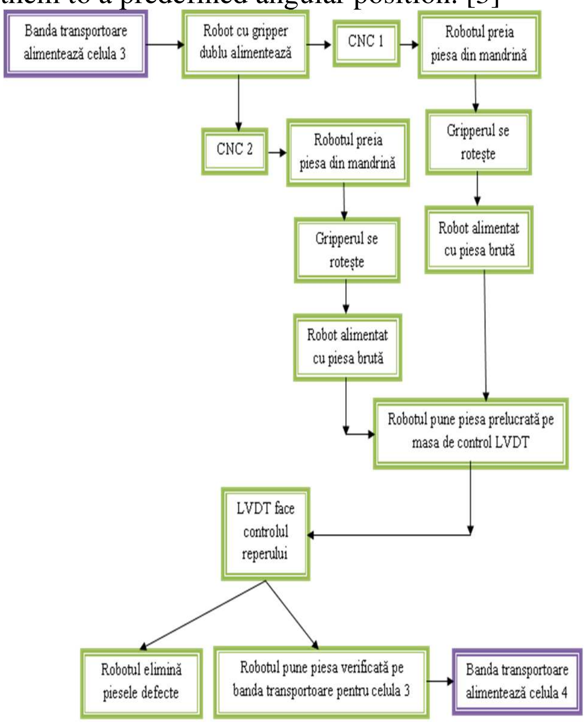


Fig.13. Flow cell III

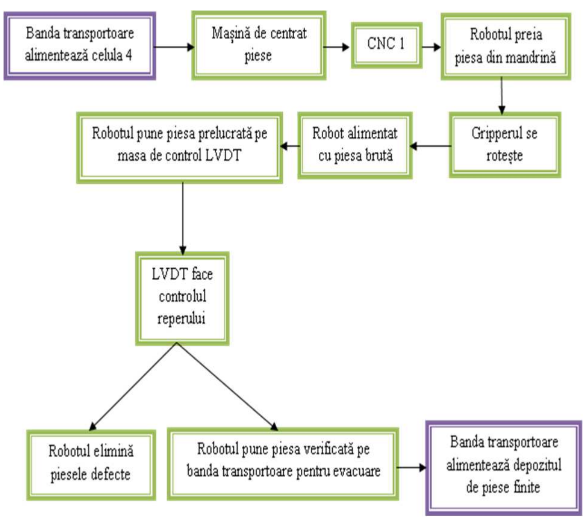


Fig.14. Flow cell IV

In this cell, the profile of the rack is made (fig.15) and at the exit, the cell has an industrial washing machine with the role of cleaning and degreasing the parts. The final point is the dimensional control.

The final control follows fig.16:
- Deviation
- Tooth wear
- Damage to the teeth
- Surface condition

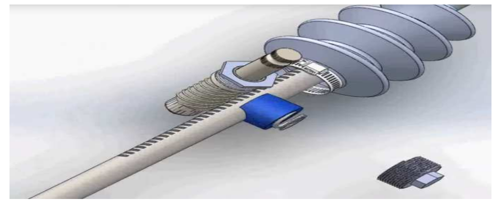


Fig.15. Steering box component shaft [17]

Fig.16. Spindle control [17]

The control of the equipment is done by means of a PLC for the centralized control of the entire installation.

The advantages of such a robotic system are: relieving the human operator of dangerous and repetitive tasks, increasing productivity by decreasing the times per cycle, eliminating errors and reducing the number of scraps. [3]

2.2. The robot line graph

Petri nets have been used to mathematically represent discrete systems and to analyse active transitions at each step [10]

We used the HPSim program for the simulation, which can be found for free on the net. It is a simple program that allows the generation of simulation vectors automatically. [15]

The HPSim has a graphical editor that provides basic editing and simulation of Petri nets. The tool is useful for beginners such as students to get familiar with Petri nets. [12]

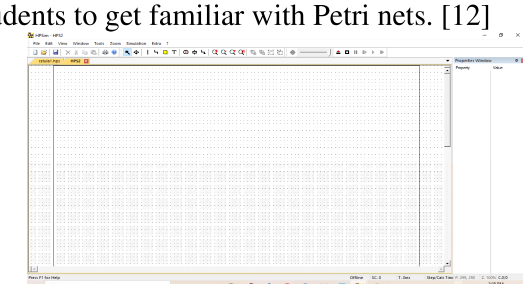
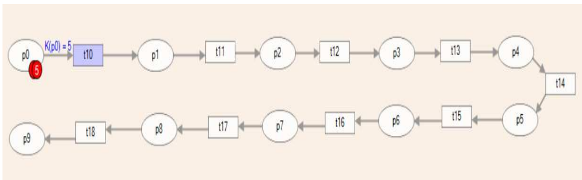
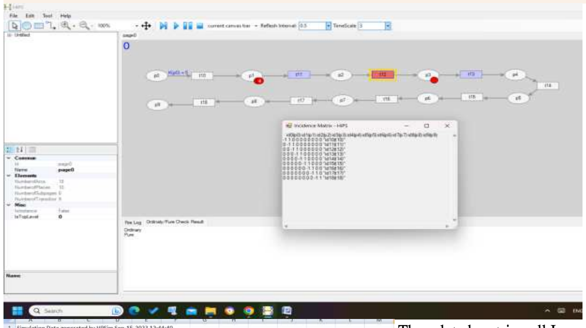


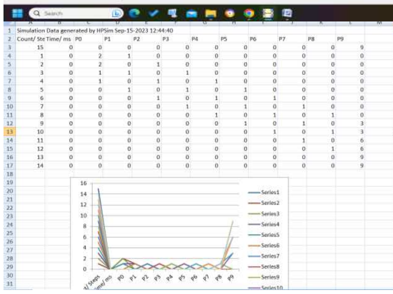
Fig 17. HPSIM program window

We performed simulation for each cell, thus obtaining:

Cell I



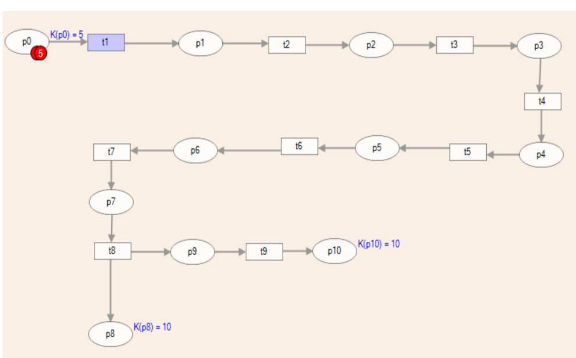


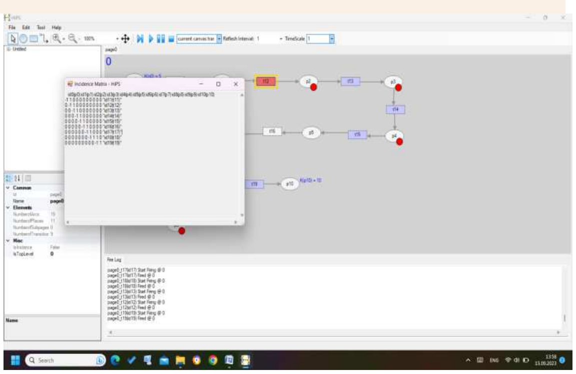


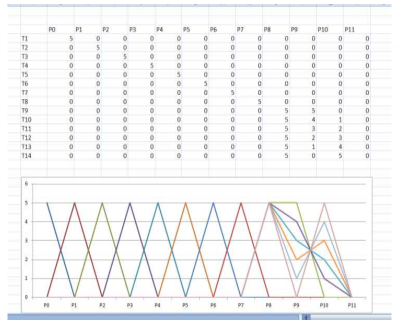
The related matrix cell I:

0 1 -1 0 0 0 0 0 0 0
0 0 1 -1 0 0 0 0 0 0
0 0 0 1 -1 0 0 0 0 0
0 0 0 0 1 -1 0 0 0 0
0 0 0 0 0 1 -1 0 0 0
0 0 0 0 0 0 1 -1 0 0
0 0 0 0 0 0 0 1 -1 0
-1 0 0 0 0 0 0 0 1 0
1 0 0 0 0 0 0 0 0 -1

Cell II



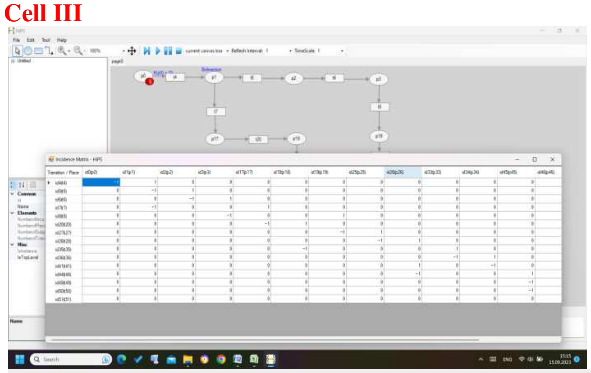


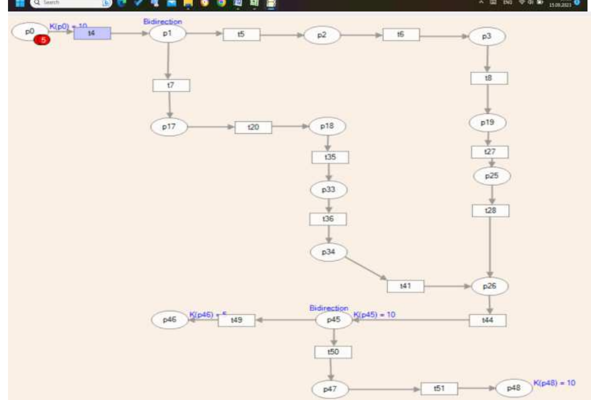


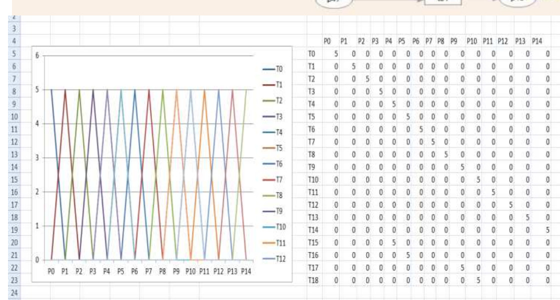
The related matrix cell II:

(5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)
(0, 5, 0, 0, 0, 0, 0, 0, 0, 0, 0)
(0, 0, 5, 0, 0, 0, 0, 0, 0, 0, 0)
(0, 0, 0, 5, 0, 0, 0, 0, 0, 0, 0)
(0, 0, 0, 0, 5, 0, 0, 0, 0, 0, 0)
(0, 0, 0, 0, 0, 5, 0, 0, 0, 0, 0)
(0, 0, 0, 0, 0, 0, 5, 0, 0, 0, 0)
(0, 0, 0, 0, 0, 0, 0, 5, 0, 0, 0)
(0, 0, 0, 0, 0, 0, 0, 0, 5, 5, 0)
(0, 0, 0, 0, 0, 0, 0, 0, 5, 4, 1)
(0, 0, 0, 0, 0, 0, 0, 0, 5, 3, 2)
(0, 0, 0, 0, 0, 0, 0, 0, 5, 2, 3)
(0, 0, 0, 0, 0, 0, 0, 0, 5, 1, 4)
(0, 0, 0, 0, 0, 0, 0, 0, 5, 0, 5)

Cell III



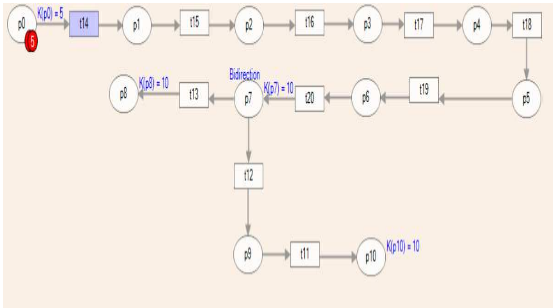


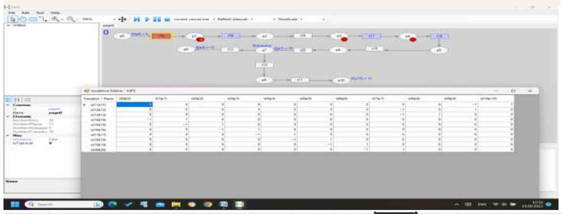


The related matrix cell III:
5-bounded

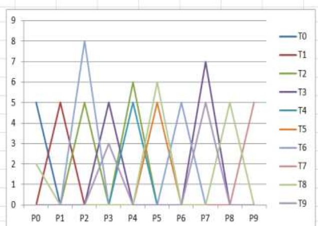
(5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)
(0, 5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)
(0, 0, 5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)
(0, 0, 0, 5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)
(0, 0, 0, 0, 0, 0, 5, 0, 0, 0, 0, 0, 0, 0, 0)
(0, 0, 0, 0, 0, 0, 0, 5, 0, 0, 0, 0, 0, 0, 0)
(0, 0, 0, 0, 0, 0, 0, 0, 5, 0, 0, 0, 0, 0, 0)
(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 0, 0, 0)
(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 0, 0)
(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 0)
(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5)
(0, 0, 0, 0, 5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)
(0, 0, 0, 0, 0, 5, 0, 0, 0, 0, 0, 0, 0, 0, 0)
(0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 0, 0, 0, 0, 0)
(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 0, 0, 0, 0)

Cell IV





	P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
T0	5	0	0		0	0	0	0	0	0
T1	0	5	0	0	0	0	0	0	0	0
T2	0	0	5	0	6	0	0	0	0	0
T3	0	0	0	5	0	0	0	7	0	0
T4	0	0	0	0	5	0	0	0	0	0
T5	0	0	0	0	0	5	0	0	0	0
T6	0	0	8	0	0	0	5	0	0	0
T7	0	0	0	0	0	0	0	0	0	5
T8	2	0	0	0	0	6	0	0	5	0
T9	0	0	0	3	0	0	0	5	0	0



The related matrix cell IV:
5-bounded
(5 0 0 0 0 0 0 0 0 0)
(0 5 0 0 0 0 0 0 0 0)
(0 0 5 0 6 0 0 0 0 0)
(0 0 0 5 0 0 0 7 0 0)
(0 0 0 0 5 0 0 0 0 0)
(0 0 0 0 0 5 0 0 0 0)
(0 0 8 0 0 0 5 0 0 0)
(0 0 0 0 0 0 0 0 0 5)
(2 0 0 0 0 6 0 0 5 0)
(0 0 0 3 0 0 0 5 0 0)

The simulation carried out gives us the certainty of the efficiency of the robotization and automation of the manufacturing of the axle in the steering box.

3. CONCLUSION

The companies are facing increasing pressure to meet low-cost production targets, and the recent pandemic has highlighted manufacturing vulnerabilities.

All this creates opportunities for companies that offer solutions based on artificial intelligence and that are willing to provide robotic variants that allow the replacement of humans in areas with high productivity, while also offering the possibility of professional reorientation to the new segments offered by intelligent technology.

The industrial AI can give companies the ability to produce more, faster and better at lower cost

4. ACKNOWLEDGEMENT

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SIMULAREA ALIMENTĂRII MAȘINILOR-UNELTE FOLOSIND BRAȚE ROBOTIZATE

Rezumat: Într-o perioadă în care se vorbește mult despre eficiența utilizării inteligenței artificiale în industrie, lucrarea dorește să prezinte un studiu de caz, pornind de la o celulă automată de întreținere a mașinilor-unelte propusă de compania Fanuc. Am studiat eficiența unor astfel de celule creând o simulare a ajutorului rețelelor Petri pentru a vedea ce operațiuni trebuie înlocuite și cum putem automatiza zona mai eficient, astfel încât să putem eficientiza producția indiferent de crizele sociale care sunt sau vor veni. Perioada de pandemie ne-a dat un impuls în acest sens, iar crizele de pe piața muncii ne îndeamnă să găsim soluții pentru ca producția să nu sufere și, astfel, problemele sociale să nu se intensifice.

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