UTILIZATION OF ROBOTS IN INDUSTRIAL PRACTICE

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Engineering companies, which are concerned with manufacturing activities in forming and welding technologies, consider with such a degree of an automation of the production process that will bring production improvement, lower production time and also economic benefits with return of investment. In the present time, businesses depend on a market economy conditions. Therefore, it is necessary to design production systems as very flexible with easy response to changes in a product range. In forming and welding technologies, which belong mostly to an area of wasteless technologies, an application of systems with a certain level of intelligence means a wide use of robots that replace the physical potential of people. They have a positive effect on a production quality and also on an ecology. [Hasse 2020]

KEYWORDS

manipulator, robot, material manipulation, expert system, forming technology

1 INTRODUCTION

Four years ago we designed (in a hectic atmosphere) an expert system called “KAUZA” to support the design and evaluation of logistic processes. The name was derived from the theory of causal positions, which in our opinion is an excellent starting point for scientific work organisation as early as in the phase of designing the logistic systems [Maynard 1995]. It supports the design of original techniques of logistic processes without the necessity of copying samples and thus supports the creation of unique solutions. It is partly similar to the MTM, WF and other corresponding methods. While these methods make it possible to compile a technique of work process including its time demand evaluation, “KAUZA-X“ can automatically compile the optimum logistic process out of the selected elements and evaluate its cost.

The design process according to this theory starts with the defining and classification of the positions and determining the motion operations, and it finishes with searching for creative processes to find the most suitable logistic operations, considering the particular objects and conditions of the logistic process. As the non-automated practical application of the theory of causal positions requires extensive theoretical knowledge and user´s application skills limiting its broader use, we started designing a computer expert system which makes it possible for users without expert knowledge to evaluate and improve the existing logistic processes and to design new ones interactively. [Hasse 2020]

While the criterion for the optimum performance assessment in the old “KAUZA” was energy demand, the evaluation of which was based on a non-exact expert estimate (the system was processed by the obsolete Turbo-Basic concept), the new “KAUZA-X” will use initial and operating cost as the performance criterion. There follows a very brief summary of basic data necessary for understanding expert system function.

In the present time, requirements for human are constantly increasing by technological development of a forming technology and a welding technology. Therefore, a production automation represents an impact of progressive development of production. There is an effort to alleviate manual work, which is very demanding, physically and mentally, in these technologies, also with regard to increasing requirements for production quality and full human integration into management and control functions. This process is particularly used in a mass production, where the automation is easier and technically more feasible due to steady production program. Initially, the automation was aimed only at own technological processes rather than on non-technological processes like service processes, because service processes in forming and welding technologies are carried out by the same methods as before more than 10 years ago. [Nemejc 1999], [Byron 2022]

Logical way to further increase of productivity is to finalise the automation, i.e. automate operators of production machines and thus replace humans in this phase of the production process. An automatic machine, which is equipped with necessary motion, sensory or decision-making properties as well as human. This machine is flexibly programmable and usable for lower production types is known worldwide as an industrial robot. [Stroner 2005], [Byron 2022]

2 CHARACTERISTICS OF ROBOT AND HUMAN

Although, today's industrial robots shape resemblance to a human is eliminated (not an "android"), but construction of robots is based on imitation of human characteristics anyway. Therefore, it is necessary to think about limiting areas between the human and the robot – cybernetic machine, because this view allows to build these machines as a replacement of work of humans. It also allows to make a knowledge by which Norbert Wiener defined cybernetics as "human use of human characteristics." [Byron 2022], [Hasse 2020]

A full replacement of a human, with respect to his movement characteristics supplemented by sense organs and decision-making capability, is still very difficult to implement. To solve objectives in engineering, it is not necessary. In the analysis of working activities, for example human movement can be reduced to a few basic functions, such as grabbing, holding, rotation, ejection etc. In the first stage, this is sufficient to replace a stereotypical and a mechanical work by the robot.

Even then, the human replacement is not a simple problem, because his function in the production process is multiple, i.e. he performs the function of controller, maintenance man, fixer etc., he manipulates with material and, he mainly manufactures himself. In order to completely replacement of the human factor, other functions must be automated or eliminated, i.e. transfer to another work place, besides manipulation. Therefore, certain assumptions must be met, for the robot deployment, namely:

- the manufacturing process must be fully automated,
- auxiliary functions are discarded as unnecessary, converted elsewhere, or automated,
- the manufacturing system must be highly reliable with requiring no correction for a certain time,
- the human operator is engaged mainly with manipulation.

For today's generation of robots, it is necessary to add additional limitations:

- item, which is manipulated, must be on the same place in the same position (with the same orientation),
- manipulation functions must be relatively simple and feasible at an acceptable time.

Despite the limitations, it demonstrates that the robot can compete with the human operator, because its advantage consists in the following:

- the robot can work quite regularly and without fatigue for 24 hours per day,
- set program is repeated without errors,
- it is still as accurate (more precisely inaccurate),

it has no problem with a difficult environment (it can work, "upside down" without affection by noise, dust, heat, gases, etc.). [Stroner 2007], [Hasse 2020]

3 CLASSIFICATION OF INDUSTRIAL MANIPULATORS AND ROBOTS

3.1 Single-Purpose Manipulators

They are often an integral part of an operated machine and they are controlled by it. In some cases, they do not have their own propulsion (e.g. transfers for forming machines). Shapes and design concepts of single-purpose manipulators are usually subordinated to machines, which controls them. They have limited functionality. They are called "feeders" (e.g. pneumatic sheet metal strips feeder for shearing tools) or "autooperators" (e.g. forging manipulator, which is used for shooting of an ingot in depends on forging amount of coarse casting structure). Their name "single-purpose" means that they are intended for manipulation with one specific object or geometrically similar objects, namely in a relatively small range of dimensional changes. In some cases, they may be called as manipulators with hard automation. In the forming technology, their application is e.g. in coupling of cam kinematics and mechanism of sheet metal feeder, which feeds sheet metal strips into a shearing tool during a stroke of press. Usually, it applies to older machines.

Single-purpose manipulators are mainly used for the automation of manipulations of special machines and lines, which are primarily intended for a large-lot production and a mass production. In the area of forming technology, a suitable example of such a device can be, for example, the single-purpose manipulator, which is used for collating of metal sheets into a magazine of eccentric punch press. [Hasse 2020]

3.2 Universal Manipulators

They are the opposite of single-purpose manipulators in terms of control, independence of the operated machine, design etc. Universal manipulators have their own propulsion and functions. Furthermore, they are divided into synchronous manipulators and programmable manipulators.

3.2.1 Synchronous Manipulators

Control of these manipulators, sometimes also called teleoperators, is performed by an operator. Because of these, the synchronous manipulator is actually an amplifying equipment of force and kinetic parameters, which are caused by the operator. A human with his control function is in a closed loop with an executive part of the manipulator. This fact is usually expressed as "man on-line". For exact copying of a worker movement by the synchronous manipulator, position and orientation of hands in the workspace, a control device is directly attached to arms and hands of worker, whose motion is then transmitted to an operating lever. There are the following types of synchronous manipulators, which are used in forming and welding areas:

- "master-slave" manipulators, where an executive system is separate. They are positioned outside the worker (they are using, for example, for welding in a radioactive environment).
- "exoskeletons", with which the worker can move. For example, they allow to weld in areas, which are badly accessible for the worker with respect to his physical abilities (static determination of its position). Secondarily, they may contribute to maintaining the technological parameters of welding (determination of an optimal position, guidance and automatic welding speed due to electrode feeding).
- "Synchronous manipulators with adaptive control", which are controlled by the worker only by basic functions. Detailed control is performed by the manipulator itself, which represents a combination of manual control and adaptive control, i.e. control systems where the manipulator has a certain independence (autonomy) of behaviour. In the field of forming technology, they are used, for example, in processing of sheet metal coils, where it is necessary to insert a sheet and start the line, which corrects an output speed of the straightener and feeder itself by using sensors (photocells etc.).
- "Industrial balancers", i.e. auxiliary lifting device facilitating lifting and positioning of heavy workpieces in operation. Load movement in a free space is ensured directly by direct movement of the worker. The load is counterbalanced by the manipulator so that the motion is possible. For example, they are used for relocation of forged crankshafts with an asymmetrical centre of gravity. [Kolibal 2016], [Hasse 2020]

3.2.2 Programmable Manipulators

Programmable manipulators are controlled by software system. They are independent of operated machines due to design, functions, drive and control system. Further, they are subdivided into:

- "manipulators with fixed program", which program is unchanged during their operation. Program changes are simple, generally by using a mechanical-electrical control system.
  Their advantages are simple structure, reliable operation and lower cost.
- "manipulators with variable program" that allow to switch program options. They are controlled by adaptive electronic control systems and they have significant autonomy (adaptivity).
- "cognitive robots" with so called mechatronic systems, i.e. mechanical systems with a higher degree of integrated electronics. Cognitive robots are equipped with perception possibilities and rational decision-making (without possibilities of free negotiations and emotional perception). These systems can also have its own level of learning and recognition of the specific situation. In many cases, only characteristics of an environment is entered to the robot, not a program. It is a desired feature of robots in this highest category. [Kolibal 2016], [Hasse 2020]

3.3 Basic Kinematic possibilities of Industrial Robots

A final operating space, which is generated after a substitution of translation by using rotation can be:

a) cuboid (rectangular, Cartesian workspace), it is a combination of three translational kinematic pairs "TTT", see Fig. 1a,
b) cylindrical segment, which is a connection of one rotational kinematic pair and two translational kinematic pairs "RTT", see Fig. 1c,

c) spherical segment, it is a connection of two rotational kinematic pairs and one translational kinematic pair "RRT", see Fig. 1b,
d) toroid (anthropomorphic, angular) segment, which represents connection of three rotational kinematic pairs "RRR", see Fig. 1d. [Hasse 2020]

a) b)

c) d)

Figure 1: Workspaces of robots

4 METHODOLOGY OF OPTIMAL PROCESSES COMPILATION

A new term was invented for modern design, especially in the area of automation and robotisation: "elementary motion operation" (hereinafter EMO). It can have several definitions. The sum of EMOs creates an overall handling process.

Different energies and costs are needed to perform individual EMOs). The classification, coding and functions of elementary motion operations can be described as follows [Hlavenka, 2003]:

g - gravity operations (free fall, chute, rolling), for example object's fall into a box, etc.,
d - transport operations (gripless motion, no unloading), for example conveyor belts driven by roller conveyors, etc.,
gd - gravity/transport operations (combinations of g and d), for example a tipping trolley,
du - semi-repositioning operations (gripping and transporting by one machine with the object staying on the transporter), for example dual line suspension transporters
p - repositioning operations consist of (du + dg); (gripping, transport, positioning of an object), for example robots,
pg, pu, pug - modifications of the repositioning operations, for example loaders, bucket elevators, etc.

Each logistic process can then be very briefly described with the above symbols.

For example, p - dg - g - p describes the repositioning of a workpiece to a conveyer with a manipulator (p), then reloading (dg) on a gravity transporter (g) and repositioning to the working position of the next machine by a manipulator (p).

Characteristics of the trajectory is another quality indicator of an elementary motion operation. This depends mostly on the manipulator type and can be:

a) fixed trajectory,
b) defined trajectory,
c) delimited trajectory,
e) free trajectory.

Considering the demanded continuity, automation and mainly the motion economic, the optimum sequence of elementary operations has been designed: g (gd) – d (dg; du) – p (pg; pu; pug). This sequence of elementary operations together with economic requirements of the technology that performs them will form an expert system criterion function searching for the optimum logistic process. [Hlavenka 2002]

Defining Initial and Operating Cost

Manipulator depreciation cost: we use its purchase price, service life as specified by the manufacturer, its time fund, the time needed to manipulate the manipulation unit along a 1 m trajectory and along the total transport distance:

$$N_{A\,(1\,m)} = C \cdot t \;\Rightarrow\; N_{A\,(t.\,d.)} = C \cdot t_k \qquad (1)$$

$N_{A\,(1\,m)}$ – manipulator depreciation per meter of manip. [CZK],
$N_{A\,(t.\,d.)}$ –manipulator depreciation [CZK],
C – portion of manipulator price used in 1 second [CZK·s^{-1}],
t – time needed for manipulating with the manipulation unit on a 1 meter trajectory [s],
t_k – total manipulator transport time to cover the distance [s].

Manipulator electricity cost: we use the calculation of the 1 second or 1 hour machine operating cost and the time needed to perform the manipulation:

$$N_{E\,(1m)} = e \cdot t \;\Rightarrow\; N_{E\,(t.\,d.)} = e \cdot t_k \qquad (2)$$

$N_{E\,(1m)}$ – manipulator energy cost per meter of manipulation [CZK],
$N_{E\,(t.\,d.)}$ – energy cost [CZK],
e – cost per second of machine operation [CZK·s^{-1}],
t – time needed for manipulating with the manipulation unit on 1 m trajectory [s],
t_k – total manipulator's transport time to cover the distance [s]

Manipulator fuel cost: we use the fuel price per hour or second of machine operation and the time needed to perform the manipulation:

$$N_{P\,(1m)} = p \cdot t \;\Rightarrow\; N_{P\,(t.\,d.)} = p \cdot t_k \qquad (3)$$

$N_{P\,(1m)}$ – fuel cost per m of manipulation [CZK],
$N_{P\,(t.\,d.)}$ – fuel cost [CZK],
p – cost of fuel consumed in 1 second of manipulator operation [CZK·s^{-1}],
t – time needed for manipulating with the manipulation unit on 1 m trajectory [s],
t_k – total manipulator's transport time to cover the distance [s].

Labour cost: we use the calculated monthly number of working hours and the salary of the transporting worker:

$$N_{M\,(1m)} = M \cdot t \;\Rightarrow\; N_{M\,(t.\,d.)} = M \cdot t_k \qquad (4)$$

$N_{M\,(1m)}$ – salary cost per m of manipulation [CZK],
$N_{M\,(t.\,d.)}$ – salary cost [CZK],
M – worker's labour cost per second [CZK·s^{-1}],
t – time needed for manipulating with the manipulation unit on 1 meter trajectory [s],
t_k – total manipulator's transport time to cover the distance [s]. [Stroner 2003], [Kumar 2023]

5 FEATURES AND TOOLS THE EXPERT SYSTEM KAUZA-X

To run the application open “Project.exe”. An access form is displayed in which the name of the software product under development appears as follows: **“KAUZA-X, an expert system for the evaluation and design of logistic processes”** with the important access and exit menus. For standard exit from the application, click on the exit menu **“End”** or the cross in the upper right corner of the screen (just like in Windows). It further contains a list entitled **“Selection of manipulator”** providing access to the main menu enabling selection of a manipulator classified in accordance with the above theory of causal position. The last menu in the access form is **“Display results”** enabling to display the initial results and perform an economic analysis. The access form is presented in Fig. 2 below:

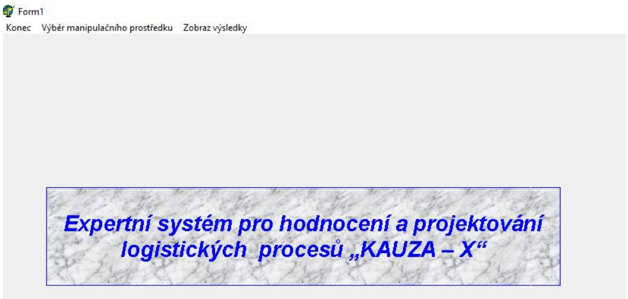

Figure 2: Access form of the expert system “KAUZA-X”

From the access form, the user should access the already mentioned menu **“Selection of manipulator”** where the manipulators are sorted into groups by energy consumption in accordance with the theory of causal position, as shown in Fig. 3 below, 24 options have been created out of the total 36 options. In addition, the form contains radio buttons for switching between the selections of manipulators, **“Save results into Option”**, with **“Option 1”** and **“Option 2”**. These will be used to fill in the manipulators into the databases of the two possible options, which can further be assessed after the calculation is made by selecting the menu **“Display results”**.

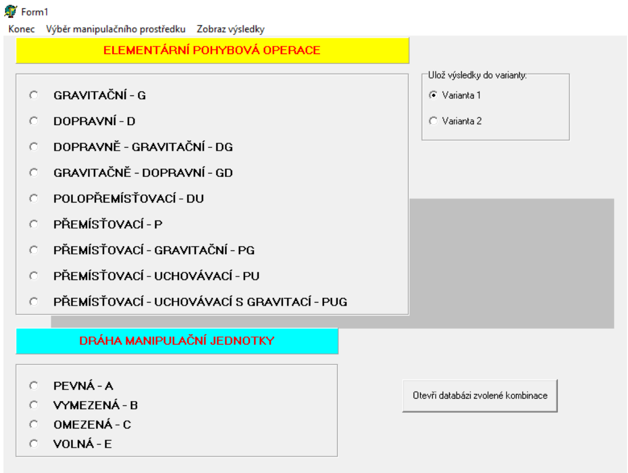

Figure 3: List “ Selection of manipulator”

After a trained user has reached this stage, he may select a suitable type of operation and trajectory combination by ticking in the radio buttons, such as repositioning operation and defined trajectory. With the button **“Open database of selected combination”**, the user will from any option reach the **“Source database”** and **“Selection database”** where the upper **“Source database”** is filled with manipulators corresponding with the selected combination (operation + trajectory). In our example, these will be robots and manipulators (see Fig. 4), and the selected manipulators can be added from the current cursor line into the empty **“Selection database”** using the button **“Select manipulator”** or by double clicking on the given position on the database line. The upper **“Source database”** can be easily deleted using the button **“Delete database”** where the system asks you once again **“Are you sure you want to delete the entire manipulator database?”** to avoid mistakes as the database carries important historical data of the system. The arrow keys on the keyboard are used to navigate in the databases. Data operations (deleting, adding manipulators, navigation through the database, etc.) can also be made using a **“navigator”** which is a great facilitator.

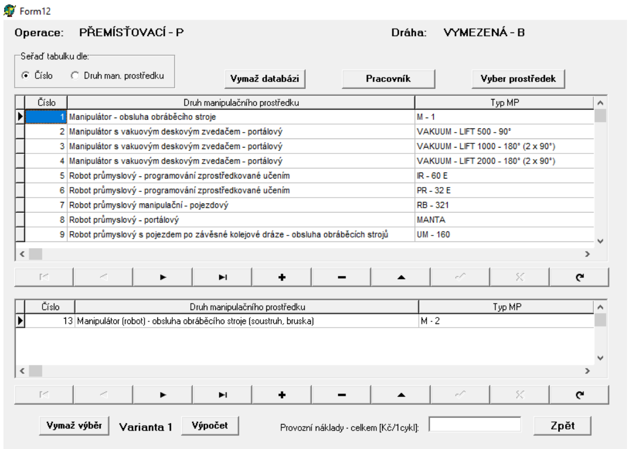

Figure 4: Form “Source and Selection databases”

The lower **“Selection database”** can be deleted directly using the button **“Delete selection”**, and the data contained in it are stored only in the operating memory. A button entitled **“Worker”** is contained in each form of both the **“Source database”** and **“Selection database”** which can at any time be added to the given manipulator and/or independently. After selecting from the **“Source database”**, we can e.g. transfer a manipulator into the **“Selection database”**, then view and check the data on the line and finally, depending on the type of drive, enter the data needed for a calculation, for example if an electric drive is concerned, a coefficient of power utilisation and manipulation trajectory will be entered. After entering the data, the calculation is made by clicking on **"Calculation"**, which at the the same time transfers the given manipulator internally into the database of the form **"Display results"**, into **"Option 1"** and saves into the respective line of the database the number of the manipulator, type of operation, type of trajectory, initial costs, operating costs, sort of manipulator, type of manipulator, life of manipulator, depreciation costs, total dependent costs, manipulation trajectory, speed of manipulator and time study. At the moment however, we still find ourselves in the form **"Source and Selection databases"**, repositioning operation, defined trajectory. If we select **"Back"**, we return to the position "Selection of manipulator" in the form where, using the radio button, we change option to **"Option 2"** and ticking in the radio button, we can similarly select and fill in the exit database for **"Option 2"**. After selecting all the manipulators for both options, we return back to the form **"Selection of manipulator"** where we click on **"Display results"** and have an opportunity to compare the options not only in terms of the costs of the entire logistic route through the manipulation unit, but also display a chart show the payback of the more expensive option (see Fig.4) [Stroner 2007], [Strnadova 2023], [Kumar 2023]

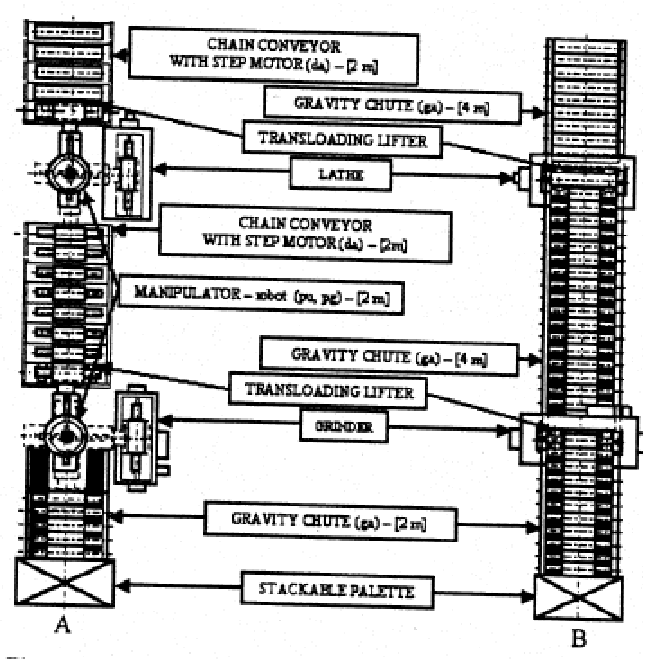

Figure 5: Comparison of 2 manipulation processes:

A) Line with manipulators and conveyors
B) Line with gravity chutes

Comparison of the manipulation cost of the whole logistic process in one cycle (see Fig. 4, Fig. 5, Fig. 6, Fig. 7):

Variant 1) Manipulation costs of the whole logistics process with:

A) Line with manipulators and conveyors: **N_C = 0,56 CZK**

Variant 2) Manipulation costs of the whole logistics process with:

B) Line with gravity chutes: **N_C = 0,00065 CZK**

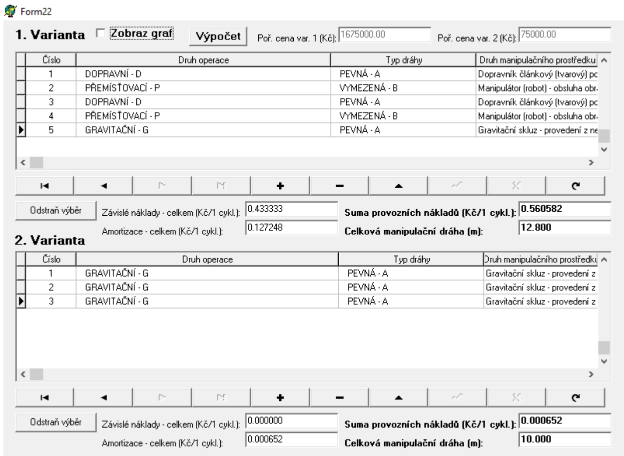

Figure 6: Resulting form "Display results"

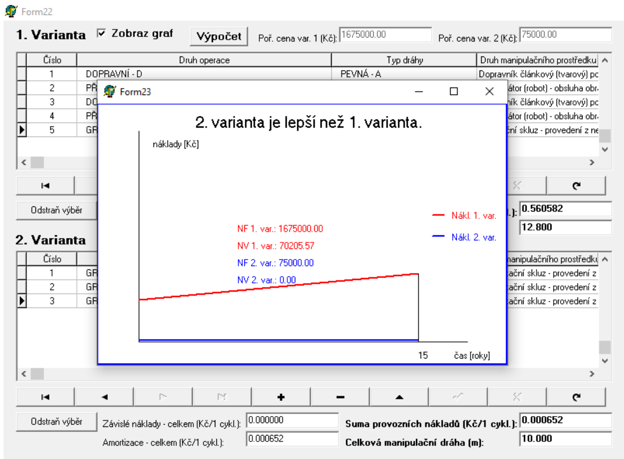

Figure 7: Resulting form "Graf display results"

6 WORKING WITH THE EXPERT SYSTEM KAUZA-X

The expert system has been written in the Borland Delphi environment. The operation of such a newly-created problem-oriented expert system is based on the design of a logistic chain (the user selects tools from a knowledge base), the use of an inference mechanism for the calculation of this logical chain cost indicators, updating, and extending the knowledge base.

The user first selects all manipulators he wants to include in the logistic chain from the knowledge base. Once the selection is made, the inference mechanism calculates cost indicators for each selected manipulator and the cumulated cost, i.e. cost associated with the manipulation process as such. [Stroner 2004], [Strnadova 2023]

Comparison of Manipulation by Robot and by Human

The expert system KAUZA-X is based on primary principle of integration of individual manipulation devices depending on a theory of causal locations (combination of different energy-consuming elementary operations and types of tracks. In the present time, 24 new possible variations were developed of 36 total variants. Robots are integrated into the basic category of combinations, i.e. a displacement operation (grabbing of the subject, its transportation and the consequent imposition) and path in a defined space (given by technical equipment).

At first, the criterion for evaluation of manipulation systems is based on finding a suitable connection of criterion function. Further evaluation is focused on an economy, based on acquisition costs and main operating costs, which are associated with the manipulation unit in one pass thru the entire logistics chain in the case of a free manipulation, thus the solution becomes a unique in a certain sense. In next, the calculation process is illustrated through two manipulation variants for comparison of the human and the robot. [Stroner 2007]

Variant 1: M4 robot is used with input power of 8 kW. In this case, a workspace is described in cylindrical coordinates by using a point control with the rotating possibility of 360°. The manipulation with products, whose weigh is from 0.9 kg to 1.8 kg and dimensions are 815 x 205 x 2 mm, is contemplated. The robot was made by VUKOV Prešov. Acquisition costs were 750 000 CZK. Robot works on the track with lenght of 3.4 m. It includes a time study of rotation (2 x 90°) and time for insertion/removal of the product (4 seconds), see Fig. 8. For this robot, a theoretical calculation starts as well as for other manipulators. In this case, amortization costs and energy equipment costs are counted.

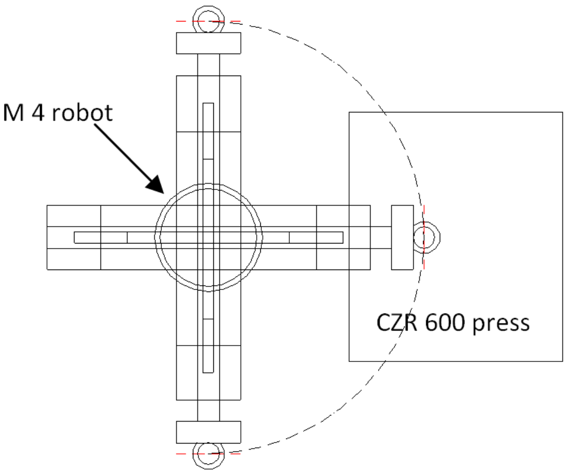

Figure 8: Forming machine with M4 robot

Variant 2: an operator of the press is the worker, who has 30 seconds as the time for insertion/removal of the product by the time study. His monthly salary is 20 000 CZK. Expenses for employee wages are part of the company's costs.
In both cases, stamped part is produced from a sheet metal blank. The sheet metal blank is transported by a step conveyor to the robot and also to the worker.

Lower operating costs for the robot are evident from the calculation by using KAUZA-X, for 1 cycle with change of the sheet metal blank. It is 0.205943 CZK compared to the worker, where operating costs are higher, namely 1.041667 CZK. Recoverability of the robot is approximately 4 years according to an output chart of the expert system, see Fig. 9. With regard to lifetime of 8 years, this it quite propitious time. Therefore, it is advisable to consider with application of the robot for this operation, because the recoverability represents a half of the robot lifetime.

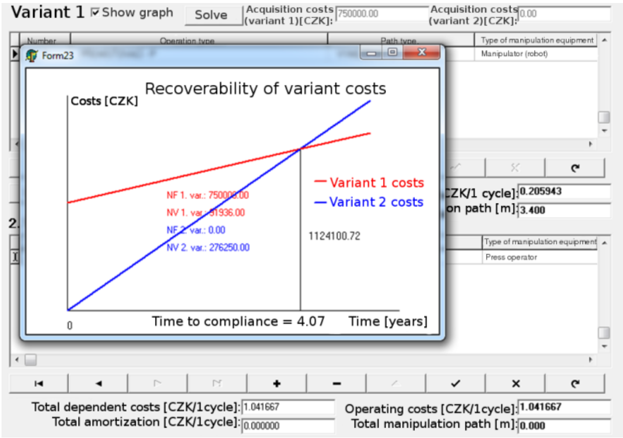

Figure 9: Forming machine with M4 robot Output form of KAUZA-X

7 DISCUSSION AND CONCLUSIONS

In conclusion, a utilization of humans as a cheap labour is the main reason why the machine control, the material manipulation, the automation and the robotics are still unused in many companies.
In this paper, the example for two variant was solved by the newly developed expert system KAUZA-X. An utilization of the robot for the forming line was assessed. Costs associated with the manipulation unit thru the entire logistics chain were also determined as well as the return on investments for the robot acquisition. The expert system KAUZA-X is very universal, but it cannot evaluates connections between different manipulation devices yet, which is currently dependent on a user. Therefore, it is necessary to reflect on an extension of the system with an editor of elimination conditions that will take into account interdependencies between selected devices.
Another disadvantage to the discussion of the given new modern system "KAUZA-X" is that it advantageously solves lines that are mainly organized by subject. Other lines solve, but the result may not always be realistic. The most difficult thing was to enter the robots and manipulators into the knowledge base for the given expert system. I finally found the solution after a very detailed analysis of the kinematic movements of specific robots and their trajectories, but if the robot performs a chaotic movement that cannot be described mathematically, I simply resorted to the fact that I introduced a time study and the movement can be timed and then express the cost consumed per second and multiply these by the given time. This makes this expert system unique compared to other industrial systems.
I believe that the new expert system "KAUZA-X" could be beneficial for modern project practice and will become a supporting tool for designers in the creation of new conventional and automated solutions and rationalization of existing logistics processes right here in the Czech Republic. [Stroner 2024]

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