EXPERT SYSTEM FOR MINIMISING THE COST OF LOGISTIC PROCESSES

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This paper demonstrates how to use the theory of causal position in practice for evaluation, systematic design, mechanization and automation in logistic processes namely in manipulation with material. For a broader usage of this complicated theory we started designing an expert system „KAUZA – X", which will be easy to operate even for non expert. The theoretical bases of a system are: the systems approach (Logistic system is made up of a set of elements and relationships.) and the theory of cauzal position (The cause of the motion of an object lies in the types of its position and in the relationships between them). The properties of the object and its utilization result in individual positions, which form a continual chain in space and are technically and organizationally interrelated. For each of many linkages, there is a process of searching for the rationality of technical – economic optimums.

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 the phase of designing the logistic systems. It supports the design of original techniques of logistic processes without the necessity of copying models 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

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technique of work process including its time demand evaluation, "KAUZA" 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 by defining and classifying of the positions and determining the motion operations, and it finishes by 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.

While the criterion for the optimum performance assessment in the old "KAUZA" was the 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. A very brief summary of the basic data necessary for understanding the expert system function now follows.

2. CONCEPTIONAL AND METHODOLOGICAL BASES OF A SYSTEM

The theoretical bases of a system are: **the systems approach** to the logistic process and the **theory of causal position**. According to the systems approach, the logistic process can be regarded as a system that is made up of a set of elements and relationships (Hlavenka, 2000).

The elements of a system are:

K_v – workers of the logistic process
P – facilities and tools used in the logistic process
S – materials, semi-products, subdeliveries, and products that are moved, weighed, packed, stored, etc. in the logistic process.

The relationships in a system are:

T – working procedures and technological principles used in the logistic process (weighing, packing, moving)
E – different kinds of energy consumed in the logistic process

K – moving, storing and packing services within the logistic process
O – organizational relationships which in their totality form the organizational quality of logistics.

From various specific points of view the logistic process can be subdivided into the:

- activities subsystem
- information subsystem
- organization subsystem
- personnel policy subsystem
- logistic methods subsystem
- technical facilities subsystem.

The theory of causal position starts from the knowledge that the cause of the motion of an object lies in the types of its position and in the relationships between them. The properties of the object and its utilization result in individual positions, which form a continual chain in space and are interrelated philosophically, technically and organizationally. One of the propositions of the above theory says that for each of the many linkages there exists a process of searching for the rationality of technical-economic, organizational, and ethical-philosophical optimums which can be further worked out for technologies, processes and facilities. For the practical application of automation it is important that the searching process can be algorithmized.

The expert system designed should lead the assessor or designer to the above-mentioned optimum manipulation technology and manipulation devices. Since the currently used decomposition of a logistic event into processes, partial processes, logistic operations, etc. has certain drawbacks that primarily result from limited exactness, we want to use the more versatile conceptional apparatus of the “elementary moving operation” (EMO).

Performing individual EMOs entails various energy demands and thus cost demands. To establish the logistic optimum it is necessary to take into consideration, in addition to the classification of elementary moving operations, also the type of motion of the object being handled (synthetic characteristic of the trajectory of motion of the object) and the length of motion.

Today, when processing technologies are specialized and concentrated, the processing position is governed by the requirement for material motion continuity via automation, and also simplicity and usefulness of motion, thus ruling out any unnecessary relationships and motion.

3. THEORY OF CAUSAL POSITION

The theory of causal positions is of great significance in systematic evaluation and design of the mechanization and automation of logistic operations. Already in the stage of designing manipulation systems, the theory creates conditions for the application of scientific organization of work. It provides for setting up one's own technology of manipulation without the necessity of copying any models and thus creates preconditions for the appearance of unique solutions.

According to this theory, the basic process of evaluating and designing starts by defining and classifying positions and operations, and terminates by searching for creative processes that will establish the most convenient logistic operations with respect to specific objects and conditions of manipulation (Svoboda, 2000).

3.1. Types of position and their relationships

The theory of causal positions starts from the knowledge that the motion of an object is caused by the types of position and by the relationships among them. The types of object position characterize its basic rest-state positions.

Natural position (P) is the primary position that natural substances, raw materials, organisms, etc., are found in, and which are mined and obtained in the mining industry, agriculture, animal production, etc.

Technological positions (T) are the result of further human activities in the technological, manufacturing and distributing processes. They are in the form of raw and refined materials, semi-products, components, and end products.

From the viewpoint of their relationship to the technology of processing the above technological positions fall into:

- *Processing positions (Z)* – the positions of processing, in which a technological change in the object takes place (shape – by machining, properties – by heat treatment, etc.)
- *Manipulation positions (M)* – the positions of the object remaining at rest, which forms an undesirable but frequently indispensable passive component of the service process.

These manipulation positions are further subdivided into:
(Z) – positions on the ground (the most natural position of an object)
(V) – positions in layers, stacks
(A) – positioning positions, on positioners
(B) – storing positions, on shelves, in bins
(C) – transporting positions, in cases, containers, on pallets
(D) – positions in the moving element of a transport device

- *Consumption positions (S)* – these are the final positions of practical motion of objects at the end-user's.

Individual positions follow from the properties of the object and its utilization. The positions form continual chains in space, which have mutual philosophical, technological and organizational continuity. For the present-day rational consumption-oriented man the sequence of positions is as follows: S, P, T, (Z, M), which shows that consumption positions are the most important, coming before natural and technological positions.

All the three basic positions (S, P, T) are denoted as *non-manipulation (N)* positions, which are more significant than the *manipulation (M)* positions. Here, too, a sequence of one-way relationships can theoretically be established: N-N, N-M or M-N, M-M. If we observe the relationships between the basic positions in human-related sciences, the predominant relationships are S-S, S-P, S-Z and S-M while in natural sciences they are P-P, P-Z and P-M.

However, what we, technology and logistics designers, are most interested in are the relationships in technical sciences and manipulation:
- technical sciences (general technology) Z-Z, Z-M
- materials manipulation (logistic technology) M-M.

A very interesting item of knowledge in the theory described is the one that says that for each of the above linkages there exists a process of searching for the rationality of technical-economic, organizational and ethical-philosophical optima, which can be further developed for technologies, operations and tools. For practical application and automation it is important that the searching process can be expressed in algorithms.

At the level of operations it can be used for prognosticating, at the technology level for setting up new technological methods, and at the tool level for determining new machines and equipment.

4. ELEMENTARY MOVING OPERATIONS (EMO)

The analysis and structure of moving activities are very important in the design of a material handling system. Up to now we have decomposed manipulation activities into processes, part-processes, operations, actions, moves (Figure 1).

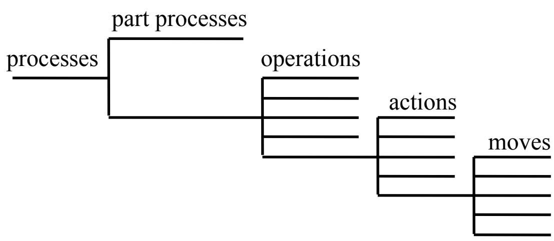

Figure 1. Decomposition of manipulation processes

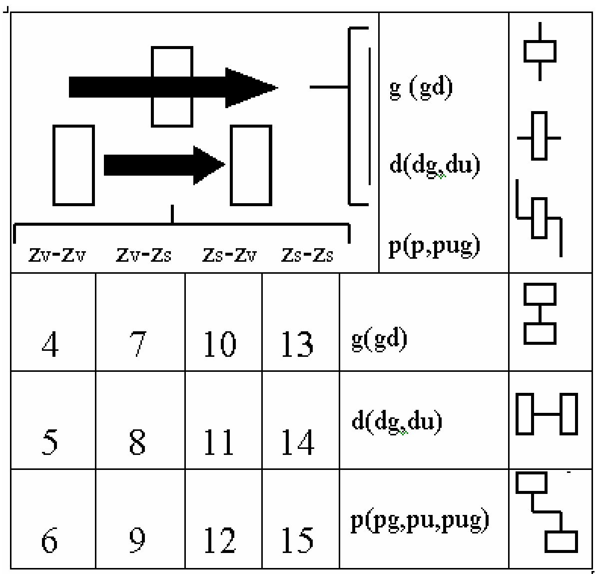

Figure 1. Choosing algorithm

This decomposition and mainly the terminology systems were criticized as not exakt enough. With the development of automation and robotics a new terminology system "elementary moving operations" was discovered. Its definition is versatile. One part of the definition tells us that EMOs are compact function moving activities which are performed by technical systems or by man or both.

The manipulation process which is evaluated or designed, has first to be analysed and described in terms of EMOs:

- g – gravity operation (fall down, slip) e.g. a detail falls into a box.
- d – transport operation (transport without grasp and unload), e. g. the caterpillar and rolling manipulation systems.
- gd,dg – gravity – transport operation and viceversa is a combination of g and d operations e.g. a lorry with unloading mechanism.
- du – semimoving operation (grasp and transport).
- p – moving operation is operation (du+dg) grasp transport and put down on a place e. g. a robot.
- pd – modifications of the operation.
- pu – modifications of the operation.
- pug – modifications of the operation.

Each manipulation process can be described with help of these EMOs symbols. For example the group of symbols “p-dg-g-dg-p” tell us that a detail or product is moved by a manipulator on the transporter, then it is transferr on the gravity transporter and finally the manipulator transfers the detail to the working position on the cylindrical grinding machine. Describing manipulation with material by the symbols helps us to automate a designing process and use a computer in the process (Figure 2.) (Hlavenka, 1998).

Another important property of EMO is trajectory of movement, which may be:

- fixed - marked (a) - chute,
- locally limited - marked (b) - robot,
- limited in larger area - marked (c) - crane,
- free trace - marked (e) - lorry.

Each of these movements has its own length and this is another important quantitative property of movement.

According to the level of automation, continuity and mainly economy of movement, a sequence of the manipulation operations which was established are ranked one after another from those with minimal energy demand, up to the most energy demanding ones. The sequences are ga-da-db-dc-de-pa-pb-pc-pe.

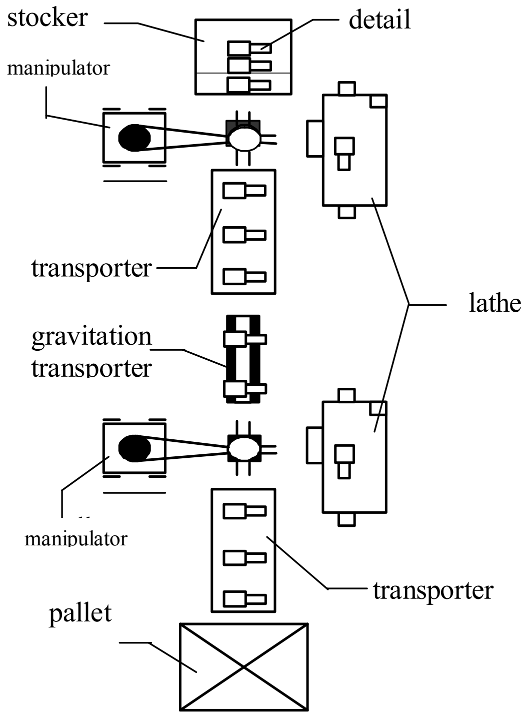

Figure 2. Described manipulation process

The theory of causal position recommends that the principle of continuity (movement of detail during technology position and manipulation processes) is applied. From this point of view technological position can be a static (Zs) or moving (Zv) variable. On these principles we can design a choosing alghorithm (procedure) as follows (see table 1.). Non-automated evaluation according therefore we to this method is laborious, proposed a computer aided system (Svoboda, 1998).

5. STOCKTAKING OF MANIPULATORS AND DETERMINING THEIR INITIAL AND OPERATING COST

The basic division of manipulator types into groups was one of the starting points for the construction of the "KAUZA-X" expert system. The groups were defined according to the above optimum sequence of elementary operations. For example: **ga** type (chutes, roller conveyors, wheel conveyers, etc.); **da** type (belt conveyors, conveying troughs, etc.). s manipulators can be included in more than one group, we have performed their stocktaking from brochures and catalogues and sorted them according to their types (Polata, 1998). This stocktaking will serve as a basic database for the selection and sorting of these manipulators into the "KAUZA-X" knowledge base.

5. 1. Defining initial and operating cost

As stated in the introduction, the performance criterion in the old system was energy consumption based on inaccurate rating, reflecting expert opinions. As the same energy consumption of a compressed-air-driven and electricity-driven transporter represents considerably different costs, we came to the conclusion that a comparison of individual operations should be made as to their purchase and operating costs per metre of manipulation. We have not complicated the calculation by adding the aspect of the workpiece weight, assuming that a manipulator with dimensions corresponding with the particular operation's demands is always selected. In order to simplify the calculation, we have included only the most significant items in the operating cost, i.e. depreciation, energy and operator (labour) cost (Synek, 1996).

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:

$$N_{A\,(1\,m)} = C \cdot t \qquad \Rightarrow \qquad N_{A\,(\text{transport distance})} = C \cdot t_k \qquad (1)$$

- $N_{A\,(1\,m)}$ – manipulator depreciation per m of manipulation [CZK.m^{-1}],
- $N_{A\,(\text{transport distance})}$ – manipulator depreciation [CZK.m^{-1}],
- C – portion of manipulator's purchase price used in 1 s [CZK.s^{-1}],
- t – time needed for manipulating with the manipulation unit on a 1m of 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:

$$N_{E\,(1\,m)} = E \cdot t \qquad \Rightarrow \qquad N_{E\,(\text{transport distance})} = E \cdot t_k \qquad (2)$$

- $N_{E\,(1m)}$ – manipulator energy cost per m of manipulation [CZK.m^{-1}],
- $N_{E\,(\text{transport distance})}$ – energy cost [CZK.m^{-1}],
- E – cost per second of machine operation [CZK.s^{-1}],
- t – time needed for manipulating with the manipulation unit on 1 m of 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:

$N_{P\,(1\,m)} = P \cdot t \quad \Rightarrow \quad N_{A\,(transport\ distance)} = P \cdot t_k$ (3)

- $N_{P\,(1m)}$ – fuel cost per m of manipulation [CZK.m^{-1}],
- $N_{P\,(transport\ distance)}$ – fuel cost [CZK.m^{-1}],
- P – cost of fuel consumed in 1 s of manipulator operation [CZK.s^{-1}],
- t – time needed for manipulating with the manipulation unit on 1 m of 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:

$N_{M\,(1\,m)} = M \cdot t \quad \Rightarrow \quad N_{M\,(transport\ distance)} = M \cdot t_k$ (4)

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

If two logistic processes with the same manipulation trajectory, similar technological arrangement and the same output (product) are compared, the manipulation cost increases or decreases, reflecting the EOM energy demand. The cost comparison of two such logistic processes is presented in Fig. 3.

Arrangement of manipulating devices, EMO and trajectory length in:

A) Line with manipulators

Fig. 1: 1. op. chain conveyor (da); [2 m] + 2. op. transloading lifter (dg) + 3. op. manipulator (robot) (pu, pg); [2 m] + 4. op. chain conveyor (da); [2 m] + 5. op. transloading lifter (dg) + + 6. op. manipulator (robot) (pu, pg); [2 m] + 7. op. gravity chute (ga); [2 m].

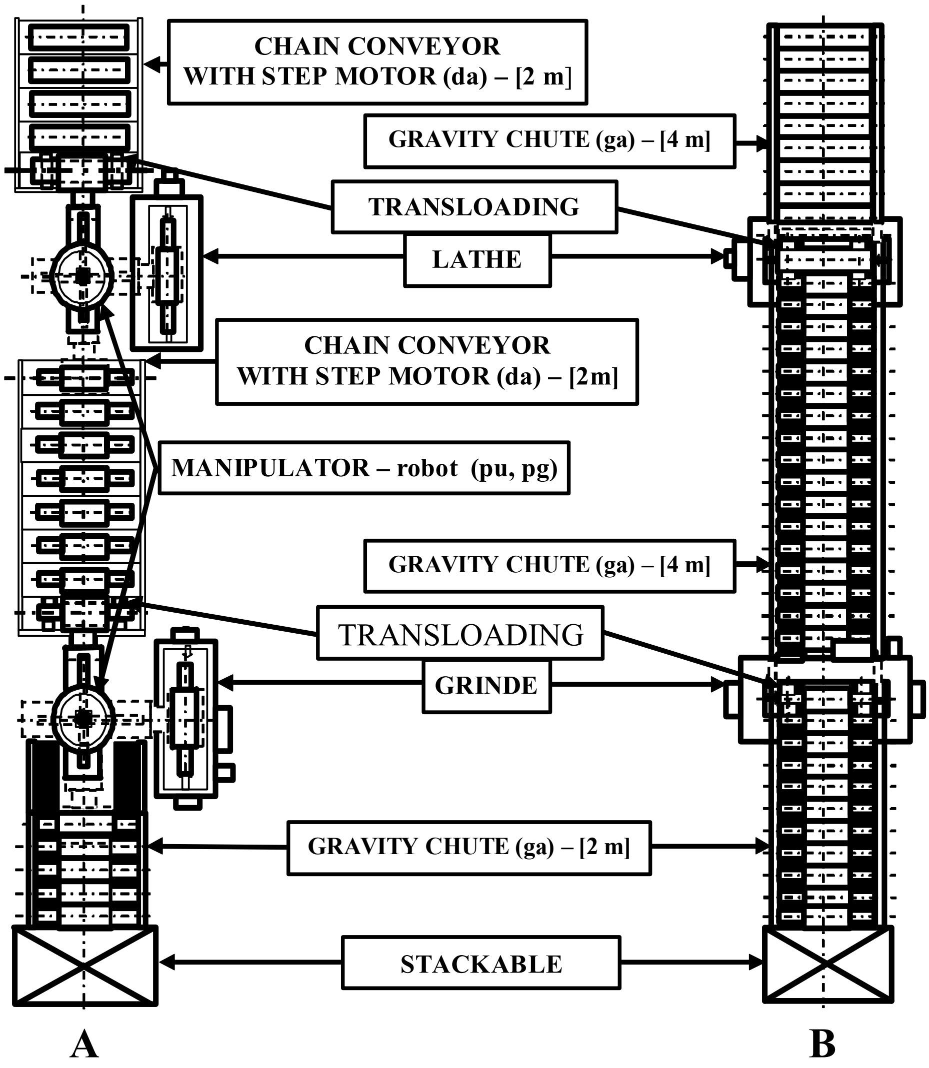

Figure 3. Comparison of two manipulation processes:
A) line with manipulators; B) line with gravity chutes

Arrangement of manipulating devices, EMO and trajectory length in:

B) Line with gravity chutes

Fig. 1: 1. op. gravity chute (ga); [4 m] + 2. op. transloading lifter (dg) + 3. op. gravity chute (ga); [4 m] + 4. op. transloading lifter (dg) + 5. op. gravity chute (ga); [2 m].

Comparison of the manipulation cost of the whole logistic process (see Fig. 1):

I.) Manip. cost of the whole log. process with
A) Line with manipulators: $N_c = 9{,}30$ CZK

II.) Manip. cost of the whole log. process with
B) Line with grav. chutes: $N_c = 0{,}0005$ CZK

The line using gravity chutes and transloading lifters consumes much less energy thanks to the help of gravity. The operation type and the trajectory is (ga + ga + ga).

6. WORKING WITH THE EXPERT SYSTEM

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 the cost indicators of this logical chain, 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 the cost indicators for each selected manipulator. Each selected manipulator has the following sums calculated: manipulator transport cost per m, total transport cost for the transport distance, and the cumulated cost, i. e. cost associated with the manipulation process as such. The user can then decide for the more expensive or cheaper alternative, taking into account the cost of the whole manipulation process (cumulated cost) and the anticipated investment return period in case of the more expensive alternative.

7. CONCLUSION

We believe that the system for the design and evaluation of logistic processes we are working on will be beneficial to practising designers. Currently design centres usually have capacities for designing just their own projects and only a very limited number of this type of software packages from domestic suppliers can be found on our market. The theory of causal positions is an ideal basis for this expert system. The available studies of the most successful logistic processes have confirmed their links with the preferred operations (g, d). Operations of the (p) type are much more expensive due to their technical complexity and discontinuity.

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EKSPERTNI SUSTAV ZA MINIMIZIRANJE TROŠKOVA LOGISTIČKIH PROCESA

Sažetak

U ovom se radu prikazuje praktična uporaba teorije kauzalnog položaja prilikom evalucije, sistemskog dizajna, mehanizacije i automatizacije logističkih procesa, i to manipulacije materijalom. S ciljem šire primjene ove složene teorije, autori su počeli dizajnirati ekspertni sustav *"KAUZA - X",* koji će jednostavno moći koristiti i ne-eksperti. Teoretsku bazu ekspertnog sustava čine: sistemski pristup (logistički sustav se sastoji od skupa elemenata i odnosa) i teorija kauzalnog položaja (razlog kretanja objekta leži u vrsti njegovog položaja i u odnosima između objekata). Svojstva pojedinog objekta i njegove primjene imaju posljedicu na pojedinačne pozicije, koje su tehnički i organizacijski povezane. Za svaku od brojnih veza među objektima, postoji proces traženja tehničko - ekonomskog optimuma.