SCIENTIFIC PROBLEMS
OF MACHINES OPERATION
AND MAINTENANCE
1 (153) 2008

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Decision-making system of transport devices supporting operation reliability process shaping

K e y - w o r d s

Reliability, decision-making processes, transport, overhead crane, exploitation.

S ł o w a k l u c z o w e

Niezawodność, procesy decyzyjne, transport, suwnica pomostowa, badania eksploatacyjne.

S u m m a r y

The article describes an operation system, which is executed by the transport unit in cooperation with the operator. The purpose of the system is to define tasks concerning the object-directed actions. The scheme of the system was shown and the decisive processes PD1 (action) and PD2 (workspace) were described. Solutions concerning the monitoring of the workspace using visual systems and object-positioning systems were presented. The outcome of my own research was also included, which is useful in the decisive processes and also techniques useful for gathering information about the exploitation of the gander crane were presented. Finally, an availability crane model, composed of subsystems with two standby levels, was shown.

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1. Introduction

In recent years, an evolution of transportation and production systems towards automation and the usage of information technologies and artificial intelligence have been observed. The main aim of those processes is to minimise the role of humans, which is the weakest factor in the operator-machine-environment system. Accordingly, the human is concerned with the following issues: the responsible control of the machinery, the dissemination of skills and preparing tasks awaiting fulfilment. This is pursued to ensure safety, the reliability of the machinery and an acceptable exploitation cost.

For the purpose of the article, it was assume that the transport control system under operation encompasses the following three subsystems:

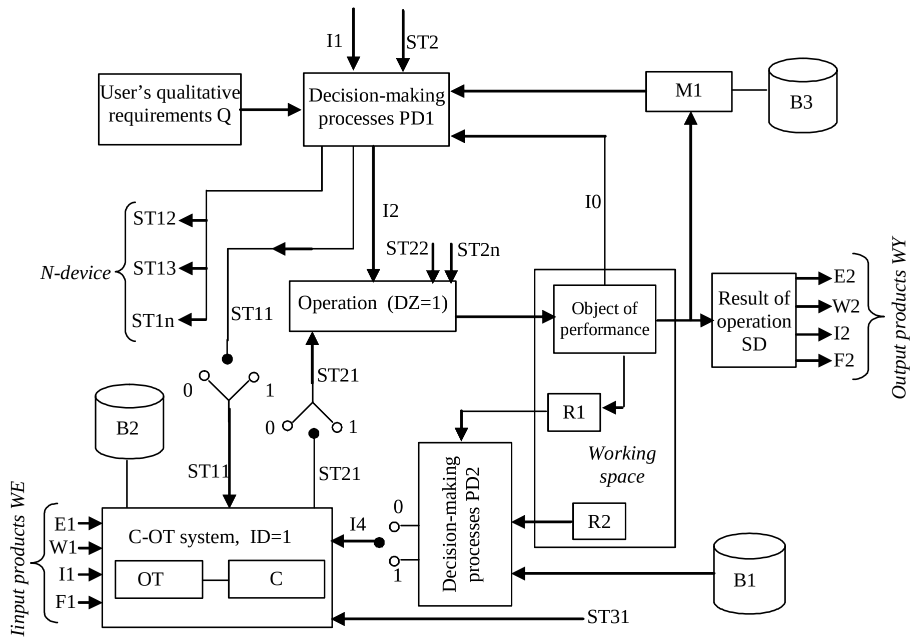
- Direct action system (PS1) – fulfilment of the task using the C-OT system, and the evaluation of it using beforehand established indicators that will evaluate the level of fulfilment of the expectations of the user;
- Supporting system (PS2) – expressed as the exploitation potential of the human-machine system, which is being depredated during the exploitation and being restored during the maintenance process, and which analysis allows to evaluate the purposefulness and the possibility of the fulfilment of the task; and,
- Co-ordinating system (PS3) – its purpose is to coordinate decisive actions in the fragmentary goals, executed by the human-machine system, and the following phases of its life, in order to ensure achieving the assumed goals.

The paper presents the direct action subsystem, which was described in detail using an example of short-distance transportation – a gander crane.

2. System characteristics

In the direct action subsystem (Fig.1), the pressure is put on the action, which is executed by the vehicle in cooperation with the operator. The purpose of the process is to define an action focused on the object (load). To make the process possible, the following input products have to be defined:

- Energy (E), which is indispensable to fulfil the task of both human (food, rest) on the machinery (electricity, hydraulic power);
- Information (I), which encompasses data acquired by the operator, using his senses or sensors, for the needs of the operator or the machinery;
- Funds (F), which are the cost of the enterprise; and,
- Knowledge and abilities achieved (W) by operator or gathered in electronic form for control requirements.



List of the used signatures:

B – database,
B1 – reference characteristics of the object and the environment,
B2 – input products of the process,
B3 – output products of the process,
I0 – the object of the process,
I1 – the task to be executed,
I2 – the effect of the action (and the output product) from the M1 monitoring,
I3 – external actions,
I4 – knowledge about the object and the environment,
M1 – monitoring of the effects of the actions of C-OT system,
ST – control unit,
ST1 – decisions coming from the production--transport C-OT system coordinator in accordance to the range defined by the C-OT system,
ST2 – intentional action executed by the C-OT system, directed to the DZ action and aimed on meeting the needs of the operator.
PD – decisive process,
PD1 – on the system co-ordinator level, including the analysis of the task and the evaluation of the quality of the effect,
PD2 – related to the features of the object and the environment,
Q1 – quality and quantity requirements of the object and the environment,
R – monitoring of the object and the environment,
R1 – quality and quantity identification of the object,
R2 – identification of the environment,

Fig. 1. Block scheme of the direct action subsystem
Rys. 1. Schemat blokowy podsystemu bezpośredniego działania

During the process utilising the machinery, the input products (W1, I1, E1, F1) are being transformed into the output products (W2, I2, E2, F2), which indicate the level of the user's satisfaction. It can be indicated by the quality evaluation indicator (e.g. time and cost of the process, precision) of positioning).

Devices oriented on the object of the action and product desired by the user are an important role of the production system. An action is an intentional and deliberate human behaviour, which is fulfilled with the use of certain tools or machinery.

The effect of the work of the C-OT system is being monitored (M1) and compared according to the needs of the user, which means whether or not the task is qualified as complete or not. The objects of the monitoring are the following:

- Load is characterised by
  - certain features,
  - mass Q,
  - location in the work space,
  - intentional actions (concerning the location of the object),
- Time of the process,
- Energy used during the process,
- The change of the exploitation potential of the device and the operator (if the task can be executed), especially the effect of the event, the reason, object of the event, time and range of service, cost of service and any further costs, and
- The trajectory of the object's movement.

3. Data gathering process

Modern exploitation and transport process control and monitoring systems often have advanced functions, related to the control, data gathering, storing and visualising, alarm control and report generating algorithms. Simultaneously, we can observe the growing complexity of the systems, especially on the data processing layer. For the operators more and more data sources are available, differing in the level of accuracy and distraction. The data gathering process for the gander crane is show on the scheme (Fig. 2).

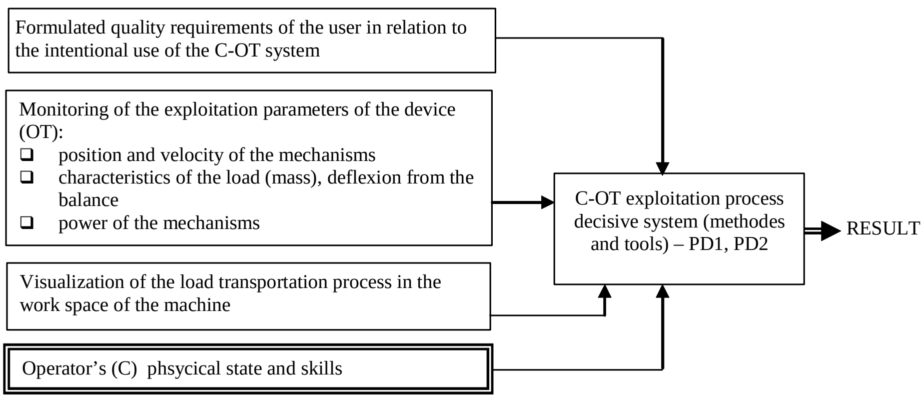


Fig. 2. Process of creation of the device's exploitation decisive system
Rys. 2. Proces budowy systemu decyzyjnego w zakresie eksploatacji urządzenia

The acquired data is being used in and for the following:

- The task realised by the control device using the appropriate techniques (exploitation process);
- The change of the environmental conditions during the process;
- The history of the device's malfunctions and its subsystems, including their reasons;
- The history and range of maintenance works;
- The time of usage of the machinery; and,
- The border values of the gander crane's exploitation parameters needed to qualify the device to a certain exploitation readiness state.

Data gathering methods:

- Documentation, complemented by the reports from the staff, according to the valid regulations (e.g. acquiring from the operators information about the exploitation process);
- Questionnaires (pool survey); and
- On-line measurement points of the exploited machinery.

In the mentioned subsystem (Fig.1.), object-oriented (PD2) and task-oriented (PD1), decisive processes take part. The PD1 decisive process encompasses quality requirements Q1, which are defined by the safety function of the whole system (B1), the readiness of the system (A1) and the cost of exploitation (C1).

4. Decisive process PD1 in the fulfilment of the task

Each device is classifying to one of the state of readiness, which determines the exploitation process (Fig. 3.).

In Figure 4, exemplary times of exploitation of the gantry crane's subsystems are shown. The device can be only in one of two states – activity and maintenance. In the activity state, the object fulfills its tasks (solid line); and, in the maintenance state, the object is being restored to full usefulness (dashed line).

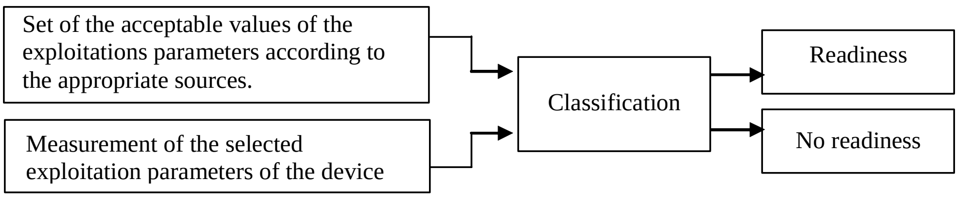


Fig. 3. Classification of the device's state
Rys. 3. Klasyfikacja stanu urządzenia

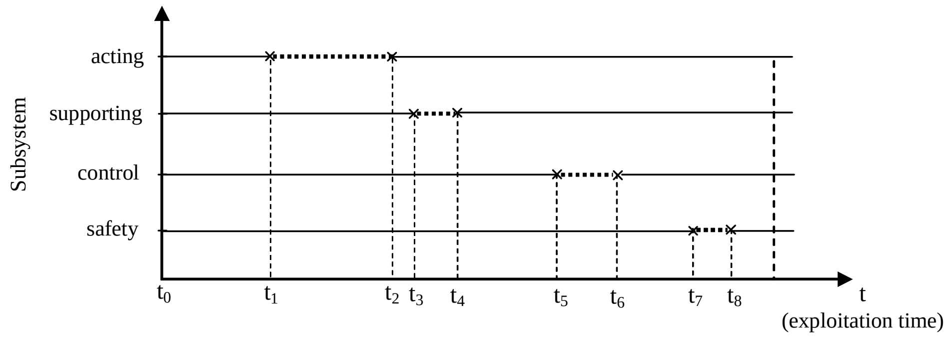


Fig. 4. Exemplary intervals of readiness and lack of readiness for the selected subsystems of the gander crane
Rys. 4. Przykładowe przedziały zdatności i niezdatności eksploatacji dla wybranych podsystemów suwnicy pomostowej

The gander crane exploitation process can be also shown as follows [1]:

I - state of activity (work)
II - stoppage
III - maintenance (which does not mean the device is not in the state of readiness)

} Readiness (A)

………………………..

IV - diagnostics (assessment of the current technical state of the device)
V - awaiting for the maintenance
VI - proper maintenance

} Lack of readiness (B)

The transition from state A to state B can be followed by transition from readiness to lack of readiness, which is caused by a malfunction of the gander crane, finishing the working day, maintenance etc. The sequence of the states, shown in the Figure 5, is also valid.

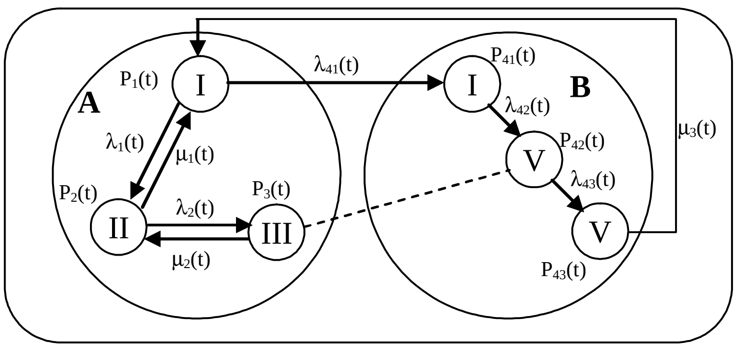


Fig. 5. Scheme showing the change of the states of the gander crane
Rys. 5. Schemat zmiany stanów suwnicy pomostowej

where:

$P_1(t)$ – probability of being the device in the state of usefulness (being used at the moment),

$P_2(t)$ – probability of being the device in the state of usefulness (awaiting for being used),

$P_3(t)$ – probability of being the device in the state of usefulness (being in maintenance),

$P_4(t)$ – probability of being the device out of the state of usefulness (awaiting for services P_{41}, P_{42}, P_{43},

$\lambda_1(t)$ – intensity of change from the state of activity to the state of inactivity,

$\lambda_2(t)$ – intensity of change from the state of inactivity to the state of maintenance,

$\lambda_3(t)$ – intensity of change from the state of activity to the state of service,

$\mu_1(t)$ – intensity of change from the state of inactivity to the state of activity,

$\mu_2(t)$ – intensity of change from the state of maintenance to the state of activity (stoppage),

$\mu_3(t)$ – intensity of change from the state of maintenance to the state of activity (work).

In case of malfunction, the device will pass through step IV (diagnostics), state V (awaiting service) state VI (maintenance) and returns to state I (work). If the gander crane is to change from state VI to state II (end of work day), then such transition is done through state I, but can be in this state very briefly, which corresponds to the fact that it is working and can change to state II (stoppage) – Figure 6.

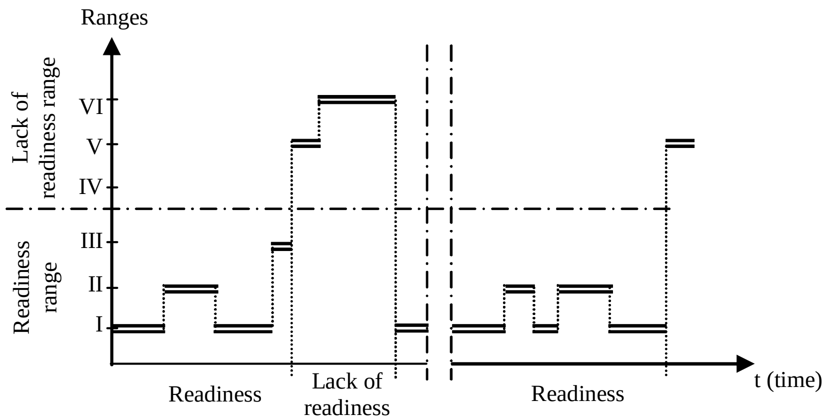


Fig. 6. Graphical presentation of the exploitation process of the gander crane
Rys. 6. Graficzny sposób przedstawienia procesu eksploatacji suwnicy pomostowej

The C-OT type systems are characterised by the reversibility of their malfunctions, as the effect of proper maintenance. An exemplary model of such a crane, with subsystems in two different states of readiness, is shown in Figure 7.

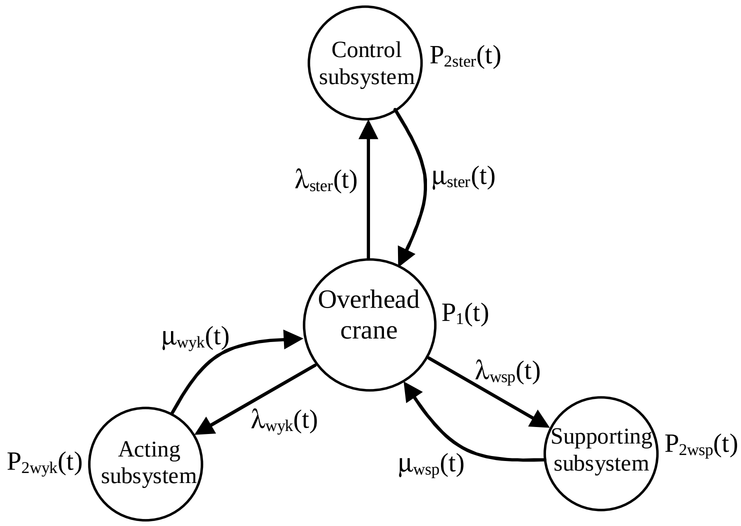


Fig. 7. Model of a gender crane, with subsystems in two different states of readiness
Rys. 7. Model niezawodnościowy suwnicy pomostowej złożony z podsystemów o dwóch stanach gotowości

It was assumed that the gander crane is composed of independent subsystems (acting, supporting, and control) which have a serial structure. If any of the elements is damaged, the device looses its readiness. When the damaged element is serviced, the whole system returns to readiness.

The structure of the model involves the following:

$P_1(t)$	–	probability of being the device in the state of readiness in the moment t
$P_{2wyk}(t)$, $P_{2wsp}(t)$, $P_{2ste}(t)$	–	probability of being the selected elements in the state of lack of readiness in the moment t
$\lambda_{wyk}(t)$, $\lambda_{wsp}(t)$, $\lambda_{ste}(t)$	–	intensity of transition from the standby state to the state of maintenance (intensity of malfunction)
$\mu_{wyk}(t)$, $\mu_{wsp}(t)$, $\mu_{ste}(t)$	–	intensity of transition from the maintenance state to the state of readiness (work)

The system of equations has the following structure:

$$P'_1(t) = \{-P_1(t) \cdot [\lambda_{wyk}(t) + \lambda_{wsp}(t) + \lambda_{ste}(t)] + [P_{2wyk}(t) \cdot \mu_{wyk}(t) + $$
$$+ P_{wsp}(t) \cdot \mu_{wsp}(t) + P_{ste}(t) \cdot \mu_{ste}(t)]\} \tag{1}$$

$$P'_{2wyk}(t) = P_1(t) \cdot \lambda_{wyk}(t) - P_{2wyk}(t) \cdot \mu_{wyk}(t) \tag{2}$$

$$P'_{2wsp}(t) = P_1(t) \cdot \lambda_{wsp}(t) - P_{2wsp}(t) \cdot \mu_{wsp}(t) \tag{3}$$

$$P'_{2str}(t) = P_1(t) \cdot \lambda_{str}(t) - P_{2str}(t) \cdot \mu_{str}(t) \tag{4}$$

$$P_1(t) + P_{2wyk}(t) + P_{2wsp}(t) + P_{2wyk}(t) = 1 \tag{5}$$

Assuming that $\lambda_{wyk}(t) = \lambda_{wyk}$, $\lambda_{wsp}(t) = \lambda_{wsp}$, $\lambda_{ste}(t) = \lambda_{ste}$ and $\mu_{wyk}(t) = \mu_{wyk}$, $\mu_{wsp}(t) = \mu_{wsp}$, $\mu_{ste}(t) = \mu_{ste}$ we receive such equations [2]:

$$P_1 = \frac{1}{1 + \frac{\lambda_{wyk} + \lambda_{wsp} + \lambda_{ste}}{\mu_{wyk} + \mu_{wsp} + \mu_{ste}}} \tag{6}$$

$$P_{2wyk} = \frac{\lambda_{wyk}}{\mu_{wyk}\left(1 + \frac{\lambda_{wyk} + \lambda_{wsp} + \lambda_{ste}}{\mu_{wyk} + \mu_{wsp} + \mu_{ste}}\right)} \tag{7}$$

$$P_{2wsp} = \frac{\lambda_{wsp}}{\mu_{wsp}\left(1 + \frac{\lambda_{wyk} + \lambda_{wsp} + \lambda_{ste}}{\mu_{wyk} + \mu_{wsp} + \mu_{ste}}\right)} \tag{8}$$

$$P_{2ste} = \frac{\lambda_{ste}}{\mu_{ste}\left(1 + \frac{\lambda_{wyk} + \lambda_{wsp} + \lambda_{ste}}{\mu_{wyk} + \mu_{wsp} + \mu_{ste}}\right)} \tag{9}$$

The calculated probability of the system being in a certain state is the consequence of the device’s characteristics, the input products and the effectiveness of the operating, and maintenance processes.

Based on the recorded events, it is possible to make a qualitative and quantitative assessment of the device’s subsystems and to make cause-and-effect analysis of the events that occurred.

The Figures from No 8 to No 10 show the exemplary results of the research concerning the malfunctions of the gander crane’s mechanisms. Data was gathered through a survey, carried out by the authors among the users of gantry cranes. Thirty-three (33) individual cranes were examined, in the time period of 41 months.

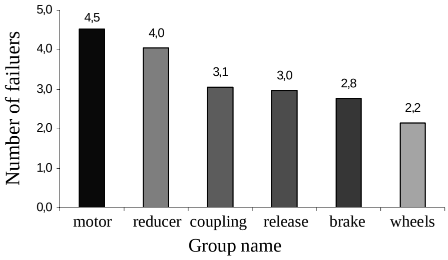


Fig. 8. Characteristics of the malfunctions of the gantry crane for the bridge mechanism
Rys. 8. Charakterystyka uszkodzeń zespołów suwnicy pomostowej dla mechanizmu jazdy mostem

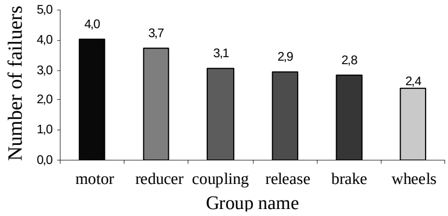


Fig. 9. Characteristics of the malfunctions of the gantry crane for the trolley mechanism
Rys. 9. Charakterystyka uszkodzeń zespołów suwnicy pomostowej dla mechanizmu jazdy wózkiem

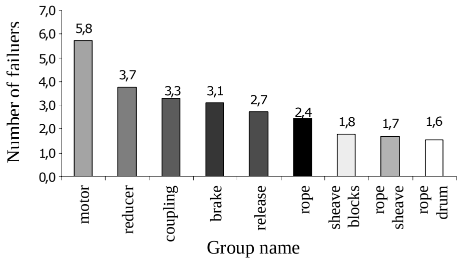


Fig. 10. Characteristics of the malfunctions of the gantry crane for the lifting mechanism
Rys. 10. Charakterystyka uszkodzeń zespołów suwnicy pomostowej dla mechanizmu podnoszenia

Another method of identification of the event that occurred is the analysis using the Ishikava cause-and-effect diagram. An exemplary analysis was done based on a malfunction of the gander crane's bridge drive (Fig. 11).

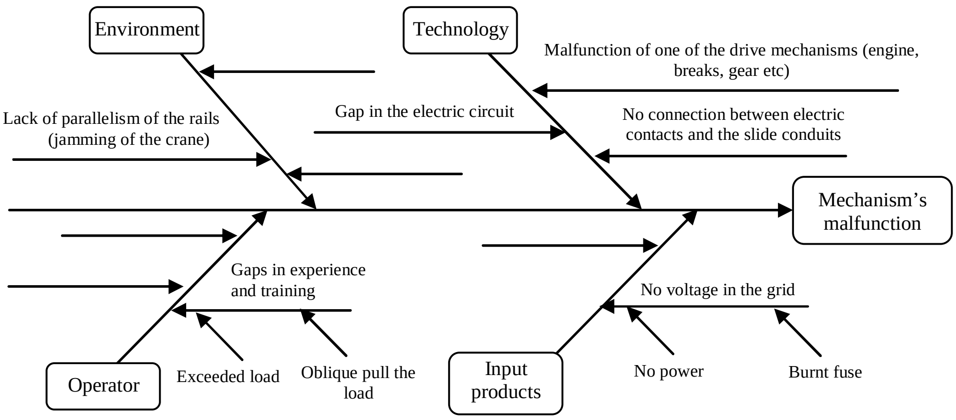


Fig. 11. Example of usage of the Ishikava diagram for the gantry crane's drive mechanism
Rys. 11. Przykład zastosowania diagramu Ishikawy dla mechanizmu jazdy suwnicy pomostowej

The presented set of events, which occur in the process of usage the C-OT system, can become a material for visual presentations utilising tools like the following which allows making the proper decisions: block schemes, Pareto diagrams, graphs, control charts, control cards and others, based on which allows the proper descisions te be made.

For the purpose of decision making, it is essential to know the history of the tasks, especially the mass of the load and the position of the mechanism in space (expressed by the trajectory of the executive part movement) as well as the total cost of the process.

5. PD2 decisive process within the work space

In the PD2 decisive subsystem, the object and the environment are identified, while the ST2 steering is done using the input products.

In Figure 12, one may see the method of monitoring the workspace of the gander crane using a set of CCD cameras, paying special attention to the load. A picture of the workspace and selected circuits of the gander crane are available in the operators' cabin and allow making effective decisions during the exploitation process.

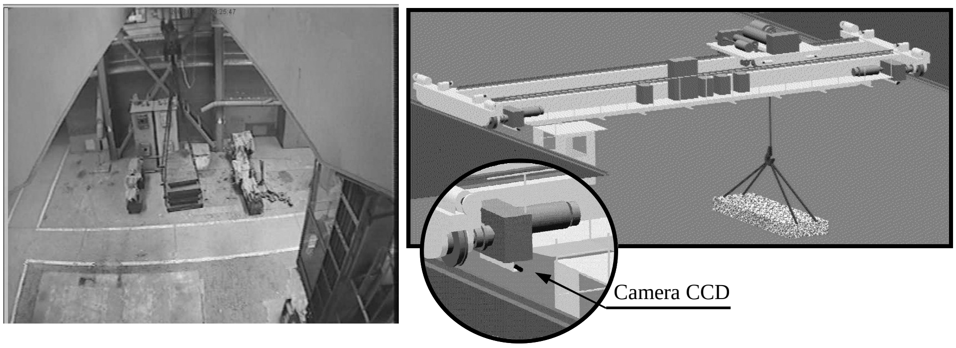


Fig. 12. Example of monitoring of the works space using set of cameras installed on the gander crane
Rys. 12. Przykład monitoringu przestrzeni roboczej z wykorzystaniem kamer zainstalowanych na suwnicy pomostowej

Figure 13 presents the gander crane remote control system. A set of CCD cameras connected to the digital recording card (HICAP) was installed on the crane, which records data essential for the user. Wire and wireless networks were combined in the system.

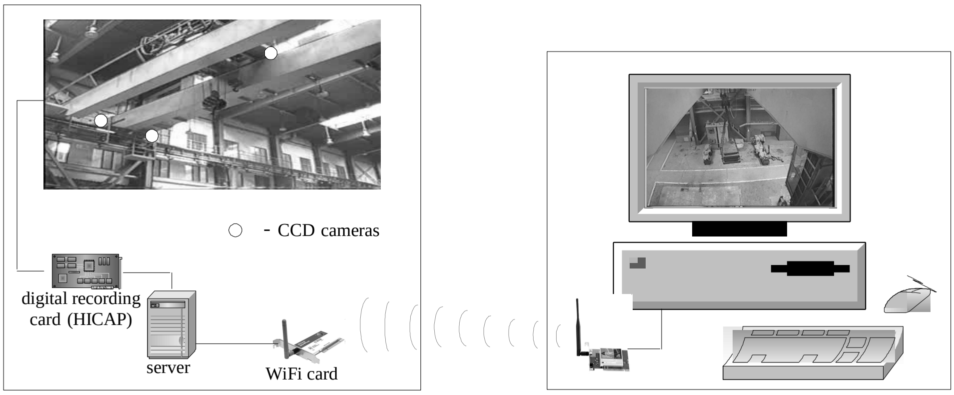


Fig. 13. Scheme of the work space monitoring using visual systems [3]
Rys. 13. Schemat monitorowania przestrzeni roboczej z pomocą układów wizyjnych [3]

Exceptionally useful features of the visual systems are their ability to carry out observation remotely and in real-time. It essentially influences the level of the automatism of the systems, the supervision of their technical condition, and allows building integrated control systems. They also influence to the system safety level and reliability.

Important for the load movement process is the proper design of the movement trajectory [4]. This design includes the operator's knowledge about the characteristics of the load, satisfying start and ending positions, layout of the workspace, characteristics of the machinery, and practical skills for fulfilment of this task.

For the needs of the gantry crane's operator, an aiding control panel (Fig. 14), which enhances the process of planning the automatic movements of

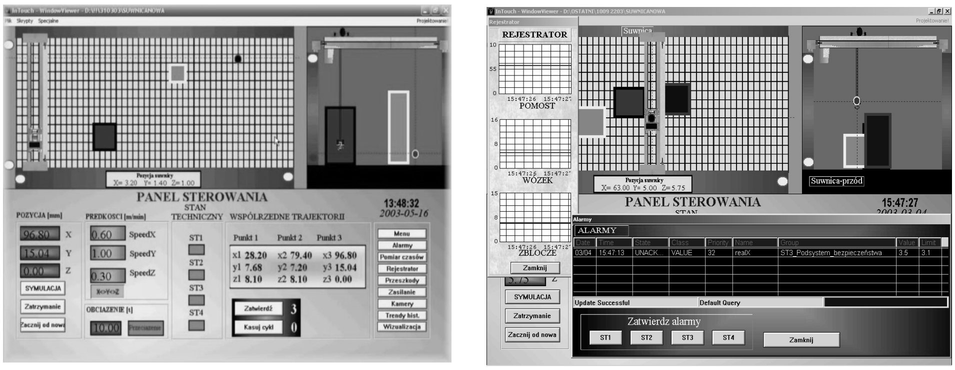


Fig. 14. An exemplary operators' window made in the InTouch application [6]
Rys. 14. Przykładowe okna operatora suwnicy pomostowej wykonane w programie *InTouch* [6]

the device within the work space and the course of any additional events (working period of certain mechanisms, mass of the load, energy used), was designed using the InTouch environment [5]. The control panel allows supervising the crane from the cabin or from a separate room.

Using the data gathered from the measurements, further analysis and the assessment of the effects is possible. The supervision of the exploitation process provides data about certain parameters, which can be later put into analysis. These are the following:

- The influence of the control technology on the technical condition of the device: overloading of the structure;
- The influence of the technical condition and the technology utilised on quality of the transportation (accuracy, time of the full work cycle, muffling of oscillations etc);
- The influence of the distribution of the load on the bridge's structure and overload of the drive mechanism on the technical condition of the wheel-rail system and on the unfavourable events that take place in this system (e.g. extra friction).

For the purpose of the ST2 control subsystem, an *operator-device* (crane) model was designed and shown in the Figure 15.

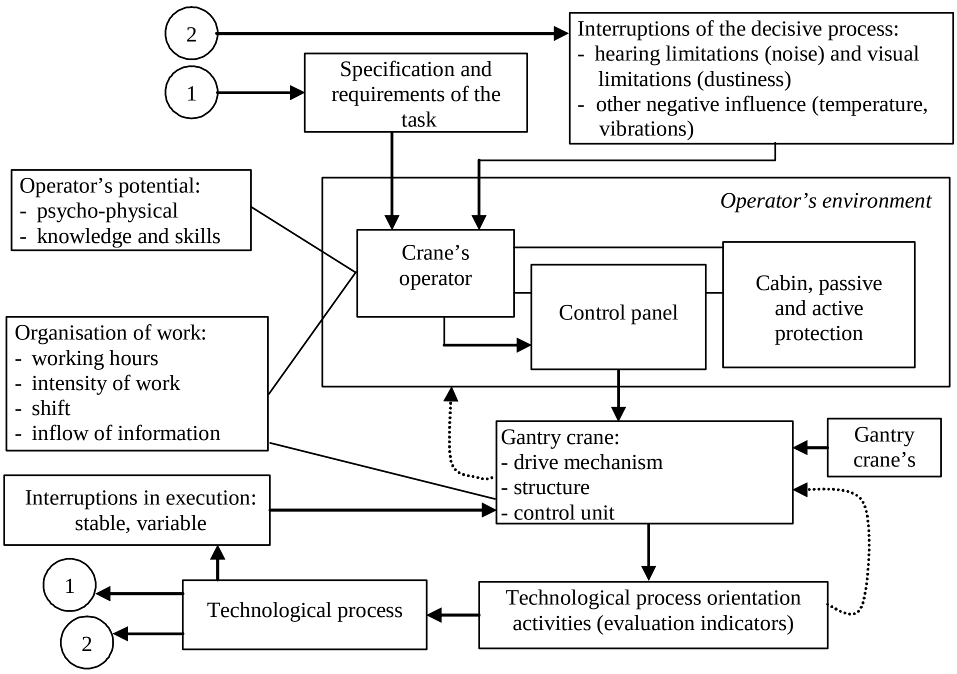


Fig. 15. Operator-crane system model [7]
Rys. 15. Model układu operator–suwnica [7]

In the model, there were a number of items whiche were distinguished: operator of the device working in a certain environment, gander crane used in the exploitation conditions, and the object of the action as the elemental task in the process. The task to be fulfilled in the technological process is being analysed and processed by the operator, taking into account the possibility and method of completion (process of decision) and then executed as a sequence of elemental actions with the use of the machinery (execution). Both the operator and the machinery are characterised by a certain exploitation potential.

Another object of research [8] was the techniques of steering the gander crane's bridge drive mechanisms by using proper alternators and controllers in the mechanism. The research has proved that the type of settings and the seat in the cabin, together with the utilised control systems, have a direct influence on the quality of the task fulfilled by the operator.

The research carried out among a group of gander crane operators discovered that the operators, especially those working with a constant flow of objects and those dealing with dangerous loads are exposed to serious stress, which is the basic reason of occupational diseases. What is more, another effect of stress can be wrong decisions, concerning steering the crane, made by the operators. This leads to overloading the crane and other dangerous events. This is why it is expected to take actions aimed on minimising the stress factors that have a direct influence on the operators, as well as proper selection of employees, according to their psychical and physical abilities.

The gander crane's operator decides about the start and stoppage characteristics of the device by properly selecting the interval of changes of the starting resistance in the engine's rotor circuit. During the control process, the load of the gander crane and the influence of the environment should be taken into account. The operator is affected by disruptions resulting from tiredness or/and external factors. The characteristics of starting and stoppage of the device are influenced by skills, knowledge and the current psychophysical state of the operator.

The issue of minimising the time of transport with the proper accuracy of the action and minimising oscillation of the load has been steadily growing in importance. The requirements towards the means of transport concerning improving the quality are possible to achieve because of designing and introducing new systems, based on artificial intelligence. Introducing fuzzy-logic and artificial neural networks for the purpose of controlling the transport allows construction of adaptive control systems, in which information about the process is analysed and processed using the heuristic method or the knowledge stored in the neural network.

Using the artificial intelligence in the means of transport requires abandoning traditional paper documentation of the exploitation history and utilising digital databases. The Electronic Knowledge Databases containing data about the events occurring during the exploitation of the machinery are useful in planning a strategy of using that machinery and also for making quick prototypes of the transport system. Furthermore, it was observed that the number of workers, directly involved in operating the machinery, was decreased, replacing them with remote supervisors backed by the LAN-type digital network.

Utilising intelligent technologies in controlling the means of transport is generally aimed at decreasing the cost of exploitation and increasing safety and reliability. Meeting the listed requirements is possible to achieve by using intelligent sensors, aiding the decisive system for the purpose of exploiting the device as well as using non-contact sensors, built into the control subsystem that aid the device working in the works pace, according to the proper quality parameters.

6. Summary

The process of exploitation of the means of transport is accompanied by constant evaluation done by the user, according to his requirements concerning functionality (usefulness) and quality (requirements towards the object or the environment). The needs of the user would evolve over time, and meeting them is possible as the result of certain decisions in the field of execution and service, including any type of modernisation. The effectiveness of such a decisive process is influenced by the database containing data about the events accompanying the exploitation of the certain device and other devices from that class.

The technical conditions of the device changes in time and has a direct impact on its usability and affects its ability to fulfil its tasks on the required quality level. If the change of the exploitation parameters passes certain thresholds, then the technical condition is not satisfying, the quality is unacceptable, cost of exploitation grows and the device needs maintenance. To prevent such an effect, a constant monitoring should be applied. Proper supervision prevents malfunctions and allows finding and eliminating the reasons of the malfunction before they occur. Monitoring requires finding a characteristic exploitation parameter, which observation can be the basis of stopping and servicing the device.

In economic categories, exploitation of the device encompasses variable costs (energy, spare parts, supplies, service, and unjustified stoppage of the device) and fixed costs (price of the device, amortisation, cost of liquidation, costs of using the infrastructure, and costs of management). Decreasing the exploitation costs is possible as a result of increasing the accuracy of the operators, decreasing the cost of management, and by introducing new solutions in technology and organisation. The diminishing potential of the device, resulting from its ageing, which occurs despite proper maintenance, also has a serious influence on the exploitation cost. The reason why each gander crane is used for a long period is thse high cost of that device and the lack of the user's attention to the issue of the exploitation cost and the quality of executed operations. It is common to have more transporting potential than required for the current needs.

Acknowledgement

The research project was financing from the Polish Science budget for the years 2005–2008.

Manuscript received by Editorial Board, September 09, 2007

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Metodyka budowy systemu decyzyjnego środka transportu na potrzeby kształtowania jego niezawodności eksploatacyjnej

S t r e s z c z e n i e

W artykule przedstawiono metodykę budowy systemu wspomagającego proces decyzyjny układu złożonego ze środka transportu i operatora. Implementacja takiego systemu w praktyce umożliwia kształtowanie procesów decyzyjnych ukierunkowanych na kształtowanie jego wymaganego poziomu niezawodności eksploatacyjnej. Przedstawiono schemat blokowy systemu oraz opisano procesy decyzyjne PD1 (realizacji działania) i PD2 (przestrzeni roboczej). Przedstawiono własne rozwiązania dotyczące monitorowania przestrzeni roboczej za pomocą układów wizyjnych oraz układów pozycjonowania ładunku w przestrzeni roboczej. Przedstawiono przykład aplikacji na suwnicach pomostowych. Zaprezentowano wybrane wyniki badań, przeprowadzone na suwnicach pomostowych, a także opisano wybrane techniki pozyskiwania informacji towarzyszących procesowi ich eksploatacji. Przedstawiono również model niezawodnościowy suwnicy pomostowej złożony z podsystemów o dwóch stanach gotowości.