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INTELLIGENT CONTROL OF REPAIR PROCESS OF INDUSTRIAL FACILITIES WITH DISTRIBUTED INFRASTRUCTURE ON THE BASIS OF CPS

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Abstract: The paper presents a brief description of engineering and scientific problems which arise at the steel plant PJSC "ArcelorMittal Kryvyi Rih" when organizing a repair workshop to fix industrial equipment. The attention is paid to innovative methods of repair process based on intelligent agents and Industry 4.0 principles.

Index Terms: **Control Systems, Cyber-Physical Systems, Predictive Maintenance, Smart Services, Industry 4.0, Big Data.**

I. INTRODUCTION

Over more than three hundred years of scientific and technological progress there could be pointed out four key stages (inventions), which later became known as the industrial revolution of our time [1]. The last stage of intellectual production automation (Fig. 1) is associated primarily with the implementation of Cyber-Physical Systems (CPS) [2]. CPS are often associated with the presence of such technologies as processing Big Data, autonomous robots with different sensors, simulators for 2D- and/or 3D-modeling, 3D-printers, the Internet of Things, virtual reality, etc. [3]. Thus, according to recent estimations of the world's leading experts, these trends will shape the main vector of modern competitive industries [2–5].

II. PERSPECTIVES OF CPS FOR INDUSTRIAL REPAIR AND MAINTENANCE

Considering the above mentioned, a promising project has been developed for more than six months in SIHE "Kryvyi Rih National University" at the Department of Computer Systems and Networks, Department of Informatics, Automation and Control Systems together with the Department of automation PJSC "ArcelorMittal Kryvyi Rih" employees. The project aims to implement an intelligent management system to repair industrial objects with geographically distributed infrastructure on the basis of CPS. The purpose of this work is to introduce the main challenges, ideas and design solutions. Let us consider the main reasons for such innovations in terms of this enterprise.

The plant PJSC "ArcelorMittal Kryvyi Rih" (AMKR [6]) as the main platform for the future project implementation nowadays is one of the largest steel plants. The production facilities operate on a distributed area over 100 km^2, the number of units (shops) is more than 50, working staff is more than 30 thousand workers, the total number of engaged nomenclature (including equipment, technology components, operations, etc.) is about 10^7. For example, only existing number of control and measuring devices (equipment) is more than 60 thousand units. Each year equipment count of the company grows. Thus, from 2010 to 2015 15,406 new devices were purchased, it is about 24.2 % of the operated devices. But at the same time a quarter of active devices are outdated, as released in 1960–1999. That is why the average fault tolerance of control and measuring devices for the company is low, and the devices are not interchangeable because of a large model assortment. For this reason, every year thousands of devices fail and are to be written off. Those written off and defective devices are stored at the enterprise, which along with the stocks constitutes a significant number of frozen devices.

Seven services of automation department are involved for maintaining the existing company equipment. These include repair service as well. The analysis of activities of this service shows a very low value of key performance indicators (KPIs) [7]. It depends on the duration of device absence because of its breakage or maintenance. Reducing this value will increase the KPIs not only of repair service, but other services as well.

To ensure smooth and efficient operation of measurement, maintenance, repair and automation in 2016 the company launched its own investment "Program for optimization of repair and maintenance processes of measuring and automation instruments, mass measurement means and computer technics". The main goal of the program is to organise a new centralised service of repair and maintenance at the plant. It includes reconstruction of buildings, developing intelligent and flexible automated production environment. In order to maximize the realization of the last two program components it was decided to engage a scientific community with a variety of funding sources in developing and implementing design solutions.

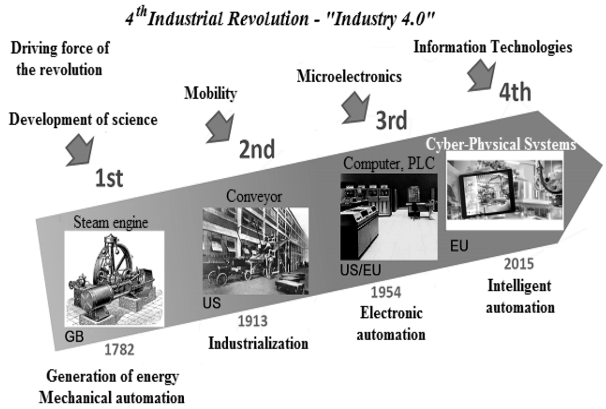

Fig. 1. Milestones of scientific and technical progress

The conducted comprehensive analysis of the problem has conclusively proved that the effective management of repairs (planned and unplanned) at such large industrial factories requires the most precise interaction of distributed warehouses, shops, transport services, staff within existing information systems on account of a large number of criteria and restrictions, main of them being the environment, energy, economy (overhead storage balances, etc.). It has been conclusively proved that the effective solution of these issues is impossible without the use of Cyber-Physical Systems (CPS) based on the concept of Industry 4.0.

In view of the result of the project working group, it was decided to distinguish between research and application components of the project. The solution of scientific problems of the first group will be carried out by an international consortium, including a number of European universities. Practical implementation of the proposed solutions, approaches and technologies will be fulfilled by specialists of PJSC AMKR involving the world leading vendors.

At present as a result of this collaboration the main task of the project has been formulated – to develop an intelligent and flexible automated environment for repair and maintenance service aimed at the effective support of the personnel. The purpose of the project is to develop a complex of information and communication technologies and automation facilities in order to:

– increase promptness, effectiveness and quality of maintenance and repair:

– organize a comfortable, safe and ergonomic workplace for personnel;

– reduce the total number of errors which occur when analyzing data on equipment and equipment failures statistics;

– minimize written off equipment through the effective use of its working parts.

The means for achieving the project objectives are multi-agent CPS, interacting through the cloud with the use of specially designed for this protocols. It is planned to use the following key approaches, technologies and standards: Data Mining, Data House, OLAP, ISA95-ISA88, Industry 4.0, 5S, Big Data.

According to the scheme of information and material flows of the future system (Fig. 2), the smart production environment includes:

– smart warehouse of spare parts and equipment with intelligent system for optimizing their range and number;

– workplaces optimized for diversification of repairing tasks;

– systems for collecting statistics, history of repairs analysis and formation of repair order;

– programmable universal stands for calibration of measuring equipment;

– intelligent transport systems, which include some automated intelligent transport agents that communicate among themselves, autonomously carry out optimization of their routes on the basis of accepted interfaces, standards and protocols (Fig. 4).

The functioning algorithm of the system, shown in Fig. 2, is depicted in Fig. 3. Both external (motor vehicles) and internal (roller, conveyor) travel agents are involved in the initial stages of the algorithm.

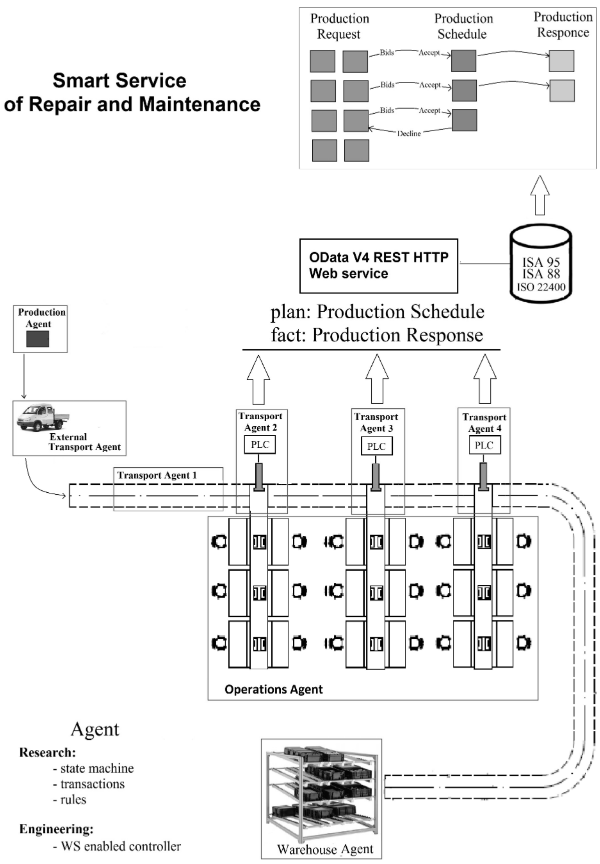

Fig. 2. Structural diagram of information and material flows of system

The figure shows the following blocks:

– block 0 – start of the algorithm;

– block 1 – input of information obtained through the use of transport agents;

– block 2 – decomposition tasks of parts processing;
– block 3 – preparation for parallel processing;
– block 4 – entering threads running simultaneously in critical section;
– block 5 – parallel processing of information flows;
– block 6 – output parallel threads from the critical section;
– block 7 – forming parallel data streams for processing in the PLC;
– block 8 – data processing in the PLC1-PLCn;
– block 9 – data transferring to a database for further processing and storage;
– block 10 – transferring data in Warehouse Agent; block 11 – end of the algorithm.

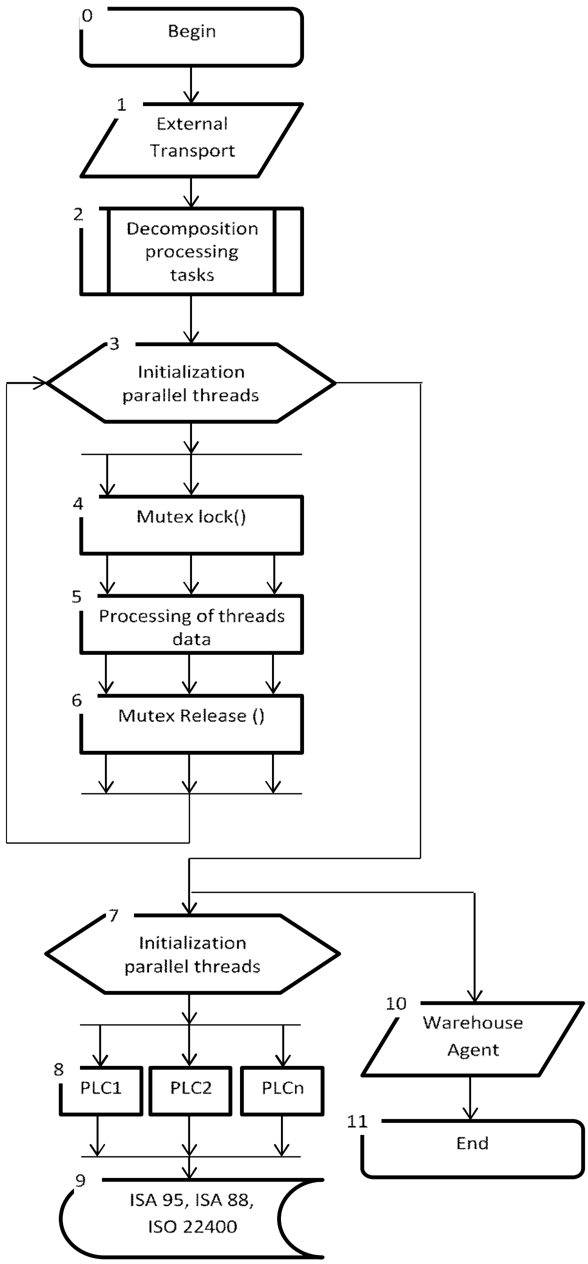

Fig. 3. Parallel algorithm of smart information system functioning

The proposed algorithm uses modern approaches for handling data streams using the technology of parallelization. For this purpose, algorithm provides decomposition of task for parts processing. After forming data streams for parallel processing, mutex mechanism is used, to avoid conflicts between parallel processes that try to access to the shared data. After entering into the critical section (function mutex lock ()) data processing is occured, and upon completion of work on a common resource is carried out with a critical section by calling mutex lock().

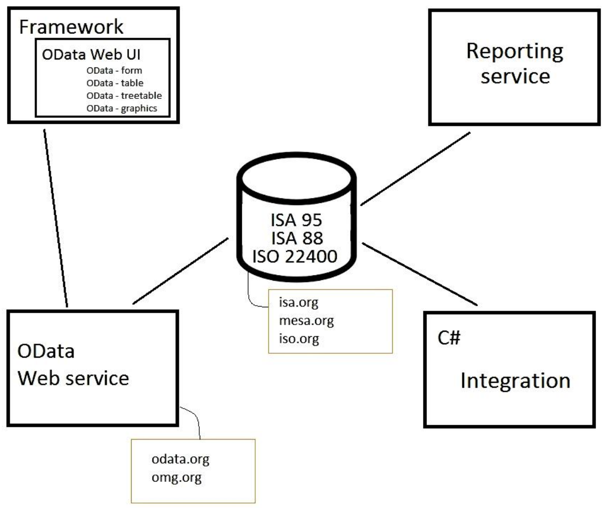

Fig. 4. The main interfaces and standards for interaction between the smart-agents (CPS)

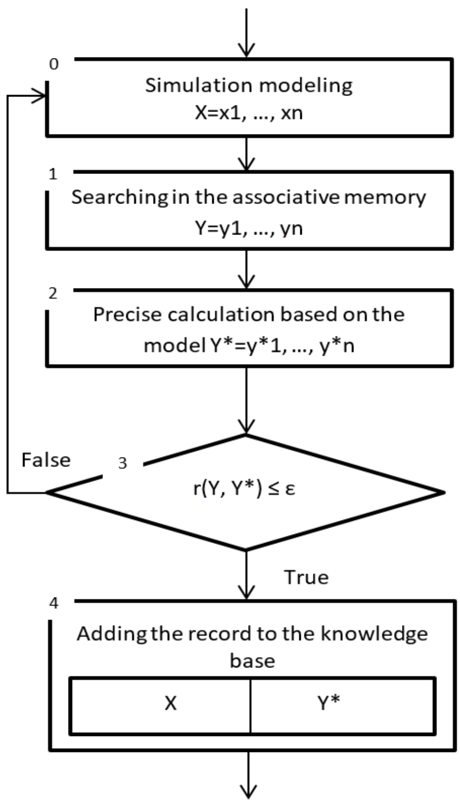

Fig. 5. Fragment of block diagram used for control and predictive tasks

After processing of parts they are transferred to the warehouse (Warehouse Agent). Information that is obtained by this processing via PLC (PLC) is transferred for further processing and storage in a database that is built according to the standards ISA 95, ISA 88, ISO 22400.

For task management and forecasting that are difficult to formalize, to increase performance of a computer system situational control should be used. This approach is based on the fact that for each value of the vector that describes the current situation three is the known value of the vector that describes the solution that should be taken. If it is impossible to describe all situations, then you need to use interpolation.

The initial situation is characterized by the vector X = {x1, x2, …, xn}. Y decision is made by the X vector components. Y is also vector Y = {y1, y2, …, ym}. Associative memory is used by this approach. The main idea is based on confronting each X situation with Y decision.

It is advisable to carry out education of the system with precise model, which uses the most accurate calculation of component solutions. Applying the model to study not only used for specifically prescribed by step training system, but also beyond the real cycle management, along with functional control. Algorithm of its work shown in Fig. 5.

In this block diagram Y* – vector control actions that are precisely designed for model, ε – specified precision, r(Y, Y*) – distance between vectors Y and Y*.

The figure shows the following blocks:

– block 0 – simulation modeling of technological situation;

– block 1 – determining the decision from associative memory according to the simulated technological situation;

– block 2 – calculation of new solutions using certain model;

– block 3 – determining the optimal new solutions that meet specific criteria: $r(Y, Y^*) \leq \varepsilon$;

– block 4 – adding new solutions to knowledge base.

To optimize technological processes of repair and maintenance in corresponding departments of PJSC AMKR, it is expected to develop and implement:

– system of the centralized service of repair and maintenance operation management;

– automated warehouse system of the centralized service of repair and maintenance;

– transport system of external interconnections in the central service of repair and maintenance;

– transport system of internal interconnections in the central service of repair and maintenance;

– centralizing, standardizing and establishing a single reserve;

– optimizing workplaces for testing and repair of thermal, electronic, physical and chemical facilities etc.

Smart warehouse performs the following functions (Fig. 4):

– automated accounting of equipment;

– intelligent analysis of equipment list and its optimization;

– automated calculation of equipment assortment and minimum number of parts and devices for storage;

– ergonomic equipment location for fast searching;

– automated delivery of goods by the transport system.

Smart transport agents have the following required characteristics:

– a set of independent transport agents are controlled by their own program and do not require additional operator intervention;

– each agent takes its own decisions on route planning, according to the objectives and messages from other agents;

– idle time while waiting for the necessary parts and devices tends to zero.

Ergonomic workplaces have the following required characteristics:

– organization of workplaces according to 5S system;

– a complete set of tools required for typical maintenance and repair operations;

– a monitor with repair instructions, instructions are composed automatically;

– Web application for registration of the performed operations.

The conducted retrospective analysis of available sources showed that there are no analogues or prototypes of implementing such solutions at large geographically distributed enterprises as well as necessary scientific methodology.

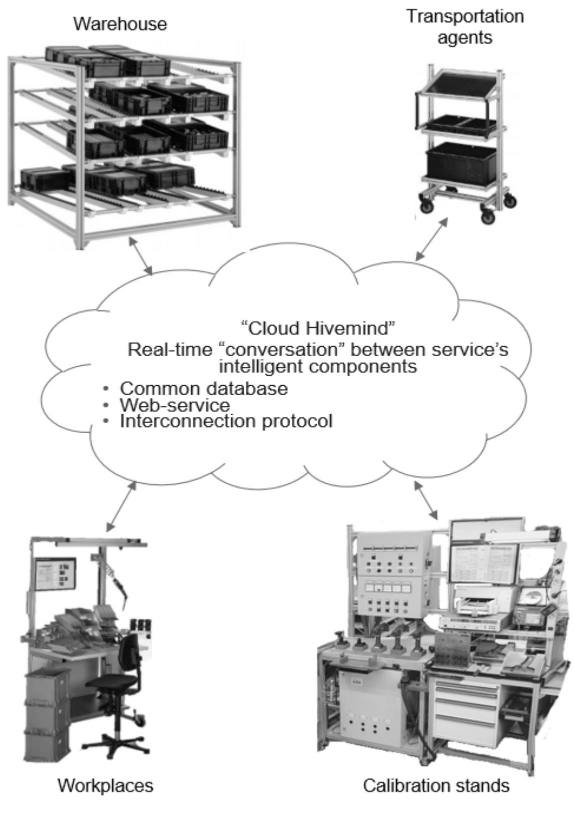

Fig. 6. Scheme of intellectual interaction between individual objects (CPS)

To enable realizing the above mentioned decisions a number of research tasks are to be solved:

– optimal control of nomenclature with the ability to autofill distributed databases (DB or Big Data) from all available sources (local and global) with maximum relevance to the existing structure in multi-agent environment of CPS;

– operational description construction of technological operations and processes chains and their link with the required nomenclature with maximum relevance in multi-agent environment of CPS;

– operational planning of logistics delivery with rational choice of routes, dynamic adjustment and optimization according to different criteria;

– creation of information technology to minimize the time for maintenance and repair of industrial equipment;

– improving enterprise management, according to the conceptual approach Industry 4.0, "flexible" employment and agile methodologies of maintenance and repair of industrial equipment;

– development of an expert system for planning the supply of parts and tools depending on the type of device that is served and the type of its failure by means of independent transport agents;

– development, standardization and optimization of the database structure to create spare parts smart-warehouse. Creation of information technologies based on computational intelligence techniques designed to find analogues on condition of insufficient information. Determining the minimum required range and number of spare equipment and parts in the warehouse;

– research of the statistical characteristics of industrial equipment failures. Identification of seasonal trends, analysis of indicators of quality and resilience of automatic control systems sensors.

III. CONCLUSIONS

The most important results of the project in terms of science are improving the methodology of distributed cyber-physical systems of intelligent management for solving optimization tasks of industrial equipment maintenance and repair, according to the concept of Industry 4.0.

Preliminary calculations show that if the conducted research and created intelligent technology will be implemented by the corresponding services at the enterprise AMKR, they will provide:

– reducing idle time to zero by decreasing the response, duration of repair and maintenance;

– reducing production costs;

– optimizing equipment kits at the plant, reducing the equipment range and minimizing the required number of parts and devices;

– reducing costs for the purchase of spare parts due to a more effective use of written-off equipment functioning parts ;

– improving the quality of repair and maintenance;

– increasing safety, functionality and comfort of staff operations;

– the creation of new job profiles.

Given the novelty and urgency of the problems not only in Ukraine, now PJSC "ArcelorMittal Kryvyi Rih", SIHE "Kryvyi Rih National University" in cooperation with European partners are preparing to implement the research part of the project within one of the international program "HORIZON 2020" challenges [8].

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Andriy Kupin was born in Slovianoserbsk, Luhansk region, Ukraine, in 1972. He received the engineering degree in robotic systems and complexes from East-Ukrainian State University, in 1994 and Ph.D. degree in automation from Kryvyi Rih Technical University, in 2001.

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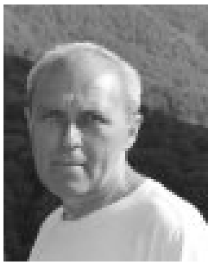

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