The design of the automated control system for warehouse equipment under radio-electronic manufacturing

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Abstract. In the paper, the aspects of design, development and implementation of the automated control system for warehousing under the manufacturing process of the radio-electronic enterprise JSC «Radiosvyaz» are discussed. The architecture of the automated control system for warehousing proposed in the paper consists of a server which is connected to the physically separated information networks: the network with a database server, which stores information about the orders for picking, and the network with the automated storage and retrieval system. This principle allows implementing the requirements for differentiation of access, ensuring the information safety and security requirements. Also, the efficiency of the developed automated solutions in terms of optimizing the warehouse's logistic characteristics is researched.

1. Introduction

Russian high-tech companies that have significant technological and organizational competencies, proprietary know-how, the use of which allows them to compete with leading foreign companies, have a relatively low degree of a business-process automation. The reduction of backwardness, costs and improvement of the efficiency of manufacturing processes can be accomplished through comprehensive automation of production processes by creating the Integrated Information Environment (IIE). During the creating IIE for the radio-electronic enterprise, which is characterized by a wide variety of materials purchased and home-manufactured components, assembly units, equipment and tools, a significant role is played by the automation of warehouse equipment. The aim of this automation is creating computer-controlled systems for automatically placing and retrieving loads from defined storage locations. This should ensure the integration of automated storage and retrieval systems (AS/RS) with inventory control systems and the enterprise resource planning system to increase the efficiency of warehouse logistic processes, reduce expenses and improve product competitiveness [1, 2].

Usually, the enterprise management system is being developed as a coherent set of interaction automation systems from the limited range of vendors and own designed information systems, which are reworked for creating the IIE. Automated warehouses are embedded in this infrastructure as the purchased new equipment (AS/RS modules) under upgraded algorithms of management of accounting processes. During the deployment process of warehouses and automated control systems, it should strive to high integration of warehouse control systems and manufacturing scheduling systems. Under such conditions, the warehouse equipment must be organized as a complex of AS/RS modules, which operates according to the unified corporate rules.

2. An approach to warehouse automation under radio-electronic manufacturing

It is interesting to discuss the warehouse automation and design of the automated control system for warehouses by the example of the radio-electronic enterprise JSC «Radiosvyaz» (Krasnoyarsk, Russia). This company is engaged in designing, developing and manufacturing of satellite communications equipment, GLONASS/GPS measuring equipment and phase navigation systems. The company has its own R&D department whose activities are integrated with manufacturing in shops. The scheduling manufacturing system of JSC «Radiosvyaz» manages orders and terms start orders in manufacturing, considering of priority products. The scheduling system also provides the information about product manufacturing stages and the execution of the production plan to engineering and technical staff. In accordance to the production plan, assembly shops draw up application forms to enterprise's Central Picking Shop (CPS). The scheduling office of CPS creates orders for picking on the basis of received application forms from assembly shops. These orders contain a list of items and storage place for every item in warehouse [3, 4]. At the time of implementation, the AS/RS, the IIE are being deployed. It has been required to create a home automated control system with implementation integration software for purchased AS/RS modules in IIE. From the hardware viewpoint, the upgrade of company's warehouses consists in changing of the existing mechanized storage systems by AS/RS vertical lift modules "Kardex Shuttle XP". These AS/RS modules have been distributed throughout the shop-level warehouses with the aim to reduce the number of inventory moving between shops and CPS [5].

A large amount of movement of inventory between shops, caused by large nomenclature of home-manufactured items, requires a high-speed processing of orders for picking. In turn, this causes difficulties when operating with storage equipment only in manual (mechanized), because it does not exclude searching steps storage place and calling the desired tray (pallet). For this reason, it is necessary to use the automated control system (ACS) for warehousing. The use of the software from the AS/RS vendor under such considered conditions is impractical because of high costs, redundancy and proprietary protected software architecture. Besides, the use of the proprietary software does not eliminate the necessity of gateway software development for integration with Warehouse Management System, Manufacturing Execution System and PDM solution – this is a non-optimal solution in view of established corporate rules and policies under IIE creation [6-8].

To ensure the integration of home ACS for warehousing in IIE, a data transfer mechanism to picking and tracking the flow of items from storage should be provided in the PDM-system. Let us suppose that there is an order for picking ($order_i$) and it must be performed. Then, in accordance to the rules of proper functioning of IIE,

$$order_i \in ORDER = \{PART, STPT, OTPT, INV\}, \tag{1}$$

where the following is specified: $ORDER$ – order for picking a matrix consisting of:

- $PART$ – column matrix of purchased items, included in an order for picking;
- $STPT$ – column matrix of own manufactured components, included in an order for picking;
- $OTPT$ – column matrix of other components, assemblies, included in an order for picking;
- INV – matrix of items, components, recorded in the enterprise inventory management system and linked with the current order for picking.

Matrix $ORDER$ must correlate (in general case) with the matrix of product plan execution $PLAN$ in terms of the correct and timely order's picking process:

$$C(t,t') = \langle plan(t), order(t') \rangle . \tag{2}$$

If correlation (2) is carried out, it becomes necessary in technical separation of information networks into two parts: the network with orders for picking and the network with product plan execution. This is the reason to determine the paired function for $order_i$ – $wrhs_i$, intended for monitoring the order's picking process:

$$order_i \equiv wrhs_i \in WRHS . \tag{3}$$

Considering (1)–(3), we have the following surjection:

$$order_i : ORDER \to \{WRHS\}. \tag{4}$$

The implementation of this is possible with the flag variable that tracks the status of order picking:

$$flag_i = \begin{cases} 1, \text{if } wrhs_i = order_i; \\ 0, \text{if } whrs_i \neq order_i. \end{cases} \quad (5)$$

Implementation of expressions (4), (5) means the appearance of the outlet function in ACS for warehouse automation:

$$outlet_i : OUT \rightarrow \{WRHS, ORDER, FLAG\}\,. \quad (6)$$

Implementation of (6) entails a change in the enterprise inventory management system, related with ACS for warehouse automation through expression

$$INV = WRHS \setminus OUT\,. \quad (7)$$

Expressions (4)–(7) show the interdependence of dissimilar entities that affect the operation of the ACS. In view of these dissimilar entities, for the correct description the functioning and for further design of the ACS, we can use the visual modeling methods such as Petri nets, UML, BPML, etc [9–11]. Based on the aspects presented above, the ACS operation in conjunction with the warehouse complex “Kardex Shuttle XP” can be described by the state machine in a UML notation (Fig. 1). Unlike the Petri nets, the UML’s state machine offers significant opportunities for automated design and developing of the ACSs software [12, 13]. The designed diagram (Fig. 1) shows a cycled request procedure to database for current existed orders for picking and connecting warehouses for service messages. Input and output data of ACS is the information readings and writings to the database and the information received from the AS/RS (warehouse). The data are exchanged with the database about current orders and warehouse’s service messages. After starting the program, the request is entered to the database and ACS performs the next steps:

- incorrect entries recovery – update «status»;
- reading configuration of AS/RS – the data are extracted from all database’s configuration AS/RS tables columns.

After ACS started, it sends the request to component for data exchange with the Database Management System (DBMS) and the incorrect items recovery is started. The uncorrected data can appear because of improper shutdown, abnormal power off the server. Then, it reads the configuration of AS/RS. For parallel picking orders, the ACS creates the streams for each AS/RS module. In each stream the entrance in circle is realized, the output from which is carried out by checking the flag variable or by manual closing of the program. If an error occurs in the warehouse module, the ACS will send the confirmation message to the monitor receiving information and the request to repeat the current operation. This is necessary for the implementation of the possibility of resuming work after an error occurs when the manual operation panel disconnected. After each iteration of the cycle, the stream switches to a sleep mode for 1 second to avoid the unnecessary loading on the database server and on the controlled modules. The structure of ACS (Fig. 2) consists of a control server with ACS, connected to networks: the network with the DBMS server with orders for picking and the network with AS/RS modules.

The main elements in the architecture of ACS are a dynamically linked library (dll) with control commands and server application for data exchange with DBMS for implementation of the seamless integration in IIE. The other elements are typical solutions from vendors AS/RS, DBMS or solutions, which are already in use. The proposed ACS is a unified dll as an integrating link between manufacturing equipment (AS/RS modules), the inventory management system and the manufacturing execution system. The developed solution is a system application configured as a hardware-independent library with possibilities of unification and scaling.

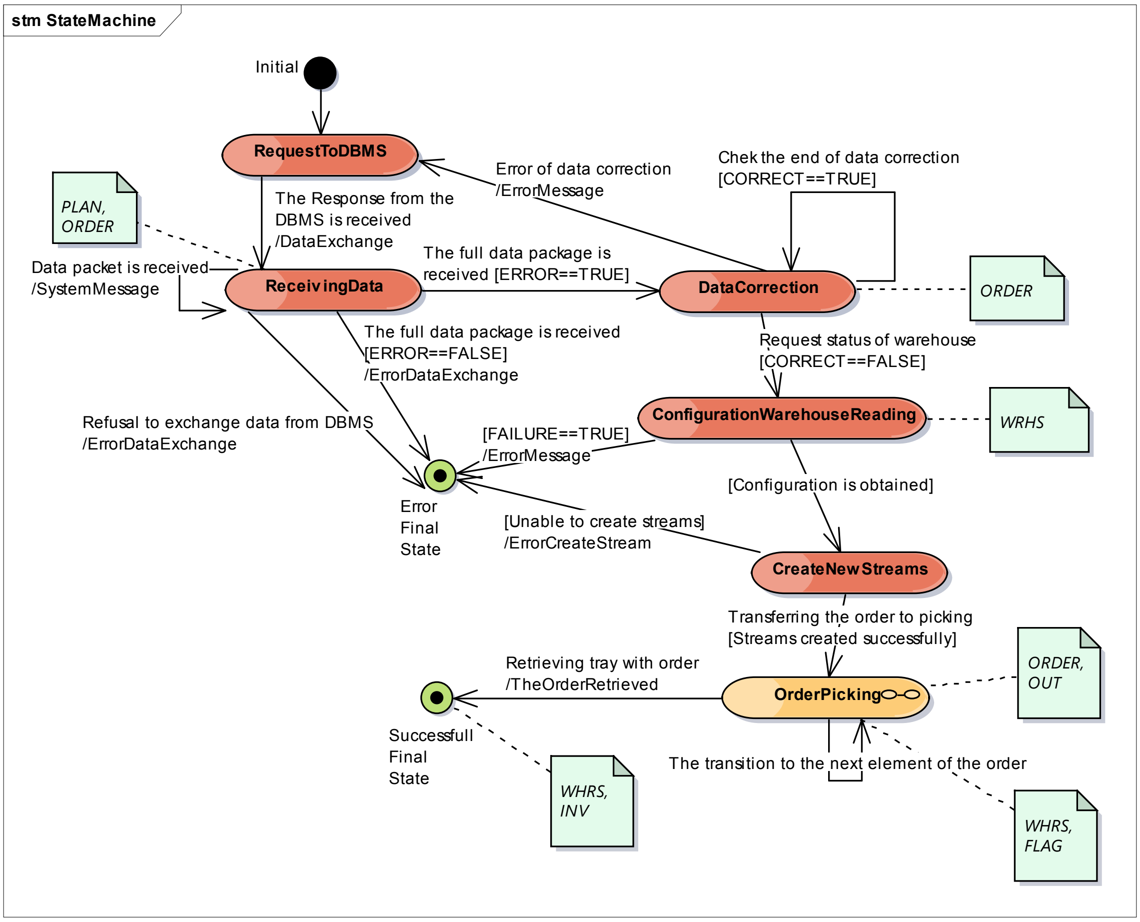

Figure 1. A behavioral model of the automated control system for the warehouse equipment

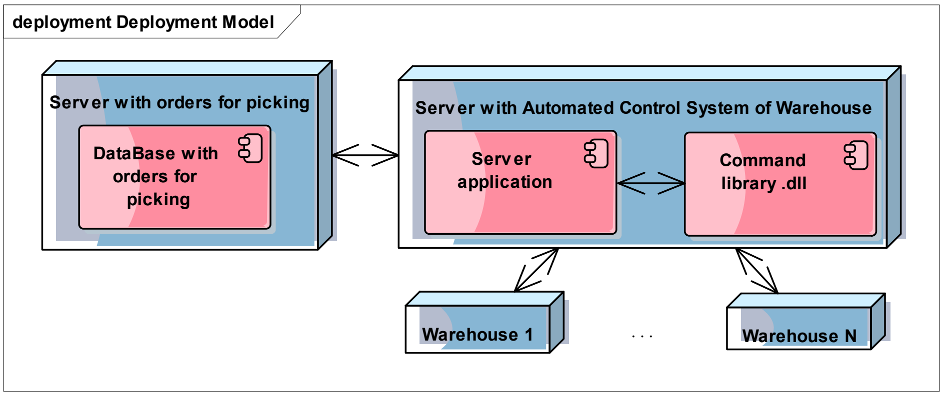

Figure 2. A structural model of the automated control system for the warehouse equipment

3. Evaluation of proposed automation warehouse solutions

One of the main problems during the implementation of automated hardware-software systems are the high material costs for their purchasing and possible high cost for ownership in the future. In contrast to data flow systems, PDM solutions, manufacturing execution systems, ERP platforms, the positive effect of AS/RS implementation is obvious, but requires a quantitative evaluation [14]. Table 1 shows the major comparative key performance indicators of warehouse operating before and after automated systems implementation.

Table 1. Evaluation metrics (key performance indicators) for the quality of warehousing processes in JSC «Radiosvyaz»

Evaluation metrics	Before the AS/RS implementation	After the AS/RS implementation	After the implementation of ACS for warehousing
The annual turnover of the warehouse (Q), items per year	1 481 373	1 961 309	2 816 941
The storage capacity (E), items	2 431 954	2 919 866	2 919 866
The life time of items in storage (t_{item}), days	30	22	17
The number of working days in the year for the warehouse (T_{year}), days	298	307	315
Items turnover of the most busy month ($Q_{month\ \max}$), items per month	186 618	233 551	341 944
Average monthly turnover (Q_{month}), items per month	51 436	143 442	234 745
The efficiency of using warehouse volume, %	20	80	80
The uneven loading warehouse ($\gamma = 1 - Q_{month}/Q_{month\ \max}$), %	72	39	31

The development and implementation of the automated control system for AS/RS modules makes it possible to achieve the maximum effect of manufacturing execution system opportunities. This significantly reduced the time and costs associated with the document flow and information exchange, picking manufacturing orders. The designed architecture of ACS, in which AS/RS modules are deployed in a private subnet, separated from the server with orders for picking, makes possible the implementation of differentiation for access to the information about manufacturing planning, which has a positive impact on the stability and reliability of enterprise's manufacturing planning and execution systems.

4. Conclusion

The implementation of automatic storage and retrieval systems increases the efficient of inventory management and brings transparency in manufacturing planning processes. It becomes possible to make the integration of inventory control processes with the manufacturing planning process. But at the same time, the implementation of hardware-software solutions from one vendor entails high financial costs and does not eliminate the need to revise and rework the purchased automated control system to the specifics of a particular subject area (scope). In addition, if it is necessary to integrate purchased automated warehouse modules in IIE of an enterprise, a warehouse equipment vendor usually cannot solve the problems of this integration. The proposed approach to automation of warehouse equipment consists in carrying out an initial examination of existing enterprise information infrastructure, determination of the key technologies and software platforms, which is a base for the integrated information environment, design and implementation of the architecture of the automated control system for warehouse equipment, as a composition of the unified software with the demanded behavior, and developing the library-formed solution of the automated control system. In the development software solution a method of picking assemblies, comprising the forming of the list of priority warehouse's trays according to the list of items, its storage places and the cyclic survey of confirming movement to the next tray is implemented. This approach allows ensuring the stability of warehouse operation, achieving the unification and scalability of the automated control system, which makes it possible to expand the set of control commands using the databases and warehouse equipment of different types and vendors. The modular architecture of the automated control system allows implementing the requirements for differentiation of access, ensuring the information safety and security requirements by separating the networks. The performance indicators of the enterprise resource planning system confirm the effectiveness of such approach. The sharp decline in labor intensity and the time of manufacturing order's picking, in the appearance of errors caused by human factor was quite noticeable.

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