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IMPROVING THE QUALITY OF PROCESS MODELS IN OIL REFINERY INFORMATION SYSTEMS

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Abstract: *The paper considers the ways to improve the quality of oil refinery process models in information systems at various management levels (ERP, APS, MES). The authors demonstrate the necessity to introduce a universal (basic) for all management systems in order to ensure their effective interaction and integration. It has also been shown that a universal basic model is a subset of models of interacting systems based on balance principles. The results of the practical implementation of the present approach at oil refineries are presented in the article along with the proposed ways to optimize the basic model. It should be noted that the development of a universal model can improve knowledge transfer and increase labour efficiency of personnel.*

Keywords: *Management systems, Quality, Knowledge transfer, Oil refinery*

1. Introduction

Automated systems of the ERP (Enterprise Resource Planning), APS (Advanced Planning and Scheduling), and MES (Manufacturing Execution System) class are currently widely used in all industries, including oil refining. Methods and approaches to implementation of such systems, as well as their interaction, are widely discussed in the literature. Incorrect implementation methodologies could lead to demotivation and internal resistance of personnel since such methods can cause significant changes in terms of methods philosophy (Kraemmerand et al., 2003; Silva et al., 2013).

Operating efficiency of automated systems at an industrial enterprise depends both on the quality of IT-solution of the system itself and on the mathematical model of the enterprise used by the system. Quality criteria for such models are normally characterized by such parameters as fidelity in describing processes of production/economic activities, a reasonable time for solving the model (if the automated system uses a model solver), the simplicity of the analysis of the results.

Models of oil refineries usually have large dimensionality. This is especially the case with mathematical models developed for APS systems. APS models of optimized operational planning comprise a production component (flow logistics at the oil refinery, unit capacities, oil-storage tank capacities), a technological component (operation modes of technological units, flow qualities, interdependence of various parameters, etc.), and an economic component (information on amounts and prices of buying and selling, costs of auxiliary raw materials, materials and energy, profit margin). The adequacy of the description of production processes using such models and recommendations for their improvement is still discussed extensively in the literature (Menezes et al., 2009; Guerra

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& LeRoux, 2011; Alattas et al., 2013; Chen, 2016). However, excessive attempts to increase the fidelity of the model by trying to account for the maximum number of its parameters and dependencies result in an increase of its dimensionality. The latter may lead to errors in the solution of such a model due to the limited potential of contemporary solvers used in LP-systems (the so-called non-convergence of the solution). Besides, complex, multidimensional models are more difficult to analyze, which may lead to errors in finding optimal plans and to financial losses. That is why, despite considerable experience in the field of constructing models for optimization of APS systems, in practice, experts often trade off a certain degree of fidelity for the convergence of the solution and simplicity of handling the model.

The development of objective and user-friendly production models is a nontrivial task for MES as well. The primary task of MES at oil refineries is automation of processes of production accounting and performance, which are closely related with planning and management. As a rule, coordination of all these parameters requires a whole complex of MES systems, including real-time database, production record system, material balance reconciliation system, and system of user report generation.

In this connection, the issues of effective coordination and integration of MES systems are vitally important. The most complicated of these issues in terms of modeling MES at oil refineries is the material balance reconciliation system. This system is described by a nontrivial mathematical model, solved using optimization methods. Managerial decision-making and work of operators must be based only on adequate information about the production. False or garbled information can lead to incorrect managerial decisions. If managers repeatedly keep receiving garbled information, they will eventually start regularly rechecking it, thus, losing time for effective decision-making. Obtaining adequate information is important not only for operative production management but also for correct technological and economic analysis. In this regard, this system has been given considerable attention in the literature (Ozyurt & Pike, 2004; Erokhyn et al., 2008).

It is hard to imagine a modern oil refinery that does not use an ERP system. Despite the fact that ERP systems are still viewed “as structuring, integrating and centralizing information systems” (Silva et al.,2013), and the issues of their implementation and operation are extensively discussed in the literature (Cardoso et al., 2004; Hwang & Grant, 2011; Cheng & Xiao-Bing, 2013), there is a general trend for using them at oil refineries as simply systems for registering accounting transactions, raw material supplies, and finished product shipments, as well as for managing warehouses of auxiliary material and technical resources. Control over the majority of elements of the production process, such as planning, management, and production accounting, at oil refineries is given to the APS and MES systems. ERP systems are used, to a considerable degree, to operate with the data obtained or processed by APS and MES.

The importance of the effective interaction of various systems is particularly noted in (Chu & You, 2015): “the performance of a system relies not only on the behaviour of the constituent subsystems but also on the interaction among the subsystems”. In this connection, issues of interaction and methods of integration of ERP, APS, and MES class systems are considered in the literature (Mustafa & Mejabi, 1999; Liu et al, 2002; Mertins et al., 2008; Ugarte et al., 2009; Hu, Feng & Rong, 2011; Kucharska et al., 2015). Such an approach makes it possible to improve production economics through the dynamic delivery of adequate information about the current state of affairs, as well as through synchronization and transparency of business processes at the enterprise (Westerlund, 1996; Rondeau & Litteral, 2001; Martinez et al., 2016). Specialized software that makes it possible to integrate various systems is constantly being developed and introduced (Rolandi & Romagnoli, 2010).

When modeling business processes under consideration, scholars commonly use mathematical methods of operations research (Taha, 2001). To date, the theoretical aspects of building models in factory information systems such as optimal production planning and scheduling systems have been studied in considerable detail (Ciriani & Leachman, 1994; Kelly, 2004; Khor & Varvarezos, 2017, etc.). Theoretical studies of reconciliation of the material balance of oil refineries are considered in (Romagnjli & Sanchez, 1999; Ozyurt & Pike, 2004, etc.). At the same time, despite the availability of a significant number of academic works on optimizing production processes, there currently exists a significant gap between academic and applied tasks, which is the result of the complexity of day-to-day refinery operations (Khor & Varvarezos, 2017). In addition, there is no clear practical description of approaches for building models with the aim of ensuring the effective integration of several information systems. Usually the literature on this subject is limited to fairly general recommendations lacking any mathematical justification. In this regard (Joly, 2012) points out that poor integration as well as hard model maintenance and consistency assurance among business layers may be cited, since redundant efforts from the refinery staff will be required.

In an effort to solve problems of integration and unification of models of different systems, oil refineries in most practical cases try to deal with the same supplier of automated systems in hope that such an approach might provide a better interaction among the different systems. However, the effectiveness of this approach is also limited, as, firstly, judging from the experience, one software producing company, as a rule, cannot address all the needs of an oil refinery in the field of automation of planning, management, and accounting. Secondly, almost every oil refinery requires a set of certain methods and approaches to be integrated into each of the systems in order to provide the interaction of different business processes. Otherwise, mistakes in the interaction among the systems occur, labour costs increase, and manageability of the enterprise decreases as a whole, leading to economic losses.

Thus, for the correct exchange of information between ERP, APS, and MES, models of these systems must be unified in a certain way. In this regard, the research question of this work is formulated as follows: how should the process models be formed in various information systems so that, in addition to improving the qualitative modeling of individual processes, they ensure the high quality of interaction between information systems at oil refinery? To solve this task, the authors are considering the mathematical process models in management systems. The study primarily focuses on the construction of models in the systems of production planning and material balance reconciliation.

2. Integration of ERP, APS, MES systems using a basic model

ERP systems are widely used for unifying the main business functions of an enterprise (planning, production, supply, sales, management accounting). At the same time, the architecture of ERP-solutions themselves, aimed at transactional functioning based on DBMS, is not designed for large amounts of computation in solving optimization problems. That is why some of the functions of the operational unit are often separated into specialized software products and function as separate classes of applied software. They include APS systems designed for operational managerial planning, and MES systems used for synchronization, coordination, and optimization of production output.

ERP, APS, MES systems function based on their intrinsic mathematical models. To a large degree, the operating efficiency of such systems is determined by the quality of the related models (Arsovski et al., 2012). In this respect, we can study two extreme cases (ways) of constructing interaction models of such systems. The first way is to form a separate model for each business process with all the specifications required for its description. To provide the interaction among the systems, additional software should be developed. One of the main drawbacks of such an approach is the complexity of providing data exchange among the systems due to a large number of connections among the models. Besides, because of the different structures of the models in different systems (ERP, APS, MES), they are difficult to work with, as each of them has its own structural design.

An alternative approach to modeling business processes of an enterprise using ERP, APS, MES is a concept of constructing models of such systems based on a common model, which will be called a basic (universal) model. (Rolandi & Romagnoli, 2010) mention that construction of such a model must be based on the three fundamental laws of conservation: conservation of mass, energy, and kinetic momentum. The main advantage of such an approach is the considerable simplification of integrating different systems into common informational space. This is due to the fact that the additional software components necessary for data exchange and for matching similar elements in different systems are no longer required in this case. It becomes much easier for the user to work simultaneously in several systems, as the model for each of them remains the same. The term “basic model” was also introduced in (Vujovic et al., 2013), but it has the different meaning and application.

Let us define the notion of a basic model for an oil refinery. To this end, let us consider modeling of two different and the most difficult business processes at such enterprises: production planning and reconciliation of material balance of oil and oil products flows. Production planning at oil refineries is done using optimal planning systems (software), such as PIMS (AspenTech), RPMS (Honeywell) and others. These systems belong to the APS class and are based on linear programming methods. The optimization criterion here is the marginal profit maximization. In the matrix form, the problem of linear programming for real variables $x_1, x_2, \ldots, x_n$ for the objective function $L(x_1, x_2, \ldots, x_n)$ can be formulated as follows:

$$\mathrm{A}\mathbf{x} \geq \mathbf{b}, \;\; \mathbf{x} \geq 0$$

$$L_{\max}(\mathbf{x}) = \mathbf{c}^T \mathbf{x} \to \mathbf{max}$$

where A is a matrix $\left\| \alpha_{ij} \right\|$ with dimensions $m \times n$,

$$\mathbf{c} = (c_1, c_2, \ldots, c_n)^T, \; \mathbf{b} = (b_1, b_2, \ldots, b_m)^T,$$

Vector components c_i and b_i are constant, while T designates the transposition.

To reconcile data on material flows and calculate the material balance of the refinery, specialized software, such as Production Balance (Honeywell), Sigmafine (OSIsoft) and others, is used. Formulation of the problem of data reconciliation is normally formalized in the form of a square-law function minimization problem. The problem of material balance reconciliation can be written as follows:

$$\mathbf{By} = 0,$$

$$L_{\min}(\mathrm{y}) = (\mathrm{y} - \mathrm{y}_0)^T \mathrm{K}(\mathrm{y} - \mathrm{y}_0) \to \min$$

Here, **y** is a vector of variables, describing flows, stock, technological expenditures, and losses; **B** is a matrix of balance equations; $\mathbf{y}_0$ determines the vector of measured values. The optimization criterion is taken to be the minimization of square form $L_{\min}(\mathbf{y})$ expressing deviations of observed and calculated values. **K** is a diagonal matrix characterizing errors of the related measurements.

Equations and inequalities determine models of optimal production planning of an oil refinery and material balance reconciliation. These models will be designated as M_1 and M_2, respectively. The planning and reconciliation processes interact with each other and exchange information. When the processes are automated, this interaction is realized at the system level. Automated systems, in turn, interact based on the models. It is quite clear that the more similar are the system models, the more effective is their interaction. It means that if models M_1 and M_2 exchange information in the part of their submodels $\widehat{M}_1 \in M_1$ and $\widehat{M}_2 \in M_2$, then equality $M = \widehat{M}_1 = \widehat{M}_2 = M_1 \cap M_2$ will make it possible to provide effective interaction between the systems (and the processes). Model M will be considered a basic model for the systems of optimal production planning and material balance reconciliation. In the case of a larger number of systems, the size of the basic model is determined based on the intersection region of all the interacting systems:

$$M = \sum_{ij} M_i \cap M_j,\ i \neq j,$$

$$\forall (M_i \cap M_j) \to \widehat{M}_1 = \widehat{M}_j.$$

A basic model for three systems is qualitatively shown in Figure 1 in the form of an Euler diagram. In the example considered in the figure, M includes regions 1, 2, 3, 4, which are determined by the intersection of the "boundaries" of models M_1, M_2, M_3.

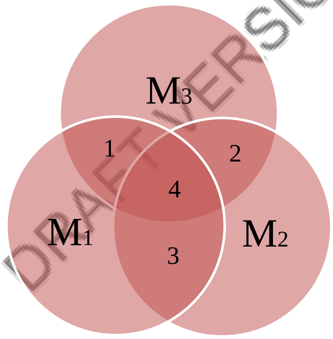

Figure 1. Euler diagram for the models of three interacting systems

3. Approaches to the basic model formation

Let us consider the application of a basic model, using the example of modeling of business processes of production planning and material balance reconciliation of oil and oil products flows. In order to study such a model while maintaining its generalized nature, we used a simplified scheme of material flows at an oil refinery (see Figure 2) in the form of two units and two blendings of oil products in storage tanks. Optimization problem for the model of the oil refinery shown in Figure 2, will have the following form:

$$L' = c_{12}x_{12} + c_{13}x_{13} \to \max$$

with the equations:

$$x_1 - x_2 - x_3 = 0,\ x_2 - x_4 - x_5 = 0,$$
$$x_3 - x_6 - x_7 = 0,\ x_4 - x_8 = 0,$$
$$x_5 - x_{10} = 0,\ x_6 - x_9 = 0,\ x_7 - x_{11} = 0,$$
$$x_8 + x_9 - x_{12} = 0,\ x_{10} + x_{11} - x_{13} = 0,$$
$$x_1, x_2, \ldots, x_{13} \geq 0.$$

Here, L' is the objective function, x_i are scheduled values of flows (product, components, semi-manufacture), c_{12} and c_{13} are prices of commercial output x_{12} and c_{13}, respectively. It is evident that the simultaneous linear algebraic equations, in fact, reflect the mass conservation law.

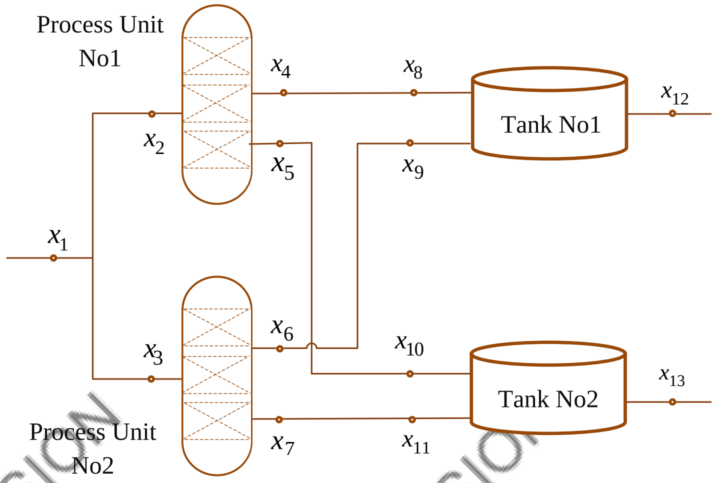

Figure 2. A simplified model of material flows at an oil refinery with two production units and two storage tanks

Apart from balance equations, a constraint matrix of an optimal production planning problem can have a more complex structure, mainly due to the existence of additional constraints on the quality of commercial output (according to standards and specifications), for instance:

$$\lambda_8 x_8 + \lambda_9 x_9 \le \lambda_{12} x_{12},$$

$$x_{12} + x_{13} \le b,$$

where b is constraint on sales, λ_i are quality parameters.

The objective function of the data reconciliation problem for the model shown in Figure 2, is written as:

$$L'' = \sum_{i=1}^{13} k_i \left(\frac{y_i - \tilde{y}_i}{\tilde{y}_i} \right)^2 \to \min$$

where $\tilde{y}_i$ are observed values, and y_i are calculated (reconciled) values of flows shown in Figure 2, k_i are expert weight coefficients.

It is evident that, first, x_i is a planned value, and y_i is an observed (reconciled) value of the same flow, and, second, in determining the minimum of objective function L'' it is necessary to use constraints, accounting for the substitution of y_i for x_i. That is, the model of optimal production planning and model of material balance reconciliation have principally different objective functions, but have a common model of flows, characterized by simultaneous linear equations. Such a model serves as a basic model for both systems.

It is noteworthy that in the optimal production planning problem, apart from, there are other constraints on the region of acceptability of x_i, represented by inequalities. However, it can be readily shown that these constraints do not perturb the basic model of material flows of an oil refinery, since they are only a particularization of the model for a particular system (in this case, in the optimal production planning system). That is why use of additional constraints type does not complicate the basic material flow model and does not affect data exchange between the two systems. In a similar way, there are possible complications of the accounting and balance reconciliation models. Nevertheless, the basis of the models of these systems, which in this article is referred to as "basic model" and is used for the integration and interaction of the systems, remains common.

Thus, in the case discussed above, the basic model is a subset of models used by the systems, which mathematically expresses the law of conservation of mass. Along with the two systems in the above example, a modern oil refinery usually has a scheduling system, a process flow control system, a real-time database, a production record system, a performance system, a laboratory information system. In this case, the experience of forming a basic model shows that its mathematical formulation continues to be based on balance equations. The latter is determined by the fact that such an element of system models as **c** and **b** or flow quality is, by some means or other, related with material flows, and, thus, need not be separated into a special part of the basic model. Accompanying support of the basic model provides synchronous alterations on all its levels.

Economic efficiency of managerial decision-making is closely related with the plan/actual analysis, which in turn leads to a constant increase in the demand for quality of models of planning and balance reconciliation and their integration into the information space of an enterprise (Kuvikyn, 2018). Experience has shown that the key role in the application of such systems is played by the mathematical model of data integration (basic model). Let us consider the process of creation of a basic model using a flow diagram for the system of material balance reconciliation (SMBR) (Figure 3) and optimal planning system (OPS) (Figure 3) during the production of two types of oil-products by a process unit. Each of the products can be stored in two tanks. SMBR is commonly using a detailed modeling of oil-products flow through each processing facility of an oil refinery.

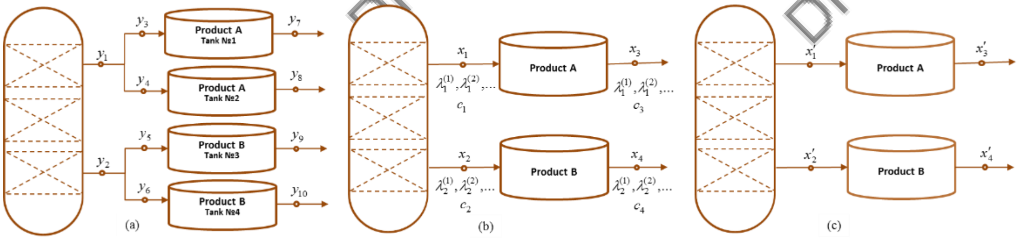

Figure 3. Example of the basic model formation for production planning and material balance reconciliation systems

Let each process unit over the balance period produce components with masses y_1, y_2, which are later separated into subcomponents y_3, y_4, y_5, y_6 and transferred to the tanks No. 1-4 for processing into products A and B. The oil-products dispatched from the tanks are characterized by the variables y_7, y_8, y_9, y_{10}.

The system of equation, in this case, will be written as follows:

$$y_1 - y_3 - y_4 = 0,\ \ y_2 - y_5 - y_6 = 0,$$
$$y_3 + \delta_1 - y_7 = 0,\ \ y_4 + \delta_2 - y_8 = 0,$$
$$y_5 + \delta_3 - y_9 = 0,\ \ y_6 + \delta_4 - y_{10} = 0,$$

where δ_i, $i = (\overline{1,4})$ are the stocks in *i*-tank.

If the production planning is optimal, on the one hand, it uses simplified models of material flows, where there is no need to provide a description for each individual tank, since it is enough to simply account for the total capacity of the tank farm for each product. On the other hand, the OPS model includes the description of the quality of material flows (see Figure 3), as well as their production costs and sales costs. In order to provide an adequate quality of production planning (and to maintain the optimal planning model, which adequately reflects the production capacity of the oil refinery), engineers, responsible for the formation of an optimal plan have to coordinate such a plan with data obtained from SMBR. It is evident that for that purpose an engineer simply needs to download material flow data y_1, y_2, and total for the commercial products $y_7 + y_8$, $y_9 + y_{10}$ from the SMBR. Let us write flow chart variables (Figure 3) as x'_1, x'_2, x'_3, x'_4. Then the material flow equations will look as follows:

$$x'_1 + \Delta_1 - x'_3 = 0,$$
$$x'_2 + \Delta_2 - x'_4 = 0.$$

Here Δ_1, Δ_2 are stocks of Product A and Product B respectively.

In turn, the operating records specialists have to coordinate the data obtained from SMBR with the OPS data in order to analyze the actual plan performance of process units and of commercial production facilities. For that purpose, it is necessary to obtain plan data x_1, x_2, x_3, x_4 (Figure 3), or something similar for the virtual flows x'_1, x'_2, x'_3, x'_4 (Figure 3). That is why the introduction of a mathematical model with variables x'_1, x'_2, x'_3, x'_4 into SMBR and OPS, which will be referred to as basic for these systems, allows for a substantial simplification of their interaction and provides fidelity, high performance of collection and physical interpretation of data for plan/actual analysis. Despite the fact that oil refineries in each of the systems, objectively speaking, are different (see Figure 3), the basic part for variables x'_1, x'_2, x'_3, x'_4 remains the same throughout both of them.

The same approach is used to create a basic model of the entire oil refinery, where the number of variables in models can reach tens of thousands. In this case, it can be quite hard to create adequate planning and accounting models without the basic model. Operational production accounting for the leadership of a company, planning and balance specialists, production and logistics managers is built around the basic model, which fosters interaction of specialists of different levels for delivery of effective managerial solutions and improving the quality of planning and reporting.

4. Results and discussion

In the previous section, we have demonstrated a mechanism of formation of a basic model used for the integration and interaction between different systems of an oil refinery. It should be noted that, whereas the necessity of coordination of the model with material flows raises no doubt, the optimal degree of detailed elaboration of such a model is not obvious. The number of material flows at an oil refinery amounts to several hundred. Moreover, different kinds of raw materials or products can pass through the same sector (pipeline). This can be illustrated by a simple example (see Figure 4). Let a gasoil process unit be able, over a certain time interval, produce various kinds of products (for example, gasoil №1 and gasoil №2). Both kinds of gasoil pass through the same sectors of the process unit and are recorded by the same devices. However, they are directed into different tanks for loading. The total number of such changes of operational modes or flow directions (switching) for the entire refinery even during one day can be very large, which significantly complicates accounting. (Somov et al., 2009) proposed to solve the above problem by taking into account the informational model of the refinery at all the instances of flow switching, which, undoubtedly, would lead to large amounts of manual data input and to the complication of the informational model of the refinery.

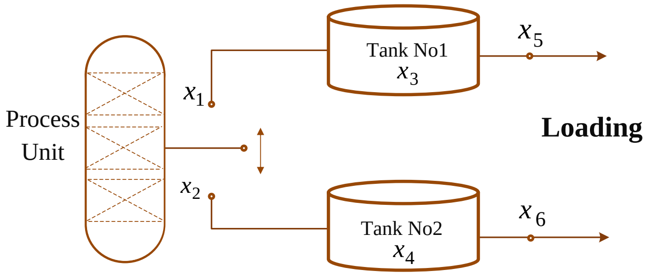

Figure 4. A simplified model of process unit producing two types of products

In terms of programming, such a model represents a large number of conditional branches, which makes it rather confusing. Increasing the amount of switching in an informational model of an enterprise leads to such a structure of this model as described by the term “spaghetti-code”, which means that it is weakly structured and difficult to support. One of the founders of structural programming E. Dijkstra argued about the necessity of formal mathematical analysis of the chosen algorithm and its implementation in the form of a simplest structured program (Dijkstra, 1974). In (Yang & Liu, 2017) it was mentioned that before starting solution search procedure one should optimize the mathematical model of production operation scheme in the system. This paper argues for the same alternative approach. The introduced method is based on the principle of optimal location of measuring means for an unambiguous reconciliation of material balance and minimizing the amount of “switching” of flow directions (Kuvykin & Kuvykina, 2016). Thus, it can be readily shown that in the scheme presented in Figure 2, in order to determine unambiguously all the material flow values $x_1, x_2, \ldots, x_{13}$, it will suffice to measure only four of them – x_4, x_5, x_6, x_7; the rest of the data can be easily determined from relations. Naturally, despite the fact that four measurements are sufficient in Figure 2, the availability of additional instruments undoubtedly increases the statistical reliability of determining flow values.

Indeed, if there are, for example, only four measurements, x_4, x_5, x_6, x_7, and one of the instruments is out of order, material balance reconciliation according to the scheme depicted in Figure 2 becomes impossible. On the contrary, if all the flows $x_1, x_2, \ldots, x_{13}$ have been measured and one of the instruments is out of order, the reliability and quality of material balance reconciliation remain high. However, the installation of additional measuring instruments is not always justified due to their high cost. A more detailed mathematical substantiation of the adequacy of the installed measuring instruments is discussed in (Kuvykin & Kuvykina, 2016).

Elimination (minimization) of manual input of information (switching) in the model of a refinery is an important advantage, because the regular introduction of alterations, for example, by the dispatching department, leads to errors of the informational model (due to unavoidable mistakes during input). The higher the amount of manual switching (Somov et al., 2009), the higher the probability of such mistakes. A single input mistake can considerably distort the real material balance of a refinery. As a result, the reliability of the reconciled data can significantly decrease. Let us consider a simple example.

For 24 hours, a processing unit has been producing only type 1 gasoil (see Figure 4) with the final amount of $x_1 = V \neq 0$ ($x_2 = 0$). At the same time, when inputting flow information into the informational model of the refinery, all the amount of the gasoil produced by the unit was erroneously indicated as sent to a storage tank with type 2 gasoil. That is, $x_2 = V \neq 0$, while a zero value is assigned to x_1 ($x_1 = 0$). As a result of an operator's mistake, the program will output either an erroneous solution or no solution at all. Detecting an error in a real model of oil refinery, which due to a large amount of switching is weakly structured, can be a difficult task.

At the same time, eliminating the use of manual switching of flow directions in the considered example allows the material balance reconciliation program to determine automatically the amount and type of gasoil produced by the unit during the period in question. Indeed, taking account of the data on shipped product (x_5, x_6), which is always a measured value, and the variation of residues in the tanks (x_3, x_4), which are also measured values at oil refineries, one can easily determine the amounts of various components of the marketable product produced by the process unit during the time interval in question: $x_1 = x_5 - x_3$, $x_2 = x_6 - x_4$. Thus, in the example considered, the material balance reconciliation system automatically determines not only amounts of technological flows, but also their type (quality).

Naturally, a model of a real oil refinery is more complicated than the example shown in Figure 4 and contains several hundreds of flows. At the same time, experience shows that a material balance reconciliation system makes it possible to determine amounts and types of technological flows with a high degree of accuracy. Additional dispatching is required only in exceptional situations, primarily, when measurements are not sufficient.

5. Conclusion

The authors have considered the principles of improving process models of an oil refinery for accounting and planning systems. They have demonstrated that developing models in APS, and MES systems based on a universal (basic) model of an oil refinery considerably improves interaction and integration of these systems into a unified informational space. A basic model is a subset of the used models and can be determined by the intersection of sets. It has been shown that mathematically a basic model is written in terms of a balance equation matrix. It should be noted that other parameters of system models, such as flow quality or infrastructural constraints, are closely related with technological flows; thus, it does not make sense to treat them as separate components of the basic model. The basic model should be able to respond synchronously to alterations made in it at all levels.

The article also presents approaches to improving the quality of a basic model of a refinery. Minimization of dispatching ("switching") material flow directions within the refinery in the model of a refinery is shown to be vital for improving its structure and reducing errors in the model (due to inevitable input errors).

The methods and approaches to constructing models of business processes described in the paper are successfully used at the "LUKOIL - Nizhegorodnefteorgsintez" (Russia) and "Petrotel-LUKOIL" (Romania) refineries for integration of the planning, material balance, and accounting systems. These enterprises are equipped with the ERP system (SAP R/3), which provides control over accounting transactions, raw material supplies, and finished product shipments, and is also used for managing warehouses of auxiliary material and technical resources. The refineries use the following APS: optimal production planning (LP) system, production scheduling system (Scheduling), as well as the whole set of MES: system for production records, system for material balance reconciliation, production performance system and system for dispatch control (see Figure 5). All these information systems provide automation of business processes of planning, accounting, and production control. Although the abovementioned systems belong to different levels of management (ERP, APS, MES), mathematical models for describing material flows contain a common part, and solutions for such flows satisfy the fundamental laws of conservation of mass and energy.

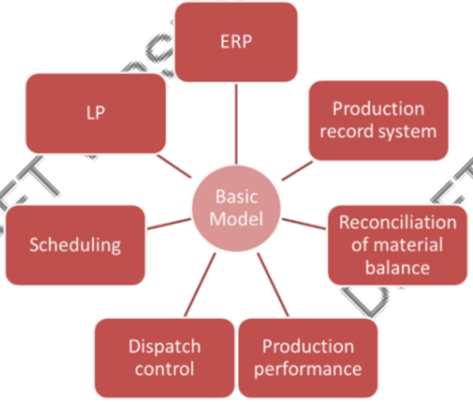

Figure 5. Integration of ERP, APS, MES at Petrotel-LUKOIL refinery based on the basic model

Use of a universal model in these systems has contributed to a qualitative growth of interaction efficiency of the related business processes, resulting in the improvement of the production and marketing activities of the above oil refineries. The introduction (and use) of these systems has improved the planning accuracy and reduced the irretrievable losses of oil and oil products. The latter led to an increase in economic indicators and to the improvement of the ecological situation. The speed of formation and reliability of the plan-actual analysis significantly improved the quality of management decisions.

Introducing changes to the base model implies making appropriate adjustments to the models of all the systems shown in Figure 5.

It is noteworthy that the use of the universal model resulted in a new quality level of the process of knowledge transfer among the personnel participating in the above-mentioned business processes. It is recommended by (Nonaka & Takeuchi, 1995) to pay special attention to non-formalized “tacit” knowledge, which exists at the individual level and is difficult to formalize. It is closely connected with the experience of a particular person and his/her habits. It is difficult to acquire and transfer such knowledge to other people, even if it is done within a controlled process. It is necessary to turn tacit knowledge into explicit knowledge in order to facilitate its dissemination. Whereas the use of a universal model makes it possible to formalize (encode) knowledge and speeds up knowledge transfer among the personnel of the enterprise. In addition, specialists can achieve operational efficiency in several systems of the enterprise, as they all use the same models.

Thus, the results obtained in the article can be considered original because they comprise a new approach to improving the quality of integration of business processes at refineries based on the unification of their models. The solution is focused on creating such relevant mathematical models of business processes that provide the system links between them within the entire production (plant) as a whole. The authors propose a method for systems integration based on mathematical modeling and systematic approach for processes of different levels, which uses a basic model common for all systems. Its implementation contributes to the creation of a single information space and the organization of reliable information exchange between accounting, planning, dispatching, and production management systems. This approach has been implemented in practice at two refineries.

The results are relevant for the industry due to the current trend of transition from the direct operation of individual information systems that automate and improve the quality of single processes to the integration of several interacting systems for increasing the efficiency of a refinery as a whole. Further development of the proposed systematic approach is aimed both at automating the update processes of the parameters of enterprise models based on the basic model, as well as at synchronous modification of mathematical models of business processes, when the technological flow patterns change.

References:

Alattas, A.M., Grossmann, I.E., & Palou-Rivera I. (2013). Integration of nonlinear crude distillation unit models in refinery planning optimization. *Industrial and Engineering Chemistry Research*, *50*(11), 6860-6870. doi: 10.1021/ie200151e

Arsovski, Z., Petrovic, D. R., Milanovic, I., Rankovic, V., Kalinic Z. (2012). Measuring the data model quality in the e-supply chains. *International Journal for Quality Research*, *6*(1), 47-53. http://www.ijqr.net/journal/v6-n1/6.pdf

Cardoso, J., Bostrom, R.P., & Sheth, A. (2004). Workflow management systems and ERP Systems: differences, commonalities, and applications. *Information Technology and Management*, *5*(3), 319-338. doi: 10.1023/B:ITEM.0000031584.14039.99

Chen, Y.X. (2016). Integrated optimization model for production planning and scheduling with logistic constraints. *International Journal of Simulation Modelling*, *15*(4), 711-720. doi: 10.2507/IJSIMM15(4)CO16

Cheng, W., & Xiao-Bing, L. (2013). Integrated production planning and control: A multi-objective optimization model", *Journal of Industrial Engineering and Management*, *6*(4), 815-830. doi: 10.3926/jiem.771

Chu, H., & You, F. (2015). Model-based integration of control and operations: Overview, challenges, advances, and opportunities. *Computers and Chemical Engineering*, *83*(1), 2-20. doi: 10.1016/j.compchemeng.2015.04.011

Ciriani, T.A., & Leachman, R.C. (1994). *Mathematical programming and modeling techniques in practice*. New York: J. Wiley&Sons.

Dijkstra, E.W. (1974). Programming as a discipline of mathematical nature", *The American Mathematical Monthly*, 81 (6), 608-612.

Erokhin, V.I., Laptev A.Y., & Lisitsyn, N.V. (2008). Reconciliation of material balance of a large petroleum refinery in conditions of incomplete data, Journal of Computer and Systems Sciences International, *49*(2), 295-305. doi: 10.1134/S1064230710020140

Guerra, O.J., & Le Roux, G. (2011). Improvements in petroleum refinery planning: 1. Formulation of process models. *Industrial and Engineering Chemistry Research*, *50*(23), 13403-13418. doi: 10.1021/ie200303m

Hu, Y., Feng, Y., & Rong, G. (2011). Model management for refinery multi-level simulation and optimization. *Proceedings of the 18th IFAC World Congress*, 10397-10401.

Hwang, Y., & Grant, D. (2011). Understanding the influence of integration on ERP performance", *Information Technology and Management, 12*(3), 229-240. doi: 10.1007/s10799-011-0096-3

Joly M. (2012). Refinery production planning and scheduling: the refining core business. *Brazilian Journal of Chemical Engineering, 29*(2), 371-384. http://www.scielo.br/pdf/bjce/v29n2/a17v29n2.pdf

Kelly, J.D. (2004). Formulating production planning models. *Chemical Engineering Progress*, *100*(1), 43-50.

Khor, C.S., & Varvarezos, D. Petroleum refinery optimization. (2017). *Optimization and engineering*, *18*(4), 943-989. doi: 10.1007/s11081-016-9338-x .

Kraemmerand, P., Moller, C., & Boer, H. (2003). ERP Implementation: An integrated process of radical change and continuous learning. *Production Planning and Control, 14*(4), 338-348. doi: 10.1080/0953728031000117959

Kucharska, E., Grobler-Deebska, K., Gracel, J., & Jagodzinski, M. (2015). Idea of impact of ERP-APS-MES systems integration on the effectiveness of decision making process in manufacturing companies. *BDAS 2015*, 551-564. doi: 10.1007/978-3-319-18422-7_49

Kuvykin V.I., & Kuvykina E.V. (2016). Computer algebra application for measuring instrument quantity optimization for material balance. *International research journal*, (12), 133-136 (in Russian).

Kuvykin, V.I. (2018) Optimal Planning and Analysis of Continuous Production Models *Automation and Remote Control*, *79*(2), 384-390. DOI: https://doi.org/10.1134/S0005117918020170.

Liu, W., Chua, T.J., Lam, J., Wang, F.Y., Cai, T.X., & Yin, X.F. (2002). APS, ERP and MES systems integration for semiconductor backend assembly. *In: Proceedings of the 7th international conference on control, automation, robotics and vision, ICARCV 2002, Marine Mandarin, Singapore: Nanyang Technological University Singapore, Singapore,* 1403-1408.

Martinez, M.E.C., Aranda, D.A., & Gutierrez, L.G. (2016). IT integration, operations flexibility and performance: An empirical study. *Journal of Industrial Engineering and Management*, *9*(3), 684-707. doi: 10.3926/jiem.1869

Menezes, B.C., Kelly, J.D., & Grossmann, I.E. (2013). Improved swing-cut modeling for planning and scheduling of Oil-Refinery Distillation Units. *Industrial and Engineering Chemistry Research, 52*(51), 18324-18333. doi: 10.1021/ie4025775

Mertins, K., Rabe, M., & Gocev, P. (2008). Integration of factory planning and ERP/MES systems: Adaptive simulation models. *In IFIP International Federation for Information Processing*, 257, 185-193. doi: 10.1007/978-0-387-77249-3_19.

Mustafa, Y., & Mejabi, O. "An approach for developing flexible MRP systems", *Information Systems Management, 16*(2), 1999, 58-63. doi: 10.1016/j.compchemeng.2015.04.011

Nonaka, I., & Takeuchi, H. The knowledge – creating company. Oxford University Press, 1995, p. 284.

Ozyurt, D.B., & Pike, R.W. (2004). Theory and practice of simultaneous data reconciliation and gross error detection for chemical processes. *Computers and Chemical Engineering*, *28*(3), 381-402. doi: 10.1016/j.compchemeng.2003.07.001.

Rolandi, P.A., & Romagnoli, J.A. (2010). Integrated model-centric framework for support of manufacturing operations. Part I: The framework. *Computers and Chemical Engineering*, *28*(1), 17-35. doi: 10.1016/j.compchemeng.2009.08.006.

Romagnjli, J. A., & Sanchez, M.C. (1999). Data Processing and Reconciliation for Chemical Process Operations. Orlando: Academic Press.

Rondeau, P.J., & Litteral, L.A. (2001). Evolution of manufacturing planning and control systems: from reorder point to enterprise resource planning. *Production and Inventory Management Journal*, *42*(2), 1-7.

Silva I.M.N., Matias J.C.O., Santos F.M.B.C., & Brojo F.M.R.P. (2013). Integration of the information systems in the production process: a case study. *Production planning and control*, *25*(16), 1386-1399. doi: 10.1080/09537287.2013.840014

Somov, V.E., Lisitsyn, N.V., & Kuznichkin, N.V. (2009). Improving production accounting system. *Neftepererabotka i neftehimia*, (2), 3-9 (in russian).

Taha, H. (2007). Operations research. Eighth Edition. Prentice Hall.

Ugarte, B.S., Artiba, A., & Pellerin, R. (2009). Manufacturing execution system – a literature review. *Production Planning and Control,* *20*(6), 525-539. doi: 10.1080/09537280902938613

Vujovic, A., Krivokapic, Z., Jovanovich, J., Pekovich, S., Micunovich, R. (2013). Business process improvement by applying benchmarking based model. *International Journal for Quality Research*, *7*(3), 373-382. http://www.ijqr.net/journal/v7-n3/7.pdf

Westerlund, T. (1996). ERP and MES integration: reducing cycle time. *Proceedings of the 1996 industrial computing conference, ICS/96, Chicago, IL: Instrument Society of America Research Triangle Park NC USA*, 91-96.

Yang, K., & Liu Y. (2017). Optimization of Production Operation Scheme in the Transportation Process of Different Proportions of Commingled Crude Oil. *Journal of Engineering and Technology review*, *10*(6), 171-177. doi: 10.25103/jestr.106.22

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