An application of simulation for foundry plants investment projects estimation of efficiency

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***Abstract*—**Methods and software enabling the estimation of efficiency and the comparisons of alternative designs of foundry plants on the basis of moulding lines are discussed. Problem of estimation of efficiency of investment projects of foundry plants is formulated in the terms of decision theory. Presented approach is based on the reduction of multicriterion problem of estimation of investment project to one-criterion problem. This paper describes: the structure of set of outcomes of admissible alternatives, set of vectorial estimations of outcomes, mapping of set of outcomes of acceptable alternatives to set of vectorial estimations of outcomes and structure of decision maker's preferences. Decision rule which allows carrying out required operation over the set of admissible alternatives is formulated. Application of simulation for estimation of technological and structural decisions, which was made during the plant design, is the central feature of presented approach. Model of moulding line refers to discrete-event class. Object-oriented approach was applied for designing of the model and programming language C++ for its implementation. Application of detailed simulation model of moulding line allows carrying out an accurate estimation of technological and structural characteristics of involved projects. Presented methodology of estimation of investment projects of foundry plants on the basis of moulding lines is tried-and-true method which applies on the phase of designing and engineering of foundry plant.

***Keywords*—**simulation, investment projects estimation of efficiency, decision-making support, moulding line.

I. Introduction

GREEN sand moulding is currently the most widely used of all casting manufacturing methods. Moulding line is the main synchronizing element of the complex technological system of casting production in green moulds. Value of ethroughput and economical characteristics of foundry plant are depending of moulding line's work.

In this paper methods and software enabling the estimation of efficiency and the comparisons of alternative designs of foundry plants on the basis of moulding lines are discussed. Estimation of efficiency is caring out with respect to specific of produced castings, current market situation and individual preferences of decision-makers. Estimation of efficiency could be conducted as for one individual project, as for group consisted of several alternative projects. In case of several alternative projects the most preferable project is chosen. As results of the estimation the following decisions could be made: if values of all characteristics of the best project are satisfying for decision-makers than follows decision of this project implementation, otherwise "bottlenecks" of the project are analyzed, some corrections implemented and the procedure of estimation for this project is repeated.

In general investment project *P* could be presented by the following model [1]:

$$P = \{IC_j, CF_k, p, r\},$$

where: IC_j – investments in the year j, $j = 1, 2, \ldots, q$, $q \le p$; CF_k – cash flow in the year k, $k = 1, 2, \ldots, p$; p – project's length (period of time for the implementation of the project); r – discount rate.

For the efficiency estimation of such projects usually the following criterions are used [1], [2]: Net Present Value (*NPV*), Profitability Index (*PI*), Internal Rate of Return (*IRR*), Payback Period (*PP*), Discounted Payback Period (*DPP*), Accounting Rate of Return (*ARR*) and Modified Internal Rate of Return (*MIRR*).

1. Criterion *NPV* is based on comparison of overall value of investments (IC_j) with overall value of discounted cash flows (CF_k). Because cash flows are distributed in time, they are discounted by the means of discount rate r. The value of r is determined by the decision-maker. The following rule is existed for project's efficiency estimation with application of criterion *NPV*. If the value of criterion NPV > 0, then the project must be accepted for implementation. If the value of criterion $NPV < 0$, then the project must be rejected. If the value of criterion $NPV = 0$, it means that the project is nor profitable nor unprofitable.

2. Criterion *PI* is a ratio of overall value of discounted cash flows to the overall value of investments. The following rule is existed for project's efficiency estimation with application of criterion PI. If the value of criterion $PI > 1$, then the project must be accepted for implementation. If the value of criterion $PI < 1$, then the project must be rejected. If the value of criterion $PI = 1$, it means that the project is nor profitable nor unprofitable.

3. Under criterion *IRR* we understand the value of discount rate r, when criterion $NPV = 0$, i.e. $IRR = r$, when $NPV = f(r) = 0$. *IRR* is reflecting expected profitability of project. If the value of criterion $IRR > CC$, then the project must be accepted for implementation. If the value of criterion $IRR <$ CC, then

the project must be rejected. If the value of criterion *IRR* = *CC*, it means that the project is nor profitable nor unprofitable. Where parameter *CC* is reflecting capital's costs.

4. If calculated value of criterion *PP* (or criterion *DPP*) is less than certain maximum payback period, then the project must be accepted for implementation. Otherwise the project must be rejected. In case of calculation of criterion *DPP* discounted values of cash flows are used. In case of calculation of criterion PP values of cash flows are not discounted.

5. Criterion *ARR* is a ratio of average yearly income to average value of investments. Usually calculated value of criterion ARR is compared with the minimal admissible value (which is chosen be the decision-maker). If this minimal admissible value is less than calculated value of criterion *ARR*, then the project must be accepted for implementation. Otherwise the project must be rejected.

6. Criterion *MIRR* is modification of criterion *IRR*. It allows to take in account reinvestments. *MIRR* is reflecting expected profitability of project. If the value of criterion *MIRR* > *CC*, then the project must be accepted for implementation. If the value of criterion *MIRR* < *CC*, then the project must be rejected. If the value of criterion *MIRR* = *CC*, it means that the project is nor profitable nor unprofitable. Where parameter *CC* is reflecting capital's costs.

Investment project estimation of efficiency could not be solved as only one criterion problem. For the complex analysis of all characteristics of the project it is recommended to use several criterions. It is evident that it is very hard (often impossible) to find the project which would be the best by all criterions. On practice very often the following method is used. All criterions are combined in the one complex criterion. Nowadays several methods of complex criterion constriction exist. In spite of the fact that all of them have some drawbacks there are in the wide use for the reduction of multicriterion problems of estimation of investment project to one-criterion problems.

II. Decision-making problem definition

Decision-making problem can be formulated conceptually in a following way: there is a set of decision variants (alternatives), every alternative realization leads to some event (outcome) each outcome is characterized by a set of vectorial estimations. It is needed after studying all decision-maker's preference to design a model of alternative choice better in some specific sense.

Decision-making problem can be described formally by the following tuple [3]:

$\langle A, \Omega, E, F, P_s, D, T \rangle$,

where A – a set of admissible alternatives, Ω – a set of outcomes of admissible alternatives, E – a set of vectorial estimations of outcomes, F – mapping of a set Ω to a set E, $F:\Omega \to E$; P_s – structure of decision-maker's preferences.

It is necessary to find some decision rules or algorithm D to provide needed action T on a set of alternatives A: to select a set of non-dominating alternatives, to find the most preferable alternative, to produce linear ordering of admissible alternatives and etc.

Needed action T: on a set of alternatives A characterizes the type of decision-making problem (choice, ordering and etc). Environment and a system of preferences are granted with elements Ω, E, F, P_s, D. Single result (deterministic or random) which is characterized with vector estimation corresponds to each alternative. The system of preferences is described by some total combination of sets (criterions, alternatives, results, for example) with preferences relations and is some empirical system with relations. Structural representation of decision-maker's preferences as a system with relations will be named decision-maker's preferences structure. This structure defines the procedure of estimations comparison $e(\omega)$ and the decision rule or algorithm – the principle of elements choice from set A on the basis of comparison results in conformity with required action T.

In the considered problem elements of the tuple above are [5]–[7]:

1. The set of admissible alternatives outcomes Ω.

Outcome $\omega \in \Omega$, corresponding to alternative $a \in A$ is characterized with the vector of following type [4]–[7]:

$$\omega = \begin{pmatrix} \omega_1, \ldots, \omega_{ec}, \omega_{ec+1}, \ldots, \omega_{con+ec}, \omega_{con+ec+1}, \ldots, \\ \omega_{tec+con+ec}, \omega_{tec+con+ec+1}, \ldots, \omega_{pro+tec+con+ec} \end{pmatrix},$$

where $\omega_1, \ldots, \omega_{ec}$ – components which are describing economic parameters of project (costs for castings, raw materials, energy and etc); *ec* – is a number of components describing economic parameters of project; $\omega_{ec+1}, \ldots, \omega_{con+ec}$ – components which are describing structural parameters of project (a number of continuous-handling systems for cooling, devices for transporting of moulds and etc); *con* – is a number of components describing structural parameters of project; $\omega_{con+ec+1}, \ldots, \omega_{tec+con+ec}$ – components which are describing technological parameters of project (number of moulding sand components, recommended values of technological characteristics for all issued casting types and etc); $\omega_{tec+con+ec+1}, \ldots, \omega_{pro+tec+con+ec}$ – are components describing parameters which characterize line throughput (a number of definite type good castings produced on moulding line during a year; capacity factors for equipment in production sites of a line and etc); *pro* – is a number of components describing line throughput.

2. Mapping F: $\Omega \to E$ is following vector function [5]–[7]:

$$F(\omega) = \begin{pmatrix} NPV(\omega), PI(\omega), IRR(\omega), PP(\omega), \\ DPP(\omega), ARR(\omega), MIRR(\omega) \end{pmatrix},$$

where $NPV(\omega)$ – is a function of the criterion Net Present Value, $PI(\omega)$ – is a function of the criterion Profitability Index, $IRR(\omega)$ – is a function of the criterion Internal Rate of Return, $PP(\omega)$ – is a function of the criterion Payback Period, $DPP(\omega)$ – is a function of the criterion Discounted Payback Period, $ARR(\omega)$ – is a function of the criterion Accounting Rate of Return and $MIRR(\omega)$ – is a function of the criterion Modified Internal Rate of Return.

3. A set of vectorial estimations of outcomes *E*. Set elements are vectors $e(\omega) \in E$, which components values correspond to criterions values (*NPV, PI, IRR, PP, DPP, ARR* and *MIRR*), calculated for the corresponding outcomes [5]–[7].

4. Needed action *T* over a set of admissible alternatives *A*. It is necessary to find the most preferable alternative $a^* \in A$ [5]–[7].

5. Decision rule *D* [5]–[7]. It is necessary to find such alternative $a^* \in A$, for which corresponding outcome $\omega^* \in \Omega$, ensures the maximum meaning of efficiency function:

$$U(\omega) = \sum_{i=1}^{7} \rho_i \cdot UN_i(F_i(\omega)),$$

where $U(\omega)$ – is project (alternative) efficiency $a \in A$ corresponding to the outcome $\omega \in \Omega$;

$\rho_1, \ldots, \rho_7$ – are weight coefficients reflecting the relative impotence of corresponding criterions values. They are assigned processing from individual decision-maker's preferences reflecting his preferences structure P_s,

$$\rho = \{\rho_i\} = \left\{\rho_i : \rho_i \geq 0,\ i = 1, \ldots, 7,\ \sum_{i=1}^{7} \rho_i = 1\right\}.$$

Criterion function $NPV(\omega)$, $PI(\omega)$, $IRR(\omega)$, $ARR(\omega)$ and $MIRR(\omega)$ are maximized and $PP(\omega)$ and $DPP(\omega)$ are minimized. To maximize the value of selected efficiency function $U(\omega)$ it is necessary to have all criterion functions maximized. That is why it is necessary to change the purpose direction (replacement «min» to «max») for criterions $PP(\omega)$ and $DPP(\omega)$. For this we use the following transformations: $F_4(\omega) = -PP(\omega)$ and $F_5(\omega) = -DPP(\omega)$.

Now it is necessary to conduct the procedure of criterions normalization and ranking because we propose using multicriteria choice of economically rational investment project of foundry plant, but criterions chosen for its evaluation have different dimensions. The given procedure means taking criterions to none-dimensional view with the help of certain transformation. That transformation has to satisfy the following qualities: 1) to have the mutual beginning of counting out and single change values order for the whole set of admissible alternatives; 2) to be monotonous (that is to say this transformation has to keep preference relation for whole set of admissible alternatives).

$UN_i(F_i(\omega)), i = 1, \ldots, 7, \omega \in \Omega$ – are monotonous functions transporting every criterion function $F_i(\omega), i = 1, \ldots, 7, \omega \in \Omega$ to normalized (non-dimensional) view, $F_1(\omega) = NPV(\omega)$; $F_2(\omega) = PI(\omega)$; $F_3(\omega) = IRR(\omega)$; $F_4(\omega) = -PP(\omega)$; $F_5(\omega) = -DPP(\omega)$; $F_6(\omega) = ARR(\omega)$; $F_7(\omega) = MIRR(\omega)$.

For criterion normalization let us use the procedure of full normalization:

$$UN_i(F_i(\omega)) = \frac{F_i(\omega) - F_i^{\min}}{F_i^{\max} - F_i^{\min}},\ i = 1, \ldots, 7,\ \omega \in \Omega,$$

where $F_i^{\min}$ and $F_i^{\max}$ – the least and the greatest (correspondingly) criterion function value $F_i(\omega)$ at the set of admissible alternatives results Ω. This normalization reflects initial criterion values to a segment [0, 1]. The best value of normalized criterion equals 1, the worst one equals 0.

6. The relation of preference.

Let us consider that the alternative a_1 is more preferable than alternative a_2 ($a_1 \succ a_2$) if for corresponding outcomes ω_1 and $\omega_2 \in \Omega$ the following inequality is true: $U(\omega_1) > U(\omega_2)$. In case $U(\omega_1) = U(\omega_2)$ we consider alternative a_1 and a_2 are equal or equivalent ($a_1 \sim a_2$).

III. Criterions computation and variant generation

There are two most widespread approaches to the computation of mentioned above criterions (*NPV*, *PI*, *IRR*, *PP*, *DPP*, *ARR* and *MIRR*) of investment projects evaluation [1], [2], [8]–[10]: deterministic and stochastic (related upon statistical tests method). When using the deterministic approach the values of all cash flow parameters sets on the bases of experts' estimations. When we use stochastic approach we can divide these parameters into two groups: 1) meanings of those arranged by decision-maker personally and 2) random values for which decision-maker sets only intervals of change, random distribution types and parameters reflecting (according to decision-maker's opinion) certain regularity of given parameter value change. Thus in general view correlation for *NPV* criterion computation will be as follows (it is possible to produce correlation for computation other criterions in the same way):

$NPV = f(\chi_1, \ldots, \chi_i, \ldots, \chi_l, \xi_1, \ldots, \xi_j, \ldots, \xi_s)$,

where χ_i – are stochastic parameters (components of cash flow; they are random values); l – is a number of stochastic parameters; ξ_j – are deterministic parameters (components of cash flow which after analysis were defined as independent values or weakly depending on environment and so will be considered as deterministic values); s – is a number of deterministic parameters. Then with the help of special software statistical modeling is provided and on this basis the valuations of criterions sought values are obtained.

Essential shortage of above approaches is great estimation result dependence on decision-maker's opinion: all deterministic parameters values, intervals, types and random distributions characteristics for stochastic parameters are fixed by decision-maker on a subjunctive basis. One of the ways out of this situation is using simulation model for throughput parameters values estimations of moulding line project under consideration [4]–[7]. When using this approach decision-maker sets the values of economic parameters on the basis of experts' estimations. Values of structural parameters are set in accordance with technological regulations, cards and expert's evaluations. Values of structural and technological parameters influence throughput parameters values. Simulation model of moulding line allows estimating throughput parameters values of considering moulding line project changing technological and structural parameters.

Quantity of good castings producing in a year is the main parameter among all moulding line throughput parameters. With market requirements and price this parameter influences very much on income value of production realization in a year. In its turn realization production income for the year, summary production costs for the year and profit tax pay in a year are the main parameters which are taking in account when computation yearly cash flow (CF_k) is taking place. Annual yearly cash flows depending on investment project under realization are taken in account when criterions *NPV*, *PI*, *IRR*, *PP*, *DPP*, *ARR* and *MIRR* are calculated.

We shell name casting as a good one if all values of its technological characteristics are in the certain limits [4]–[6]. Let's name the technological characteristics of casting: 1) time from semimould production till mould assembly; 2) time from mould assembly till its casting; 3) metal temperature when mould was cast; 4) duration of casting cooling in a mould; 5) duration of casting cooling after its shaking-out; 6) content of bentonite and 7) content of a special technological addition in moulding sand which this mould was produced from. Structural features of specific moulding line, equipment stoppage in the moulding line, staff qualification and some other factors influence values of those parameters. We shall consider a casting bad even if only one of its characteristics will be out of permissible meanings.

IV. Main principles of simulation model design

The theory of aggregative system [11] has been chosen for formal description of moulding line. In this approach state of each unit is described by a vector which components are time functions. Time dependence can be continuous (casting temperature, for example) and discrete (positions in continuous-handling system, for example).

Let us consider moulding line as an aggregative system consisting of four aggregative subsystems. They are corresponding to production sites of moulding line (casting and cooling, shaking-out and cooling after this, moulding sand preparation and moulding). In its turn each aggregative subsystem consists of limited number of aggregates describing equipment included in the production sites of given subsystem. Each aggregate in any aggregative system can be classified from one of the following groups [4]: 1) transporting device: device for transporting semimoulds, moulds and castings; 2) continuous-handling system: system for semimoulds, casting, cooling and castings cooling after shaking-out; 3) device for making object: moulding machine and device for assembly of moulds; 4) mixer/bunker for moulding sand: mixer and bunker for moulding sand; 5) casting machine with flooding scoop; 6) device for object disassembling: shaking-out device and device for flask disassembling; 7) belt feed conveyor. Algorithm for presentation of aggregates belonging to each groups is being made on the base of general aggregate model which describes common features for all aggregates in this group features.

Simulation model of moulding line is built on the basis of four autonomous models of production sites [12]. Models of all moulding line production sites consist of two modules: structural module and algorithms of its elements interactions. Common modules of moulding lines models are modeling monitor and user's interface. Discrete-events method was used for model design. The mechanism of time advancement with a constant step was used as a principle of time changing. Object-oriented approach was used for design and language C++ was used for model implementation.

All model elements were described as classes (in C++ notation). The library of these classes was designed and this permits easily to add new elements into the model. All library elements are the heirs of basic class or the heirs of basic class heirs. Heirs of basic class are classes describing groups of devices (specified above) such as transporting device, continuous-handling system and etc. Heirs of classes describing groups of elements are classes describing devices of moulding line (such as devices for mould transporting, continuous-handling system for cooling and etc). Description of model elements interaction algorithm was based on conditionally-events principle. Such approach to the implementation of control mechanism permits to easily modify the function system algorithm and to model any non-permanent situation. New elements could be integrated into structural part of the model without changing of already existed function algorithm [4], [12].

V. Example of projects estimation

Let's take a good look at the implementation of discussed methodology on the following example. Two alternative projects of foundry plants on the basis of moulding lines are estimated. Let's mark them – Project 1 and Project 2. So in this case A – set of admissible alternatives consists of two elements a_1 and a_2. Range of produced castings for both two projects is the same. The main differences of these two projects are specifications of casting and cooling site of moulding line design, the amount of initial investments and costs of castings manufacture. The amount of initial investments and costs of castings manufacture for Project 1 are higher (in compare to Project 2). Estimation of these projects conducted by described above methodology gave the following results:

	Project 1	*Project 2*
NPV	4,22 mil. USD	3,018 mil. USD
PI	2,34	1,97
IRR	25,1%	23,5%
PP	2 years	2,2 years
DPP	2,5 years	2,8 years
ARR	55,3 %	52,8 %
MIRR	23,1 %	21,7 %
$U(\omega)$	0,83	-0,16

It is evident from the presented data that variant a_1 is more preferable than variant a_2 ($a_1 \succ a_2$), because for corresponding to them outcomes ω_1 and $\omega_2 \in \Omega$ the following inequality is true: $U(\omega_1) > U(\omega_2)$.

Values of all criterions and value of efficiency function in case of Project 1 implementation are more preferable than values of the same criterions and efficiency function in case of Project 2 implementation. Values deterioration of all criterions and efficiency function in case of Project 2 implementation were analyzed. It was reveled that this significant deterioration was conditioned by specifications of casting and cooling site of moulding line design. On the projected moulding line it is supposed to produce castings for which permissible meaning of technological characteristic “duration of casting cooling in a mould” is above 3 hours. On the Figures 1 are presented histograms of durations of casting cooling in a mould distributions for Project 1 and Project 2 respectively.

In case of the implementation of Project 1 duration of casting cooling in a mould for all moulds would be above 3 hours. In case of the implementation of Project 2 duration of casting cooling in a mould for 14.44% of moulds would be less than 3 hours. Because technological characteristic “duration of casting cooling in a mould” for this castings is out of permissible meanings we consider this castings as wasted. Decreasing of produced good casting amount leads to values deteriorations of all criterions and efficiency function in case of Project 2 implementation.

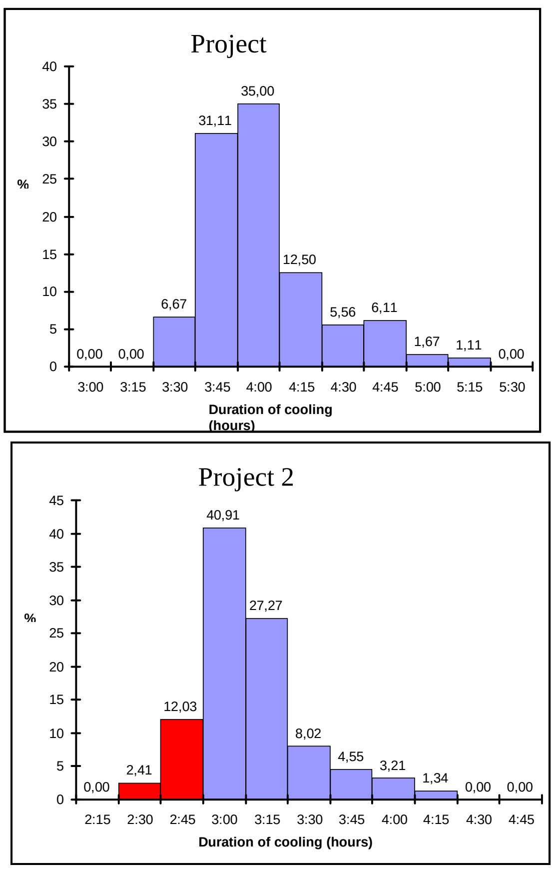

Fig. 1. Durations of casting cooling in a mould distribution.

From this example you can see that adopted on the earlier stages of project implementation construction concept could lead to production of considerable amount of wasted castings, which in turn leads to values deteriorations of all criterions and efficiency function. In spite of the fact that on the first account it was supposed that this construction concept could allow shortening expanses significantly, without any negative effect. Discussed above traditional methods of investment projects estimation (deterministic and stochastic) aren’t permit to take into account structural and technological parameters of project. Because production efficiency significantly depends from values of these parameters it is better to use different approaches for estimation of such kind of projects. Presented in this paper approach is based on the application of simulation model of moulding line for the estimation of structural and technological parameters of the considered project. Application of this approach improves decision-making efficiency, especially on the earlier stages of project implementation.

VI. Conclusion

Presented evaluation method for investment projects of foundry plants on the base of moulding lines has proved effective on designing and engineering stages of project’s implementation. Problem of estimation of efficiency of investment projects of foundry plants on the basis of moulding lines is formulated in the terms of decision theory. Presented approach is based on the reduction of multicriterion problem of estimation of investment project to one-criterion problem. This paper describes: the structure of set of outcomes of admissible alternatives, set of vectorial estimations of outcomes, mapping of set of outcomes of acceptable alternatives to set of vectorial estimations of outcomes and structure of decision maker’s preferences. Decision rule which allows to carry out required operation over the set of admissible alternatives is formulated. Application of simulation for estimation of technological and structural decisions, which was made during the plant design, is the central feature of presented approach. Model of moulding line refers to discrete-event class. Object-oriented approach was applied for designing of the model and programming language C++ for its implementation. Application of detailed simulation model of moulding line allows carrying out an accurate estimation of technological and structural characteristics of involved projects. Presented methodology of estimation of investment projects of foundry plants on the basis of moulding lines is tried-and-true method which applies on the phase of designing and engineering of foundry plant.

We have successful results of using considered method and never the less we have some plans for its improvement. Now the thorough revision of moulding line simulation model is made in accordance with agent modeling principles [15]. Agent technologies are connected with the concept of intellectual agent as some intellectual robot (active element) purposely interacting with other such elements and environment under taking conditions. There are a lot of successful examples of implementation of agent-based simulation models of different production systems [16], [17]. It is very impotent for us because moulding line is also a production system.

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