System-dynamic Model for Managing Financial and Intellectual Resources of a Digital Project

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Abstract
The article proposes a unified approach to the development of structures of scalable flow diagrams of system dynamics, as well as the construction of an experimental simulation system-dynamic model for managing financial and intellectual resources of a digital project.

Keywords 1
System dynamics, modelling, project management, financial resource, intellectual resource.

1. Introduction

It is known a variety of dynamics approach applications in the management of complex systems [1],[2],[3],[4],[5], for instance, in economics and finance spheres [6],[7],[8],[9]. But many researchers avoid considering the issues related to the optimal or, at least, rational distribution of financial and intellectual resources between individual tasks and phases of digital projects. In our opinion, the reason for this is the lack of a standardized approach to the development of scalable system-dynamic models of project execution processes, the development of which would not lead to a cascading and avalanche increase in the number of internal connections and, as a consequence, to a loss of understanding of the logic of the model even by the developer himself.

The ambiguity in the development of such an approach is associated with insufficient elaboration of the idea of transforming possible formats for structuring controls. As a rule, a tabular-tuple representation is used for project management, which is quite logically implemented in a discrete-event approach to simulation, and system dynamics tends to scalar flows with a constant discrete.

In this regard, the task of developing a unified approach to the description of vector project management processes in scalable flow diagrams of system dynamics arises, which determined the purpose of this work.

2. Method and results

Today, the range of corporate applications for the tasks of improving the development strategy of complex interaction systems based on the methods of system dynamics is developing mainly in two directions: the so-called "systems thinking of managers", formed with the help of casual or cause-effect diagrams in the formation of mental models of management, and serious scenario strategic research carried out on simulation models, detailed for the strategic tasks of managing processes in business systems. The development of the architectural approach, as a continuation of the systemic one, in the tasks of designing processes, including project management processes, as well as the rapid development

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of data and information management technologies in companies, orients top managers to the use of standard and effective approaches to substantiating management decisions.

The transition of companies to data-driven management has shown the need to develop digital projects to create new digital products and services, use digital design technologies, as well as web applications for managing analytics and customer data. The demand has increased for the development of web-oriented digital projects for managing the transformation of production and creating a supply network, as well as the introduction of corporate digital platforms for information interaction and electronic document management of distributed companies, etc.

Such project activities require funding. However, traditional methods of financial control are not always suitable for assessing the effectiveness of the use of financial resources of digital projects. The architectural approach implies the existence of different levels of architecture for the designed control system. In this regard, the system dynamics method forms the basis for detailing high-level definitions and design of business architecture and information technology at various levels of management. The question is in the application of the technology of decomposition of complex systems and in what level should be given priority for certain solutions [2].

The article proposes a system-dynamic model for managing the resources of a digital project, which, by simulating the contribution of such factors as the speed of completion of work on the project, the average cost of digital projects, the average number of completed projects per year, etc. (see Figure 1: Cause-effect diagram for a digital project resource management model), will determine the best strategy for the distribution of financial and intellectual resources of the project according to the criterion of its profitability. The levels, as accumulators of resources in the proposed model, are determined: labor intensity of work, the regulator of the intensity of the intellectual load of the project personnel, the amount of outstanding work on the project, accumulated capital, net cash flow, net discounted flow, project implementation time, payback period, the amount of profitability.

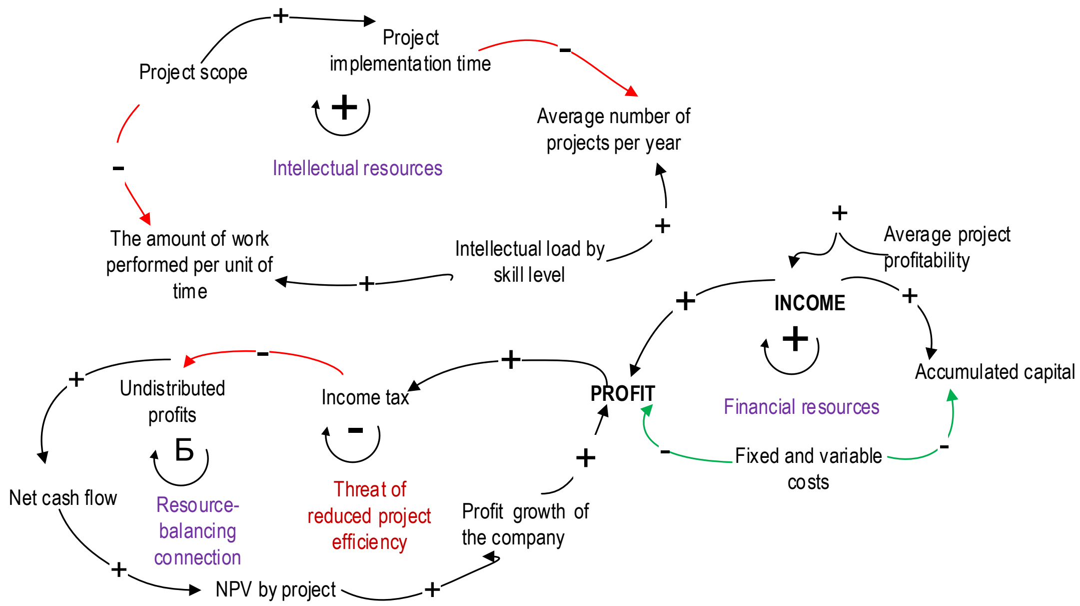

Figure 1: Cause-effect diagram for a digital project resource management model

Let us consider in detail the financial block of the model, which simulates the forecast indicators of the effectiveness of the investment support of a digital project, including the possibility of regulating the intellectual workload of the project personnel.

The general view of the «NPV calculation» block is shown in Figure 2: General view of the "NPV calculation" block of the system-dynamic model of resource management of a digital project. Description of model parameters is presented in Table 1.

Indexes used in the model:

$t \in \{t_0, t_0 + \Delta t, \dots, t_N\}$ – the simulation period, the planning horizon is taken as 1491 days,

where t_0 – the initial moment of time adopted in the model;

t_N – the final moment of time adopted in the model;

Δt – modeling step (1 day).

Initially, all works (tasks) of a digital project set by the $Wrk2Do$ level are initialized by the labor input in $WrkAmnt$ hours and executed in accordance with the labor input of Wrk. It has been determined that the execution of project works is possible only for unblocked works that have the $NoBlockWork$ or NBW sign:

$$NoBlockWork: N_{i,j} = \begin{cases} 0 | G_{i,j} = 1 \wedge W_j \neq 0 \\ 1 \end{cases}, \quad (1)$$
$$NBW: n_j = \prod_i N_{i,j}.$$

Signs of blocking work, that is, unavailability of its execution at the current time, are: the presence of previous work (hereinafter, prerequisites); non-zero backlog for at least one prerequisite.

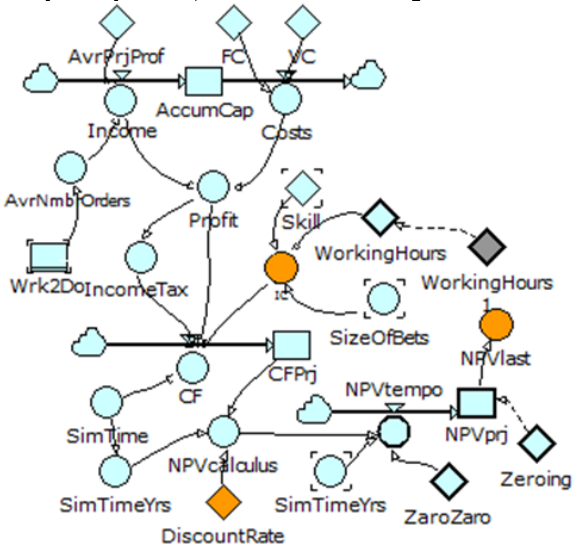

Figure 2: General view of the "NPV calculation" block of the system-dynamic model of resource management of a digital project

Table 1
Description of model parameters

Parameter	Description
Model levels	
Wrk2Do	Backlog of the project phase
AccumCap	Accumulated capital
CFPrj	Cash flow
NPVprj	Project net discounted flow
Model tempo	
Income	Income of project
Costs	Consumption
CF	Cash flow
NPVtempo	Net discounted flow
Model variables	
NPVcalculus	Calculation of net discounted flows
AvrNmbrOrders	Average number of orders for projects
Profit	Profit

Labor costs Wrk are determined by the Eff variable, which determines the ratio of the volume of work on the project to the actual duration of the working day, and is also regulated by the multiplier for the volume of work $Skill$, which for each experiment sets the intensity of the intellectual workload of the project staff, taking into account their qualifications. Let us formalize the main levels and variables of the model (formulas 1-13) to determine the dynamics of the main indicators of the model (endogenous variables) at time t.

Net Present Value is the sum of the discounted simultaneous differences between the benefits and costs of the project.

1. Net present Value is determined by:

$$NPV_t = \sum_{i=1}^{t} \frac{CF_i}{(1+DiscountRate_t)^i}, \tag{2}$$

where CF_i – net cash flow at time i; $DiscountRate_t$ – discount rate

2. Net cash flow:

$$CF_t = \begin{cases} Profit_t - IncomeTax_t - IC_t, t < 2 \\ Profit_t - IncomeTax_t, t > 1 \end{cases}, \tag{3}$$

where $Profit_t$ – profit; $IncomeTax_t$– sum of profit tax; IC_t – initial investment.

3. Profit:

$$Profit_t = Income_t - Costs_t, \tag{4}$$

where $Income_t$ – income; $Costs_t$ – costs.

4. Sum of profit tax:

$$IncomeTax_t = Profit_t \cdot 0{,}2, \tag{5}$$

5. Initial investment amount:

$$IC_t = LaborCosts_t + ProjectCosts_t, \tag{6}$$

where $LaborCosts_t$ – labor costs of the project;
$ProjectCosts_t$ – other costs for launching the project.

6. Project labor costs:

$$LaborCosts_t = LaborCosts_{t-1} + \Delta LaborCosts, \tag{7}$$

The size of the project's labor costs depends on the qualifications of the workers.

Payback period - the expected period of recovery of the initial investment from net cash receipts.

7. Payback period:

$$PB_t = PB_{t-1} + \Delta PB, \tag{8}$$

Profitability index - the discounted value of cash receipts from the project per unit of investment. Shows the relative profitability of the project.

8. Profitability index:

$$PI_t = \frac{NPV_t}{IC_t}, \tag{9}$$

9. Average profitability:

$$AvProf_t = \frac{\sum_{i=1}^{t} \frac{Income_i}{Profit_i}}{t}, \tag{10}$$

Indicators of the financial efficiency of a digital project make it possible to determine the conditions for the distribution of financial resources for the work and tasks of the project, taking into account the regulation of the intellectual workload of the project personnel.

For simulation experiments, we will introduce the assumption that with an increase in the intensity of the intellectual load of the project personnel, taking into account the certain qualifications of the participants, the financial efficiency of the project will increase. At the same time, the marginal growth of financial efficiency will be stopped at the point where an increase in the intellectual load of the project personnel will no longer guarantee the growth of its financial indicators.

A common limitation for a digital project, as a relatively closed system for management, is the fixed amount of the initial investment allocated to the project. In this case, the finding of an optimal variant of using the intellectual resources of the involved personnel allows reducing the timing of the project and the cost of its development.

The qualification of workers is determined by the time during which a certain amount of work will be completed. Thus, the basic qualification level of the conventionally standard project participants is taken as 1, then the qualifications of workers who perform the same amount of work in less time will be determined by the ratio:

$$Skill = \frac{WorkTime}{WorkTime_0}, \tag{11}$$

where $WorkTime$ – the time during which the project participants completed a certain amount of work. $WorkTime_0$ – time during which conventionally standard project participants perform a certain amount of work.

When calculating the wage rate of a project participant, we introduce the function of regulating the intensity of the intellectual load from the level of basic qualifications, in the form of a multiplier, which is determined by the formula:

$$Bet = Bet_0 \cdot M, \quad (12)$$

where Bet – the bet of remuneration of the project participant.

Bet_0 – the bet of a conditionally standard project participant according to the base value of competencies.

M – personnel load growth multiplier.

The multiplier of the growth of the workload on personnel is a power function that characterizes the change in the value of the qualification level of the project participant in the model:

$$M = Skill^n, \quad (13)$$

where n – is a number from 1 to 2.

If the number n is equal to one, then in this case project participants with higher qualifications will receive the same remuneration, performing a certain amount of work faster. If the number n is greater than one, then workers with higher qualifications will receive higher remuneration for completing a certain amount of work.

Based on a series of simulation experiments, we will find out the limiting value of the degree n, at which the distribution of the intellectual load of the project participants and the financial return of the digital project reach the limiting value of their effectiveness. The experimental results are summarized in Table 2.

Table 2

Data from simulation experiments of a model for managing intellectual and financial resources of a digital project

Financial indicators of the project	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
	n=1	n=1.1	n=1.2	n=1.3	n=1.4
PB	3,62	3,76	3,92	4,09	4,27
AvProf	0,36	0,36	0,36	0,36	0,36
PI	2,48	2,07	1,68	1,3	0,93
NPV, (RUB)	16878723,21	16398495.36	158833801.97	15332166.17	14740937.56
IC, (RUB)	12002750.00	12703474.31	13454492.04	14259412.91	15122105.73
PrjTime	468,93	468,93	468,93	468,93	468,93
	Skill=1.2	Skill=1.4	Skill=1.6	Skill=1.8	Skill=2
PB	4.48	4.34	4.25	4.17	4.09
AvProf	0.42	0.45	0.45	0.45	0.45
PI	1.08	1.16	1.21	1.25	1.3
NPV	14085293.20	14534783.62	14820247.85	15065811.89	15332166.17
IC	12551625.55	13039698.88	13481121.08	13885435.05	14259412.91
PrjTime	795.27	689.43	610.05	539.49	468.93

As experiments have shown, with an increase in the intellectual load on the project participants, considering the level of their qualifications, the financial performance indicators of the project implementation improve. At the same time, the level of initial costs also increases. Experimentally, we find that the best strategy for managing the intellectual and financial resources of a digital project corresponds to: the project implementation period is 468.93 days; the maximum increase in the complexity of tasks in accordance with the value of the multiplier of the increase in the load on the project personnel in the degree $n \leq 1.3$. Due to the fact that the regulation of the intensity of the intellectual load of the project personnel is directly related to the determination of labor costs and is taken into account when calculating the salary rates for the project personnel, it is proposed, for the conditions of this example, to establish the maximum replacement rates for labor costs and financial resources of the project at level 1.3, since an increase in this value leads in Experiment 5 to an unacceptable decrease in the profitability index by 0.93.

3. Conclusion

The presented model is easily extensible without changing the core logic. The most promising areas of development for the application of the model are: the use of standard optimization tools to improve the performance of the project, increase the productivity of individual employees and labour productivity in general, ensure optimal use of resources and assign employees to certain jobs; distribution of performers for work within qualifications by changing priorities; time management of individual employees; planning the number of personnel and determining a rational system of remuneration for individual specialists, taking into account their involvement in the implementation of the project; personnel planning and outsourcing; planning personnel development programs aimed at acquiring new competencies that provide access to participation in solving specific project tasks, as well as aimed at increasing marginal productivity; setting tasks in the complex of the project economics; modelling the activities of the company as a whole by building a super-project.

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