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THE USE OF INFORMATION FLOW ANALYSIS FOR BUILDING AN EFFECTIVE ORGANIZATION

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Abstract. Information technologies have great influence on the performance of organization. They are related with the changes in organization activities and structure of organization. A view to organization as a three-layer system where information flows connect material flows with decision makers is presented in this article. Three criteria (time, cost and path) are used in a formal model that evaluates organizations information flow effectiveness. This article presents a methodic for choosing information technologies that fit organization needs by performance and cost. Petri nets are used for modeling.

Keywords: Information Flows, Organization Modeling, Information Processing, Decision Making.

1. Introduction

Rapidly changing information technologies urge the organizations to adapt to modern technological solutions. However is it always necessary to buy the most up-to date solutions? A proper implementation of information technologies should fit organization activities by performance and cost. An analysis of organization activities would help to find a solution that corresponds to organization needs.

Organization‘s information flows are the mirror of the activities in organization. Information flows support the material flows (or the activities that directly build the main products/services of organization) and are the connector between material flows and decision makers. Modeling of organization activities helps to build an effective organization. Ways how to use information flows in organization process modeling are analyzed in latter works.

Recent literature analyzes the relationship between organizations overall performance and information flows [5]. The research of the impact of information technologies to organization performance leads to evaluation of information system effectiveness [7] [8] [13]. The rapidly developing information technologies are even one of the factors for business process reengineering [1], [2], [3], [10]. Question how information technologies influence organization structure is analyzed in [14]. The use of information flows for organization process modeling is poorly presented in theoretical research works. Some authors use formal models for organization modeling, build organization ontologies [4], [6], [9]. However the separation between material and information flows is not clear. Petri nets for organization activities modeling can also be used [11].

The objective of this article is to analyze the benefit of information flow modeling when building an effective organization. Without proper modeling the information technologies may be used inefficiently in organization thus reducing the gain from them.

In this article, a methodic of organization information flow modeling is presented. Three formal parameters (path, time and cost of information flow) are used to measure the effectiveness of organization’s information flow net. The use of formal modeling and evaluation methods allows us to represent the implementation of information flows and to formally evaluate the effectiveness of it as well. The widely used semiformal models can represent the information flows well but they lack of formal parameters that would allow measuring the quality of the information flow net. It is shown that the developed optimization technique helps to choose proper information technologies by several criteria at a time.

2. Organization modeling by information flows

Each working organization regardless of whether it is a manufacturing enterprise or a service provider (business-oriented or nonprofit, public office) has two kinds of activities:

- direct activities that manufacture production or provide services and
- supporting activities that administrate direct activities (informational activities).

Information (about orders, activities being executed, products in-production, products made, workers, work process etc) is gathered (registered), saved (stored), transferred, analyzed (processed), used for manufacturing or decision making processes. These informational activities are necessary for each organization though they are non-added-value. Operative work coordination, well-timed presentation of full ordered information to the decision makers depend on effective execution of these activities. Thus the effectiveness of overall organization activities depends on these processes.

This article analyzes activities of the second kind only and not the reorganization of manufacturing process. The article presents methodic that lets one effectively organize informational activities and implement information technologies within an organization.

We look at an organization as a three layer system (see Figure 1). The organization's material flows (activities of the first kind) are in the ground layer. Decision makers, managers of organization are on the top. Organization's information flows are the connection between them. The middle layer receives the information from the bottom, processes it and presents it to the decision makers. Decisions made in the top layer influence the bottom layer activities. The aim of this work is to optimize the work of the middle layer by thinning it.

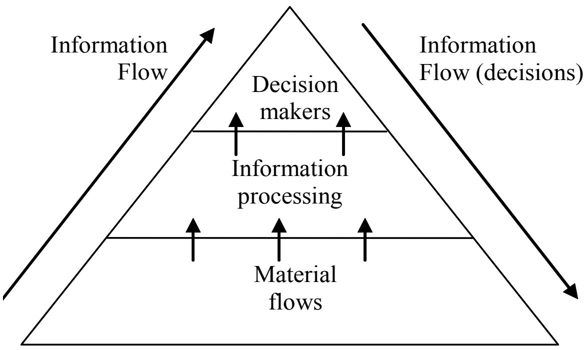

Figure 1. Organization macro model

To be able to make qualitative decisions the organization managers need to receive qualitative information on time. Decisions need to be delivered to material flows full and on time. Qualitative realization of these information flows is ensured by the middle layer. Later the formal parameters of this layer will be presented.

Most often in a working organization the activities are executed according to some steady (often – specified) business rules. All activities are (or can be) stated in economical/financial documentation of enterprise and models of organization processes can be built. Models that describe the information flows in organization are often presented in UML or DFD. Models like these describe *how* the activities should perform (or are performing). But is it an effective process realization? Will information be delivered to decision makers on time? Is that information qualitative? Can these information flows be implemented cheaper? How many people and how much IT hardware/software is necessary to perform some concrete functions? How to distribute activities among the subdivisions/working places? These problems influence the quality of organization processes. It is impossible to solve them by simply looking at the process diagrams. For that purpose, formal analysis of organization activities may be used. An analysis including other formal parameters is very useful to enrich the organization's informational processes semiformal models (how and where information is born, stored, processed and used).

In formal analysis of the information flows of an organization three formal parameters are used in this article.

Cost shows how much the current (or alternative) implementation of informational processes cost.

Time shows the speed of information transfer to the user of information (for instance, how much time it takes for a decision maker to receive the necessary information from material flows). This parameter is the most important one for decisions on time.

Path gives the knowledge about the amount of information flow net elements that information must go through to be received by information user.

These parameters are tightly related with each other thus making the analysis more complicated. New IT means can process information faster (reduce time) but can also increase costs dramatically. Shortening of path may lead to increase in cost or time. New investments in IT may not be required, if the reduction in time is less important than low cost of information system. Most often improving one parameter worsens the values of other parameters. Thus any investment in the middle layer (see Figure 1) should be done only after a proper formal analysis. For instance, if analysis shows that decision maker receives the information too late a decision to buy more powerful IT means (that would perform the tasks faster) thus reducing time, changing path but increasing costs of organization's middle layer can be made.

When building (or reorganizing) organization's information system the evaluation of possible alternatives by formal parameters lets use funds effectively. Organization managers or experts decide which parameters are important during the analysis. They also determine the acceptable values for them (for instance, decision makers need to receive the information from material flows in 2 days).

To make the implementation of information flow net in organization effective, the analysis of organization's information flow net effectiveness should be done together with analysis of organization structure. Information flow net is mapped by the structure of organization – every action from information flow net that needs to be processed is implemented by a workplace in organization. Some work can be made by human, some – by computer. Either way in each such workplace of organization human/computer worker implements some elements of information flow net. The workplaces of organization form an organization structure.

The organization's information flow net can be implemented in different ways. In some organizations, work with information can be fully automated (computer-assisted), in others – made only by humans. The IT means that can be chosen to implement some of information flow net elements also differ by speed, cost and other important factors. Only managers of organization or experts can decide which criteria are the most important when building an effective organization. For instance, if they choose that the most important factor for them is the time that information takes since being registered on material flow points till being given to decision maker fully processed, they can buy the expensive IT means that will replace some of the human workers and present the information as fast as it is necessary. So the criteria that are used to evaluate the effectiveness of information flow net (Time, Cost and Path) bind to the analysis of organization structure.

The effective analysis of information flow net in organization should include not only the structure of the net itself but some properties of organization as well. There are parameters that show speed, cost and the number of human-workers in information flow net, for instance: actual IT means that are used in each node of information processes, who – human or computer – executes the working tasks (activities). Such parameters should be included in analysis process. A wide variety of other organization parameters might also be included in analysis process if the analysts found them significant. Information flow implementation that suits the expectations of organization managers' best can be found by changing the values of model parameters.

In next sections mathematical models of the above are presented.

3. Formal evaluation of organization's information flow net effectiveness

In this section, a formal model of the above described organization's information flow net effectiveness analysis is presented. The description of the model is based on the mathematical optimization theory and presented using its notations.

The following model evaluates the effectiveness of existing (or designed) information flow net in organization. It also helps to choose between several possible implementations by formal criteria thus enabling the optimization of it.

Organization's information flow net (and related organization structure) may be presented formally as a system with feedback relation: data from material flow points $M = (M_1, M_2, ..., M_{nm})$ are registered in registration points $R = (R_1, R_2, ..., R_{nr})$, stored in data stores $S = (S_1, S_2, ..., S_{ns})$, processed in data processing/analysis points $A = (A_1, A_2, ..., A_{na})$ and given to decision makers $D = (D_1, D_2, ..., D_{nd})$. The made decisions get back as information to the material flows. Two additional functions relate each data flow $F_i \in F$, $F = (F_1, F_2, ..., F_{nf})$ with its source $IN(F_i)$ and target $OUT(F_i)$. Figure 2 shows organization's information flow net. More formal specification is presented in [12].

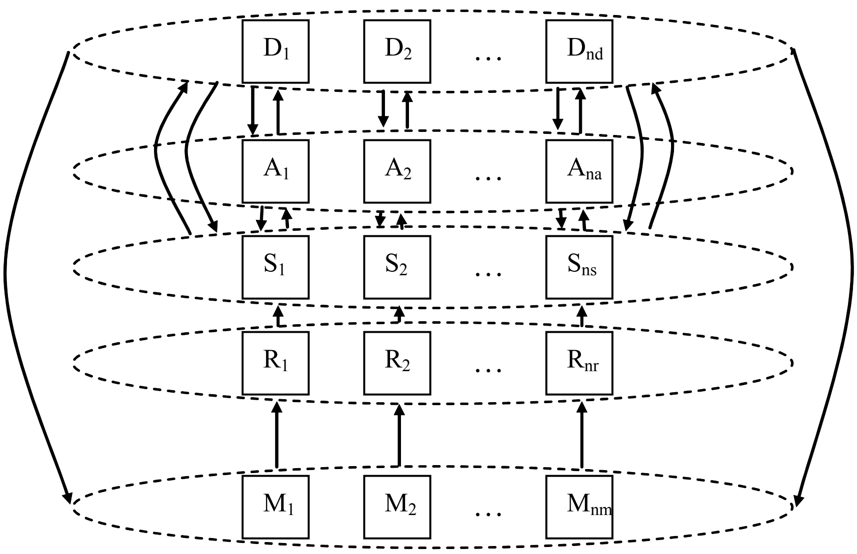

Figure 2. Organization's information flow net. Here arrows present information flows

Effectiveness of organization's information flow net (and related organization structure as well) is evaluated by three formal parameters (introduced in the above sections): Path *P*, Time *T* and Cost *C*.

Each of them depends on particular information flow net realization and a set of organization parameters – i.e. triplet $\langle P,T,C\rangle$ is a matrix function of organization's information flow net Ω and structure parameters Θ:

$$\langle P,T,C\rangle = \varphi\ (\Omega,\Theta)\,, \qquad (1)$$

here

$$\Omega = \langle M,D,R,A,S,F\rangle\,,$$
$$\Theta = (\Theta_1,\Theta_2,...,\Theta_n)\,.$$

The expression of function φ depends on particular organization and is, in general, unknown. It may be found empirically.

The structure parameters $\Theta_1,\Theta_2,...,\Theta_n$, such as IT used for information processing, data structuring degree, human/machine ratio in particular workplace describe *how* information flow *is implemented* in organization.

In simple cases they show only the IT solutions that are implemented in each place of organization information flow net. Experts in each particular case decide which parameters and how much of them to include into the model.

Note that the characteristics (such as time and cost) of each middle point (registration, storing or processing point) of organizations information flow net may be found from the set of structure parameters.

Equation (1) shows that by knowing particular organization's information flow net Ω, values of organization structure parameters Θ and their relation φ, we can find the values of the triplet $\langle P,T,C\rangle$.

Calculated from (1) (either from equations or from modeling), the values $\langle P^1,T^1,C^1\rangle$ are formal estimation of effectiveness of existing (or designed) organization's information flow net.

In most cases process of organization's information flow analysis consists of several possible implementations. Several implementations can show several possible ways to perform the same tasks – to deliver the processed information from material flow to decision makers. Several might even use the same information flow net structure and only differ in IT being used. However, each implementation comes with its own values of the triplet $\langle P,T,C\rangle$. Choosing the best implementation is a problem of multiobjective optimization which can be very difficult to solve. For instance, which implementation is better: $\langle P^1,T^1,C^1\rangle$, $\langle P^2,T^2,C^2\rangle$ or $\langle P^3,T^3,C^3\rangle$ if $\dim(P^1) <$ $\dim(P^2) < <\dim(P^3)\,, T^3 < T^1 < T^2,\ C^2 < C^3 < C^1$? Here function $\dim(P)$ is the number of elements in P, P is a tuple of information storing and processing points the information flows through.

Organization managers or experts (consultants) decide whether the current (being analyzed) realization of organization information flow net satisfies them or not. They need to evaluate either the values of the parameters $\langle P,T,C\rangle$ (in this case it's multiobjective optimization) or the objective function $f(P,T,C)$. An example of simple objective function might be

$$f_1(P,T,C) = a_1 \cdot \dim(P) + a_2 \cdot T + a_3 \cdot C\,, \qquad (2)$$

where $a_i \in \boldsymbol{R}, i=\overline{1,3}$.

The main goal of analysis is to find the implementation that fits the expectations of organization managers' best.

The most effective (optimal) implementation is found by solving the optimization problem:

$$\begin{aligned}
&f(P,T,C) \to \min\,, \qquad (3)\\
&\langle P,T,C\rangle = \varphi\ (\Omega,\Theta)\,,\\
&\Omega \in \Omega',\ \Omega' = \{\Omega^1,\Omega^2,...,\Omega^k\},\\
&\Omega^i = \langle M^i,D^i,R^i,A^i,S^i,F^i\rangle,\ i=\overline{1,k}\,,\\
&\Theta \in \Theta',\ \Theta' = \{\Theta^1,\Theta^2,...,\Theta^l\},\\
&\Theta^i = (\Theta_1^i,\Theta_2^i,...,\Theta_n^i),\ i=\overline{1,l}\,,\\
&\dim(P) < \dim(P')\,,\\
&T < T'\,,\\
&C < C'\,.
\end{aligned}$$

Ω' shows all information flow net implementations being analyzed, Θ' describes all collections of structure parameters being analyzed. The last three inequalities describe constraints for (respectively) path, time and cost. P', T' and C' are specified by organization managers or experts. They simplify the search of effective implementation of organization information flow net. Unconstrained optimization on several parameters might lead to unsolvable optimization problems. Besides, they also show the maximum values that the organization managers can afford.

P, T and C depend on Ω and Θ from (3). By knowing the expression of φ, the equations of constraints from (3) might be solved thus eliminating the unsatisfying values from Ω' and Θ'.

Formal descriptions of P, T and C are presented in the next sections.

4. Qualitative parameters of organizations information flow net

In this section the definitions of organization's information flow qualitative parameters cost, path and time are presented. It is assumed that the information flow net has one decision maker. This condition simplifies the definitions and is correct because each information flow net can be decomposed into several nets with one decision maker.

The model from Section 3 allows defining the cost, path and time parameters in both directions – from material flow points to decision maker and backwards. In the following sections all definitions are for information flows from material flow point to decision maker. For information flows from decision maker to material flow point, the methods for parameters' calculations can be formed analogously.

4.1. Cost

The cost of organization's information flow net implementation C is found by adding costs of registration C_r, storing C_s and processing C_a:

$$C = C_r + C_s + C_a . \quad (4)$$

4.2. Path

Path from material flow to decision maker is a tuple

$$P = (P_1, ..., P_{np}), \; np \le nr + ns + na + 2,$$

$$P_1 \in M, \; P_{np} \in D, \; P_i \in R \cup S \cup A, \; 2 \le i \le np - 1,$$

$$IN(P_{j+1}) = OUT(P_j), \; j = \overline{1, np-1}.$$

When information flow net has only one material flow point and only one decision maker, for the purpose of simplicity, organization's information flow net path may be defined as:

$$P = (P_1, ..., P_{np}), \; np \le nr + ns + na,$$

$$P_i \in R \cup S \cup A, \; 1 \le i \le np,$$

$$IN(P_{j+1}) = OUT(P_j), \; j = \overline{1, np-1}.$$

The number of P elements $\dim(P) = np$ shows the complexity of information path to decision maker.

Most often the organization's information flow net consists of more than one path. All possible paths from material flow point to decision maker compose a set $\{P^1, ..., P^{npn}\}$, where *npn* is the number of paths,

$$P^i = \left(P_1^i, ..., P_{npi}^i\right), \; npi \le nr + ns + na + 2,$$

$$P_1^i \in M, \; P_{npi}^i \in D,$$

$$P_j^i \in R \cup S \cup A, \; 2 \le j \le npi - 1,$$

$$IN(P_{j+1}^i) = OUT(P_j^i), \; j = \overline{1, npi-1}, \; i = \overline{1, npn}.$$

The coordinates of these paths (middle points) are not necessarily unique and repeat in the set $\{P^1, ..., P^{npn}\}$. The set of all points that information (for a decision maker) goes through is

$$\mathbf{P} = \left\{P_j \mid P_j = P_k^i, \; j \le nm + nr + ns + na + nd, \; 1 \le k \le npi, \; i = \overline{1, npn}, \; P_s \ne P_t, \; s \ne t\right\}.$$

The number of elements of this set *dim(**P**)* is a qualitative parameter that shows the complexity of information processing in the organization.

4.3. Time

If information is delivered to decision maker by one path (*linear structure* of information flows), then the time of information transfer may be defined as:

$$T = T_r + T_s + T_a , \quad (5)$$

here T_r – registration, T_s – store, T_a – processing times.

Most often information flows (from material flow points to decision makers) in organization have *non-linear (net) structure*. Information to decision maker may come by different paths from the same or different sources (different material flow points). Decision maker can't make a decision while the last piece of information (necessary for a decision) hasn't arrived. Here formula (5) that shows information's time from being registered till being delivered to decision maker by one path is no longer correct. Such information flow net can be represented with directed graph where the weights on edges correspond to the middle (registration, storing, processing) times. Time of information transfer form material flow to decision maker will match the longest path in this directed graph from a vertex without incoming edges to vertex without outgoing edges. I.e. if $\{P^1, ..., P^{npn}\}$ are all possible paths from material flow point to decision maker then *the time from material flow to decision maker* may be defined as:

$$T = \max_{1 \le i \le npn} T(P^i), \; T(P^i) = \sum_{k=1}^{npi} T(P_k^i),$$

assuming that

$$T(P_k^i) = 0, \text{ when } \left(P_k^i \in M\right) \vee \left(P_k^i \in D\right),$$

$$k = \overline{1, npi}, \; i = \overline{1, npn}.$$

Such problems are usually solved by the means of graph theory. Various simulation methods may also be used for a search of the time values.

When middle times are nondeterministic, then the problem of a longest path searching becomes more complicated and the simplest way to solve it is by simulation. In this article, for a search of time values timed Petri nets are used.

5. Optimization of organization information flow net by time and cost

We use the above presented approach (methodic) to find the most effective implementation of organization's information flow by time and cost parameters.

Figure 3 shows subdivisions of a manufacturing organization that are interconnected by information flows:

Analysis_1 analyses information from material store,

Analysis_2 and Analysis_3 analyze information from manufacturing subunits 1 and 2, respectively,

Analysis_4 summarizes all information and presents it to managers for decision making.

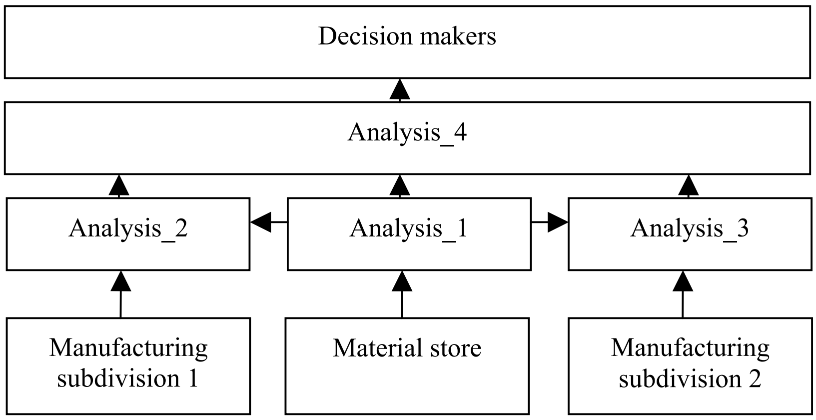

Figure 3. Simplified scheme of information flows between subdivisions of organization

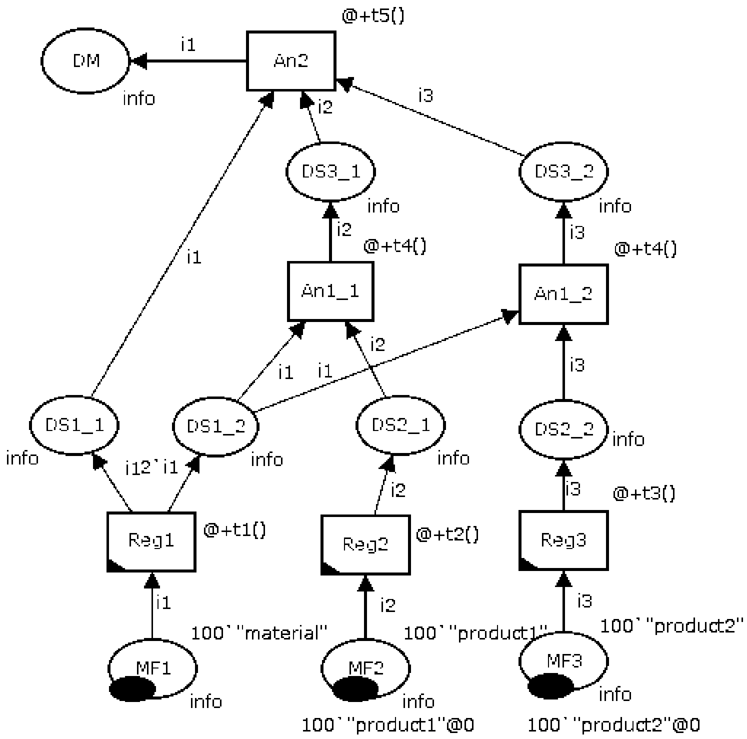

Figure 4. Model of manufacturing organization information flow

Petri net model is formed to demonstrate processes and to calculate values for organization's information flow time. It is shown in Figure 4.

Three sources provide data to information system. Information about materials (ordered materials, arrived new ones, material quantity in store etc) is registered by *Reg1*. Information from 2 production units (production process, workers etc) is received by *Reg2* and *Reg3*, respectively. Registered production unit information is analyzed together with material information, respectively, by *An1_1* and *An1_2*. Processed information from both production units together with information about materials is summarized by *An2* and given to decision maker. Thus decision maker gets all information for decision making.

Several alternatives (hardware, applications) might be chosen for the same tasks. Registration processes (*Reg1*, *Reg2* and *Reg3*) can be implemented by one of two solutions: IT1 or IT2. Information processing from the manufacturing subdivisions (*An1_1* and *An1_2*) can be implemented by one of three solutions: IT3, IT4 and IT5. Final information processing (*An2*) can be performed by either IT6 or IT7. The related values of time and cost are presented in Table 1.

Seven alternative structure parameters Θ may be chosen for implementation of organization information flow net:

$$\Theta' = \left\{\Theta^1, \Theta^2, ..., \Theta^7\right\},$$

$$\Theta^i = (\Theta^i_{Reg1}, \Theta^i_{Reg2}, \Theta^i_{Reg3}, \Theta^i_{An1\_1}, \Theta^i_{An1\_2}, \Theta^i_{An2}),$$

$$i = \overline{1,7}\,.$$

Values for each alternative Θ are shown in Table 2, together with modeling results – average time of information transfer from material flow to decision maker (*Avg(T)*) and the total cost *C*.

As we see from Table 2, the choice which Θ (which collection of IT) is best without proper objective function is complicated. Better alternatives by time (faster ones) will cost more.

Table 1. Values of manufacturing system model parameter's

IT	Related with	T	C
IT1	*Reg1 Reg2 Reg3*	T(1,3)*	8
IT2	*Reg1 Reg2 Reg3*	T(3,6)	5
IT3	*An1_1 An1_2*	T(1,3)	9
IT4	*An1_1 An1_2*	T(3.6)	5
IT5	*An1_1 An1_2*	T(6,12)	2
IT6	*An2*	T(1,3)	7
IT7	*An2*	T(3.6)	4

* T(a, b) is uniform discrete distribution in interval (a, b). So it means that parameter T(IT1) is distributed by uniform discrete distribution in interval (1, 3).

Table 2. Structure parameters of manufacture system

Θ	Θ_{Reg1}	Θ_{Reg2}	Θ_{Reg3}	Θ_{An1_1}	Θ_{An1_2}	Θ_{An2}	Avg(T)	C
Θ^1	IT2	IT2	IT2	IT5	IT5	IT7	18,5	23
Θ^2	IT1	IT1	IT1	IT3	IT3	IT6	6	49
Θ^3	IT2	IT2	IT2	IT3	IT3	IT6	9	40
Θ^4	IT1	IT1	IT1	IT5	IT5	IT7	15,5	32
Θ^5	IT2	IT2	IT2	IT3	IT3	IT7	11	37
Θ^6	IT2	IT2	IT2	IT5	IT5	IT6	16	26
Θ^7	IT1	IT2	IT2	IT4	IT4	IT7	14	32

It is easy to calculate that by given objective function

$$f_2(T,C) = 0.4 \cdot \left(\frac{T}{MIN(T)} \right) + 0.6 \cdot \left(\frac{C}{MIN(C)} \right) \rightarrow \min$$

the best information flow implementation is with Θ^3. Here $\frac{X}{MIN(X)}$ make the measures between T and C in relative proportions. Values 0.4 and 0.6 are chosen by the relative importance of time and cost to the decision makers (it's little more important that the implementation would cost less than it would be faster). The implementation with Θ^3 is only 1.5 times slower than the fastest one and cost 1.7 times more than the cheapest one. With given objective function it is the best one.

6. Conclusions

Information technologies change rapidly and force organizations to adapt to up-to-date technologies from time to time. However, it is not always necessary to buy the most modern solutions. Modeling organization information flows, using formal methods based on clearly-defined criteria (such as time, cost and path), identifies what an organization truly needs – the most modern solution may appear just not necessary. Thos paper illustrates the situation when modeling organizations information flows by several formal criteria helps to choose an appropriate implementation of information flows by performance and cost.

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