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Smart Control Mechanisms in Digital Technologies of Decision-Making

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Abstract: This paper considers the problems of adopting digital technologies in decision-making. Two types of digital decision technologies are described, namely, the direct (or traditional) technology with human decision-making based on computer-aided advisor systems and also the inverse technology with independent computer decision-making in which a human merely monitors the decision process. These technologies are compared with each other, and some applications are discussed.

Keywords: digital economy, correct mechanisms, decision support system, the Kantorovich–Glushkov conditions, direct and inverse technologies

1. INTRODUCTION

The development of digital economy as well as a wide adoption of digital technologies, not only in data processing and electronic documentation but also in solid decision-making, require a proper review of decision methodology.

The attempts to use digital technologies in decision-making were undertaken long ago [1]. In this context, note the role of Soviet Academicians L.V. Kantorovich and V.M. Glushkov. In the wake of the 1970s large-scale automation in the USSR, Glushkov suggested the idea of a computer-aided planning system for the national economy. Kantorovich designed a mechanism to coordinate national economic plans with the interests of enterprises based on his original methodology of duality. The optimal dual estimates of associated planning problems were considered as a tool of such coordination. Unfortunately, the attempt failed because the real interests of economic agents poorly fit the strict framework of duality.

Kantorovich and Glushkov formulated two prerequisites for an efficient use of digital technologies in decision-making as follows: (1) all information necessary for decision-making must be reliable and (2) the economic agents must benefit by implementing given decisions (fulfilling their plans). In the sequel, these prerequisites will be called the Kantorovich–Glushkov conditions. In the 1970s, they were difficult to satisfy [1] but the situation has dramatically changed in the recent time, following the design of smart control mechanisms: contract theory [2, 3, 5, 8], the theory of mechanism design, where the incentive compatibility conditions and the revelation principle [6, 7], as well as the work [4, 7] and many others.

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Note that the incentive compatibility conditions, and the revelation principle were originally proposed in 1971 in article [9], where the revelation principle was called the "fairplay principle". Let us discuss this class of mechanisms in detail.

Any changes in social being, particularly, control mechanisms, lead to fast consequences in human behavior. Smart control mechanisms are the control mechanisms that change human behavior for public interests, e.g., stimulate truth-telling (the provision of reliable information), decision implementation, efficient development, etc. Of crucial importance for digital technologies are the smart mechanisms that guarantee truth-telling and decision implementation: decision-making with these mechanisms satisfy the Kantorovich–Glushkov conditions.

It is possible to identify two types of digital decision technologies as follows. The first type, known as the direct technology (traditional for modern society), relies on human decision-making with computer-aided decision support systems. The development of such technologies is connected with the design of active advisor systems: after the implementation process, the decision of a human decision-maker (DM) is compared with the one suggested by an advisor system using the so-called recalculation models.

The technology of the second type (inverse) is based on independent computer decision-making while a human merely monitors the decision process without any interference (except for critical situations and force majeur). In such technologies, a decision support system (DSS) becomes a decision-making system (DMS) while a DM a person who assesses decisions (decision analyzer, DA). However, control mechanisms are designed by managers and other interested persons who are responsible for the results of functioning.

2. DIRECT (TRADITIONAL) DECISION TECHNOLOGY

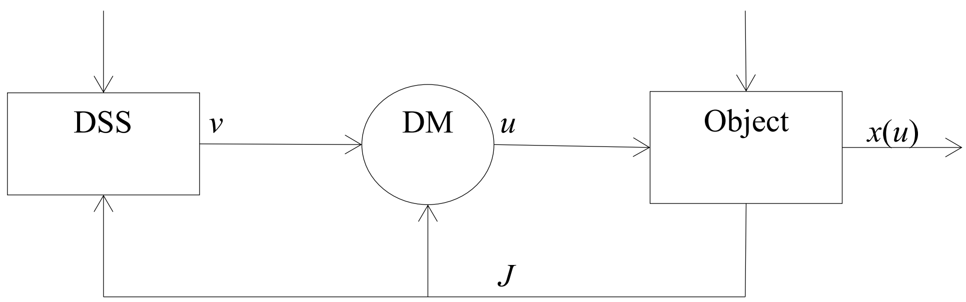

Fig. 1. Direct decision technology

The structural diagram of the direct decision technology is shown in Fig. 1. As mentioned above, the power of decision belongs to a decision-maker (DM), who uses information about an object and external environment as well as his/her experience and DSS recommendations. Figure 1 has the following notations: u as the Principal's decision (in this case, the Principal is the DM); v as the DSS recommendation; J as the available information about the object; finally, $x(u)$ as the result of decision implementation. This technology demonstrates high efficiency if the Principal well knows the object, seeks for its successful functioning and has operative tools to guarantee decision implementation. Otherwise, the DM encounters unreliable information from the object, the non-implementation of required decisions and a possible occurrence of corruption ties.

Consider the direct technology on elementary examples of order allocation.

Example 1. The Principal needs products in an amount R. There are n suppliers of these products. Denote by x_i the production plan of supplier i. Let the product cost be given by $z_i = \frac{1}{2r_i} x_i^2$, where a parameter r_i describes the production efficiency of supplier i. The Principal's problem is to find the plans x_i so that

$$\sum_i x_i = R \tag{1}$$

(the supply satisfies the demand) and the total cost $\Phi(x)$ are minimized, i.e.,

$$\Phi(x) = \min_x \sum_i \frac{1}{2r_i} x_i^2 . \tag{2}$$

For the exact values $r = (r_i)$, the optimal plan has the form

$$x_i = \frac{r_i}{H} R, \; i = 1, \cdots, n, \tag{3}$$

where H is the total efficiency of all suppliers,

$$H = \sum_j r_j .$$

However, the Principal often knows only approximate values of the parameters r_i. In this case, the information $s = (s_i)$ about these parameters is reported by the suppliers. The interest of supplier i is determined by the profit

$$Y_i(\lambda, x_i) = \lambda x_i - \frac{1}{2r_i} x_i^2 , \tag{4}$$

where λ denotes the product price established by the Principal. He/she makes some decision using a control mechanism $x = \pi(s)$ and $\lambda(s)$, where $\pi(s)$ are $\lambda(s)$ are the functional relationships between the plan (x), control (λ) and the information s reported by the suppliers.

The revelation mechanism [2] suggested in the theory of active systems is correct, i.e., guarantees truth-telling and plan fulfilment. In Example 1, the revelation mechanism has the form

$$x_i = \lambda s_i, \quad i = 1, \cdots, n,$$
$$\lambda = \frac{R}{\sum_i s_i}. \tag{5}$$

The direct technology suffers from several drawbacks as follows. First, it is difficult to construct an adequate model of an object, and even more difficult to design an adequate correct decision mechanism. Second, this technology is susceptible to corruption—possible collusions between the Principal and suppliers and also between suppliers themselves.

So, the direct technology was further refined to the two-channel control mechanisms (active advisor systems) based on recalculation models (RMs) [3]. An RM yields a more accurate estimate of the object's parameters using additional information about the results of decision implementation. This approach allows comparing the economic effects from the decisions made by the Principal and the ones suggested by a DSS. The structural diagram of decision-making processes in two-channel mechanisms is presented in Fig. 2.

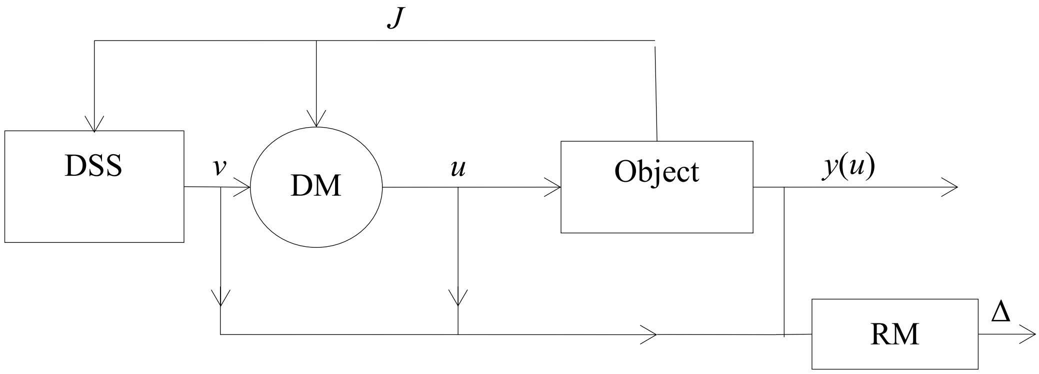

Fig. 2. Decision-making in two-channel mechanisms

Figure 2 has the following additional notations: RM as a recalculation model; Δ as the difference between the economic effects from the DM's decision and DSS recommendation. If $\Delta > 0$, the DM obtains an incentive; if $\Delta < 0$, a penalty. The two-channel mechanisms stimulate the Principal's interest in correct decisions and also reduce the corruption component.

Example 2. For the order allocation mechanism of Example 1, a recalculation model can be easily constructed in the following way. Let z_i be the real cost of supplier i ($z_i = \frac{1}{2r_i} x_i^2$). Then $r_i = \frac{x_i^2}{2z_i}$, $i = 1, \cdots, n$, and hence

$$\Delta = \left(\sum_i \frac{w_i^2}{x_i^2} z_i - z_i \right), \tag{6}$$

where w_i denotes the plan recommended by the DSS.

Consider a collusion between the DM and some supplier (without loss of generality, supplier 1). Using his/her power of decision, the DM overrates the price λ_1 for supplier 1. To this end, supplier 1 pays the DM a bribe—α% of his/her profit. The profit of supplier 1 makes up

$$(1-\alpha)\lambda_1 x_1 - \frac{x_1^2}{2r_1},$$

and his/her beneficial plan is $x_1 = (1-\alpha)\lambda_1 r_1$.

Without corruption, supplier 1 obtains the profit $\frac{1}{2}\left(\frac{R}{H}\right)^2 r_1$. The collusion makes sense for him/her if $\frac{1}{2}(1-\alpha)^2 \lambda_1^2 r_1 > \frac{1}{2}\left(\frac{R}{H}\right)^2 r_1$. So the beneficial corruption condition takes the form

$$(1-\alpha)\lambda_1 > \frac{R}{H}, \text{ or}$$

$$\frac{R}{r_1} > (1-\alpha)\lambda_1 > \frac{R}{H}.$$

Let $\lambda_1 = k\frac{R}{H}$, where $k > 1$ is some parameter adjusted by the DM if he/she enters collusion with supplier 1. Then the beneficial corruption condition can be written as

$$\frac{H}{r_1} > (1-\alpha)k > 1.$$

Note that, the higher is the supplier's efficiency, the smaller is his/her gain from collusion. Moreover, under a sufficiently large penalty for any deviations from the recalculation model-based cost, corruption becomes unbeneficial to the supplier.

The major difficulty for a practical use of two-channel mechanisms is the design of adequate recalculation models.

3. INVERSE DECISION TECHNOLOGY

Consider the inverse decision technology in which the Principal's role is played by a computer (digital decision support system, DDSS) while the Principal's supervisor monitors the decision process without any interference (except for critical situations and force majeure). Actually the supervisor and DDSS change their places, which explains the term "inverse technology".

For making this technology efficient, the mechanism should be discussed with all interested persons and then enacted as a law. In this sense, the DDSS performs a purely computational function. The whole responsibility for decisions lies on the designers of the mechanism (in the first place, the Principal's supervisor), not on the DDSS. If he/she concludes that the mechanism is inefficient (e.g., in new conditions of functioning), then the supervisor considers possible corrections. Of course, as noted earlier, the mechanism must satisfy the Kantorovich–Glushkov conditions, i.e., be correct. This forms the main problem for adopting digital technologies in decision-making and management: the correctness of mechanisms is not so trivial to guarantee.

Let us describe a possible design of correct mechanisms. Consider a system of a single Principal and n agents (enterprises, organizations, etc.). The interests of each agent i, $i = 1,\cdots,n$, are determined by his/her goal function $Y_i(\lambda, x_i)$, where λ denotes control and x_i is the plan established by the DDSS. The sequence of functioning is as follows.

1. The Principal announces the set L of admissible controls.

2. For each $\lambda \in L$, the agents report their beneficial plans to the Principal:

$$x_i(\lambda), \quad i = 1,\cdots,n, \quad \lambda \in L.$$

3. The Principal chooses $\lambda \in L$ and the corresponding plans $x_i(\lambda)$, $i = 1,\cdots,n$, that maximize his/her goal function $\Phi(x, \lambda)$.

This mechanism is correct under the hypothesis of weak contagion [2], stating that all agents do not consider the influence of their messages on the control λ. Indeed, for any values λ, the agents obtain beneficial plans and hence are interested in truth-telling and plan fulfillment.

Remark. If the set of admissible controls is large, the Principal does not need to announce all its elements. He/she may organize an iterative procedure, adding new controls at each step to increase the value of his/her goal function. Such a procedure resembles decomposition methods.

Example 3. Consider the order allocation problem as described in Example 1. Assume the Principal announces the set of admissible prices λ (Step 1) while the agents report their beneficial plans $x_i(\lambda) = \lambda r_i, i = 1,\cdots,n$. The Principal chooses λ to minimize the total cost subject to the constraint $\sum_i x_i(\lambda) = R$. For this problem, the hypothesis of weak contagion was justified in the theory of active systems in the case of sufficiently many agents [2].

An important advantage is that the inverse technology considerably reduces corruption effects. Really, the Principal's supervisor has no right to interfere into the DDSS and hence cannot affect decision-making. So collusions between the Principal and agents take no place. However, corruption may occur when the agents report information to the Principal. For struggling against this corruption component, the inverse technology should be augmented by a recalculation model.

The main stages of adopting digital technologies in economy include the following.

1) choosing a situation that can be formalized as a model;

2) designing a smart control mechanism that guarantees truth-telling and decision implementation as well as coordinates the interests of all persons involved;

3) developing a software product, rules and regulations in accordance with this mechanism;

4) implementing this mechanism, analyzing its efficiency and making periodic corrections subject to new conditions of functioning.

4. SOME APPLICATIONS OF DIGITAL TECHNOLOGIES

Consider some applications of digital technologies [3].

1. *The automated quantitative complex assessment of activity results (AKKORD).* This system was designed at Trapeznikov Institute of Control Sciences in the 1980s for assessing the efficiency of all industrial enterprises within the Ministry of Instrumentation, Automation and Control Systems of the USSR (Minpribor), following the initiative of Minister M.S. Shkabardnya. The general assessment method and procedure were discussed at the Scientific and Engineering Council of the Ministry and also at the Board of the Ministry and then approved by Shkabardnya. Calculations were performed using a special software complex without human interference.

2. *Cost-effective taxation systems.* In 1990–1991, Trapeznikov Institute of Control Sciences participated in an experiment on new taxation systems for research activities organized by the State Committee for Science and Technology of the USSR. The experts of the Institute suggested the cost-effective taxation system—a smart incentive mechanism that stimulates any organizations (even monopolies) to reduce cost and prices. The corresponding rules, regulations and software were developed after debates at the Scientific Council of the Institute. For two years, the Institute was functioning in experimental conditions, and the results confirmed theoretical expectations—it was not beneficial to overrate the cost of contract work.

3. *The reverse priority mechanism for limited resource allocation.* This smart mechanism stimulates customers to submit objective requests for a certain resource (truth-telling). The mechanism was adopted in the water resource management system of Bulgaria and highly appreciated later (awarded by The Golden Mark for High Technological Advance).

5. CONCLUSION

The article discusses two smart decision-making mechanisms based on digital technologies – direct and inverse. The question arises why such mechanisms are few in practice. We give four reasons:

1. The complexity of the smart mechanisms design. It is not by chance that several Nobel Prizes in economics were received for the development and implementation of one or another smart mechanism.

2. Weak interest of officials and managers. Indeed, the introduction of managerial innovations in an organization, region or industry is a considerable risk. Drawing an analogy with medicine, we can say that this is an operation on a living organism, which is carried out

by the patient himself. Not every leader will dare to do it. Moreover, an effective system of estimation and motivation of managers and officials for the result has not yet been created.

3. The problem of compatibility, the essence of which is that an excellent mechanism is often rejected by the organization because it is incompatible with its mentality, traditions, etc.

4. Lack of trained personnel capable of developing and implementing smart mechanisms. The theory of smart mechanisms design and the theory of active systems are studied in a small number of Universities.

Nevertheless, the authors are convinced that the future belongs to smart mechanisms.

Note the most promising directions to adopt smart digital technologies.

1. Assessment systems for the activity of managers and officials at any level, with stimulation based on activity results.

2. Allocation systems for limited resources (finances, etc.).

3. Efficiency improvement programs for organizations, municipalities, regions, etc.

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REFERENCES

1. Ivanov, V. & Malinetskii, G. (2017). Strategicheskie prioritety tsifrovoi ekonomiki [Strategic priorities of digital economy], *Strategicheskie Prioritety*, 3, 54–95.

2. Burkov, V. (1977). *Osnovy matematicheskoi teorii aktivnykh sistem [Fundamentals of Mathematical Theory of Active Systems].* Moscow, Russia: Nauka.

3. Goubko, M., Burkov, V., Kondrat'ev, V., Korgin, N. & Novikov, D. (2013). *Mechanism Design and Management: Mathematical Methods for Smart Organizations*. New York, USA: Nova Science Publishers.

4. Mas-Colell, Andreu, Michael Dennis Whinston, and Jerry R. Green (1995) *Microeconomic theory. Vol. 1*. New York: Oxford university press.

5. Bolton P., Dewatripont M. *Contract Theory*. – Cambridge: MIT Press, 2005. – 740 p.

6. Harsanyi J. (1967, 1968) *Games with Incomplete Information Played by "Bayesian" Players* // Management Science. Part I: 1967. Vol. 14. № 3. P. 159 – 182. Part II: 1968. Vol. 14. № 5. P. 320 – 334. Part III: 1968. Vol. 14. № 7. 486–502.

7. Maschler M., Solan E, Zamir S. (2013) *Game Theory*, Cambridge: Cambridge University Press, 1008 p.

8. Salanie B. (2005) *The Economics of Contracts. 2nd Edition,* Massachusetts: MIT Press. – 224 p.

9. Burkov V.N., Lerner A.J. (1971) *Fairplay in control of active systems. Differential games and related topics*, Amsterdam: North-Holland Publishing Company, 325–344.

