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Simulation modelling of complex distribution systems

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Abstract

In many lines of business distribution enterprises take over the burden of synchronization of the demand and supply aspects of the supply chain. Their part increases especially on very dynamic markets, with variable demand and a short product life cycle. Then one of the strategy is to postpone production and shift its last stage from the part of industrial companies to distributional enterprises. The article will discuss the issue of network configuration for the needs of complex realization of non-standard orders. The investigation has been conducted on the basis on enterprises designing interorganizational relations in networks of cooperating enterprises.

Selection and/or peer-review under responsibility of the Organizing Committee.
Keywords: simulation modelling, distribution networks, dynamics of management systems, cooperation

1. Introduction

Cooperation in supply networks is perceived by many distribution companies as a chance for more efficient adaptation to changes in the environment. Its role in the distribution of products increases especially on very dynamic markets with variable demand and a short product life cycle. It is so because an adequate strategy for such markets is the postponed production strategy and a shift of the last stage of production from the part of manufacture companies to distribution companies. The article discusses the meaning of cooperation from the perspective of a distributional company for the needs of extensive completion of uncertain orders. The research was carried out into the metallurgic products distribution sector. Attention was focused on distributors fulfilling the tasks of a traditional warehouse extended by the tasks connected with postponed production: longitudinal cutting (ripping) and cutting off (cross-cutting), bending. In the management literature these subjects are often called integrators, yet in the metallurgic business they are defined as Service Centres. Therefore the basic company (integrator) will be understood as a subject which links its own resources and specialized foreign resources and competences for a specified time or for the execution of a specific activity (Carvalho and Powell 2000). Simultaneously a characteristic trait of the integrator model which is well-known from the management literature (Czakon 2010, Schweizer 2005) is completion of different processes in a value added string, including production, transport and warehouse processes. Service centres in the distribution network of metallurgic products, which shape network relations, can be defined as network integrators. The authors selected for simulation modelling a representative of metallurgic business

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distributors which is the strongest in fulfilling the criterion of a network integrator in respect of diversification of the completed processes, the number of relations established in a distribution network and the tonnage of products going through the Service Centre. Therefore this subject completes tasks connected with postponed production and in this area it undertakes cooperation with other participants of the distribution network realizing functions which are complementary or substitutional in relation to the integrator. The aim of the discussion presented in the article was to indicate the meaning of cooperation in order to gain substitution resources regarding the resource decisive about efficient order completion taking into account two types of cooperation: formal and informal. The simulation modelling presented in the article concentrates on investigating the efficiency of acquiring substitutional resources regarding to the resource of the integrator which is characterized with productive abilities insufficient to fully satisfy the needs notified by the customer depending on the demand fluctuations. The objective of modelling was to find an effective form of cooperation depending on demand fluctuations and a possibility of executive resources of the integrator and the co-operator.

Simulation modelling presented in the article focuses on gaining substitutional resources in relation to the supply of an integrator which is characterized with productive abilities insufficient for full satisfaction of the needs reported by the customer.

Distribution networks were characterized in Chapter 2 as Complex Adaptive Systems and for the needs of modelling Chapter 3 one justified the dynamics of management systems. Chapter 4 includes simulation experiments and a discussion on findings.

2. Distribution networks as complex adaptive systems

In 2001 the article by Choi, Dodey and Rungtusanathnam (2001) initiated a discussion over the possibility of using the CAS (Complex Adaptive Systems) theory in a study over the structure of supply networks, taking into account the need of efficient adaptation to changes in the environment. The authors underlined in their publication that the contemporary supply chains management requires adaptation to changes in complex global organization networks. This trend is further considered by Pathak et al. (2007) as well as Nairas A., Narasimhan R. and Choi T. (2009). Pathak et al. analyse how CAS foundations can be applied in modelling of complex and adaptive structures of supply networks, including in these considerations adaptation on the level of a single company, the buyer-supplier relation, the structure of the whole supply network, changes in the environment and the feedback mechanism. Thus the authors indicate limitations of traditional solutions dedicated to integrated supply chains especially in very dynamic market conditions characterized with a large uncertainty of demand. In their research they indicate how the development of CAS for the needs of a supply network can assist the SCM discipline.

Enterprises organizing distribution networks show adaptability and can function in complex network environments with many types of relations. In connection with such a characteristic of a distribution network one can treat it as a complex adaptive system (CAS). Distribution networks realizing postponed production tasks considered in the CAS category (Choi et al., 2001; Surana et al., 2005; Pathak et al., 2007) are a collection of production and logistic nodes connected with relations showing adaptive activities in response to changes in the environment and in response to changes in the system of nodes themselves. These activities include both reaction in individual nodes and in relations between them. Therefore these nodes can evolve in time in accordance with the organizational instruction, including especially as regards changes of the type of interorganizational relation. The property of a supply network treated as CAS - a simultaneous reaction on the level of patterns of attitude of individual organizations and on the level of relations established between the nodes - it makes changes in the environment cause non-linear reactions of the network as a system. Hence, as noticed by J. Stewart (1996) a slight change in the environment can cause very strong changes in the system or, on the contrary, a strong impulse of a change in the environment can cause slight changes in the network. Pathak et al. (2007) argue that despite that fact a suitable analysis can provide certain knowledge on the pattern of factors of attitudes (antractor) which are presumable to develop in the system in time.

Choi et al. (2001) indicate that a supply network as CAS can react to changes in the environment also through exchange of individual nodes. It is so because environmental factors can cause changes to which some nodes will not be able to adopt.

Therefore the concept of the research is directed towards essential aspects connected with problems of adapting to changes in the environment from the perspective of a chain link of a supply chain responsible for the completion of distributional tasks taking into account tasks of postponed production. The concept of postponed production was originally considered in the marketing literature (Anderson 1950), and then in the strategic management and logistics literature (Eppen & Schrage, 1981; Federgruen & Zipkin, 1984; Jackson, 1988; Schwarz, 1989; Leahs 1996, Grang & Tang, 1997). Postponed production, also called delayed differentiation (Avir & Federgruen, 2001), is regarded as a strategic mechanism aimed at reducing the risk connected with a multitude of variants of products and sale uncertainty. The analytical models developed in the mentioned literature items concentrate on investigation of the advantage of delayed differentiation. This article assumes that the advantages of such a strategy in this line of business are considerable and those companies which can execute such a strategy in the distribution sector have stronger market positions than traditional warehouses. It is confirmed by the ranking of steel distributors, where the top thirty companies as regards tonnage and profit include service centres and steel yards, so they are distributors completing delayed differentiation tasks as regards flat and long products. The degree of adaptability of companies in the distribution sector is influenced by endogenic factors connected among other things with possessed resources and established relations. Research carried out into the metallurgic products distribution sector indicate two main motives of establishing cooperation: gaining rare resources in order to perform complementary tasks with relation to tasks completed on the basis of the integrator's resources and gaining substitutional resources with relation to the integrator's supply. This supply has insufficient production capacities for complete satisfaction of needs reported by the customer, consequently it is a bottleneck in the process of completion of orders. The research presented in the article considers the second from the presented cases.

Relations established in distribution networks are very complex. Hence it is so essential to select key attributes of interorganizational relations in the network. Autry and Griftis (2008) in their own research evidenced various typologies of interorganizational relations and presented a concept of classification of relations based on the length and the frequency of their duration. Simultaneously the collective work edited by Witkowski (2005) draws one's attention to types of networks depending on the range and the duration of a relation, where virtual, pulsating, dispersed and integrated networks were distinguished. Virtual networks refer to a relation with a short time horizon and a slight range of cooperation limited to information exchange. Pulsating networks are created are established for a strictly specified time resulting from the assumptions of a project which the partners develop together. Dispersed networks result from common exploitation of a specified type of resource by two or more partners. Therefore the time horizon is long but the range of cooperation is limited to this resource. Relations with the longest time horizon are characteristic for integrated networks which simultaneously embrace the greatest range of companies' cooperation. Moreover, numerous studies into interorganizational relations (Harrigan,1988), indicate that the degree of formalization of a relation is an essential attribute. Following the literature on strategic alliances one can consequently indicate relations based on informal agreements and bonds built through cooperation contracts and partial takeovers. In the carried out simulation networks of independent companies were treated as especially interesting. Hence the researchers excluded purchase and concentrated on informal cooperation (also often referred to in the literature as loose links) and cooperation based on cooperation contracts.

Golic and Mentzer (2006) prove that the power of relations is directly correlated with the results on the business level. Autry and Griftis (2008) notice that on one hand dominant strong relational bonds raise the value in the assessment of the chain of deliveries, but on the other hand other types of relations (based on weaker links) are important for considering the growth of elasticity of the logistic system both in the area of supply, production and distribution. Summing up it can be ascertained that relations which are created by organizations in a network differ primarily with the time, the intensity and the degree of formalization. Relation attributes such as intensity and duration of a relation are not sufficient to define the degree of the availability of the resource of the cooperator for the base company to complete a task. The attribute which enables such an interpretation of a relationship is the degree of formalization.

3. Modelling of cooperation in a supply network

Simulation modelling in supply chain management (SCM) touches different problems from resource modelling, through simulation of transportation and warehouse costs, simulation of material flows and many other aspects. Hence different types of simulation models are used. Three most popular classes are the Dynamics of Management Systems, Agent Base Modelling and simulation of Discreet Events. In certain publications authors combine different models in order to obtain a more extensive effect. Rabelo et al. (2008) proposed a methodology allowing one to identify reasons which stimulate the system behavior other than the forecast one. The dynamic model of a supply chain is developed using simulation based on Systems Dynamics. The neural network is trained in order to systematically forecast changes in attitudes based on earlier stages of decision making, which provides a company with an opportunity to prepare a reaction to different unforeseen situations. However, Eigenvalue's analysis is directed towards identification of unforeseen attitudes where the stability rules and inspection possibilities are used for teaching several configurations of decisions which eliminate or stimulate certain attitudes. The researchers underline that the attitude of a supply chain is dynamic and runs according to non-linear internal reactions and interactions (Szapiro, 2001). Small changes in the level of the customer's needs can, for instance, cause disproportionately big fluctuations and transfer to all chain links of a supply chain. Rabelo et al. (2008) analysed the attitude of a supply chain in three phases: the use of systems dynamics, analysis, identification and categorization of factors of changes, variabilities of system parameters for different states, identification of potential possibilities for modification in a supply chain system in reference to reduction or stimulation of unstable attitudes. Variants of investment decisions into the production and logistic infrastructure which provide a basis for the research presented in the article, are considered among other things through the use of newsvendor networks including resources community as well as flexibility, substitutionality and reloading (Van, Mieghem, Rudi, 2008). By including network cooperation and variants of a company's own flexible resources and resources of specialized partners the authors investigated possibilities of transfer and combination of resources for better responding to uncertain events. Consequently, this is an assumption similar to the one considered in the article, however, other methodology of research is applied. Similarly as in the model presented in the article the authors considered dynamic optimization of the cooperative policy and own abilities according to the lost sales criterion.

From among the mentioned simulation methods, taking into account the formulated exploratory problem, special attention was drawn on simulation with the use of the Dynamics of Management Systems. Simulation of the results of potential decisions requires creating cause and effect models and carrying out specific experiments on them. Systems dynamics in management sciences was began by Forrester (1958) and then propagated by Senge (1990). They noticed in their own works that the structure of feedbacks generates patterns of attitudes. Difficulties in finding cause and effect relationships are connected with the fact that the results of activities often arise after a certain period of time, which makes it difficult to identify the reasons. The system dynamics involves its changing with time. Therefore, when investigating the dynamics of a distribution network as a complex adaptive system one ought to find answers to similar questions posed for a traditional management system (Rokita, 2009):

- Is the system changing and are these changes possible to perceive? (e.g. two system states in a determined time span)
- Is the shift between these states characterized with constant and monotonous movement or not?
- Is it foreseeable or not?

The dynamics of management systems uses a specific method of system description on the basis of two categories: the stream and the level. The levels represent variables of the state which are observable quantities of the system, and the streams (actions) of the system cause changes in the values of the levels. The mentioned categories of description are indispensable for creating a microstructure of a loop of couplings and thus the whole system. In effect it is useful to introduce certain additional category of description called an auxiliary variable. Variables represent indirect stages of the process of defining the value of intensities of streams according to the accepted rules (decision policies) transforming information about the state the system and its environment.

Decision rules describe manners of making decision which operate flows in the system, so they show which information of the state of the system and its environment generate decisions causing activities in the system. In a classical dynamics of management systems it is assumed that decisions in the system are undertaken periodically, it is each time after a determined period of time. So, the processes of decision making and consequently their effects (changes in the values of streams intensities) have a continuous character. The form of decision rules is determined among other things by social and economic, technical and organizational factors.

4. Simulation modelling of cooperation in a distribution network of metallurgic products - model building, simulation results

In simulation modelling presented in the article the authors concentrated on gaining substitutional resources in relation to this integrator resource which is characterized with productive abilities insufficient for full satisfaction of needs notified by the customer. This resource is gained through cooperation. The model also takes into consideration the lead time at the warehouse of the co-operator taking into account the time of delivery and completation of the order, which fluctuated within 1 week. An essential trait of the shaped relations was the degree of formalization of cooperation taking into account two most popular forms of establishing cooperation in this line of business: formal cooperation based on cooperation contracts and informal cooperation. The questionnaire survey indicated the relation type significantly influences the availability of the resource of the partner. The simulation model reproduced the type of relation as a variant across the deterministic variable and the random variable defining the availability of the resource of the cooperator for the needs of tasks completion by the integrator. The model refers to an integrator realizing postponed production. Hence the reported demand (inflowing orders from a customer) is the basis for fixing the production budget which directly controls the manufacturing process. Depending on the size of the inflowing orders, taking into account the supply limit (100 tons) and the stock level of finished goods, cooperation is actuated. The fundamental aim is full completion of orders inflowing to the company in an appointed temporary standard not exceeding 3 weeks. Consequently thereby reduction of lost sale is endeavored.

The order processing process taking into consideration the resource of the co-operator is actuated after inflow of orders exceeding the warehouse stock level and the company's resource capacity. Depending on the type of cooperation, an order is processed by the co-operator either in compliance with arrangements included in the cooperation contract (resource availability on the level of 30 tons) or, in case of informal cooperation, in compliance with currently available production powers (resource availability is a random variable). In both cases the order is sent to the integrator's warehouse after earlier completation. In case of a co-operation contract the minimum quantity of supply was determined on the level of 30 tons. Informal cooperation allows one to execute a delivery from 10 tons.

Simulation modelling was carried out in the Vensim program. Vensim is one of several most widespread programs for modelling the systems dynamics. It enables model building and carrying out a number of experiments and forming conclusions. It can model variables of different probability distributions and include elements of the game theory.

The conducted experiments involved changing the value of variables of the model (quantities of flowing orders and demand fluctuations). The model was used for an experiment which involved changing the values of the model variables. The initial values which were taken into consideration in the experiments were determined on the basis of questionnaire survey executed in 2010 in the distribution sector of metallurgic products in Poland and statistical trade data. The modelling takes into account two from among three states of demand variability according to Pareto's Principle: stable demand (variability within <0-20%>), unstable demand (variability within (20-50%>). The study did not take into account the variability state - demand completely unstable with fluctuations exceeding 50%, because such states of the system were not observed in the actual data. The researchers analysed the level of utilization of resources and assumed that the limiting values of the utilization of resources which are a motive for establishing cooperation is at least 80% of the utilization of resources.

Modelling phases:

1. Questionnaire survey and analysis - The statistical analysis revealed essential elements influencing efficient completion of the customer's orders: Postponed Production (PP), Finished Products Warehouse of Integrator (FPWI), Sale (S), Lost Sale (LS), Maximum Manufacturing Capacity of the resource of the Integrator (MMCI), Productions Cycle (PC), Order Processing Lead Time (OPLT), Plan of customers orders (PCO), Production Cycle at the Co-operator (PCC), Transport Lead Time co-operator - integrator (TLT), – Maximum Manufacturing Capacity of the resource of the Co-operator (MMCC), Finished Products Warehouse of Co-operator (FPWC), Customers Demand (CD), Co-operators Production (CP), as well as relationship between the investigated variables. The statistical analysis concerned data gathered in 2010, the simulation modelling carried out in subsequent stages aimed at investigating experimentally how the system would behave in case of variability of some parameters (demand, availability of the resource of the co-operator resulting from the cooperation contract or informal cooperation).
2. Building a simulation model (fig. 1) based on essential elements obtained as a result of the analytic study, taking into account the relationships obtained in phase 2 (the relation of efficiency of each form of cooperation depending on demand fluctuations, the relation between the level of utilization of the resource of the co-operator and the demand fluctuations, the relation between productive powers of the integrator and those of the co-operator and the availability of the resource of the co-operator)
3. Conducting experiments aimed at finding an answer to the question: How will the relations change between the variables as established in phase 2 of the study depending on demand changes in time (the variability of demand was a random variable described by an expression: RANDOM UNIFORM (80, 90, 85). Depending on the presented states the study involved two forms of cooperation where the efficiency was presented in the form of unfulfilled sale. The experiments were conducted through changing the parameters of the volume of demand and the varied degree of demand fluctuations in a given time. It was investigated to which extent

concise executive possibilities of the integrator and the co-operator enable the fulfilment of a middle-sized demand, one also changed disproportions of executive possibilities between the integrator and the co-operator.

The objective of the modelling was to find an effective form of cooperation depending on demand fluctuations and the possibility of executive resources of the integrator and the co-operator

Where:
PP - Postponed Production
FPWI - Finished Products Warehouse of Integrator
S - Sale
LS - Lost Sale
MMCI - Maximum Manufacturing Capacity of the resource of the Integrator
PC - Productions Cycle
OPLT - Order Processing Lead Time
PCO - Plan of customers orders
PCC - Production Cycle at the Co-operator
TLT - Transport Lead Time co-operator - integrator
MMCC - Maximum Manufacturing Capacity of the resource of the Co-operator
FPWC - Finished Products Warehouse of Co-operator
CD- Customers Demand
CP – Co-operators Production

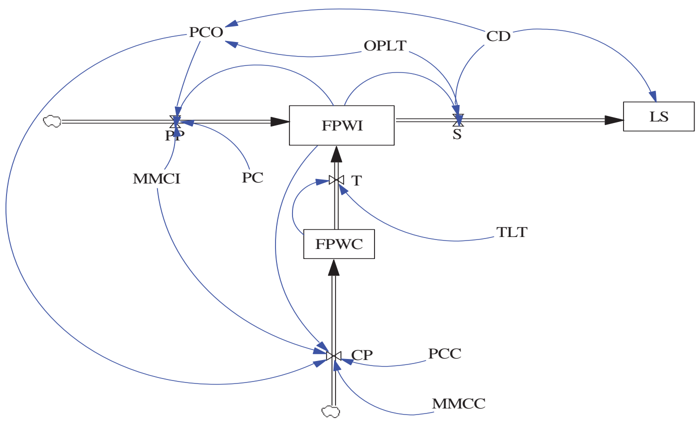


Figure 1 The model of the integrator – co-operator cooperation

Limitations adopted in the model:
OPLT – Order Processing Lead Time; OPLT = PC + TLT +PCC = max 3 weeks
PC – Productions Cycle
TLT – Transport Lead Time Co-operator - Integrator
PCC - Production Cycle at the Co-operator
Variables:
CD – Customers Demand; CD = RANDOM UNIFORM(80, 90 , 85)Units: pcs/Week
PP – Postponed Production; PP = IF THEN ELSE(MMCI<=(PCO-FPWI)/PC, MMCI, (PCO-FPWI)/PC) Units: pcs/Week
CP – Cooperators Production; CP = IF THEN ELSE(MMCI>(PCO-FPWI)/PCC, 0, IF THEN ELSE (MMCC>(PCO-FPWI)/PCC, (PCO - FPWI)/PCC, MMCC)) Units: pcs/Week

Figures 2-7 show the course and the results of the experiments.

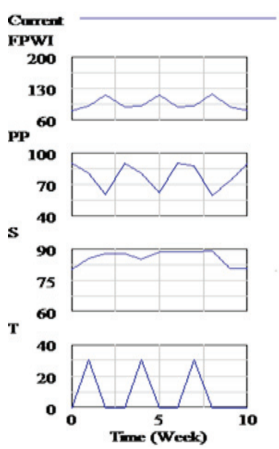


Figure 2 Unstable demand: a) cooperation contract

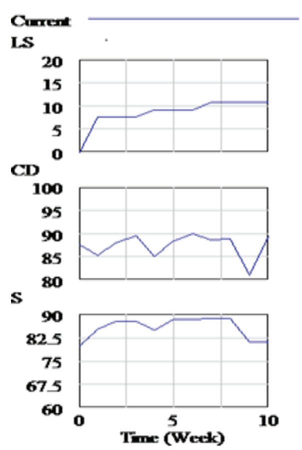


Figure 3 Unstable demand – no cooperation contract

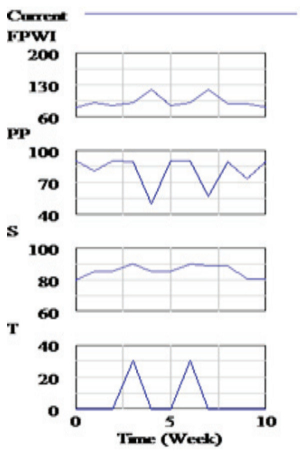


Figure 4 Stable demand – cooperation contract

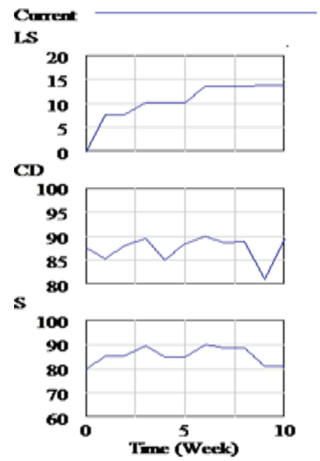


Figure 5 Stable demand – no cooperation contract

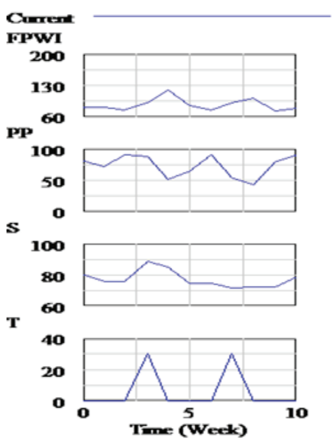
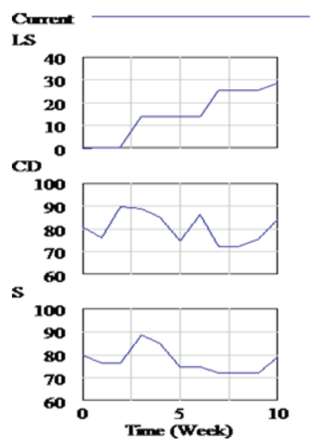


Figure 6 Unstable demand – no cooperation contract



Unstable demand – with cooperation contract

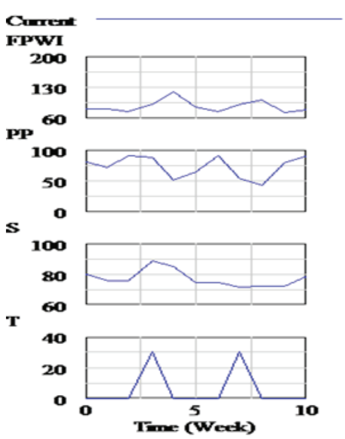
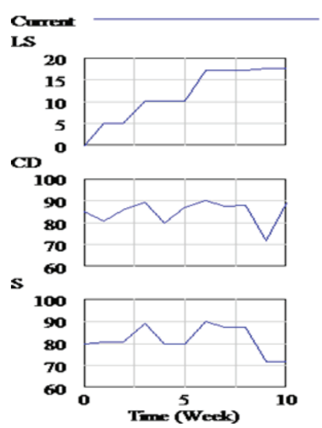


Figure 7 Stable demand – no cooperation contract



Stable demand – with cooperation contract

The course of experiments indicates that demand variability is accompanied by an increase in the significance of cooperation considering substitutional resources. With the assumptions adopted in the research formal cooperation always brings bigger advantages than informal cooperation. The possession of a cooperation contract guarantees an even load of the resources of the integrator. In the event of unstable demand lost sale for informal cooperation is higher than cooperation based on a cooperation contract. This is a result of the availability variable of the resources of the co-operator with whom no cooperation contract was concluded.

Lack of the cooperation contract results in large fluctuations in the utilization of the resource of the integrator with a slight lower average stock level of finished goods in the warehouse of the integrator. This state is distinct for stable demand. Unstable demand increases difficulties in adapting the integrator's productive powers both as regards the cooperation contract and informal co-operation. In the event of the cooperation contract and unstable demand the co-operator compensates demand fluctuations and deviations in the utilization of the productive powers of the integrator are smaller than in case of lack of the cooperation contract. In this variant the stock level of finished goods at the warehouse of the integrator is also higher in the event of the cooperation contract than informal cooperation. This state results from taking into consideration in the contract a cooperative minimum batch of supplies which is not obligatory in the event of the second type of cooperation.

5. Conclusions

Formal cooperation, which in the distribution sector of metallurgic products accounts for approximately less than 40 per cent of established relations, is profitable both in the situation of slight demand variability and unstable demand, where orders inflowing to the integrator exceed its production capacities. Loose relations among the system elements (informal cooperation) bring greater advantages in the event when companies face unpredicted situations, including large demand variability. The adopted limitations of the model did not allow showing the significance of informal cooperation with a smaller load of the resources of the integrator. The complexity of logistic systems in networks of cooperating companies allow combination of these two ways of establishing bonds, which on one hand enables maintaining stability and a relative equilibrium in the narrow area of organizations connected with strong bonds (with cooperative cooperation) and on the other hand, wide possibilities of flexible responsiveness owing to the loose association of the organization for the realization of tasks which are difficult to forecast or resulting from catching market opportunities.

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