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COORDINATION IN SUPPLY NETWORKS

Abstract

The paper is devoted to modelling and analysis of supply systems. Supply chain management is more and more affected by network and dynamic business environment. In supply chain behaviour are inefficiencies. Coordination and cooperation can significantly improve the efficiency of supply networks. There are some approaches to model and analyze the supply dynamics. Important features of this environment are established in the proposed approach. The combination of network structure modelling and simulation of dynamic behaviour of units in supply network can be a powerful instrument of performance analysis of supply networks. The problem of coordination in dynamic supply networks involves multiple units with multiple goals. Simulation approach is an appropriate tool for prediction of real supply situation. Information and communication technologies are appropriate instruments for performance improving.

Keywords

Management (K.6), electronic commerce (K.4.4), communication networks (C.2), simulation and modelling (I.6), contracts (K.5.m)

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ACM classification

K.4 COMPUTERS AND SOCIETY, K.4.4 Electronic Commerce, K.6 MANAGEMENT OF COMPUTING AND INFORMATION SYSTEMS, C.2 COMPUTER-COMMUNICATION NETWORKS, I.6 SIMULATION AND MODELING

JEL classification

L8 – Industry Studies: Services, L81 – Retail and Wholesale Trade; e-Commerce, L86 – Information and Internet Services; Computer Software, C1 – Econometric and Statistical Methods: General, C15 – Simulation Methods

INTRODUCTION

Supply chain management has generated a substantial amount of interest both by managers and researchers. Supply chain management is now seen as a governing element in strategy and as an effective way of creating value for customers. There are many concepts and strategies applied in designing and managing supply chains (see Simchi-Levi et al., 1999). The expanding importance of supply chain integration presents a challenge to research to focus more attention on supply chain modelling (see Tayur et al., 1999).

The analysis and design of the supply chains has been an active area of research. Supply chain management is more and more affected by network and dynamic business environment. The overall business environment is becoming increasingly dynamic. Demand and supply for custom products can be very dynamic. Supply chains operate in network environment as supply networks. Dynamic information and decision-making models are called to accommodate this new changes and uncertainties. Managing of supply networks is now seen as a very strong competitive advantage.

The paper presents some inefficiencies in supply networks and some instruments for reducing the effects by information sharing and coordination of actions. One of the most costly aspects of supply networks is the management of inventory. The importance of inventory management and the need for the coordination of inventory decisions has been evident for a long time. Order quantity is a very important factor in inventory management. In the paper we show some examples and approaches for optimal assessment of order quantity for the whole supply chain. The problems of double marginalization, applying the economic order quantity and risk pooling in supply networks are presented.

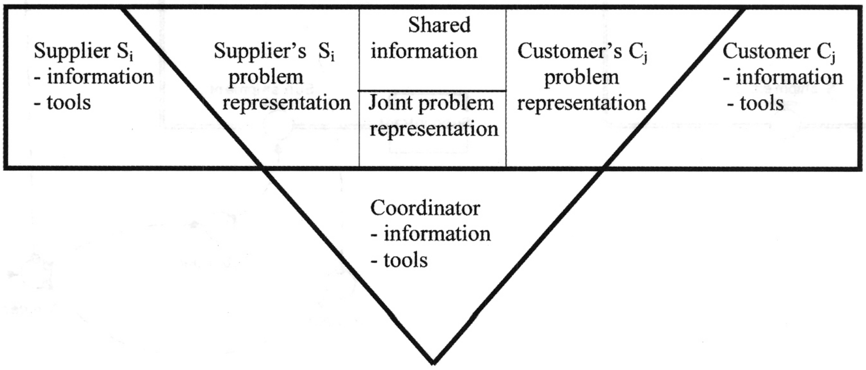
1. SUPPLY NETWORKS

A structure of supply networks is composed from potential suppliers, producers, distributors, retailers and customers etc. The units are interconnected by material, financial, information and decisional flows. Most supply networks are composed of independent units with individual preferences. Each unit will attempt to optimize his own preference. Behaviour that is locally efficient can be inefficient from a global point of view. In supply network behaviour are inefficiencies. An increasing number of companies in the world subscribe to the idea that developing long-term coordination and cooperation can significantly improve the efficiency of supply networks and provide a way to ensure competitive advantage. Once traditionally driven by pure competition, the supply chain for many successful firms has matured from an adversarial relationship to one of supply chain partnership (MacBeth & Ferguson, 1994, and Thomas & Griffin, 1996). The relationship is created to increase the financial and operational performance of each chain member through reduction in total costs, reductions in inventories throughout the supply chain, and increased levels of shared information. The partners are looking to work cooperatively in providing improved service, technological innovation, and product design. Among the solutions, supply chain contracts, which have drawn much attention from the researchers recently, are used to provide some incentives to adjust the relationship of supply network partners to coordinate the supply chain. Contracts are evaluated by desirable features as coordination of the supply chain, flexibility to allow any division of the supply chain's profit, easy to use.

System dynamics is concerned with modelling of complex economic systems. It allows policy experimentation in time simulation environment with help of causal models of the systems. Supply networks are dynamic multilevel systems with sets of suppliers, manufacturers, distributors, retailers and customers. The multiple decision-makers are interconnected with dynamic structures and dynamic linkages by material, financial, information flows and decision flows. There are some approaches to model and analyse the supply chain dynamics.

The problem of coordination in dynamic supply networks involves multiple units with multiple goals. Goals can be divided into two types, goals that are mutual for all the agents and goals that are different and require cooperation of multiple agents to achieve a consensus. A cooperative decision making requires free communication among agents and gives synergical effects in a conflict resolution. The basic trend in the cooperative decision making is to transform a possible conflict to a joint problem. Coordination of actions can be provided through information sharing (Fiala, 2005) between suppliers and customers (schematically see Fig. 1). A supplier S_i and a customer C_j have information and analytical tools for their problem representations. A coordinator helps by communication through information sharing and by formulation of a joint problem representation.

Fig. 1 **Coordination through information sharing**



2. SYSTEM DYNAMICS

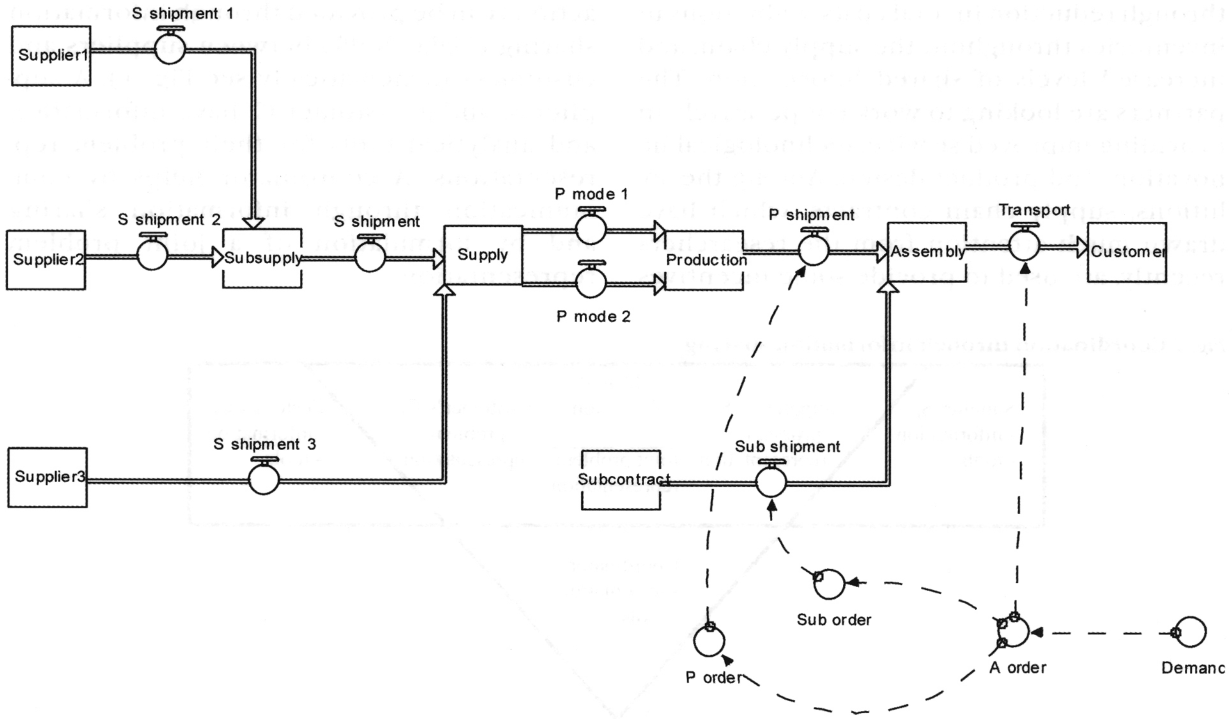
System dynamics is concerned with problem solving in living systems (see Forrester, 1961). It links together hard control theory with soft system theory. System dynamics needs relevant tools from both ends of the systems spectrum. If the possible causal factors are identified and their respective contribution to the overall dynamics are quantitatively measured and benchmarked, then it would be conducive to performance improvement by eliminating or reducing the relevant dynamics. Systems of information feedback control are fundamental to all systems. Feedback theory explains how decisions, delays and predictions can produce either good control or dramatically unstable operation.

The supply chain dynamics (de Souza, Song & Chaoyang, 2000, Swaminathan, Smith & Sadeh, 1998) lead to the increase in the cost of the units and the whole chain. A feedback control system causes a decision, which in turn affects the original environment. In supply chains, orders and inventory levels lead to manufacturing decisions that fill orders and correct inventories. As a consequence of using system dynamics in supply chain redesign we are able to generate added insight into system dynamic behaviour and particularly into underlying causal relationships. This new knowledge can be exploited in the improved design, robustness and operating effectiveness of such systems.

The so-called bullwhip effect (see Lee, Padmanabhan, & Whang, 1997), describing growing variation upstream in a supply chain, is probably the most famous demonstration of system dynamics in supply chains. The basic phenomenon is not new and has been recognised by Forrester. There are some known causes of the bullwhip effect: information asymmetry, demand forecasting, lead-times, batch ordering, supply shortages and price variations. Information sharing of customer demand has a very important impact on the bullwhip effect.

The structure of supply chains and relations in among units can be modelled by different types of networks. AND/OR networks can be applied for modelling flexible and dynamic supply chains (see Zeng, 2001). The approach follows an activity on arc representation where each arc corresponds to a particular supply chain activity. Each activity has multiple performance criteria. Nodes

Fig. 2. **Supply network by STELLA software**



represent completion of activities and establish precedent constraints among activities. The initial suppliers without predecessors and end customers without successors are represented by nodes displayed as circles. Two types of nodes are defined to specifying prior activities. AND nodes are nodes for which all the activities must be accomplished before the outgoing activities can begin. OR nodes require at least one of the incoming activities must be finished before the outgoing activities can begin.

The STELLA software is one of several computer applications created to implement concepts of system dynamics (see Ruth & Hannon, 1997),). It combines together the strengths of an iconographic programming style and the speed and versatility of computers. The instrument is very appropriate to proposed modelling framework for dynamic multilevel supply network. As an example of dynamic problem a stochastic inventory problem can be analysed with the finite time horizon. AND/OR supply network consists of a structure of suppliers, different production modes, an assembly of components and production of an end product to a customer. We can describe the behaviour of the network decision-makers and propose a dynamic system that captures the adjustments of the commodity shipments and the prices over space and time. The bullwhip effect can be demonstrated by comparison of random customer demand and orders in different stages of the supply network by decentralised information. Centralised information of customer demand can reduce the bullwhip effect.

A multilevel network model was proposed (see Fiala, 2003). The model consists of: the material network, the informational network, and the financial network. The multiple decision-makers use multiple criteria as quantity, time and cost. The efficient frontier of solutions can be identified. This network model is appropriate for analysing of system dynamics. It can be formulated a broad class of dynamic supply network problems. Dynamic behaviour of orders, inventories, prices and costs at different stages of supply network can be analysed.

3. DOUBLE MARGINALIZATION PROBLEM

Double marginalization is a well-known cause of supply chain inefficiency (see Tayur et al., 1999). Double marginalization problem occurs whenever the supply chain's profits are divided among two or more firms and at least one of the firms influences demand. Each firm only considers its own profit margin and does not consider the supply chain's margin.

We consider a supply chain with a supplier and a retailer that sells a product. The supplier produces each unit for a cost c and sells each unit to the retailer for a wholesale price w. The retailer chooses an order quantity q and sells q units at price $p(q)$, assuming that $p(q)$ is decreasing, concave and twice differentiable function.

Centralized solution assumes a single agent has complete information and controls the entire supply chain (this is referred as the firs-best solution) to maximize supply chain profit

$$z(q) = q\,(p(q) - c)\,.$$

Solution of the problem we denote q^0.

Decentralized solution assumes the firms have incomplete information and make choices with the objective of maximizing their own profits. The retailer's profit and the supplier's profit are

$$z_r(q) = q\,(p(q) - w)\,,\ z_s(q) = q\,(w - c)$$

Solution of the problem we denote q^*.

If the centralized and decentralized solutions differ, investigate how to modify the firm's payoffs so that new decentralized solution corresponds to the centralized solution.

It can be shown that the retailer orders less than the supply chain optimal quantity ($q^0 > q^*$) whenever the supplier earns a positive profit and it holds

$$z(q^0) > z_r(q^*) + z_s(q^*)$$

Marginal cost pricing ($w = c$) is one solution to double marginalization problem, but the supplier earns a zero profit. A better solution is a profit sharing contract, where the supplier earns v $z(q)$ and the retailer earns $(1\text{-}v)\, z(q)$, for $0 \le v \le 1$. The wholesale price w is now irrelevant to each firm's profits and the supply chain earns the optimal profit.

4. INVENTORY MANAGEMENT

One of the most costly aspects of supply chains is the management of inventory. In the inventory management are many inefficiencies. In the paper are presented some examples and approaches how a coordination of actions brings benefit for the whole supply chain.

ECONOMIC ORDER QUANTITY

It is assumed that the producer produces a product for which demand is relatively predictable and stable. The classic Economic Order Quantity (EOQ) model is a simple model that illustrates the trade-offs between ordering and holding costs. The question is how is applicable the model for supply chains.

We suppose that a producer produces a product for which demand is stable and the producer operates in an Economic Order Quantity type of environment. The problem arises because the order quantity that is optimal for the producer may not be optimal for the supply chain as a whole. One possibility of problem solving is focused on coordination of supply quantity between members of the supply chain. To illustrate a benefit of coordination we show a simple example.

EXAMPLE

Suppose that a supply system is composed of two members, a supplier and a producer. The producer produces D = 1000 units of a product per year at a constant rate. The producer purchases a component for the product from an upstream supplier. The ordering cost is S_P = 500 for a order and the holding cost of one component is H_P = 10 per year. Total cost for the producer is

$$TC_P = \frac{Q_P}{2} H_P + \frac{D}{Q_P} S_P.$$

The optimal order quantity for the producer is given by EOQ formula

$$Q_P = \sqrt{\frac{2DS_P}{H_P}} = 316 \text{ units.}$$

The supplier produces a bath of components with a production setup cost of S_S = 1000. The annual setup cost is a function of the producer order quantity

$$TC_S = \frac{D}{Q_P} S_S.$$

Total cost for the whole supply chain is

$$TC_C = \frac{Q_C}{2} H_P + \frac{D}{Q_C}(S_P + S_S).$$

The optimal order quantity for the whole supply chain is given by EOQ formula

$$Q_C = \sqrt{\frac{2D(S_P + S_S)}{H_P}} = 548 \text{ units.}$$

We can compare the costs for optimal order quantity for the producer and the costs for optimal order quantity for the whole supply chain (see Tab. 1).

Tab. 1 **Comparison of costs**

	$Q_P = 316$	$Q_C = 548$
TC_P	3162	3652
TC_S	3165	1825
TC_C	6327	5477

The coordination of order quantity decreases total costs for the whole supply chain, but it is necessary to reallocate the costs between units of the supply chain.

RISK POOLING

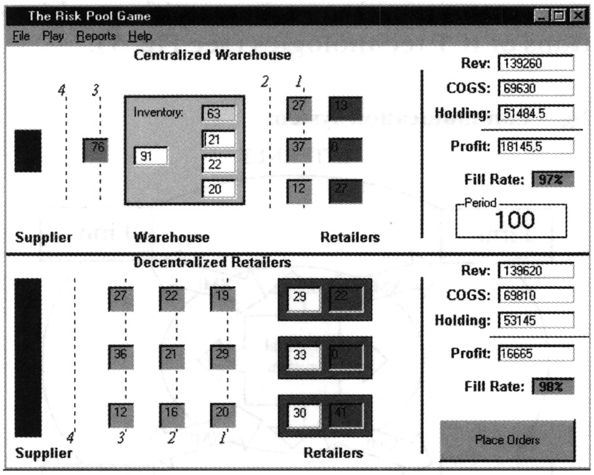
Risk pooling is an important concept in supply chain management (see Simchi-Levi et al., 1999). In a supply chain is a variable demand for a product. We analyze connections between a supplier and retailers and can compare a decentralized distribution system with a specific warehouse for each retailer and centralized distribution system with a warehouse for all retailers. Risk pooling concept suggests that demand variability is reduced by aggregation of demand. It becomes more likely that high demand from one retailer will be offset by low demand from another. The reduction of variability allows to reduce safety stock and therefore reduce average inventory. The reallocation of inventory is not possible in a decentralized distribution system where different warehouses serve different retailers. Benefit from risk pooling increases by higher coefficient of demand variation and by more negative correlation of demand by different retailers.

There is a computerized version of the risk pool game (see Simchi-Levi et al., 1999) to demonstrate effects of risk pooling concepts. The game proposes to compare a centralized system with a decentralized system by setting options:

- Initial inventories.
- Random demand parameters- mean, standard deviation, correlation.
- Inventory policy - safety stock policy, weeks of inventory policy.
- Costs- holding costs, revenue per item, cost per item.

The outputs are illustrated by reports. The screen of the Risk Pool Game see Fig. 3.

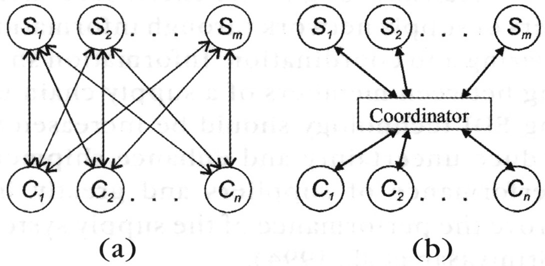
Fig. 3 **The Risk Pool Game**



4. SUPPLY CHAIN PARTNERSHIP

Supply chain partnership leads to increased information flows, reduced uncertainty, and a more profitable supply chain. The supplier-customer relations in supply chain can be taken as centralized or decentralized (see Fig.4).

Fig. 4 **Decentralized (a) and centralized (b) supplier-customer relations**



The decentralized system causes some inefficiencies in supply chains. The fully centralized system can be taken as a benchmark situation.

The strategic partnership means cooperation and coordination of actions through the supply system. The expected result is a mutually beneficial, win-win partnership that creates a synergistic supply chain in which the entire system is more effective than the sum of its individual parts.

The strategic partnerships change material, financial and information flows among participants in the supply chain. The way of information sharing is changed by information centralizing using information technology. The material flows are managed within the supply chain. In vendor managed inventory the manufacturer manages the inventory of the product at the retailer and does not rely on the orders by the retailer. The financial flows are changed also. The agents can benefit from coordination. The typical solution is for the agents to agree to a set of transfer payments that modifies their incentives, and hence modifies their behaviour.

The partnership relations are based on supply contracts. The contracts are evaluated by multiple criteria as time, quality and costs. There are different approaches to modelling multi-criteria negotiation processes to reach a consensus among participants. The problem of coordination in supply chains involves multiple agents with multiple goals. Goals can be divided into two types, goals that are mutual for all the agents and goals that are different and require cooperation of multiple agents to achieve a consensus. There are two very important aspects of group decision making: assertiveness and cooperativeness. Assertiveness is satisfaction of one's own concerns and cooperativeness is a tendency to satisfy others. A cooperative decision-making requires free communication among agents and gives synergic effects in a conflict resolution. The basic trend in the cooperative decision-making is to transform a possible conflict to a joint problem.

TYPES OF CONTRACTS

Contracts provide a means for bringing the decentralized solution to the centralized solution. Contracts also facilitate long-term partnership by delineating mutual concessions that favour the persistence of the relationship, as well specifying penalties for non-cooperative behaviour.

The contracts can be classified by clauses as:

- Specification of decision rights
- Pricing
- Minimum purchase commitments
- Quantity flexibility
- Buyback policies
- Allocation rules
- Lead time
- Quality

Pricing is often used principle to modifying the behaviour of parties. We consider a simple supply chain that consists of a single supplier and single buyer and three types of contract:

- One-part linear contract
- two-part linear contract
- two-part nonlinear contract

One-part linear contract consists of wholesale price (w), not depending on the order quantity q.

Two-part linear contract (w, S) consists of wholesale price w and side payment S from the supplier to the buyer, where both are independent on the order quantity q. When $S > 0$, the side payment can be interpreted as a slotting fee. When $S < 0$, the side payment can be interpreted as a franchise fee.

Two-part nonlinear contract $\{w(q),S(q)\}$ consists of wholesale price w(q) and side payment S(q) from the supplier to the buyer, where both are dependent on the order quantity q. Two-part nonlinear contract generalizes the one-part linear contract and two-part linear contract. It is sufficient to formulate the supplier's problem for the two-part nonlinear contract and analyze different types of contracts as special cases.

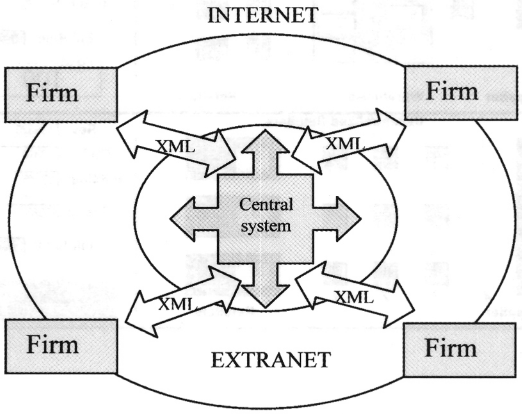
The types of contracts depend on amount of information. When there is complete information, the supplier knows the actual value of the buyer's internal marginal costs. When there is information asymmetry, the supplier does not know the actual value of the buyer's internal marginal costs.

The analysis of the simple cases of contracts gives recommendations for more complex real problem. Real problems in supply chains are solved by joint problem solving in supply chain partnership.

5. INFORMATION AND COMMUNICATION TECHNOLOGY

Managing of supply networks is now seen as a very strong competitive advantage. This has intensified with the development of information and communication technologies (ICT) that include electronic data interchange (EDI), the Internet and World Wide Web (WWW) to overcome the ever-increasing complexity of the systems driving buyer–supplier relationships (Gunasekaran et al., 2004). The complexity of supply networks has also forced firms to go for online communication systems. Supply networks use communication systems with combinations of ICT technologies (see Fig. 5).

Fig. 5 **Communication system**



For example, the Internet increases the richness of communications through greater interactivity between the firms and the customers. The Internet plays substantial role in building commercially viable supply networks in order to meet the challenges of virtual enterprises. There is beginning of an evolution in supply networks towards online business communities.

Supply chain management emphasizes the overall and long-term benefit of all members of supply network through information sharing and coordination. Information sharing between members of a supply chain using EDI technology should be increased to reduce uncertainty and enhance shipment performance of suppliers and greatly improve the performance of the supply system (Srinivasan et al., 1994).

CONCLUSIONS

The new very important features in supply systems are dynamic network structure, and cooperative decision making by coordination. Information asymmetry is one of the most powerful sources of inefficiencies in supply networks. The aim is coordination of units and managing supplier-customer relations also. Building of different types of strategic partnerships and different type of contracts among participants can significantly reduce or eliminate inefficiency in supply networks. The expected result is a mutually beneficial, win-win partnership that creates a synergistic network in which the entire network is more effective than the sum of its individual units. Supply network partnership leads to increased information flows, reduced uncertainty, and a more profitable supply network. The ultimate customer will receive a higher quality, cost effective product in a shorter amount of time. Supply network inventory management goes out the situation that supplies are usually operated by independent units with individual preferences. To be a supply network more efficient as a whole it is necessary to apply coordination techniques to manipulate the behaviour of one unit to the advantage of another. The Internet and other information and communication technologies have affected inventory management most dramatically in the ability to be proactive and cooperative in the management of inventory systems. The paper presents some examples and approaches for coordination and cooperation activities in supply networks.

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