Computers and Chemical Engineering 71 (2014) 116–129

Contents lists available at ScienceDirect

Computers and Chemical Engineering

journal homepage: www.elsevier.com/locate/compchemeng

Synchronous and asynchronous decision making strategies in supply chains

Nihar Sahay[a], Marianthi Ierapetritou[a,*], John Wassick[b]

[a] Department of Chemical and Biochemical Engineering, Rutgers University, Piscataway, NJ, United States
[b] The Dow Chemical Company, United States

ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 27 June 2014
Accepted 13 July 2014
Available online 4 August 2014

Keywords:
Synchronous and asynchronous decision-making
Supply chain management
Hybrid simulation based optimization

ABSTRACT

A supply chain is a network of entities involving an interplay of different individual behaviors. For an industrial scale supply chain, this network can be very complex. For a large scale supply chain, the structure is usually distributed with the different functions being performed both synchronously and asynchronously. A supply chain may consist of entities belonging to the same or different organizations. The behavior of the overall network evolves as a mixture of these synchronous and asynchronous business processes. In this work, we demonstrate the importance of capturing the synchronous and asynchronous decision-making strategies of different supply chain entities. We use agent based simulation models and embedded optimization models to study how the behavior of the network evolves as a result of the individual synchronous and asynchronous functions. Hybrid simulation based optimization is used to predict the optimal operation under the two scenarios.

1. Introduction

A chemical supply chain is a network of suppliers, production facilities, warehouses and markets designed to acquire raw materials, manufacture and store and distribute products among the markets. The individual entities in such a network have their own goals and objectives. A supply chain network may comprise entities belonging to the same or different organizations. Due to the way the different business processes operate and update information, there is often a disconnection between the physical actions of the entities and information. The different business processes have their own individual goals and objectives and operate on the basis of their own time-scales. Therefore, in an actual supply chain, it is not practical to synchronize the operations of all the processes. The overall operation of the supply chain, therefore, is a mix of synchronous and asynchronous processes.

In the case of real-world supply chains, it is impractical for a single decision maker to have access to all the relevant information and make decisions for the whole network. There are usually multiple decision makers who have access to their own sets of information and make their own independent decisions. These decisions are not synchronized and therefore the operations also take place at their own individual rates and times. Due to this asynchronous nature of operations, the individual decision makers make decisions based on the information available at those specific times.

Simulation models have been widely used to depict supply chain networks. The main idea behind using detailed simulation models is to be able to capture the true dynamics of the network. In a practical scenario, no supply chain operates completely synchronously or asynchronously. It is therefore essential for the simulation models to include the synchronicities and asynchronicities present in the network in order to capture the true dynamics. The way these models are coded is important to get the right set of results. Here is a brief description of some of the important works available in the literature related to modeling of synchronous and asynchronous processes.

2. Literature review

In a practical scenario, asynchronous decision making within a supply chain is quite common. There are quite a number of works which cover the distributed and asynchronous nature of decision making (Ghosh et al., 2000; Mathews et al., 2009; Burgoon et al., 2010; Soubie and ZaratÉ, 2005; Wang et al., 2004; Vakili et al., 2013; Ilcinkas and Pelc, 2008; Ghosh, 2001). We discuss some of those works related to modeling of synchronous and asynchronous processes, particularly related to supply chains. Carle et al. (2012) propose an agent-based metaheuristic to solve

* Corresponding author. Tel.: +1 8484454943; fax: +1 7324452581.
E-mail addresses: marianth@soemail.rutgers.edu, mierapetritou@gmail.com (M. Ierapetritou).

http://dx.doi.org/10.1016/j.compchemeng.2014.07.005
0098-1354/

Nomenclature

Indices

t	planning period
s	state
i	task
j	unit
n	event point
wh	warehouse
m	market
P	production site
sup	supplier
r	raw material
pr	product

Sets

T	planning periods
S	states
I	tasks
J	units
WH	warehouses
M	markets
PS	production sites
SUP	suppliers
R	raw materials
PR	products

Variables

$wv_{i,j,n}$	binary whether or not task i in unit j starts at event point n
$st_{s,n}$	continuous, amount of state s at event point n
$d_{s,n}$	amount of state s delivered at event point n
$b_{i,j,n}$	continuous, batch size of task i in unit j at event point n
r_s	requirement for state s at the end of the time horizon
$Tf_{i,j,n}$	time that task i finishes in unit j while it starts at event point n
$Ts_{i,j,n}$	time that task i starts in unit j at event point n
$C_r^{p,t}$	amount of raw material r consumed at production site p during time t
$D_{pr}^{wh,m,t}$	amount of product pr transported from warehouse wh to market m during time t
$D_{pr}^{p,wh,t}$	amount of product pr transported from production site p to warehouse wh during time t
$D_r^{sup,p,t}$	amount of raw material r transported from supplier sup to production site p during time t
$P_{pr}^{p,t}$	amount of product pr produced at production site p during time t
$U_{pr}^{m,t}$	backorder of product pr at market m at time t
$Inv_r^{sup,t}$	inventory of raw material r at supplier sup at time t
$Inv_{pr}^{wh,t}$	inventory of product pr at warehouse wh at time t
$Inv_{pr}^{p,t}$	inventory of product pr at production site p at time t
$Inv_r^{p,t}$	inventory of raw material r at production site p at time t

Parameters

h_{pr}^{wh}	inventory holding cost for product pr at warehouse wh
h_{pr}^{p}	inventory holding cost for product pr at production site p
h_r^{p}	inventory holding cost for raw material r at production site p
h_r^{sup}	inventory holding cost for raw material r at supplier sup
u_{pr}^{m}	backorder cost for product pr at market m
$VarCost^p$	production cost at production site p
$d_{pr}^{wh,m}$	transportation cost per unit product pr between warehouse wh and market m
$d_{pr}^{p,wh}$	transportation cost per unit product pr between production site p and warehouse wh
$d_r^{sup,p}$	transportation cost per unit raw material r between production site p and supplier sup
$stcap_r^{sup}$	inventory holding capacity for raw material r at supplier sup
$stcap_{pr}^{wh}$	inventory holding capacity for product pr at warehouse wh
$stcap_{pr}^{p}$	inventory holding capacity for product pr at production site p
H	time horizon
$\beta_{i,j}$	variable term of processing time of task i at unit j expressing the time required by the unit to process one unit of material performing task i
$\alpha_{i,j}$	constant term of processing time of task i at unit j
$v_{i,j}^{min} v_{i,j}^{max}$	minimum amount, maximum capacity of unit j when processing task i
$\rho_{s,i}^{p} \rho_{s,i}^{c}$	proportion of state s produced, consumed by task i, respectively
st_s^{max}	available maximum storage capacity for state s

large-scale multi-period supply chain network design problems. Using the concept of asynchronous agent teams (A-teams), they propose an efficient hybrid metaheuristic called Collaborative Agent Team (CAT). The generic model integrates design and modeling concepts and can be used to reengineer real-world supply chain networks. They compare the results for large-scale networks with those obtained with CPLEX. Tolone (2000) focuses on agility and time-based manufacturing as critical factors for manufacturing enterprises in today's world. He considers a multi-company supply chain planning and execution environment and emphasizes the importance of real-time and asynchronous collaboration technology in allowing manufacturers to increase their supply chain agility. They propose Virtual Situation Room technology to find and engage quickly the relevant members of a problem solving team. The members are supported by highly interactive access to information and control. They are enabled by business processes, security policies and technologies, intelligence and integration tools. Zheng et al. (2009) present a multi-agent architecture for SCM systems in which asynchronous teams (A-team) of agents exchange results and cooperate to give non-dominated solutions that show the tradeoffs between objectives. They consider the complex processes, objectives and constraints in today's supply chains and state that agent-based architectures for supply chain management are difficult to implement and maintain. Luh et al. (2003) focus on the issue of coordination of activities across a network of suppliers to quickly respond to market conditions. They combine mathematical optimization and the contract net protocol for make-to-order supply network coordination. The overall problem is decomposed into organizational sub-problems. Scheduling of activities by the individual organizations is based on their internal situations and inter-organization prices. Coordination is carried out in a distributed and asynchronous manner. Bond (1990) states that most work is organized, that is it is carried out by many people cooperatively solving a set of shared problems. He outlined his research in two areas, (i) cooperation in a vertical structure of an organizational hierarchy and (ii) horizontal cooperation among