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Decision support for integrated refinery supply chains
Part 1. Dynamic simulation

Suresh S. Pitty [a], Wenkai Li [a], Arief Adhitya [b], Rajagopalan Srinivasan [a,b,*], I.A. Karimi [a]

[a] *Department of Chemical and Biomolecular Engineering, National University of Singapore, 4 Engineering Drive 4, Singapore 117576, Singapore*
[b] *Institute of Chemical and Engineering Sciences, A*STAR (Agency for Science, Technology and Research), 1 Pesek Road, Jurong Island, Singapore 627833, Singapore*

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Abstract

Supply chain studies are increasingly given top priority in enterprise-wide management. Present-day supply chains involve numerous, heterogeneous, geographically distributed entities with varying dynamics, uncertainties, and complexity. The performance of a supply chain relies on the quality of a multitude of design and operational decisions made by the various entities. In this two-part paper, we demonstrate that a dynamic model of an integrated supply chain can serve as a valuable quantitative tool that aids in such decision-making. In this Part 1, we present a dynamic model of an integrated refinery supply chain. The model explicitly considers the various supply chain activities such as crude oil supply and transportation, along with intra-refinery supply chain activities such as procurement planning, scheduling, and operations management. Discrete supply chain activities are integrated along with continuous production through bridging procurement, production, and demand management activities. Stochastic variations in transportation, yields, prices, and operational problems are considered in the proposed model. The economics of the refinery supply chain includes consideration of different crude slates, product prices, operation costs, transportation, etc. The proposed model has been implemented as a dynamic simulator, called Integrated Refinery In-Silico (IRIS). IRIS allows the user the flexibility to modify not only parameters, but also replace different policies and decision-making algorithms in a plug-and-play manner. It thus allows the user to simulate and analyze different policies, configurations, uncertainties, etc., through an easy-to-use graphical interface. The capabilities of IRIS for strategic and tactical decision support are illustrated using several case studies.

Keywords: Supply chain; Dynamic model; Simulation; Refinery; Disruption management

1. Introduction

A supply chain (SC) is the system of organizations, people, activities, information, and resources involved in transforming raw materials into a finished product and delivering it to the end customer. Supply Chain Management (SCM) encompasses the planning and management of all activities involved in sourcing, procurement, conversion, and logistics to ensure smooth and efficient operations. SCM is an important element in enterprise management in this era marked by globalization (Srinivasan, 2007). SC optimization is a preferred way to reduce costs, improve performance, and manage the business amidst various uncertainties. A SC is typically characterized by forward flow of materials and backward flow of information. A hierarchy of decisions with large economic implications have to be made in a SC – strategic, tactical, operational, and ad hoc. Numerous decisions have to be made at the right time, despite uncertain information. Effects of these decisions range in the time-scale from order of hours to years. Each decision could be a function of other decisions. The difficulty in SC decision-making is further amplified by the complex maze of the network, geographical span of the SC, limited visibility, and involvement of varied entities with conflicting objectives. Clearly, decision-making in a SC has to be integrated and coordinated among likeminded entities participating in the SC so as to maximize benefits.

Geographically distributed exogenous events – occurring in the premises of SC entities (strikes, accidents) or elsewhere in the globe (terrorist attacks, earthquakes, hurricanes, etc.) – can

* Corresponding author. Tel.: +65 65168041; fax: +65 67791936.
E-mail address: chergs@nus.edu.sg (R. Srinivasan).

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Nomenclature

Indexes

- c types of crude oils
- d demand cycle
- f fraction of a processing unit
- i procurement cycle
- k position of a crude parcel in the parcel unloading sequence
- l production cycle
- p product; $p = G$, JF, D, FO indicating Gasoline, Jet Fuel, Diesel, and Fuel Oil, respectively
- r VLCC
- s supplier
- t time
- u, u' refinery processing unit; $u = C, D, R$ indicating the Cracker, CDU, and Reformer, respectively

Parameters

- AWT_r allowable wait time of VLCC r
- Cost_c mean cost of crude c
- Cost_{sc} cost of crude c from supplier s
- $\mathrm{Cost}O$ refinery operation cost
- $\mathrm{Cost}_c^{\mathrm{EC}}$ emergency procurement cost of crude c
- CT length of a production cycle
- DC length of a demand cycle
- D_p^{mean} mean demand of product p
- FIL forecast inaccuracy limit
- H planning horizon
- IMax_c maximum available capacity for crude c
- $\mathrm{InvCost}_c$ inventory cost for crude c
- $\mathrm{InvCost}_p$ inventory cost for product p
- LT_s lead time of supplier s
- Pdelay pipeline delay of a parcel
- PC length of a procurement cycle
- PenD penalty for demurrage costs
- PenP_p penalty for demand deficit of product p
- PenS penalty for CDU shutdown
- PM_{cp} production mode recipe
- PPV^c percentage of crude c price variation
- PPV^p percentage of product p price variation
- PR pump capacity
- Price_p mean price of product p
- PV pipeline volume
- $\mathrm{QI}_p^{\mathrm{seed}}$ random seed for QA_{dp}
- SA_{sc} amount of crude c that supplier s can provide
- SS_c crude safety stock parameter
- SS_p product safety stock parameter
- SVL seasonal variation limit
- TD_s transportation lag
- $\mathrm{TP}_{\min}$ minimum CDU throughput
- $\mathrm{TP}_{\max}$ maximum CDU throughput
- V_{tank} volume of each tank
- Y_p aggregate yield of product p
- Y_{cfu}^{assay} yield of fraction f from crude c for processing unit u obtained from crude assay data
- YO_p yield of the processing unit to convert off-spec product to on-spec product
- YV_u yield variation upper bound for unit u
- $\alpha_{\mathrm{occurence}}^{\mathrm{seed}}$ random seed for $\alpha_{\mathrm{occurrence}}$
- $\alpha_{\mathrm{magnitude}}^{\mathrm{seed}}$ random seed for $\alpha_{\mathrm{magnitude}}$
- $\alpha_{\max}$ upper limit for α
- β_p^{seed} random seed for β_p
- $\lambda_p^{\mathrm{seed}}$ random seed for λ_p
- μ_c^{seed} random seed for μ_c
- μ_p^{seed} random seed for μ_p
- $\tau_{\max}$ upper limit for τ

Variables

- AD_{dp} actual customer demand for product p at demand cycle d
- AT_{cr} arrival time of crude parcel c in VLCC r
- AT_k arrival time of kth parcel in the unloading sequence
- CostS_{is} procurement cost from supplier s at procurement cycle i
- CP_l crude amount to be processed at production cycle l
- CR_i total amount of crudes to procure at procurement cycle i
- CR_{ic} amount of crude c procured at procurement cycle i
- CR_{ics} purchase order of crude c to supplier s at procurement cycle i
- $\mathrm{CR}_{ic}^{\mathrm{EC}}$ amount of emergency crude c procured at procurement cycle i
- CR_{ip} amount of crude required to satisfy the demand for product p at procurement cycle i
- CSI_{dp} Customer Satisfaction Index for product p at due date d
- D_{dp} amount of product p dispatched by the refinery at due date d
- Def_{dp} demand deficit of product p at due date d
- DP_r demurrage period of VLCC r
- EX_{dp} excess product inventory of product p at demand cycle d
- EX_{ic} excess crude inventory of crude c at procurement cycle i
- FD_{dp} forecast demand of product p at demand cycle d
- $\mathrm{FR}_u(t)$ feed rate for processing unit u at time t
- $\mathrm{IC}_c(t)$ inventory of crude c at time t
- $\mathrm{IP}_p(t)$ inventory of product p at time t
- $L_{\mathrm{in}}(t)$ crude dispatched to shipper at time t
- $L_{\mathrm{out}}(t)$ crude output from shipper at time t
- $\mathrm{NSD}(t)$ occurrence of CDU shutdown at time t
- OSP_{lp} amount of off-spec product
- P_c actual crude price
- P_p actual product price
- $P_{\mathrm{in}}(t)$ pipeline input at time t
- $P_{\mathrm{out}}(t)$ pipeline output at time t