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A global optimization for sustainable multi-domain global manufacturing

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ABSTRACT

A multi-period and domain nonlinear optimization model is developed in this article. The model incorporates the design of forward–reverse manufacturing networks topology, product platform and operation capacity planning. The model takes into account the lead times and costs for each period of planning and is formulated as mixed integer nonlinear programming (MINLP). A two stages branch and bound (B–B) with cutting planes and under-estimators is proposed, which exploits the problem structure by solving problem relaxation at the first stage upper bound (UB) and generates cutting planes and under-estimators at the second stage lower bound (LB). The application in a three-echelon forward–reverse global manufacturing network shows that the proposed algorithm is capable of efficiently handling large scale and non-convex problem formulation in order to achieve a global optimum. Some important results from the model are presented in terms of their impacts on the sustainability of global manufacturing.

1. Introduction

Global manufacturing is an alternative solution to parent enterprises that enables them to reduce costs, increase revenues and improve reliability. However, substantial geographical distances in these global situations not only increase transportation costs, but complicate decision making due to inventory cost trade-offs that are the result of increased lead-times in the supply chain. A lack of infrastructures in developing countries diminishes the effectiveness of business processes and also potentially raises environmental problems such as carbon dioxide emissions into the atmosphere, as well as water contamination that are related to the capacity of proper waste reuse or the disposal thereof [13]. From time to time, the rate of consumption of non-recyclable raw materials continues to increase; in fact, at some levels such consumption happens to be higher than its replenishment. Therefore, a global environmentally responsible solution should be implemented as countries′ environmental initiatives. However, environmental initiatives in different countries provide different levels of potential success, which can affect said countries′ economic indicators [47].

In terms of problem complexity, environmentally conscious global manufacturing is more difficult to manage than local manufacturing [9,27]. In addition to economic dynamics across the globe, which includes the variability and uncertainty of currency exchange rates, economic and political instability [9], network topology is a crucial factor for reducing carbon foot-prints and at the same time, improves manufacturing competitiveness. Internally, such variability and uncertainty is likely to affect the entire decision making process, including those pertaining to product prices, delivery lot size, order interval and capacity investment. However, managing the mentioned risks will give a global manufacturing company a competitive advantage.

The research theme of this article is that of developing a dynamic and stochastic model of global manufacturing. The model aims to complement previous contributions related to integrated multi-echelon supply chain design with inventories under endogenous and exogenous uncertainties [45] by comprehensively approaching product design, manufacturing and logistics as a whole, rather than separate parts. The practical contribution of the model is illustrated by exhibiting the following properties: 1) multi-domain; 2) dynamic (multi-period); 3) has several sources of endogenous and exogenous uncertainties; 4) large scale and involves thousands of variables and decision making parameters. The solution methods available for these types of problems are still at relatively early stages of development [5] and their capabilities still limited, due to their potentially significant computational expenses [35]. Therefore, the solution method that combines branch and reduce technique [38] and interior point method [42] in order to handle a large scale model is the theoretical contribution made by this article. The linear assumptions of design, quality

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Notations

Indices

i	manufacturing domain index at country i, for $i \in N$
d	product domain index of design parameter $d \in DP$
$i1$	product domain index of product module at supplier country i, $i1 \in M$
t	period of planning, $t \in T$
h	production ramp up stage, $h \in H$
s	stochastic scenario, $s \in S$
v	index of vehicle $v \in V$
r	index of transportation route $r \in R$

Sets

Ω	feasible vehicle routings
A^r	transportation arcs
$G^r = (V^r, A^r)$	a set of binary network flows variable that has a unity value if there is a pairing from t to t' to configure a route r
$\rho^r_{ii'}$	feasible route and is included in the set of extreme points of $\forall p \epsilon \rho^r_{ii'}$ for direct routes and $\forall p \epsilon \rho^r_{ii1i'}$ for transshipped routes through location $t1$. Each route can be first $rfirst_{ii'} \epsilon \rho^r_{ii'}$ or last route $rlast_{ii'} \epsilon \rho^r_{ii'}$. Each r is composed by linking one location τ to another τ' in such a way that the combination of some feasible routes forms a single shortest path can be served by a vehicle $v \in V$. Thus each feasible route that is included into a certain path p can be rewritten as $Z^r_{tt'vt}$
$vlast_{trt}$	end route at a feasible route $\rho^r_{ii'}$
$N(i,i',i'')$	manufacturing domain set of operational sequence for supplier, manufacturer and distributor countries
$N(i1,i1',i1'')$	product domain set of operational sequence for for supplier, manufacturer and distributor countries

Parameters

$EX_{ii'st}$	U(0;0.1;0.5) of real, foreign exchange rate between two countries under sequence from i to i' under scenario s and period t
DUT_{is}	U(0;0.3) of real, import duty at country i and import duty scenario s
$yield_{ist}$	U(0.8;1.0) of real, production yield at country i and period t and scenario s
$\tilde{R}_{iht}$	target of production and material consumption ramp-up /0.0/
$TAX_{i't}$	U(0.2;0.3) of real, tax at country I' at period t
W_{T1}, W_{T2}, W_{T3}	U(1;3) of real, operations costs due to production ramp-up, production control and production target deviation
$fixedDesignCOST_{dm}$	U(200;400) of real, fixed cost related to the design of product design parameter d for product platform m
$VarDesignCOST_{dm}$	U(1;2) of real, variable cost related to the design of product design parameter d for product platform m
$shipcost_v$	(vehicle type 1: 300, vehicle type 2: 350) transportation cost using vehicle type v
$shiptime_{rv}$	U(1;30) of real, transportation lead time through route r by using vehicle type v
$MP_{i't}$	U(1;1.5) of real, market price at destination location I' at period t
DEM_{it}	U(100;300) of integer, demand at location i at period t
$PS_{mm'it}$	U(0;1) binary, product structure from module m to immediate module m' at location i and period t
$A_{mm'm''it}$	U(0.1;1) of real, pipeline inventory cost for the product structure with components sequence m,m',m'' at location i and period t
$q1_{mi}$	customer service level of manufacturing module m at location I /0.95/
h_{rv}	transportation time to deliver products from i to i', by using vehicle v through route r
$hmax_v$	U(500;600) of real, the maximum allowable ship time by using vehicle v
$Z_{rii'}$.	U(100;300) integer, the vehicle capacity to transport goods from location i to i' through route r
q	unit transportation cost for loading and unloading a vehicle / 1 /
$\theta1_{mm'it}$	U(0,1,1), annual unit cost of pipeline inventory from module m to module m'
$t1_{mm'it}$	U(1,7)(integers), order processing time of module m' if it is served by module m at location i and period t
$h1_{mit}$	U(0,0.5,1) unit inventory holding cost of module m at location I and period t
$\lambda1_{mit}$	0,96, safety stock factor of location i in producing module m at period t
$\sigma_{mm'it}$	U(0,50), daily variance of demand of module m at location i and period t
SIi	U(1,5) (integers), guaranteed service time of plant i
f_i	U(150, 160) fixed cost for installing a facility at location i
h1i	U(0,1,1) unit inventory holding cost at location i and period t
$S_{m'it}$	maximum guaranteed service time of module m' to immediate location from location i at period t, /0/
$GST_{m'it}$	maximum guaranteed service time of module m' to end customers from location i at period t, /0/
c1(a)	cost of a flight hour with type a
q	unit cargo cost for loading and unloading a transporter / 1 /
pc	unit penalty for undelivered cargo / 1300 /
$VMAX_{it}$	maximum number of landings allowed in i / 25 /
$PAYLOAD_v$	maximum payload of a vehicle v
$hmax_v$	U(500;600) of real, maximum shipping hours for transporter mode v
$hmin_v$	U(200;300) of real, minimum shipping hours for transporter mode v
$DPmax_{dmit}$	U(8;10) of real, maximum design parameter d of module m at location i and period t