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A best-matching protocol for order fulfillment in re-configurable supply networks

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ABSTRACT

Order fulfillment is a process which encompasses all the activities from the inquiry of goods by the customer to the final delivery of goods to the customer. The most important activity of the order fulfillment process is the selection of the order fulfilling agent in the supply network. The selection of the agent involves multiple criteria based on quantitative and qualitative metrics and requires several self-interested agents and organizations to dynamically form and configure supply chain. This article describes a methodology for selection of an order fulfillment agent in a collaborative, geographically distributed network by developing a Best Matching Protocol (BMP). The BMP developed, enables better matching of fulfillment agents with customers in a given supply network, by determining which agent best satisfies the pre-defined quality and cost requirements of the customer. The protocol enables collaboration between the agents of the Supply Network (SN) and provides a scalable solution for the increasing size of the SN.

1. Introduction

Computer and communication networks have changed the way in which humans interact with the world around them, enabling the emergence of new phenomena, e.g., social networking, and challenging the paradigm of traditional activities. Commerce, defined as any activity involving the sale or purchase of goods or services, is not impervious to the transformational force of these networks. Electronic commerce, or e-Commerce, emerged as a new activity enabling distributed agents in multiple supply networks to buy, sell, and exchange products or services using a variety of interconnected computer and communication systems. Over time, this new way of conducting business gained more popularity, mainly fueled by the expansion of Internet access and mobile technologies, the improvement of transaction security and privacy, and the shared benefits for all participants involved (e.g., lower prices and ease of use for buyers, higher profit with lower overheads for suppliers).

E-Commerce transaction and supply networks are highly complex. Sales operations encompass business-to-business (B2B) transactions (e.g., Staples), direct selling (i.e., suppliers selling products or services directly to customers, e.g., Wal-Mart, Best Buy, Dell, Home Depot), and indirect selling (i.e., suppliers selling products or services to customers through a third party such as Amazon or eBay). Sales are followed by order fulfillment decisions, i.e., defining which agent in a SN will ship products or provide services to a customer and selecting a delivery mode. Lawrence et al. [1] discuss five alternative configurations for order fulfillment: (1) pure e-channel, (2) manufacturer-controlled e-channel, (3) retailer controlled e-channel, (4) mixed e-channel, and (5) independent e-channel. In a pure e-channel, a manufacturer sells its products directly to its customers, fulfilling orders from its own supply network (SN). In manufacturer- and retailer-controlled alternatives, the controlling agent is responsible for managing the order fulfillment process, which is always executed from the retailer's SN. In mixed channels, manufacturers and retailers share control over the fulfillment process which is executed from either the manufacturer or the retailer SN. Finally,

Abbreviations: AHP, analytical hierarchy process; B2B, business-to-business; BFI, best fit index; BMP, best-matching protocol; DP, dynamic programming; EVM, economic value of a match; LP, linear programming; MIP, Mixed-integer programming; MP, Mathematical programming; MINLP, Mixed-integer non-linear programming; OFD, order fulfillment decisions; PRIO, parallel, re-configurable, inter-organizational SNs; PRIO-BM, best-matching-based protocol for parallel re-configurable inter-organizational SNs; SN, supply network; SSQA, supplier selection and quantity allocation.

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Nomenclature

a	SN agent
A	Set of SN agents
A^D	Set of demand agents
A^F	Set of fulfillment agents
$b_{a^*}[d_{a,i,t}]$	Bid submitted by agent a^* to fulfill order $d_{a,i,t}$
$b_{a^{OPT}}[d_{a,i,t}]$	Optimal bid selected in PRIO-BM
c	Bid cost
c^L	Lowest cost at which a^* is willing to fulfill $d_{a,i,t}$
c^H	Maximum price a customer is willing to pay for $d_{a,i,t}$
$C(\boldsymbol{q}^{s^*}, S^*)$	Set of constraints of a mathematical program
$d_{a,i,t}$	Order placed by agent a for product i at time t
$dist(a^*, a)$	Distance between agent a and α^*
$f_{BMP}(\boldsymbol{X})$	Objective function in a best-matching problem
$f_{LW}(w, \boldsymbol{q}^s)$	Evaluation function in a linear weighing decision
$f_{MP}(\boldsymbol{w}, \boldsymbol{q}^s)$	Objective function of a mathematical program
L	Set of links among agents in A
lt	Leadtime requested in a bid
O_τ	Set of orders $d_{a,i,t}$ placed over τ
p_{a^*}	Penalization to agent a^* for lack of execution
$\boldsymbol{q}^s$	Vector of performance measures q_i^s for supplier s
q_i^s	Performance measure i for supplier s
qty	Quantity ordered
$r_{a,i,t}$	Requirements for order $d_{a,i,t}$
s	Supplier
S	Set of suppliers s
S^*	Set of optimal suppliers s selected by some policy
$SN(A, L)$	Supply network with agents A connected by links L
t	Time
$\boldsymbol{w}$	Vector of evaluation weights w_i
w_i	Evaluation weight for performance measure i
α	Time-to-money conversion factor
β	Cost per unit of distance to deliver an order
$\varphi[b_{a^*}[d_{a,i,t}], r_{a,i,t}]$	Comparison function to evaluate bid b_{a^*} based on requirements $r_{a,i,t}$.
τ	Planning horizon

independent
e-channels consist on 3rd party agents which handle the electronic channel for a given product and manage order fulfillment from either the manufacturer or the retailer SN.

The numerous combinations emerging from the above-discussed complexity in e-commerce networks combined with the increasing volume of electronic transactions require scalable coordination mechanisms to enable order fulfillment from parallel, re-configurable, inter-organizational (PRIO – after [2]) supply networks. Furthermore, these mechanisms need to be executed dynamically as orders are placed, re-evaluating previous multi-criteria decisions in order to continuously optimize the global fulfillment process and maintain service level agreements [3–5].

The decision process behind the selection of a fulfillment agent resembles a traditional problem in supply chain management: supplier selection [4]. In order to satisfy customer demand, supplier selection models optimize multi-criteria decisions, encompassing qualitative and quantitative performance measures. Weber et al. [6] classify supplier selection models in three main categories: (1) linear weighing models, (2) mathematical programming models, and (2) statistical/probabilistic models. Linear weighing models integrate multiple criteria into a single performance evaluation function, usually by subjectively selecting weights to normalize and prioritize selection criteria. Mathematical programming methods, e.g., linear programming, combine weighed performance evaluation with the ability to incorporate constraints on suppliers performance, e.g., minimum requirements. Statistical models can account for randomness in the selection process, as opposed to (1) and (2). Despite abundant availability of approaches in each type of model, there is a dearth of methods which can effectively enable dynamic, decentralized collaboration among agents in PRIO e-commerce SNs to optimize global order fulfillment while adhering to existing service level agreements.

To address the above-discussed emerging issues in order fulfillment decisions, this article introduces a dynamic best-matching protocol for parallel, re-configurable, inter-organizational SNs (PRIO-BM). PRIO-BM dynamically selects fulfillment agents based on global optimal matching, enabling collaboration among geographically distributed PRIO e-commerce SNs. PRIO-BM provides support for optimal and sub-optimal solutions where sub-optimal solutions have the advantage of being more efficient because of the greedy approach. The performance of PRIO-BM is evaluated and compared to solutions obtained from exhaustive analysis (i.e., global optimization) under various demand and supply scenarios, delivery strategies, and SN topologies.

The remainder of this article is organized as follows: Section 2 discusses previous research related to supplier selection and order fulfillment in e-commerce networks; Section 3 introduces PRIO-BM protocol for order allocation, Section 4 evaluates performance of PRIO-BM under various scenarios and analyzes relative advantages and shortcomings vs. traditional approaches; Section 5 presents the conclusions of this research article and outlines future work directions.

2. Background

Order fulfillment decisions are receiving increasing attention from researchers due to their impact on e-commerce profitability. In the beginning, focus of e-commerce operations was placed on offering low cost, short leadtime deliveries to its customers by adequately allocating product to geographically disperse fulfillment centers to serve demand. With increasing volume of deliveries, optimization opportunities arise to better plan fulfillment from these distributed centers. Xu et al. [7] propose a neighborhood search heuristic to improve myopic fulfillment decisions made sequentially as online orders are placed. Starting from the current (feasible) solution, the heuristic searches, among orders not yet picked, for single product shipments that can be fulfilled from centers different than the one currently assigned, to avoid the need for duplicate shipments in multi-product orders containing such product. In this way, the number of shipments required to serve demand is reduced, resulting in lower delivery costs. Mahar and Wright [5] develop a similar quasi-dynamic