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A multi-objective intelligent water drop algorithm to minimise cost Of goods sold and time to market in logistics networks

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ABSTRACT

The Intelligent Water Drop (IWD) algorithm is inspired by the movement of natural water drops (WD) in a river. A stream can find an optimum path considering the conditions of its surroundings to reach its ultimate goal, which is often a sea. In the process of reaching such destination, the WD and the environment interact with each other as the WD moves through the river bed. Similarly, the supply chain problem can be modelled as a flow of stages that must be completed and optimised to obtain a finished product that is delivered to the end user. Every stage may have one or more options to be satisfied such as suppliers, manufacturing or delivery options. Each option is characterised by its time and cost. Within this context, multi–objective optimisation approaches are particularly well suited to provide optimal solutions. This problem has been classified as NP hard; thus, this paper proposes an approach aiming to solve the logistics network problem using a modified multi–objective extension of the IWD which returns a Pareto set.

Artificial WD, flowing through the supply chain, will simultaneously minimise the cost of goods sold and the lead time of every product involved by using the concept of Pareto optimality. The proposed approach has been tested over instances widely used in literature yielding promising results which are supported by the performance measurements taken by comparison to the ant colony meta-heuristic as well as the true fronts obtained by exhaustive enumeration. The Pareto set returned by IWD is computed in 4 s and the generational distance, spacing, and hyper–area metrics are very close to those computed by exhaustive enumeration. Therefore, our main contribution is the design of a new algorithm that overcomes the algorithm proposed by Moncayo-Martínez and Zhang (2011).

This paper contributes to enhance the current body of knowledge of expert and intelligent systems by providing a new, effective and efficient IWD-based optimisation method for the design and configuration of supply chain and logistics networks taking into account multiple objectives simultaneously.

1. Introduction

Increasing competition in today's global market has forced enterprises to configure and evaluate their supply chain (SC) and many logistics providers have recognised that an optimal SC design (SCD) is a paramount part for any business strategy. When the SC is designed, one of the most important objectives is to deliver products to customers in due time at the lowest possible cost (Simchi-Levi, Kaminsky, & Simchi-Levi, 2008). This is important because an optimal SCD results in cost reduction by 10% and decrements in service time by 40% (Harrison, 2001).

The design process is not easy due to several factors, e.g. market expansion, wide range of suppliers, customers' waiting time, and competitors. Although those factors are important, the cost of goods sold (CoGS) and the lead time (LT) (or time to market) have been recognised as the most important objectives to optimise (Aslam & Ng, 2010; Ho, Xu, & Dey, 2010).

Traditionally, the SC is modelled as a network in which the nodes represent facilities such as suppliers, manufacturing plants, warehouses, retailers, and customers. The SCD problem has been limited to select the number of facilities and determine the amount of units to flow among them. Moreover, it is assumed that the suppliers, plants, warehouses, and retailers have been selected. This severely reduces the opportunity to optimise the overall SC cost because the selected option may increase both CoGS and

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Nomenclature

i	a stage
I	total number of stages
j	an option
J_i	total number of options j than can perform stage i
V	set of stages i
E	set of edges representing the stages relationship (i, i')
$DS \subseteq V$	subset of delivering stages
$CoGS$	cost of goods sold
LT	lead time or time to market
c_{ij}, t_{ij}	cost and time of the option j to perform stage i
C_i, T_i	cost and time of the selected option to perform stage i
y_{ij}	binary variable equals 1 if j performs i. Otherwise, it equals 0
ξ	company's interval time of interest
μ_i	demand at stage i
a_v, b_v, c_v	velocity updating parameters
a_s, b_s, c_s	soil updating parameters
HV	heuristic value
r	river
d	water drop
R	total number of rivers
D	total number of water drops
S_d	subset of options j selected by d, $S_d = \{j, j', \ldots\}$
s_d	a solutions created by d using S_d, $s_d = (LT, CoGS)$
SS_r	solution set computed by r, $SS_r = \{s_a, \ldots, s_d \ldots\}$
p_{ij}	probability of choosing j to perform i
ϕ_{ij}	amount of soil of $j \in i$
ϕ_d	amount of soil of d
v_d	velocity of d
θ	small constant to avoid zero division
$\Delta\phi_{ij}$	change of soil in j
ρ_n	local updating factor
ρ_w	global updating factor
ρ_w	global updating factor
τ_{ij}	time spent by a water drop to cross option j

LT, see Chandra and Grabis (2007); Goetschalckx (2011); Shapiro (2007) to check a comprehensive list of these models.

On the other hand, the SC can be represented as a Bill of Materials (BOM) in which each node represents a supplying, a manufacturing, or a delivery stage. Each stage could be performed by one or more options, e.g. a component, represented by a supplying stage, could be supplied by one or more suppliers; a sub or final assembly, represented by a manufacturing stage, could be assembled in one or more manufacturing plants or production lines; and a customer, represented by a delivery stage, could be the transportation mode used to deliver the product. Therefore, the problem is to determine: from which supplier should each component be obtained?; where will each product be assembled?; and how should each product be delivered to the customer? The complexity of the problem increases by the fact that the selected options must minimise both the CoGS and the LT for a family of products.

Those objectives are conflicting with each other since a reduction in time increases the cost, e.g. suppose two options which can perform a stage, if the cost of option one is greater than the cost of option two, then the time of the option one is less than the time of the second option (Cheshmehgaz, Desa, & Wibowo, 2013).

When the SCD problem is modelled as a BOM, the resulting problem is a combinatorial optimisation problem (COP) in which the solution is not based on a sequence but on the selection of variables that "best" perform the objective functions, i.e. the solution of this problem is to select the subset of options (or variables) that minimise the CoGS and LT. This kind of COP has been categorised as NP-hard, thus to find exact solutions in polynomial time is difficult (Garey & Johnson, 1979).

Exhaustive enumerations could be used to find the exact solutions but to compute all the possible combinations is not practical. More efficient methods should be used to find the "best" combination.

Metaheuristics have been widely used to find near–optimal solutions for hard COP in short periods of time (Talbi, 2009). Graves and Willems (2005), Huang, Zhang, and Liang (2005), and Wang and Shu (2007) solved the problem minimising only the CoGS using dynamic programming, genetic algorithm, and fuzzy sets, respectively. Moncayo-Martínez and Zhang (2011) minimised CoGS and LT, simultaneously, and Moncayo-Martínez and Zhang (2013) minimised the cost of safety stock using Ant Colony Optimisation (ACO), nevertheless their results are not compared to any other optimisation method to prove the efficiency of the ACO-based algorithm and solved only one instance. Hence, a metaheuristic called Intelligent Water Drop (IWD) that is inspired by the flow of rivers is proposed to solve the CoGS and LT in assembly SC.

This natural behaviour has been applied successfully to a number of theoretical problems such as the travelling salesman problem and multiple-knapsack problem (Alijla, Wong, Lim, Khader, & Al-Betar, 2014; Shah-Hosseini, 2007; 2008; 2009). Industrial applications include job-shop scheduling (Niu, Ong, & Nee, 2012), vehicle routing problem (Booyavi, Teymourian, Komaki, & Sheikh, 2014; Kamkar, Akbarzadeh-T, & Yaghoobi, 2010), trajectory planning in aerial vehicles (Duan, Liu, & Wu, 2009), design of irrigation systems (Hendrawan & Murase, 2011), real-life waste collection problem (Islam & Rahman, 2013), economical load dispatch (Rayapudi, 2011), parallel processor scheduling Mokhtari (2015), and capacitated vehicle routing problem which is solved by a novel IWD and cuckoo search algorithm (Teymourian, Kayvanfar, Komaki, & Zandieh, 2016).

The proposed IWD-based algorithm minimises two objectives and the Pareto optimality criterion is used to evaluate them. Computing a Pareto set to compare the performance of two algorithms is a standard method in multi-objective optimisation (Coello, Lamont, & Veldhuizen, 2006; Helbig & Engelbrecht, 2013).

This paper contributes in two aspects: (a) as nowadays the focus in research is problem-oriented rather than promoting certain algorithm (Blum, Puchinger, Raidl, & Roli, 2011; Blum & Roli, 2003), an IWD-based algorithm is proposed to solve the bi-objective SCD problem which outperforms the multi-objective metrics reported when ACO is used; and (b) the original IWD algorithm is modified to solve a bi-objective problem.

In the last decade researchers have contributed to the body of knowledge of expert and intelligent systems by focusing on developing and applying meta-heuristics and swarm-based algorithms for complex supply chain configuration and logistics problems. In such a context, our paper provides an efficient methodology based on the IWD algorithm for the complex multi-objective optimisation of logistics networks, making an analogy between the methodology and the particular application.

This paper is organised as follows. Relevant literature is reviewed in Section 2. Theory of the IWD is provided in Section 3, as well as the problem representation and the proposed solution algorithm. Seven instances are solved in Section 4 and the results are reported in Section 5. Finally, conclusions are drawn in Section 6.