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* Corresponding author. E-mail address: ina0810@gmail.com (T. Trisna) � 2016 Growing Science Ltd. All rights reserved. doi: 10.5267/j.dsl.2015.10.003 � � � Decision Science Letters 5 (2016) 283�316 Contents lists available at GrowingScience Decision Science Letters homepage: www.GrowingScience.com/dsl Multi-objective optimization for supply chain management problem: A literature review Trisna Trisnaa*, Marimin Mariminb*, Yandra Arkemanb and Titi Candra Sunartib aDepartment of Industrial Engineering, Malikussaleh University, Indonesia bDepartment of Agroindustry Technology, Bogor Agricultural University, Indonesia C H R O N I C L E A B S T R A C T Article history: Received June 25, 2015 Received in revised format: October 12, 2015 Accepted October 28, 2015 Available online October 30 2015 Multi-objective optimization is an optimization pr oblem with some conflicting objectives to be attained, simultanously.

This paper reviewed literature about multi-objective optimization problems for supply chain management. The review aimed to provide the lastest research views and recomendations for further studies. We discussed the lastest ten years publications about multi-objective optimization for supply chain management. The scope of this review was classified into five categories i.e.

problem statements, multi-objective frameworks, mathematical formulation modeling, optimization techniques, and representation of supply chain. Multi-objective optimization approaches, both classical and metaheuristic approaches, were discussed, accordingly. In this review, we conducted conclusion and recomendations about likelihood research directions in future. Science Ltd. All rights reserved. Growing6� 201 Keywords: Multi-objective optimization Supply chain Optimization technique Metaheuristic algorithm 1.

Introduction Nowaday, many problems in supply chain management have been studied. Supply chain (SC) denotes a facility and alternative distribution network that conducts function of material prosurement, transform raw material to intermedite or final product, and distribute the product to costumers (Ganeshan & Harrison, 1995). Supply chain management is a management of material and information flows among different fasilities i.e.

supplier, plant, warehouse, and distributor (Thomas & Griffin, 1996). In supply chain manegement, there are several decisions that usually be taken by company. The decisions involve i.e. 1) production, 2) inventory, 3) location selection for facilities, 4) transportation, and 5) information. In the real world, decision taker makes supply chain decisions often faces multi-objective and sometimes conflict occured that to be attained, simultanously. For instance, we can see a plant location selection problem, which aims to minimize total cost and to minimize delivery time of product to costumer, simultaneously.

284 During the last decades, many academics and practitioners have been interested in conducting research about multi-objective methods for supply chain problems and some new techniques also have been developed. Multi-objective optimization (MOO) is an optimization problem that has objective function more than one which fulfilled simultaneously and sometimes, there are conflicts among the objectives.

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The academic literatures and publications about multi-objective optimization on supply chain problem have increased during the last ten years shown in Table 1. We reviewed pu blications from several reliable sources i.e. Google scholar, Sciencedirect, Researchgate, Springer, Prorequest, EBSCO, etc. The publication types were discussed in this review including journal, proceeding conference and book section. Keywords employed for searching online publications are multi-objective optimization, �multi-objective supply chain�, �multi-objective evol utionary supply chain�, etc. We have found publications about multi-objective optimizations for supply chain sourcing from various publication types and categories.

As many as 98 publications have detected in aforementioned sources from year 2005 to 2015. We classify fiel ds of publication subjects into five categories: Industrial and Manufacturing Engineering, Computer Science, Business, Management and Accounting, Mathematical, and Decision Science. Publication other than these five fields are classified into the other fields. Most of publications used in this review source are from field of Industrial and Manufacturing Engineering followed by Computer Science as shown in Fig. 1.

Industrial and Manufacturing Engineering field comprises of publication titles i.e. Journal of Manufacturing Systems, International Journal of Operational Research, International Journal of Production Economics, Journal of Manufacturing Systems, Computers & Industrial Engineering, European Journal of Operational Research, etc. Table 1 Number of publications cited in this review in the last ten years Year of p ublication Number of p ublications Year of p ublication Number of p ublications 2005 1 2011 13 2006 2 2012 9 2007 4 2013 18 2008 10 2014 17 2009 4 2015 13 2010 7 Total 98 Fig. 1.

Publication percentage category based on field of subject 45% 27% 10% 5% 3% 10% I nd us tr ia l � and � Ma n uf a c t ur in g� E n g i n e e r i ng Co mpu te r� Sciences Busi ne ss,� Man ag em en t � and � Acco un ti ng M a t h e m a t i c al D e c i si o n � S c i e n ce s Ot he rs T. Trisna et al./ Decision Science Letters 5 (2016) 285 Comprehensive survey about evolutionary algorithm of multi-objective optimization was conducted by different people (Coello, 1999a, 1999b, 2000, 2005; Fonsecay & Fleming, 1995; Ishibuchi, Tsukamoto, & Nojima, 2008; Van Veldhuizen & Lamont, 2000). J ones et al.

(2002) reviewed different types of metaheuristic techniques of multi-objective by looking into advantages/disadvantages of those techniques in multi-objective applications. Coello (2000) carried out a comprehensive survey for optimization techniques of multi-objective based on genetic algorithm. Marler and Arora (2004) surveyed methods of multi-objective optimization used for engineering problem. They categorized methods of multi-objective optimization in three categories i.e.

method with priori articulation of preferences, method with posteriori articulation of preferences, and method without articulation of preferences. Reyes-sierra and Coello (2006) presented a comprehensive review of the various Multi- Objective Particle Swarm Optimizer (MOPSO) and reported some algorithm. Serrano et al. (2007) reviewed litertures about multi-objective for flowshop problems especially scheduling problems. Aslam and Ng (2010) reviewed multi-objective optimization for supply chain management involved both multi-objective optimization as well as multi-level and multi-objective optimization architectures for supply chains. Aslam, et al.

(2011) conduct ed a comprehensive review for multi-objective optimisation applications in supply chain management publications, both analytical-based and simulation-based. Zhou et al. (2011) conducted another comprehensive review for multi-objective evolutionary algorithm. They surveyed the development of MOEAs primarily during the last years. Iris and Asan (2012) reviewed application of genetic algorithm (GA) for both single and multi-objective in supply chain network design problem.

In their review, they classified some methods used for application of GA in supply chain network design. Recently, many literatures and researches have discussed multi-objective optimizations for supply chain problems with various network configuration and different multi-objective framework, as well as various optimization techniques. It is a motivation for us to review comprehensively literature for multi-objective optimization, so that it could give some recommendations for next researches.

The scope of literature review about multi-objective for supply chain problems involves multi-objective optimization definition, problem statement, multi-objective frameworks, mathematical formulation modeling,

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optimization techniques, and conclucion. 2. Multi-objective optimization 2.1 Multi-objective optimization definition Multi-objective optimization denotes an optimization problem that has multiple objectives and must be fulfilled, simultaneously. Moreover, there are some conflicts among the objectives.

In general, multi- objective optimization problems can be formulated as follows: min/max F(x) = [F1 (x) , F2 (x) , . . . , Fk (x)]T subject to gj (x) = 0, j= 1, 2, . . . , m , (1) hl (x) = 0, l= 1, 2, . . . , e. where k is the number of objective functions, m is the number of inequality constraints, and e denotes the number of equality constraints. x ? En is the decision variable vector, where n is the number of independent variable xi. 2.2

Pareto optimal solutions 286 Unlike single objective optimization, in multi-objective optimization, there is no single global solution, but there is a solution set which creates Pareto optimal solutions. Pareto optimal solutions are a set of trade-offs between different objectives and are non-dominated solutions, i.e., there is no other solution which would improve an objective without causing a worsening (Deb, 2001). Fig. 2. Pareto-optimal or non-dominated solutions In multi-objective optimization, a solution is determined by a set of points that all fit a predetermined definition for an optimum shown in Fig. 2. The predominant concept in defining an optimal point is that of Pareto optimality (Pareto, 1906).

Pareto optimality is defined as a point, x * ? X is Pareto optimal if there does not exist another point, x ? X, such that F(x) = F(x *), and Fi (x) at least one function. In multi-objective optimization problems there is no single optimum solution, but there is a solution set which creates Pareto optimal solutions. Pareto optimal solutions are set of trade-offs between different objectives and are non-dominated so lutions, i.e., there is no other solution which would improve an objective without causing a worsening 3.

Problem statement in supply chain cases We define the problem to discuss in supply chain problem according to optimization problem in supply chain formerly. Each supply chain has different problem type, configuration, and network where in generally can classified as follows: 3.1 Supply chain strategic There are some strategies that have been carried out by researchers and practitioners in supply chain problems. In this review, we classified supply chain strategic which solved by multi-objective approaches into several categories i.e.:

supplier selection, facility location selection, risk/disruption mitigation, etc. Supplier selection Supplier selection is an important issue in supply chain management. Weber and Current (1993) defined supplier selection problem as �which supplier(s) will be selected and how much order quantity will be assigned to each supplier selected�. An enterprise must select the best supplier from some alternative suppliers that can fulfill its multi-criteria. We found several publications about supplier selection using multi-objective approach.

For instance, Liao and Rittscher (2007) developed multi-objective model for supplier selection under stochastic demand condition. They considered supplier criteria according to the total cost, the rejection rate of product, the late delivery rate and the flexibility rate. Yeh and T. Trisna et al./ Decision Science Letters 5 (2016) 287 Chuang (2011) used multi-objective genetic algorithm approach for green supplier selection that considered four objectives i.e. cost, time, product quality and green appraisal score.

Rezaei and Davoodi (2011) developed two multi-objective mixed integer non-linear models for multi-period lot-sizing problems involving multiple products and multiple suppliers. The model developed to fulfill three objective functions involving cost, quality and service level for lot sizing and supplier selection. Prasannavenkatesan and Kumanan (2012) used multi-objective optimization for global or domestic supplier selection to satisfy two objectives i.e. supply chain cost minimum and reliability delivery maximum.

Amin and Zhang (2012) studied supplier se lection and integrated it with selection of the best refurbishing sites for closed-loop supply chain network. Moghaddam (2015) identified, ranked the best suppliers and found the optimal number of new and refurbished parts and final products in a reverse logistics network configuration. He developed model considering inherent uncertainty in customers� demand, suppliers� capacity, and percentage of returned products. Facility location selection Facility location problems correspond to how decide the location of a facility such as plant, warehouse, distribution center, etc.

in accordance with the determined criteria (Bhattacharya & Bandyopadhyay, 2010). Previous studies about

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facility locati on selection conducted by Bhattacharya and Bandyopadhyay (2010) used NSGA II to solve the problems. Latha Shankar et al. (2013) designed supply chain to determine decision of the number and location of plants, the flow of raw materials from suppliers to plants, the quantity of products to be shipped so that can minimize the combined facility location and shipment costs.

Amin and Zhang (2013) developed multi-objective facility location model for closed-loop supply chain network under uncertain demand and return. Zhang et al. (2013) designed supply chain to decide optimal plant location fo r three-phases of productions, i.e.: component manufacturing, subassembly manufacturing and end-product manufacturing in China. Amin and Zhang (2012) studied to select the best refurbishing sites for closed loop supply chain network.

They designed a facility location model for a general closed-loop supply chain network. The established model consists of multiple plants (manufacturing and remanufacturing), demand markets, collection centers, and products. The goal is to know how many and which plants and collection centers should be opened, and which products and in which quantities should be stocked in them. Ozgen and Gulsun (2014) conducted multi-objective approach to solve facility location problem. Chibeles-Martinsa et al.

(2012) established strategic decision involving the choice of facilities, warehouses and distribution centers locations, as well as of process technologies. Th e other strategies of supply chain management performed by multi-objective approach such as conducted by Serrano (2007) that develop strategy to reduce impact of supply chain disruptions. Liu and Papageorgiou (2013) conducted multi-objective approach to decide strategies of plants� capacities expansion. 3.2 Supply chain network design Supply chain network (SCN) design denotes a strategic in supply chain management that decides how determine the number, location, capacity and type of plants, warehouses, and distribution centers to be used.

Moreover, SCN establishes distribution channels, and the amount of materials and items to consume, produce, and ship from suppliers to cu stomers (Altiparmak et al., 2006). There are several studies about application of multi-objective for SCN design problems that conducted by researchers. Altiparmak et al. (2006) established SCN design for plastic products in Turkey that carried out into two stages. They consider to optimize total cost, customer service and capacity utilization balance of SCN.

Benyoucef and Xie (2011) established supply chain networks design including both network configuration and related operational decisions such as order splitting, transportation allocation and inventory control. The goals are to achieve minimum cost and maximum customer service level. Shahparvari et al. (2013) designed an integrated supply chain network considering volume flexibility. The objective functions are to minimize the total cost of supply chain and maximizing flexibility level. Govindan et al.

(2015) integrated sustainable orde r allocation and sustainable supply chain network strategic design with stochastic demand. The proposed study is to design supply chain network 288 consisting of five echelons involving suppliers, plan ts, distribution centers that dispatch products via two different ways, direct shipment, and cross-docks, to satisfy stochastic demand received from a set of retailers. 3.3 Supply chain type In general, type of supply chain in the real worl d can be divided into three categories: open loop SC, closed loop SC, and flexible supply chain.

Open loop Supply Chain In the open loop supply chain or known as the traditional supply chain system, products do not return to the original producer (Andel, 1997). The complexity of an open loop supply chain is defined by a number of echelons, facilities, and location/site selection. Usually echelon of traditional supply chain consists of suppliers, production (value-adding) process, distribution centers, retailer, and costumer. An open loop supply chain can be divided into two stages namely: forward and reverse supply chains.

In previous studies, most researchers have studied open loop forward SC in various configurations and echelons. Likewise, studies about multi-objective optimization in supply chain problem, most researchers have discussed about traditional forward SC. During the last ten years, some studies about multi-objective optimization in traditional forward supply chain problem can observed in Table 1. In open loop reverse supply chain, used products are not returned to original producers, but outsider firms recover them.

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There are few studies discussing about open loop reverse supply chain. In this case, until now, we have not found publication discussing about multi-objective optimization for open loop reverse supply chain problems. Closed-loop SC (CLSC) A closed-loop supply chain (CLSC) network comprises of both forward and reverse supply chains. In a CLSC network, end product is collected from customers to recovered by remanufacturing, recycling and reuse, as well as manage and coordinate the relationship among supply chain partners, such as manufacturers, suppliers, retailers, and/or rema nufacturers (Aydin et al ., 2015).

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Most studies on optimization of CLSC have focused on single objective and only few studies conducted by multi- objective approach. Some publications about CLSC problem are solved by multi-objective approaches, (for instance see Amin & Zhang, 2013). The authors investigated CLSC involving multiple plants, collection centers, demand markets, and products. The aim of the study was to minimize the total cost by considering environmental factors.

�zkir and Basligil (2013) established a closed loop supply chain (CLSC) model including recovery processes by regarding the consumer sourced product returns, end- of-use products and end-of-life products. They proposed a multiple objective optimization model to attain three level goals namely; maximizing satisfaction level of trade, maximizing satisfaction degrees of customers, and maximizing total CLSC profit.

�zceylan and Paksoy (2013) established a mixed integer fuzzy mathematical model which is proposed for a CLSC network including both forward and reverse flows with multiple periods and multiple parts. Nurjanni et al. (2014) performed optimization for a close loop green supply chain. Designing with the trade-offs between environmental and financial issues. The purposes of model are to minimize overall costs and carbon dioxide. Aydin et al. (2015) formulated multi-objective optimization model for CLSC problem to determine the product line solutions, pricing decisions of supply chain partne rs, and product return rate for remanufacturing. Bottani et al.

(2015) conducted optimization of the asset management process in a real closed-loop supply chain (CLSC), consisting of a pallet provider, a manufacturer and 7 retailers. The other publications discuss about multi-objective problem for CLSC i.e. conducted by Gupta and Evans, (2009), Zarandi et al. (2011), Saffar and Razmi (2015) and vahdani and Mohamadi (2015). Flexible Supply Chain (FSC) T. Trisna et al./ Decision Science Letters 5 (2016) 289 Flexible supply chain is an extension of the traditional supply chain whereby a customer can purchase goods directly from plants or distribution centers. Traditional supply chains cannot quickly respond to diversified customers� demands and adapt changing of competitive environments.

Several publications about FSC have been solved by multi-objective optimization approaches (i.e. Rad et al., 2014). The authors formulated bi-criteria multi source single pr oduct FSC model and found methods to solve it. There are two objectives to be satisfied i.e. minimization of total logistics cost and product delivery time. Cheshmehgaz et al. (2013) designed flexible three-level logistic networks with potential suppliers, distributed centers (DCs), and deterministic demands from available consumer.

The goal of their study was to reconfigure the networks in order to minimize response time to consumers and total cost in the same time. Hiremath et al. (2013) conducted multi-objective approaches to design a hybrid and flexible outbound logistic network. The supply chain network consists of a set of customer zones which customer demands can be served by a set of potential manufacturing plants, a set of potential central distribution centers, and a set of potential distribution centers.

We can see from the above description that traditi onal supply chain types solved by multi-objective approaches are the most of supply chain problem discussed by researchers. During the last five years, researchers have begun to discuss closed-loop SC and FSC under various configurations to solve with multi-objective approaches. . 3.4 Supply chain designing and planning Designing and planning of supply chain depend on characteristic and configuration of supply chain. Many characteristics and configurations of supply chain problems have been solved by multi-objective optimizations.

We classify characteristics and configurations of supply chain based on as following: - Product: single product (SP) and multi-product (MP), returned product (RP) - Raw material: single raw material (SR) and multi raw material (MR) - Sources: single source (SS) and multi-source (MS) - Demand : deterministic (DD) and stochastic/uncertainty (UD) - Period : single period (SPd) and multi period (MPd) - Inventory review policy: periodic (PI) and continous (CI) - Supply chain echelon Generally, supply chain designing and planning involve network design, production, distribution, inventory, capacity planning and also schedulin g.

Many researchers have conducted supply chain designing and planning with multi-objective optimization approach. Joines et al. (2002) and Amodeo et al. (2008) applied multi-objective optimization to determine optimal inventory in supply chain. Al- e-hashem et al. (2011) carried out product aggregate production planning under uncertainty condition for the efficient operation of a supply chain. Liu and Papageorgiou (2013) conducted optimization of production, distribution and capacity planning for global supply chains. Liu et al.

(2014) developed the scheduling of logistic tasks and allocation of recourses model for fourth party logistic. Altiparmak et al. (2006) conducted optimization for supply chain network at a plastic product company. The other supply chain network designs were carrie d out (Cardona-Vald�s et al., 2011; Chen & Lee, 2004; Dzupire & Nkansah-gyekye, 2014; Mastroci nque, Yuce et al., 20 13; Moncayo-Mart�nez & Zhang, 2014).

Designing supply chain network also considering flexibility that enable a costumer directly ordering product from suppliers or through DCs. Cheshmehgaz et al. (2013) designed flexible 290 three-level logistic networks with potential supplie rs, distributed centers (DCs), and to the potential costumers. Hiremath, et al. (2013) designed flexible logistic network with multi-objective approach. Researchers also developed supply chain design considering uncertainty condition that were conducted by Azaron et al. (2008) and Guillen et al. (2005).

Multi-objective optimizations for green supply chain network design were developed by many researchers (See Jamshid et al., 2012; Paksoy et al., 2010; Wang, et al., 2011a). Most publications about green supply chain design, generally aim to minimize total cost and gas emission. More completely, various configuration and design of supply chain have been solved by multi-objective optimization is summarized in Table 1. In addition to supply chain configurations aforementioned, the others are a closed loop supply chain (CLSC) and flexible supply chain configuration that described in section 3.2.

Generally, a CLSC configuration consist of suppliers, productions (plants), distribution centers (DC), costumers, collection centers, recovery centers, disposal centers and material recycling. 4. Multi-objective framework Generally, framework of multi-objective function in supply chain problems use total cost minimization as the main or the first objective. Furthermore, researchers use various objectives such as minimize lead time, maximize profit, maximize service level, minimize environment impact, etc.

Table shows a summary of multi-objective framework for supply chain problems. We order multi-objective framework in Table 3, according to a number publications which have been conducted. In Table 3, we can see that multi-objective of minimization of total cost and delivery lead time are cosidered the most by authors. Total cost comprises of material procur ement, transportation, production, order, holding, shortage cost, etc.

Delivery lead time is one of important problems in supply chain design due to in competitive global, enterprise must perform quick respond to customer. For instance, the authors perform this multi-objective framework are Cardona-Vald�s et al. (2011). They established supply chain design consisting of multiple manufacturing plants, customers and a set of candidate distribution centers to fulfill two objectives i.e. cost and cutomer service time.

The next multi-objective frameworks considered by authors are minimization of total cost and maximization of service level and these two objectives tend to be conflict with each other. Increasing service level increases customer satisfaction than can be conducted by adding inventory level, service center, or new plant and so on. Farahani and Elah ipanah (2008) used this multi-objective framework to develop and solve a model for just-in-time (JIT) distribution in supply-chain management consisting of multiple suppliers, wholesalers and retailers. Maximizing service level aim to minimize the sum of backorders and surpluses of products in all periods.

Moreover, multi-objective framework conducted by authors are to minimize total cost and gas emission. This multi-objective framework usually is performed for solving green supply chain problem. For instance, Wang et al. (2011) discussed s upply chain network design problem considering environmental impact. Besides total cost, they consider CO 2 emission as the environmental influence which is a popular environment index.

Furthermore, in Table 3, we summarize multi-objective framework in supply chain problems for more comprehensive. T. Trisna et al. / Decision Science Letters 5 (2016) 291 Table 2 Supply chain configurations were employed by Authors Authors (years) Product Period Supplier Plant DC Demand Raw material Inventory review SP MP RP SPr MPr SS MS SPI MPI SDC MDC DD SD SR MR PI CI Altiparmak, et al. (2006), Moncayo- Mart�nez & Zhang (2013), Validi et al., (2014) v v v v Latha Shankar et al. (2013) v v v v v Amin & Zhang (2013) v v v v v Farahani & Elahipanah (2008) v v v v v Pasandideh et al.

(2015) v v v v Cardona-Vald�s et al. (2011) v v v Al-e-hashem, et al. (2011), Nekooghadirli et al. (2014) v v v v v v Safaei (2014), Yahia et al. (2013) v v v v v Godichaud & Amodeo (2015) v v v v v v Chen & Lee (2004) v v v v v v Cheshmehgaz, et al. (2013) v v v v v Atoeia et al. (2013) v v Nikabadi & Farahmand (2014) v v v v v v Torabi & Hassini (2008) v v v 292 Table 3 Summary of multi-objective frameworks for supply chain problem Authors Multi-objective framework Liang (2008), Xu et al. (2008), Cardona-Vald�s et al. (2011), Pourrousta et al. (2012), Latha Shankar et al. (2013), Mastrocinque et al.

(2013), Moncayo-Mart�nez & Zhang (2014), , Rad et al. (2014), , Nikabadi & Farahmand, (2014), Moncayo-Mart�nez & Zhang (2013), Nekooghadirli et al. (2014); Min. total cost Min. delivery lead time Xu et al. (2008), Farahani & Elahipanah (2008), Benyoucef & Xie (2011), Cardona- Vald�s et al. (2011), Li & Chen (2013), Latha Shankar et al. (2013) Min. total cost Max. service level Wang et al. (2011), Jamshidi et al. (2012), Validi et al. (2014), Nurjanni et al. (2014), Saffar et al. (2015) Min. total cost Min. gas emission Prasannavenkatesan & Kumanan (2012), Atoeia et al. (2013) Min.

total cost Max. delivery reliability Pishvaee & Razmi (2012), Amin & Zhang (2013) Min. total cost Min. environment impact Pishvaee & Torabi (2010), Dzupire & Nkansah-gyekye (2014) Min. total cost Min. delivery tardiness Zhang & Xu (2014)) Min. total cost Max. average safe inventory levels Sadeghi, et al (2014) Min. inventory cost Min. storage space Wang et al. (2013) Min. total cost Min. shortage Shahparvari et al. (2013) Min. total cost Max. flexibility level Cheshmehgaz et al. (2013) Min. total cost Min. response time Liu & Papageorgiou (2013) Min. total cost Min.

Process time Min. sale losses Paksoy et al. (2010) Min. total cost Max. profit Min. gas emission Al-e-hashem et al. (2011) Min. total cost Min. variance of cost Max. productivity You et al. (2012) Min. total cost Min. gas emission Min. local labor cost Azaron et al. (2008) Min. total cost Min. variance of the total cost Min. Financial risk Altiparmak et al., (2006) Min. total cost Max. goods delivery Min ratio of plant-DC balance Selim, Araz, & Ozkarahan, (2008) Min. total cost Max. profit Chen & Lee (2004) Max. service level Max.

profit Max average safe inventory levels Max. delivery reliability Yeh & Chuang (2011), Zhang et al. (2013) Min. total cost Min. delivery lead time Max. product quality Max. green appraisal score Liu et al. (2014) Max. profit Min. gas emission Min. fossil use Franca et al. (2010) Max. profit Max. product quality Ruiz-Femenia et al. (2013) Max. NPV Min. global warning potential (GWP) Pasandideh et al. (2015) Min. total cost Max. the average number of products dispatched to customers Mansouri (2006) Min. total set-ups Min.

the maximum number of set-ups between the two stages supply chain Bandyopadhyay & Bhattacharya (2013) Min. total cost Min. Bullwhip effect Kamali et al. (2011) Min. total cost, Min. defective items Min. late delivered items �zkir & Basligil (2013) Max. satisfaction level of trade Max. satisfaction degrees of customers Max. profit T. Trisna et al./ Decision Science Letters 5 (2016) 293 5. Mathematical Formulation Modeling In this section, we present publications about modeling the supply chain problems in mathematical formulation by multi-objective optimization approach. We classify mathematical formulation modeling of publication based on supply chain environment inherent i.e. certainty and uncertainty environment.

In certain environment, SC is modeled by deterministic programming approach such linear programming (LP), integer programming (IP), non-linear programming (NLP), mixed integer linear programming (MILP), mixed integer non-linear prog ramming (MINLP). For uncertain environment on supply chain, the authors generally use fuzzy programming or (possibilistic programming) , robust optimization, and stochastic programming. In this review, we describe various mathematical models in supply chain problem by multi-objective approaches published within the last ten years.

Several authors formulate SC problem into incorporating between integer programming and linear programming known as mixed integer linear programming (MILP) model. Serrano et al. (2007) formulated strategy of minimizing of supply chain disruptions impact into MILP model. They used a strategy to reduce disruption impact by generating possible solutions that can minimize disruption cost. The authors determined decision whether refinery to open or not that can reduce disruption impact with minimum cost.

Farahani and Elahipanah (2008) constructed a mixed integer linear programming (MILP) to develop and solve a model for just-in-time (JIT) distribution in supply chain management. They used a bi-objective model consists of a three-echelon supply chain network, i.e. minimizing costs and minimizing the sum of backorders and surpluses of products in all periods. Binary variable was used to represent as open facility decision. Amin and Zhang, (2013) established mixed integer linear programming (MILP) for a closed-loop supply chain (CLSC) network model.

The goals of model are to choose the of potential manufacturing and remanufacturing plants locations, set of produced products, set of demand markets locations, and set of potential collection centers locations. The authors established multi-objective function using linear programming i.e. to minimize cost and minimize environment impact. Pasandideh et al. (2015b) formulated a multi-product multi-period three-echelon supply chain network into MILP model. There are tw o objectives to be satisfied i.e.

minimization of the total cost and maximization of the average number of products dispatched to customers. The decision variables are: (1) the number and the locations of reliable DCs in the network, (2) the optimum number of items produced by plants, (3) the optimum quantity of transported products, (4) the optimum inventory of products at DCs and plants, and (5) the optimum shortage quantity of the customer nodes. Nooraie and Mellat Parast (2015) used MILP model to formulate relationship among supply chain visibility (SCV), supply chain risk (SCR), and supply chain cost of new and seasonal products. The other authors used MILP model to formulate various supply chain problems that we have found i.e. (Kleeman et al.,

2007; Chibeles-Martinsa et al., 2012; You et al., 2012; Zhang et al., 2013; Hiremath et al., 2013; Liu & Papageorgiou , 2013; Mastrocinque et al., 2013; Liu et al., 2014; Nikabadi & Farahmand, 2014; Nurjanni et al., 2014; Dzupire & Nkansah-gyekye, 2014) Incorporating between integer programming and linear programming is known as mixed integer nonlinear programming (MINLP) model. Several publications formulate SC problem into MINLP model (See for instance, Altiparma k et al., 2006).

They established a mixed integer non-linear programming model to formulate a plastic-based product supply chain network design in Turkey. One of the decision in the model was to choose suppliers and to define the subsets of manufacturing plants and distribution centers. The second and the th ird objectives for the model was a nonlinear programming i.e. maximizing service level, minimizing the equity of the capacity utilization ratio for plants and DCs.

Bhattacharya and Bandyopadhyay (2010) formulated the supply chain problem as mixed integer non-linear programming (MINLP) model. The model formulation aims to solve the facility location problem for warehouse so that the total cost of both the warehouse and the supply chain as a whole are minimized. Jamshidi et al. (2012) formulated green supply chain optimization into MINLP. Supply chain design model can be formulated to attain both minimum annual cost and environmental effects. Pasandideh et al.

(2015a) formulated a multi-product multi-period three-echelon 294 supply-chain-network under uncertain environment into MINLP model. The first phase, they formulated the problem into the framework of a single-objective stochastic mixed integer linear programming model and then, they reformulated into deterministic mixed-integer nonlinear programming model. The other authors used MINLP model to formulate various supply chain problems (See for instance, i.e. Al-e-hashem et al., 2011; Ka mali et al., 2011; Latha Sh ankar, Basavarajappa, Chen, et al., 2013; S.-H.

Liao, Hsieh, & Lai, 2011; Moncayo-Mart�nez & Zhang, 2013; Mousavi, Alikar, Niaki, & Bahreininejad, 2015; Sadeghi et al., 2014; Yahia et al., 2013; Yeh & Chuang, 2011; Fuqing Zhao, Tang, & Yang, 2012) Moreover, we present publications about mathematical formulation modeling in supply chain under uncertain environment. For instance, stochastic programming formulation conducted by Azaron et al. (2008). They formulated supply chain design under uncertainty into stochastic programming.

Their model uses demands, supplies, processing, transportation, shortage and capacity expansion costs as uncertain parameters. The objectives of their study are to minimize the total cost, minimize the variance of the total cost and minimize the financial risk. Cardona-Vald�s et al. (2011) formulated a two-echelon production distribution network with multiple manufacturing plants, customers and a set of candidate distribution centers under uncertainty demand into stochastic mixed integer linear programming (SMILP).

The purpose of optimization model was to determine the warehouse location and transportatio n mode under demand uncertainty of DC�s. The model was constructed to satisfy the both economical and service quality objectives. Ruiz-Femenia et al. (2013) developed a stochastic mixed-integer linear program (SMILP) for modeling chemical supply chains (SC) by considering uncertainty demand. They analyze the effect of demand uncertainty on the multi-objective optimization of chemical supply chains (SC) considering both their economic and environmental performance. Al-e-Hashem et al.

(2011) formulated production-distribution planning problem in an uncertain environment into stochastic mixed nonlinear programming (SMNLP). Their multi-objective model includes (1) the minimization of the expected total cost of supply chain, (2) the minimization of the variance of the total cost of supply chain and (3) the maximization of the worker productivity. Nekooghadirli et al. (2014) constructed stochastic mixed integer nonlinear programming to formulate location-routing-inventory (LRI) model that considers a multi-period and multi-product system. The model considers the probabilistic travelling time among customers and stochastic costumer demands. They consider two objectives to satisfy i.e.

to minimize the total cost and maximize mean time for delivering commodities to customers. Chen et al. (2010) formulated transportation network design under demand uncertainty into SMINLP model. The other authors establish SMINLP i.e. (Franca et al., 2010) Bandyopadhyay and Bhattacharya (2013) developed two-echelon supply chain model to minimize the value of total cost and bullwhip effect using possibilistic non-linear programming (FNLP). They used triangular fuzzy number (TFN) to generate variable of order quantity, unit transported, and unit inventory.

Zhang and Xu (2014) formulated the supply chain management with quantity discount policy under the complex fuzzy environment into possibilistic or fuzzy non-linear programming. Chen and Lee (2004) developed fuzzy mixed-integer nonlinear programming (FMINP) model to solve a multi-echelon supply chain network problem with uncertain market demands and product price. The Fuzzy sets are used for describing the sellers� and buyers� incompatible preference on product prices.

A supply chain scheduling model was established as a mixed-integer nonlinear programming to satisfy several conflict objectives, i.e. fair profit distri bution among all participants, safe inventory levels, maximum customer service levels, and robustness of decision to uncertain product demands. The using of fuzzy set with ambiguous coefficients in objective functions and constraints is called as possibilistic programming (Torabi & Hassini, 2008). T. Trisna et al./ Decision Science Letters 5 (2016) 295 Xu et al.

(2008) used FMINP model to form ulate supply chain networks under random fuzzy environment in the Chinese liquor industry. Chen and Lee (2004) constructed a possibilistic mixed- integer nonlinear programming to model supply chain scheduling problem.The supply chain model constructed to satisfy several conflict objectives including as fair profit distribution among all participants, safe inventory levels, maximum customer service levels, and robustness of decision to uncertain product demands.

The authors used fuzz y sets to describe the sellers� and buyers� incompatible preference on product prices. Pourrousta et al. (2012) developed fuzzy mixed integer linear programming (FMILP) model to formulate production-distribution planning in supply chain network in uncertainty environment. All parameters used in this model are defined as trapezoid fuzzy numbers. The objective function of the proposed model was to minimize total cost and to minimize delivery times. Ghorbani et al.

(2014) formulated a reverse green supply chain design into fuzzy mixed-integer linear programming (FMILP) model. They considered three objectives to be satisfied i.e. to minimize recycling cost, rate of waste generated by recyclers and material recovery time. The authors developed mathematical model to determine the best set of recyclers in the reverse supply chain. . Torabi and Hassini (2008) formulated supply chain master planning model consisting of multi-suppliers, one manufacturer and multi- distribution centers into fuzzy mixed-integer linear programming (possibilistic MILP).The authors design supply chain model which integrates the procurement, production and distribution plans considering various conflicting objectives simultaneously as well as uncertainty of some parameters such as market demands, cost/time coefficients and capacity levels.

Pishvaee and Torabi (2010) developed possibilistic MILP to model closed-loop supply ch ain network design under uncertainty environment. Ozgen and Gulsun (2014) developed possibilistic mixed linear programming to formulate capacitated multi-facility location problem in a four-stage supply chain i.e. suppliers, plants, distribution centers, and customers. There are two objectives to be satisfied i.e. to minimize total costs and maximize total qualitative factor benefits for facility location.

They modeled supply chain network in a four-stage involving suppliers, plants, distribution centers which presented into vagueness. Liang (2008) developed fuzzy mixed integer linear programming model to solve integrated multi-product and multi-time period production/distribution planning decisions problems with fuzzy objectives. Saffar et al. (2015) developed mixed integer linear programming to formulate green supply chain network under uncertainty. The authors considered model parameter such as facility locating costs, transportation costs, production and mainte nance costs, rate of CO 2 emission, rate of returned products, rate of recoverability as form of fuzzy parameters. They conduct triangular fuzzy numbers for all fuzzy parameters. 6.

Optimization Technique for Multi-objective Optimization Recently, there are several optimization techniques for multi-objective problems that have been developed by researchers. We divide optimization techniques for multi-objective optimization problem according to Donoso and Fabregat (2007) into two categories i.e. classical and metaheuristic method. In this section, we present optimization tech niques conducted by authors to solve multi-objective optimization for supply chain problems. 6.1

Classical method Classical methods convert multi-objective problem into single objective problem by aggregating objective function i.e. optimize most important objective and carry out other objective as constraint. Several classical methods have been developed i.e. weighted sum, e -constraint, weighted metrics, Benson, lexicographic, LP- metrics method min-max, goal programming, etc. 296 Weighted Sum This method performs single objective model and weighting a number of objective function n by allocating a weight at each objective function.

The multi-objective model can be formulated with the weighted sum method, as follows: Optimize [minimize/maximize] F ' X r i * f i n subject to H(x)=0 (2) G(x) = 0 0 = ri = 1, i = {1, �, n} ? r i 1 n In this case, each function is multiplied by weight (r i) that has value must between 0 to 1. In addition, all used weights for all function must value 1. Researchers used the weighted sum method for solving multi-objective problem in supply chain i.e. Zhang et al. (2013) who developed a bi-objective model for the supply chain design of dispersed manufacturing in China.

e -constraint Method e -constraint method was introduced by Haimes et al. (1971) and furthermore discussed by Chankong and Haimes, (1983) . This method converts multi-objective into single objective whereby only one objective function to be optimized and the other objective functions will not be optimize but become model constraint. This multi-objective optimization model is stated through e �constraint model as follows: min/max F i(x)= i F( ) min xf x ? (3) subject to k(x) = e k, k = 1, �, n and k? i H(x)=0 (4) G(x) = 0 In this case, only one function of function Fi(x) is optimized and the other n-1 functions will become constraints.

The aim of this method is to convert e -value of each function and with this way, we get various optimization value in function fi(x). Application of e -constraint method for optimizing supply chain problem, for instance, was perform by You et al. (2012) who used e -constraint method for optimizing sustainable cellulosic biofuel supply chains. Liu and Papageorgiou (2013) used e -constraint method to optimize production, distribution and capacity planning of global supply chains in the process industry with multi products and multi periods. Lexicographic Method In lexicographic method, the objective functions are numbering according to the order of importance level.

In general, optimization problems are solved by lexicographic method that can be formulated as following: i min F ( ) xX x ? (5) subject to)()(* jjj xFxF ? min Fi(x), j= 1, 2, �, i-1, i > 1, i= 1, 2, �, k. (6) T. Trisna et al./ Decision Science Letters 5 (2016) 297 where i is a function�s position in the preferred sequence, and)(* jj xF represents the optimum of the jth objective function, found in the jth iteration.

Application of lexicographic method for optimizing supply chain problem was conducted by Liu and Papageorgi (2013) which used to optimize producti on, distribution, and capacity planning for global supply chain. LP- metrics method In LP-metrics method , multi-objective problems solved by considering every objective function separately and the single objective is formulated to minimize normal difference between every objective function value and optimum value of multi-objective .

� Previous publication using LP-metrics method in supply chain optimization was conducted by Al-e-hashem et al. (2011) to optimize supply chain with multi-product, multi site under uncertainty demand. Goal programming (GP) The aim of GP is to find a solution that minimizes undesirable deviations between the objective functions and their corresponding goals. The mathematical formulation of this method follows: , (7) subject to * ;? (8) (9) where and show the positive and the negative deviations of the objective functions from their goals, respectively, ? g are the preferred positive weights directly assigned to deviations, and * is the ideal value of the objective function g .

In addition , ; , (10) Application of goal programming to solve multi-objective problem in supply chain, for instance was conducted by Gupta and Evans (2009). The authors implemented goal programming for closed-loop supply chain which aims to attain beneficial both economically and ecologically by handing electronic and electrical equipment waste. Fuzzy goal programming (FGP) FGP is a development from goal programming. Fuzzy variable used in goal programming to incorporate uncertain and imprecision into the formulation.

Fuzzy approach aims to provide a framework to model the vagueness and impreciseness to a crisp mathematical formulation appropriate for various solution procedures. Selim and Ozkarahan (2008) conducted FGP to collaborative production�distribution planning problem in supply chain systems. They used fuzzy logic to represent a decision makers� impreciseness aspiration 298 levels for the goals. Tsai and Hung (2009) integrated activity-based costing (ABC) and performance evaluation in value chain structure using fuzzy goal programming approach to optimize supplier selection. Zarandi et al. (2011) conducted fuzzy goal programming approach to optimize closed-loop supply chain (CLSC) network. Ghorbani et al.

(2014) used fuzzy goal programming approach to solve a multi-objective mathematical model of reverse supply chain design. Goal attainment technique Goal attainment technique is a variation of goal programming technique with priori articulation of preference information given, which aims to solve the multi-objective problem . This method tries to find a solution that minimizes the highest weighted deviation (Z) between the individual and overall objective function values, where positive weights (w i) are assigned as ? 1 1 .

The preferred solution in this method is sensitive to the goal vector and the weighting vector given by the decision- maker known as goal programming technique (Azaron et al., 2008). Goal attainment technique solved with following mathematical problem. min Z subject to (11) fi + wiZ = fi* ; ? Z is unbounded We found publication about application goal attainment technique to solve multi-objective optimization for SC problem conducted by Azaron et al. (2008).

The authors solved multi-objective optimization for supply chain problem to minimize the sum of current in vestment costs, the variance of the total cost and the financial risk. Moreover, Pasandideh et al. (2015) optimized multi-product multi-period three- echelon supply chain network with warehouse reliability using Goal attainment technique. 6.2 Metaheuristic Methods Metaheuristic is a high-level algorithm that is used to guide other heuristics or algorithms in their search space of feasible solutions of the optimal value for the single-objective case and the set of optimal values for the multi-objective case (Donoso & Fabregat, 2007).

M etaheuristic methods include evolutionary algorithms, ant colony optimization (ACO), memetic algorithm, tabu search, simulated annealing, etc. In this section, we present several metaheuristic methods often used to solve multi-objective optimization for SC cases in the last ten years. 6.2.1 Evolutionary algorithm methods Evolutionary algorithm (EA) method imitates principal of natural evolution that results stochastic searching and optimization. In ev olutionary algorithm, population of solution candidates and process of reproduction enable to combine existing solutions to generate new solutions (Abraham & Jain, 2005).

Basically, EA has characteric to maintain a good population of solution from one generation to another which is coded as genes (Iris & Serdarasan, 2012). Prior research found that EA was suitable to solve various multi-objective optimization pr oblems because they can capture multiple Pareto- optimal solutions in one experiment. Earliest studies on evolutionary multi-objective optimization were conducted by Schaffer (1985a, 1985b), afterward, several methods are developed by researchers.

Gen et al. (2008) classified evolutionary algorithm methods for multi-objective problems according to fitness assignment as follows: T. Trisna et al./ Decision Science Letters 5 (2016) 299 1. First generation vector evaluated genetic algorithm (VEGA) developed by (Schaffer (1985b) that use vector evaluation approach as fitness assignment . 2. Second generation, fitness assignment according to Pareto Ranking and (diversity) i.e.

multiobjective genetic algorithm (MOGA) developed by Fonseca and Fleming (1993), dominated sorting genetic algorithm (NSGA) developed by Srinivas & Deb (1994). 3. Third generation, fitness assignment according to weighted sum and elitist preserve i.e. random weight genetic algorithm (RWGA) developed by Ishibuchi & Murata (1998), strength Pareto Evolutionary Algorithm II (SPEA II) developed by Zitzler & Thiele (1999) adaptive weight genetic algorithm (AWGA) developed by Gen & Cheng (2000), non-dominated sorting genetic algorithm II (NSGA II) developed by Deb et al.

(2002) and interactive adaptive-weight genetic algorithm (i- AWGA) developed by Lin & Gen (2009). Furthermore, we describe briefly some evolutionary methods that researchers often use to solve optimization for supply chain problems in the last decade. Random Weight Genetic Algorithm (RWGA) Random-weight genetic algorithm (RWGA) was developed by Murata, et al. (1996). In this algorithm, fitness assignment method is based on a weighted-sum to obtain a variable search direction towards the Pareto frontier called random-weight genetic algorithm (RWGA). The weighted-sum approach in this method is denoted as an extension of the classical method approach.

In general, different stages of RWGA described by Yeh and Chuang (2011) are as follows: Step 1: Initialization Generate an initial population that must satisfy all constraints. Step 2: Evaluation Calculate the objective function for each chromosome. When the weighted sum approach was used, first, objective functions must be normalized because they have different measure units. Each objective normalized by equation as follows: minmax min ' ii ii i ff fff ? ?? , i=1, 2, ..,

n (12) where max i f and min i f are the maximum and the minimum value of ith objective function. After first iteration, must update a tentative set of Pareto- optimal solutions. Step 3: Selection Calculate the fitness value f(x) of each string by using equation as following: f(x) = w1f1(x) + w2f2(x)+�+ wnfn(x) (13) where x is a chromosome, f(x) is a combined fitness function, fi(x) is the ith objective function, wi is a constant weight for fi(x), and n is the number of the objective function.

? ? ? q j jii rrw 1 / (14) 300 where rj are nonnegative random number between [0, 1] with n objective functions. The scalar fitness value is calculated by summing up the weighted objective value wi .fi(x). Select a pair of chromosomes from the population according to the following sel ection probability. The selection probability is calculated by equation as follows: ? ? ? ??) min min)}()({)()()(? ? ? x fxf fxfxP , (15) where f(?)= min {f(x)|x? ? } Step 4: Crossover Perform the crossover operation to generate an offspring.

Step 5: Mutation Perform the mutation operation with the mutation Step 6: Elitist strategy In multi-objective optimization problem, elitist is applied to keep the best value of each objective. Step 7: Termination test Until the iteration times is reached, or repeated Steps 2 to 6. Step 8: Obtain the final set of Pareto-optimal solutions The result of Pareto-optimal solutions can offer decision makers to select the best one Researchers use RWGA to solve multi-objective form ulation for SC problem i.e. Altiparmak et al. (2006).

They optimize plastic based product supply chain network consists of manufacturing plants, distribution centers (DCs), and customer nodes. Yeh and Chuang (2011) used weight based genetic algorithm for supplier selection in green supply chain. Non-dominated Sorting Genetic Alhorithm II (NSGA II) This method developed by Deb et al. (2002) from NSGA model. Advantage of NSGA model is that it is more eficient computationally.

Futhermore, th is method uses elitisme and crowded comparation operator that can survive variance without using parameter addition (Deb et al., 2002). After the non-dominated sort was completed, the crowding distance is assigned. If the individuals are selected according to rank and crowding distance, all the individuals in the population are assigned a crowding distance value. Non-dominated sorting approach is used for each individual (decision variable) to create Pareto rank.

This approach classifies each induvidual based on non-domination level into different classes. NSGA II applies niching that crowdes distance addition for each individual and it aims to survive population variance and form algorithm to explore searching space. Generally, procedure of NSGA II is described (Konak, et al., 2006; Seshadri, 2006) as follows: 1. Initialize population as usual. 2. Create a random parent population P0 of size N. Set t =0. 3.

Apply genetic operator (crossover and mutation) toward P 0 to create offspring population Q0 of size N T. Trisna et al./ Decision Science Letters 5 (2016) 301 4. If the stopping criterion is satisfied, then stop and return to P t. 5. Set Rt =Pt U Qt. 6. Rank population and identify the non-dominated fronts F 1, F2,..,FR in Rt using the fast non- dominated sorting algorithm, The first front (F1)is a non-dominant set for current population and the second front(F2) is dominated by the individuals in the first front only and goes so on for the next front. 7. For each objective function k, sort the solutions in Fj in the ascending order.

Let l =|Fj| and x(i,j) represent the ith solution in the sorted list with respect to the objective function k. Assign cd k(x[1,k])= 8 and cdk(x[l,k])= 8 and for i = 2,�, l-1 assign min k max k k k]1,-[ik]1,+[i],[k zz)()()(cd ? ?? xzxzx kk ki (17) 8. Sum the solution�s crowding distances with respect to each objective, i.e., cd(x)= ? k k xcd)(to find the total crowding distance cd(x)of a solution x. There are several applications of NSGA II for solving multi-objective optimization in supply chain problem.

Bhattacharya and Bandyopadhyay (2010) carrid out NSGA II to select facility location for satisfying two conflicting objectives. Rezaei and Davoodi (2011) used NSGA II for lot sizing and supplier selection supply chain configuration comprising multi-period, multiple products and multiple suppliers. Yahia et al. (2013) used NSGA II to develop multi-objective optimization model for cooperative planning in manufacturing supply chain which aims to minimize total production cost and the average inventory levels in a multi-period, multi-item environment. Validi et al.

(2014) designed capacitated distribution network for a two-layer supply chain involved in the distribution of milk in Ireland using green multi-objective optimisation model to minimize CO 2 emissions and total costs in the distribution chain. Cheshmehgaz et al. (2013) used NSGA II to redesign supply chain networks in order to minimize response time to consumers, and minimize total cost. Configuration of supply chain that they redesign comprising three-level logistic networks with potential suppliers, distributed centers (DCs), and deterministic demands from available consumers. The other studies used NSGA II to solve multi-objective optimization for supply chain i.e. (Serrano et al., 2007; Amodeo et al.,

2008; Farahani and Elahipanah, 2008; Liao et al., 2011; Benyoucef & Xie, 2011; Rezaei & Davoodi, 2011; Atoeia et al., 2013; Hiremath et al., 2013; Dzupire & Nkansah-gyekye, 2014; Nikabadi & Farahmand, 2014; Shahparvari et al., 2013; Aydin et al., 2015). Furthermore, several studies have conducted modification of NSGA II to improve performance. Kleeman et al. (2007) used modified NSGA II to solve a variation of the multi-commodity capacitated network design problem which satisfies multiple objectives must including costs, delays, robustness, vulnerability, and reliability. Bandyopadhyay and Bhattacharya (2013) conducted modification toward NSGA II called modified NSGA II.

Modification of NSGA II was conducted by applying crossover and mutation algorithm for the entire population where in original NSGA II, the mutation performed only relies on selected chromosomes. Bandyopadhyay and Bhattacharya (2013) applied modified NSGA II to minimize the value of total cost and bullwhip effect in a two-echelon supply chain. They also compared the results of the modified NSGA-II with NSGA II.

It is found that the results of the modified NSGA-II algorithm performs better than the original NSGA-II Bandyopadhyay and Bhattacharya (2014) applied modified NSGA II for solving multi-objective problem on a two echelon serial supply chain. Tri-objectives are involved minimization of the total cost, minimization of the variance of order quantity and minimization of the total inventory. Jia et al. (2013) employed modified NSGA II to solve transportation-distribution planning problem.

302 Pareto Genetic Algorithm (PaGA) Pareto genetic algorithm developed by Cheng and Li (1997) to search the Pareto optimal set. Prosedure of PaGA denotes revising basic GA techniques. There are five basic operators of PaGA which consist of reproduction, crossover, mutation, niche, and the Pareto-set filter. Niche makes individuals share their available resources and maintains diversity in a population.

Proper niche technique prevents genetic drift and, significantly, distributes a population uniformly along a Pareto optimal set. Meanwhile, Pareto-set filter pools non-dominated points at each generation, reduces effects of genetic drift, and makes a Pareto GA more robust. Pareto-set filter aims to stop the loss of Pareto optimal points by pooling non-dominated points ranked 1 at each generation and dropping dominated points (Cheng & Li, 1997). Che and Chiang (2010) conducted modified PaGA technique to solve multi-objective optimization for supply chain problem.

They conducted supply chain planning to integrate supplier selection, product assembly, as well as the logistic distribution system of the supply chain in order to meet market demands. PaGA technique in this study was modified by performing revision of crossover and mutation operations to generate offspring. Strength Pareto Evolutionary Algorithm II (SPEA II) The first strength Pareto evolutionary algorithm II (SPEA II) was introduced by Zitzler and Thiele (1999) and futher it was developed by Zitzler et al. (2001). In SPEA II, the fitness assignment procedure is a two-stage process.

First, the individuals in the external non-dominated set P� are ranked. Each induvidual (solution) i ? P� is assigned a real value si ? [0,1), called strength; si is proportional to the number of population members j ? P for which i ? j. Let n denote the number of individuals in P that are covered by i and assume N is the size of P. Then si is defined as si = n/(N+1). The fitness fi of an objective i is equal to its strength: fi = si. The second process, the individuals in the population P are evaluated.

The fitness of an individual j ? P is calculated by summing the strengths of all external non-dominated solutions i ? P� that cover j. The fitness is f j = 1+ ? ?)(jii i s ? , where f j ? [1,N]. We found only few studies using SPEA II technique for multi-objective optimization in supply chain problems. Godichaud and Amodeo (2015) conducted multi-objective optimization for closed loop supply chain considering returned product.

Optimi zation techniques were performed to find the inventory policy that fulfill good performances i.e service level and total cost. Non-dominated ranking genetic algorithm (NRGA) NRGA was developed by Al Jadaan, et al. (2006)), which combines a ranked-based roulette wheel (RBRW) selection operator with a Pareto-based population-ranking algorithm. In this method, one of the fronts is first selected by applying the based roulette wheel selection operator.

NRGA performs the same operation with NSGA-II, but the selection way to choose the parents and duplicate them in the mating pool (Pasandideh, et al., 2015a). Some studies use NRGA to solve muti-objective problem in supply chain conducted by Pasandideh et al. (2015a). They solved multi-objective optimization for a multi-product multi-period three-echelon supply-chain-network problem. In this study, they compared NSGA-II and NRGA method to optimize the problem and found that NSGA II performed better than NRGA did.

Multi-Objective Differential Evolution Multi-objective differential evolution (MODE) is a development of differential evolution (DE) for solving multi-objective optimization problems (Babu & Gujarathi, 2007). They used multi-objective T. Trisna et al./ Decision Science Letters 5 (2016) 303 differential evolution to three-stage supply chain problem involving supplier, plant and customer zones. Saffar et al. (2015) performed MODE to solve a green supply chain network design problem under uncertainty. 6.2.2

Bees algorithm Method The bees algorithm is an optimization algorithm inspired by the natural foraging behaviour of honey bees to find the optimal solution. The algorithm requires a number of parameters to be set, that is given as follows: the number of the sites (n), the number of sites selected for neighbourhood search among n sites (m), the number of top-rated (elite) sites among m selected sites (e), the number of bees recruited for the best e sites (nep), the number of bees recruited for the other (m-e) selected sites (nsp), the neighbourhood size of each selected patch for neighbourhood (local) search (ngh), and the stopping criterion.

The algorithm starts with the n scout bees being placed randomly in the search space. The fitness of the sites visited by the scout bees that is evaluated. Mastrocinque et al. (2013) designed supply chain network with multiple products and multiple delivery destinations using bees algorithm, in order to minimize total cost and lead time. Yuce et al.

(2014) enhanced existing Bees Algorithm to deal with multi-objective supply chain model and to find the optimum configuration of a given supply chain problem. The study minimized the total cost and the total lead-time. The new bees algorithm developed to enhance the basic bees algorithm that know as an adaptive neighbourhood size change and site abandonment (ANSSA) strategy. 6.2.3 Ant Colony Optimization (ACO) Ant Colony Optimization is a metaheuristic algoritm for solving optimization problems that has combination character.

When ants leave the nest to search for food, they move randomly but when they find a pheromone track, they decide whether to follow or not the track. ACO algorithm uses concept of ant colony natural, where each ant will choose the best value for every phase that impacted by prior ants and quality of each track. The impact of prior ants signed by pheromone trail, whereas quality of each track that passed by ant is heuristic information that get from mathematic function value. We found several studies about multi-objective optimization using ACO technique for supply chain problem with various configurations and frameworks. Sun et al.

(2008) optimized multi-objective for supply chain problem including minimize total cost, maximze customer service fill rates and delivery flexibility. They incorporate production and delivery in supply chain model. Zhao et al. (2012) used ant colony optimization (ACO) method to optimize supply chain design with changing business environment and various customer demands. Supply chain is designed to satisfy two objectives, i.e. cost and time.

Moncayo-Mart�nez and Zhang (2011) designed supply chain for a family of product comprising complex hierarchies of subassemblies and components. The supply chain design problem is to minimize the total supply chain cost when keep the total lead-times within required delivery due dates. Moncayo-Mart�nez and Zhang (2013) designed supply chain in order to offer a satisfactory customer service level with as low as possible total supply chain cost 6.2.4 Particle swarm optimization (PSO) Particle swarm optimization (PSO) is one of evolutionary computation techniques introduced by Kennedy as social behavior simulations developed as an optimization method by Kennedy and Eberhart (1995).

PSO algorithm starts searching a particle population and keeps surviving for all generations until searching stop is met. Each particle has some memory which helps tracking the best position it has acquired so far and the best position any other particle acquired so far within the neighbourhood. The particle will then modify its direction based on components towards its own best position and towards the overall best position. 304 This kind of systematic acceleration finally leads to convergence to the target.

PSO can be implemented easily and it is computationally inexpensive, since its memory and CPU speed requirements are low (Eberhart et al., 1996). Also, it does not require gradient information of the objective function, but needs only its values. Each individual (particle) in PSO represents a solution in an n-dimensional space. Besides, each particle also has knowledge of its prior best experience and knows the global best solution found by the entire swarm (Latha Shankar, et al., 2013).

Each particle updates its way using the equations as follows: vij= w. vij + c1.r1.(pij-xij) + c2.r2.(pgj-xij), (18) xij = xij + vij, (19) where w is the inertia factor affecting the local and global caapbilities of the algorithm, vij is the velocity of the particle i in the jth dimension, c1 and c2 are weights affecting the cognitive and social factors, respectively. r1 and r2 are uniform random variables between 0 and 1. pij is the best value found by particle i (the best of p) and pg is the global best found by the entire swarm (the best of g).

Application of multi-objective PSO in SCM conducted by Latha Shankar, et al. (2013) that designing of strategic and distribution decisions for three-echelon supply chain architecture consisting of three players; suppliers, production plants, and distribution centers (DCs). They minimize facility location and shipment costs as the objectives framework. The other PSO applications for multi-objective optimization supply chain were conducted by Prasannavenkatesan and Kumanan (2012); Zhang and Xu (2014), (Guo & Houi, 2012) Mahnam et al. (2009) solved bi-criteria model in supply chain problem including total cost and fill rate.

Supply chain problem conseiders uncertainty condition for both sources and demands. Hybridization of multi-objective particle swarm optimization and simulation optimization is conducted to solve bi-criteria model. Kamali et al. (2011) developed a multi-objective mixed integer nonlinear programming model to coordinate the system of a single buyer and multiple vendors under an all-unit quantity discount policy for supplier selection and order allocation.

They used PSO to optimize the overall performance supply chain by minimizing the total system cost, the total number of defective items and the total number of late delivered items. Pourrousta et al. (2012) used PSO algorithm to optimize production-distribution planning in supply chain network in uncertainty environment. Wei and Xu (2011) used modified particle swarm optimization algorithm to solve optimization of supply chain which have multiple suppliers with alternative quantity discounts. Modified PSO is based on fuzzy random simulation that uses fuzzy random variables (FRVs) to describe these weighting factors of suppliers. 6.2.5

Simulated Annealing Simulated Annealing (SA) introduced by Kirkpatrick et al. (1983) and it is a probabilistic method for finding the global minimum of cost function that may possess some local minimal (Bertsimas & Tsitsiklis, 1993). Simulated annealing can be applied for both single objective a multi-objective optimization problems. Mansouri (2006) applied simulated annealing for a bi-criteria sequencing problem to coordinate required set-ups between two successive stages of a supply chain in a flow shop pattern. Chibeles-Martinsa et al.

(2012) developed supply chain model to decide strategic involving the choice of facilities, warehouses and distribution centers locations, as well as of process technologies. 6.2.6 Multi-objective Biogeography based Optimization (MOBBO) Biogeography-based optimization (BBO) was introduced by Simon (2008). Furthermore, Jamuna and Swarup (2012) developed BBO for multi-objective problems. MOBBO denotes development from BBO that is population based-optimization. Population is a set of individual called as habitat. GA uses T. Trisna et al./

Decision Science Letters 5 (2016) 305 a fitness value to represent individual fitness degree. Meanwhile BBO uses habitat suitability index (HSI) replacing fitness value in GA. HSI value identifies that higher value is better solution. MOBBO application in SC problem for instance, was presented by Sarrafha et al. (2015). They developed a supply chain network design (SCND) involving suppli ers, factories, distribution centers (DCs), and retailers in multi-periodic structure.

Yang et al. (2015) used MOBBO to solve supply chain network design (SCND) with uncertain transportation cost and uncertain customer demand. 6.2.7 The other techniques for multi-objective optimization In this section, we present the other metaheuristic techniques used to solve various multi-objective optimization of supply chain problems. Summary of optimization techniques in multi-objective supply chain problems is shown in Table 4. Until now, researchers have developed many multi-objective optimization techniques.

For solving supply chain problem, most researchers employ metaheuristic method especially evolutionary algorithm approach because of complexity of SC problems that cannot be solved by classical methods. NSGA II is the most methods employed to solve multi-objective optimization for SC problem. NSGA II method is more eficient computationally and uses elitisme and crowded comparation operator that can survive variance without using parameter addition (Deb et al., 2002). The recent development of multi-objective optimization techniques for more efficient and flexible solution employies combination of two or an algorithm.

For instance, Ozgen and Gulsun (2014) combined interactive integrated two-phase possibilistic linear programming and fuzzy AHP to consider both quantitative and qualitative factors. Chen et al. (2010) integrated stochastic simulation, a traffic assignment algorithm, a distance-based method, and a genetic algorithm called simulation-based multi- objective genetic algorithm (SMOGA). They employed stochastic simulation is used to simulate the uncertainty of customer demands based on a predefined probability distribution.

GA is employed to obtain a population of solutions that can be used to generate a set of non-dominated (ND) solutions. Then, the distance-based method is employed to sort out the solutions that go into an approximate Pareto solution set. 7. Representation in Supply Chain In this section, we present representation of supply chain/tranportation problem solved by evolutionary algorithm especially genetic algorithm approach (GA). Representation in GA depends on coding technique and problem characteristics (Iris & Serdarasan, 2012).

In supply chain problem, generally, representation is conducted by tree-based representation. According to Gen and Cheng (2000), there are three ways of tree-based coding, i.e. (1) edge-based encoding, (2) vertex-based encoding and (3) edge-and-vertex encoding. GA application in supply chain problems are represented transportation/distribution problems. The early representation of transportation problem for GA is developed by Michalewicz et al.

(1991) that use matrix-based representation with edge-based encoding to represent tree-transportation. In this approach, number of sources and destinations are represented with |K| and |J|, respectively and matrix dimension |K|.|J|. Disadvantage of the methodis the need for larger memory and also the need for particular operator to get feasible solution (Altiparmak et al., 2006). Gen and Cheng (2000) successed to apply Pr? fer number for representation of tree-transportation in supply chain problem.

Pr? fer number uses vervex-based encoding and has |K|+|J|-2 digits dimension with |K| sources and |J| destinations. Pr ? fer number�s disadvantage is to need some improvement mechanism to get feasible solution after used classical genetic operator (Altiparmak et al., 2006). Xu et al. (2008) used Pr ? fer number as 306 representation of SCN to satisfy the customer demand with minimum total cost and maximum customer services for multi-objective SCN design problem.

Table 4 The other metaheuristic techniques in multi-objective for supply chain problems No Optimization techniques Description Application for SC problem 1. Memetic algorithm A memetic algorithm is combination of an evolutionary algorithm and a local search that aims to comply following two characteristics: flexibility and efficiency in time usage for searching solution (Donoso and Fabregat, 2007) Pishvaee et al. (2010) Jamshidi et al. (2012) 2 Multi-objective label correcting (MLC) algorithm MLC algorithm employs a forward search from a selected output point to all accessible points.

It processes the stack of nodes based on the last-in- first-out (LIFO) rule. For the serial way, a node in the stack is pulled out for exploration and its subsequent node(s) is (are) pushed into the stack in each iteration. After that, the MLC determines and updates the paths. When all nodes in the stack are pulled, then the algorithm terminates (Liang et al., 2013) Liang et al. (2013) 3 Combining interactive integrated two-phase Possibilistic Linear Programming�� and ��fuzzy AHP Researchers employ this approach to consider both quantitative and qualitative factors Ozgen and Gulsun (2014) 4 Modified Fruit Fly optimization algorithm (MFOA) MFOA denotes development of the fruit fly optimization algorithm which is inspired by the food finding behavior of the fruit fly.

The fruit fly itself is superior to other species in sensing and perception, especially in osphresis and vision. After fruit fly gets close to the food location, it can also use its sensitive vision to find food and the company�s flocking location, and fly towards that direction (Pan, 2012) (Mousavi et al., 2015) 5 Simulation-based multi-objective genetic algorithm (SMOGA) A procedure of multi-objective problem that integrates stochastic simulation, a traffic assignment algorithm, a distance-based method, and a genetic algorithm algorithm Chen et al.

(2010) 6 Tuned hybrid bat algorithm (HBA) HBA is a local searcher, namely particle swarm optimization (PSO) which is used to hybridize bat algorithm (BA). The HBA, consisting of swap, inversion, and reversion operators, can be used to solve permutation problems (Sadeghi et al., 2014) Sadeghi et al. (2014) 7 Multi-objective hybrid approach (MOHEV) MOHEV is a combination of the adapted multi- objective electromagnetism mech- anism algorithm (AMOEMA) and the adapted multi-objective variable neighborhood search (AMOVNS) (Govindan et al., 2015) Govindan et al.

(2015) 8 Intelligent Water Drop (IWD) IWD algorithm bases on a new nature-inspired swarm-based metaheuristic which imitates some of the natural phenomena of a swarm of water drops with the soil onto the river bed (Moncayo-Mart�nez and Zhang, 2014) Moncayo-Mart�nez and Zhang (2014) T. Trisna et al./ Decision Science Letters 5 (2016) 307 Gen and Cheng (2000) developed priority-based encoding in searching of GA for transportation/distribution problem. In priority-based encoding, a gen position used to represent a node (source/destination for transportation network). Gen value represents a suitable priority node.

In transportation problem, a chromosome consists of priorities of source and destination to get tree-transportation representation. Chromosome length in this approach is equal to the number of sources and destinations. Moreover, Altiparmak et al. (2006) used priority-based encoding for supply chain network representation that has two echelons. Altiparmak et al. (2009) developed priority- representation for multi-item case in supply chain with two types of raw materials.

In this case, a chromosome for each item is represented in different segment. In this case, chromosome length (for multi-item/product) becomes (|K|+|J|)|I|, where I is the number of item (product). Jamshidi et al. (2012) modified chromosome coding for priority-based encoding developed by Gen and Cheng (2000) so that it would no longer need improvement mechanisms. They coded chromosome for supply chain using two types of raw material to produce a product. Rad et al.

(2014) developed the other edge-and-vertex encoding algorithm to represent a chromosome for supply chain problems, namely Route Based GA (RB-GA). The algorithm is capable of improvising the constraints of the problem by a considerable ratio and with the defined crossover and mutation to solve the general bi-criteria multi-source flexible multistage logistics network (FMNL). 7. Conclusion We have presented a comprehensive review about supply chain problem solved by multi-objective approach.

This review included problem statement, type of supply chain, mathematical program modeling, representative, and optimization techniques. We have discussed various configurations of supply chain solved by multi-object ive approaches. The multi-objective used by authors was to minimize total cost as the first objective followed by the next objective in various objectives and models. There were many mathematical programs to formulate supply chain problem, which depend on variable decision forms, parameter inherent, objective and constraint formulations.

In general, we have divided mathematical formulation into two categories based on environment or parameter types i.e. certain and uncertain. The authors represented supply chain model by encoding a chromosome in multi-objective evolutionary under va rious conditions. They have de veloped several representation types i.e. matrix-based representation, Pr ? fer number-based representation, priority-based representation, modified priority-based representation, route based GA, etc.

In this review, we have discussed various types of optimization techniques for multi-objective approach used in supply chain problems. Optimization techniques for multi-objective problem were divided into two approaches i.e. classic and metaheuristic methods. There are many supply chain problem, which can be solved by multi-objective optimization methods. For next studies, we identify some necessary and important topics in supply chain problems solved by multi-objective approaches. 1. Supply chain strategic.

There are only few publications discussing about mitigation strategic to reduce risk/disruption in supply chain solved by multi-objective approaches. Researcher can develop supply chain risk/disruption mitigation strategic models into stochastic or possibilistic mathematical formulation in multi-objective optimization framework. 2. Sustainability supply chain. We have not found publication discussing about sustainability supply chain solved by multi-objective approaches. A supply chain denoted sustainability, if it fulfills three main factors, namely economic, social, and environment.

Future works can apply multi-objective optimization techniques to study sustainability supply chain to fulfill three main sustainability factors. 308 3. Multi-objective optimization methods. There are many optimization methods for multi-objective problems developed by researcheres. Supply chain denotes a complex system, so that its formulation model established into NP-hard models. Metaheuristic approaches are usually used to solve the problems. A future studies, researchers can develop multi-objective optimization methods for more efficient solutions in terms of time, memory usage, stages, and simplicity in usage. 4. Supply chain traceability. In future work, multi-objective approaches can be considered to solve supply chain traceability problems. 5.

Open loop reverse supply chain. Reverse supply chain management is an important issue for sustainable economy, product recovery and green concept. Multi-objective optimization approaches have been widely employed to solve closed-loop reverse supply chain but we have not found it implied in open loop reverse supply chain problem. It can be an opportunity solving open loop reverse supply chain problem by multi-objective approach. References Abraham, A., & Jain, L. (2005). Evolutionary Multiobjective Optimization. In Evolutionary Multiobjective Optimization Theoretical Advances and Applications (pp. 19�24). Al Jadaan, O., Rao, C. R.,

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