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A grey DEMATEL approach to develop third-party logistics provider selection criteria

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Abstract

Purpose – Third-party logistics (3PL) plays a main role in supply chain management and, as a result, has experienced remarkable growth. The demand for 3PL providers has become a main approach for companies to offer better customer service, reduce costs, and gain competitive advantage. This paper identifies important criteria for 3PL provider selection and evaluation, and the purpose of this paper is to select 3PL providers from the viewpoint of firms which were already outsourcing their logistics services.

Design/methodology/approach – This study utilized the grey decision-making trial and evaluation laboratory (DEMATEL) method to develop 3PL provider selection criteria. Because human judgments are vague and complicated to depict by accurate numerical values, the grey system theory is used to handle this problem.

Findings – The findings revealed the structure and interrelationships between criteria and identified the main criteria for 3PL provider selection. The most important criteria for 3PL provider selection are on time delivery performance, technological capability, financial stability, human resource policies, service quality, and customer service, respectively.

Practical implications – The paper's results help managers of automotive industries, particularly in developing countries, to outsource logistics activities to 3PL providers effectively and to create a significant competitive advantage.

Originality/value – The main contributions of this paper are twofold. First, this paper proposes an integrated grey DEMATEL method to consider interdependent relationships among the 3PL provider selection criteria. Second, this study is one of the first studies to consider 3PL provider selection in a developing country like Iran.

Keywords Third-party logistics, Supply chain management, DEMATEL, Grey systems theory

Paper type Research paper

1. Introduction

Logistics has a vital function in merging an industry's supply chain. With globalization, companies should concentrate on core competences which are necessary to survive, and outsource other activities to professional companies. Logistics is now considered as a significant field where industries can decrease their supply chain costs and enhance customer satisfaction (Liu and Wang, 2009; Li *et al.*, 2012).

Third-party logistics (3PL) service providers which emerged since the late 1980s are regarded as suppliers of logistics outsourcing. 3PL has been growing rapidly since the 1990s as a new business field. The outsourcing of logistics tasks to 3PL service

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providers has now become an ordinary activity due to the unique expertise and experience of providers to assist customers. It is difficult or costly for firms to acquire such valuable core competencies (Li *et al.*, 2012; Jharkharia and Shankar, 2007). The main advantages of logistics partnerships enable firms to concentrate on core competencies, to develop supply chain partnerships, to enhance their efficiency, and to decrease their transportation costs (Liu and Wang, 2009; Wong and Karia, 2010; Li *et al.*, 2012; Wang *et al.*, 2014). Recently, 70 percent of companies have outsourced main logistics tasks to 3PL providers in Japan and 42 percent of companies have performed logistic outsourcing in the USA (Li *et al.*, 2012). The survey outcomes of the 18th Annual Third-Party Logistics Study (2014) showed the average logistics cost reduction reported by shippers; the mean inventory cost reduction and the mean fixed logistics cost reduction during 2014 were 11, 6 and 23 percent, respectively (www.capgemini.com/resource-file-access/resource/pdf/3pl study report web version.pdf). Basically, a 3PL provider takes the meaning of utilizing another company to conduct logistics activities which have been performed inside of a company (Isıklar *et al.*, 2007). Particularly, a 3PL provider can supply an organization the required services such as professional logistics transportation, warehousing, freight consolidation and distribution, inventory management and cross-docking. Therefore, a 3PL provider plays an important function in the logistic tasks among the outsourcing firm and marketplace (Li *et al.*, 2012; Choy *et al.*, 2008).

The selection procedure of logistics providers may involve several different quantitative and qualitative criteria, which are often in conflict with each other. Hence, 3PL provider selection is a multi-objective decision-making problem which contains various kinds of uncertainty. Many academicians and researchers have been working on 3PL provider selection issues during past decades and have developed decision-making methods to handle this topic of concern effectively (Kannan *et al.*, 2009). Over the years, a number of mathematical models and heuristic methods have been proposed to explain a 3PL provider selection problem in the literature. A summary of methods which have been applied in the literature to evaluate and select 3PL providers will be presented in Table I and can be found in Aguezzoul (2014) and Azadi and Farzipoor Saen (2011). However, most of the mentioned approaches have assumed that 3PL provider selection criteria are independent and, moreover, few methods have been capable of considering the relationships among the selection criteria which might influence the 3PL performance. In the real world, criteria usually have a degree of interactive relationships with dependence and feedback (Chang *et al.*, 2011).

This study initiates using the grey decision-making trial and evaluation laboratory (DEMATEL) method to develop 3PL provider selection criteria. The DEMATEL method has been regarded as one of the best methods to handle importance and causal relationships among criteria (Wu and Lee, 2007; Wu, 2008; Lin *et al.*, 2009; Chang *et al.*, 2011; Tadić *et al.*, 2014). The reason for the choice of DEMATEL comes from its ability to display the interrelationships between criteria and ranking criteria based on their relationships (Wu, 2008; Lin *et al.*, 2009; Chang *et al.*, 2011). However, DEMATEL cannot express ambiguous values and deal with the lack of information, uncertain situations, and conflicted opinions. Fuzzy methods, like the grey theory, may overcome the weaknesses of the non-fuzzy methods. Because human judgments are vague and complex to depict by precise numerical values, the grey systems theory is utilized to handle this problem (Chang *et al.*, 2011; Lin, 2013). The main benefit of grey systems theory over fuzzy set theory is considering the condition of fuzziness. Also, grey systems theory is suitable for uncertain and small systems that include many

Method	References
ANP	Meade and Sarkis (2002), Jharkharia and Shankar (2007)
ANP and ISM	Thakkar *et al.* (2005)
ANN	Efendigil *et al.* (2008)
CBR	Yan *et al.* (2003)
CBR and RBR and CP	Isiklar *et al.* (2007)
AHP	So *et al.* (2006), Göl and Çatay (2007)
DEA	Haas *et al.* (2003), Min and Joo (2006), Farzipoor Saen (2009), Mi *et al.* (2009), Farzipoor Saen (2010), Azadi and Farzipoor Saen (2011), Momeni *et al.* (2015), Venkatesh *et al.* (2015)
DEA and AHP	Zhang *et al.* (2006)
ELECTRE	Aguezzoul *et al.* (2006)
TOPSIS	Cao *et al.* (2007)
AHP and TOPSIS	Qureshi *et al.* (2007), Perçin (2009)
PCA and GRA	Zhang *et al.* (2008)
AHP and DEA and LP	Falsini *et al.* (2012)
DEMATEL and ANP andVIKOR	Liou and Chuang (2010)
Fuzzy AHP and fuzzy TOPSIS	Yayla *et al.* (2015)
Fuzzy TOPSIS	Bottani and Rizzi (2006)
ISM and fuzzy TOPSIS	Kannan *et al.* (2009)
Fuzzy AHP	Zhang and Feng (2007)
Intuitionistic fuzzy LP and TOPSIS	Wan *et al.* (2015)
Fuzzy LP	Xu and Wang (2007), Liu and Wang (2009), Li and Wan (2014)
AHP and fuzzy bi-objective MILP	Garg *et al.* (2015)
Fuzzy modeling	Bansal *et al.* (2014), Li *et al.* (2012)
Interval-valued fuzzy-based method	Sahu *et al.* (2015)

Table I. Summary of methods for 3PL provider selection and evaluation

decision makers (Liu and Qiao, 2014; Xia *et al.*, 2015). Hence this paper uses grey DEMATEL to examine unclear conditions, to handle flexibility in terms of linguistic preferences, and to determine the interrelationships among the 3PL provider selection criteria. The advantages of the grey systems theory are as follows (Li *et al.*, 2007; Tseng, 2009; Bai and Sarkis, 2010; Saeedpoor *et al.*, 2012; Dou *et al.*, 2014; Xia *et al.*, 2015; Memon *et al.*, 2015):

- in comparison with conventional statistical modeling methods, grey systems generate satisfactory results using a relatively limited amount of data;
- it is better than theoretical analysis of systems with inexact and uncompleted information;
- it is superior to conventional methods, because grey systems are more robust with respect to the noise and lack of modeling information;
- the literature has shown that grey-based approaches can achieve good performance characteristics;
- the grey systems theory provides a relatively flexible, no parametric and distribution assumptions, and a general way to integrate fuzziness into a problem;
- the grey systems theory considers the condition of fuzziness which is a main advantage of grey systems theory over fuzzy set theory;

- the benefits of grey systems theory over fuzzy approach is that, it does not need any robust fuzzy membership function;
- grey system theory is developed to consider the uncertainty problem of small samples and poor information; and
- most of the real world decision problems can be considered in the grey systems due to lack of information and uncertainty.

Almost 90 percent of logistics activities are managed by 3PL companies in developed countries. Nowadays, the 3PL industry is a new subject in developing countries and a few companies outsource logistics activities to 3PL providers (Shah, 2009). A review of the current literature exhibits that only a few papers have explained 3PL in the Iranian automotive industry. Although automotive industries tend to use logistics services to help them concentrate on core competencies and cost reduction, only a small number of studies have considered 3PL selection criteria and their cause and effect relationship in this sector. Hence, this paper seeks to fill this gap and to analyze interdependent relationships between the 3PL provider selection criteria by means of grey DEMATEL methodology in SAIPA automobile manufacturing company. SAIPA has some limited experience to manage the entire supply chain. The company outsources some outbound logistics tasks such as purchasing and procurement to suppliers in recent years but other outbound and inbound logistic services such as transportation, distribution, cross-dock operations are accomplished by the company. The unsuccessful management of these activities contributes to long delivery lead times, costly production delays, high inventory costs, high storage charges and plentiful environmental footprints. Competition in the automotive industry in Iran has been much intensified in recent years. The challenge of finding new markets is putting more pressure on managers to outsource logistics activities. 3PL providers offer transportation and warehousing management, cross-docking, logistics IT solutions and other new value added services. Hence, these benefits allow the company to concentrate on its core competencies of designing, producing, and selling automobiles.

The rest of this paper is structured as follows. Section 2 outlines the main research background regarding 3PL provider selection, gap analysis and research highlights, and it presents the selection criteria for 3PL providers. Section 3 reviews grey system theory concepts and the DEMATEL method. Section 4 illustrates a real case study to implement the method. The results and discussions of the real case study are presented in Section 5. Managerial implications, concluding remarks, and future research are described in Sections 6 and 7, respectively.

2. Literature review

2.1 3PL providers

Logistics is explained as the process of planning, performing and controlling the efficient movement of raw materials, in-process inventories, and information from extracting to the utilization stage with the aim of enhancing customer satisfaction (Goor *et al.*, 2003; Hsiao *et al.*, 2010). Nowadays, outsourcing logistics and supply chain tasks to 3PL service providers is common in the world's most successful companies. Many companies worldwide outsource logistics tasks to raise their profitability and to acquire a sustainable competitive advantage in the global twenty-first century marketplace (Rajesh *et al.*, 2012). According to Capgemini, more than 70 percent of firms in Western Europe, USA, and Asia Pacific have outsourced logistics activities from basic transportation to full logistics network control (Hsiao *et al.*, 2010). In total, 70 percent of companies have outsourced main logistics tasks to 3PL providers in Japan and 42 percent of companies have performed logistic outsourcing in the USA (Li *et al.*, 2012). Also, 82 percent of logistics executives worldwide are clients of logistics service providers during 2007; this number demonstrates an increase of nearly 72 percent from the start of the 2000s (Langley *et al.*, 2007; Wang *et al.*, 2014). The 3PLs have different roles according to the level of outsourcing, from only transportation activities to complete integrated-logistics tasks (Stefansson, 2006).

There are different definitions for 3PL in the literature. According to Lieb (1992) 3PL means "utilizing another firm to execute logistics activities that have traditionally been accomplished in an organization. The tasks accomplished by 3PL provider include selected activities within the entire logistics process". Murphy and Poist (1998) defined 3PL as "a win-win connection between a shipper and third party, which has more customized offerings in comparison with basic services, contains an extensive range of service and is described by a long and mutually advantageous connection." Bask (2001) described 3PL as "a short or long term connection between supply chains members and 3PL providers, where logistics works are presented, from basic to complete integrated tasks to enhance efficiency." Recently, fourth party logistics (4PL) has also appeared to explain more modern contract planning. 4PL providers control a network of logistics providers in order to raise the client's efficiency. 4PLs often have higher capabilities to manage multiple resources and could help organizations deal with high demand complexity through network optimization (Carbone and Stone, 2005; Liu *et al.*, 2014). Van Hoek and Chong (2001) defined 4PL as "a service provider that concentrate on supply chain co-ordination. Its focus is on information and coordinates multiple asset-based players on behalf of its clients." The 3PL provider selection subject has been examined in many papers.

2.2 Analytic methods applied to 3PL provider selection and evaluation

The results review of some techniques in the realm of 3PL provider selection and also a brief description of their applied analytic methodology are discussed here.

Meade and Sarkis (2002) considered four clusters (i.e. product life cycle stages, organizational performance criteria; reverse logistics process works; organizational role of reverse logistics) to determine the best 3PRL provider utilizing analytic network process (ANP) method. Thakkar *et al.* (2005) provided a list of 26 selection criteria and proposed a hybrid approach of interpretive structural model and ANP to select suitable 3PL service providers. Their model developed insights on real-life managerial issues. Their results prioritized three 3PL providers from an organic Indian food sector. Bottani and Rizzi (2006) presented a framework of criteria to select the most suitable 3PL service providers utilizing a fuzzy technique for order preference by similarity to ideal solution) in a real case application. So *et al.* (2006) implemented analytic hierarchy process (AHP) to evaluate and selected the best Korean 3PL provider. They considered five aspects of 3PL service quality including tangibles, reliability, responsiveness, assurance and empathy. Min and Joo (2006) proposed a data envelopment analysis (DEA) model to help 3PLs identify potential sources of inefficiency and establish detailed policy guidelines in prioritizing the use of financial resources. The findings revealed that the strength of 3PL service performances is connected to 3PLs long-term financial stability. Aguezzoul *et al.* (2006) proposed a software tool utilizing ELimination Et Choix Traduisant la REalite method in order to select the 3PLs providers and provided an illustrative example. Jharkharia and Shankar (2007) presented an ANP approach for 3PL provider selection. Their methodology included preliminary screening of the available providers and ANP-based final selection. They applied their model in a case company and the results revealed which provider among three providers is the first choice. The findings revealed compatibility is the most significant criteria followed by cost, reputation and quality. Göl and Çatay (2007) utilized an AHP method at Tofas-Fiat automotive company to redesign logistics tasks and to select a worldwide 3PL provider. The findings of this study indicated that 3PL providers in Turkey must enhance their abilities and do proactively in order to provide value-adding activities. Isiklar *et al.* (2007) presented a hybrid method consisted of case-based reasoning, rule-based reasoning and compromise programming techniques in fuzzy environment for 3PL selection. They applied their proposed framework in a real industrial case. Zhang *et al.* (2008) applied principal components analysis in order to choose principal components and then utilized grey relational analysis to rank 3PL providers. Efendigil *et al.* (2008) applied a two-step model on the basis of an artificial neural network and fuzzy logic in order to determine the most significant 3PRL provider. They provided a numerical example to reveal steps of their proposed model. Liu and Wang (2009) presented an integrated fuzzy method to evaluate and select 3PL providers. Their method included fuzzy Delphi method in order to recognize significant criteria, fuzzy inference methodology to omit inappropriate 3PL providers and fuzzy linear assignment approach for 3PL selection. They applied their method in an actual industrial application. Liou and Chuang (2010) proposed a hybrid MCDM model included DEMATEL, ANP and VIKOR (VIseKriterijumska Optimizacija l kompromisno Resenje in Serbian), meaning multi-criteria optimization and compromise solution. The DEMATEL build a relational structure among criteria. The ANP determine the relative weight of each criterion with dependence and feedback. Finally VIKOR method is used to prioritize alternatives. They applied their model in a Taiwanese airline to demonstrate their method. Azadi and Farzipoor Saen (2011) proposed a new chance-constrained data envelopment analysis in order to help managers to decide the best 3PL provider while considering both dual-role factors and stochastic data and presented a numerical example for implementing of the proposed model. Falsini *et al.* (2012) proposed a hybrid method of AHP, DEA and linear programming to evaluate 3PL service providers. Their model's aim was to overcome the drawback of AHP method. They applied their model to an international 3PL provider. Li and Wan (2014) constructed new fuzzy multi-objective programming models with trapezoidal fuzzy numbers in order to solve the 3PL provider selection problem. They applied their proposed method in outsourcing IT activities to a 3PL provider. Garg *et al.* (2015) utilized AHP to select 3PL providers on the basis of firm's selected criteria. Then, a fuzzy bi-objective mixed integer linear programming problem was formulated with the aim of minimizing cost and maximizing performance in a real case study.

Tables I and II summarize the methods and main papers based on 3PL selection and evaluation, respectively.

Several criteria for 3PL provider selection have been presented in the literature. The main criteria contain cost, service quality, flexibility, responding to customers, and financial ability. For example, Aghazadeh (2003) proposed the following steps for 3PL selection: deciding on using 3PL, expanding 3PL provider selection criteria, preparing a list of potential 3PL providers, and selecting the best potential ones. Zhou *et al.* (2003) presented a fuzzy evaluation system for 3PL assessment and emphasized important criteria such as market competitiveness, business capacity, organization and management. Vaidyanathan (2005) introduced six factors: IT, quality, cost, service, performance metrics,

References	Article abstract
Harrington *et al.* (1991)	Provided a 3PL performance evaluation model for a health care provider
Menon *et al.* (1998)	Considered how a company's competitive environment influences 3PL's selection measures
Meade and Sarkis (2002)	Provided an AHP decision model for third-party reverse logistics provider (3PRLP) selection and evaluation
Yan *et al.* (2003)	Proposed a case-based reasoning (CBR) methodology for 3PL selection
Aghazadeh (2003)	Identified the most effective ways of choosing a 3PL provider
Zhou *et al.* (2003)	Examined a fuzzy assessment method for 3PL'competitiveness and concentrated on four features including market competitiveness, business capacity, management and organization
Lieb and Bentz (2004)	Examined the results of a survey of American manufacturers which utilized 3PL services and conducted in 2004
Moberg and Speh (2004)	Studied the 3PL selection process with the aim of warehouse outsourcing
Thakkar *et al.* (2005)	Applied an integrated interpretive structural model (ISM) and ANP method for 3PL selection
Sohail *et al.* (2006)	Undertook a comparative analysis of the use of 3PL services by manufacturing companies in Singapore and Malaysia
Arroyo *et al.* (2006)	Considered 3PLs applications as a global and uniform strategy in Mexico
So *et al.* (2006)	Applied AHP to assess the service quality of 3PL
Bottani and Rizzi (2006)	Presented fuzzy TOPSIS method for 3PL provider selection
Zhang *et al.* (2006)	Proposed an integrated AHP and DEA model for 3PL provider selection in 4PL
Jharkharia and Shankar (2007)	Used ANP method to categorize 3PL selection criteria in three levels
Rafiq and Jaafar (2007)	Proposed a logistics service quality framework to assess the service quality of 3PL in UK industry
Jharkharia and Shankar (2007)	Utilized ANP to categorize 3PL criteria selection into three groups
Qureshi *et al.* (2007)	Presented a methodology to select 3PL services providers using TOPSIS
Isiklar *et al.* (2007)	Proposed a hybrid framework of CBR, RBR (rule-based reasoning) and compromise programming in fuzzy context for 3PL selection
Zhang and Feng (2007)	Used fuzzy AHP to discuss a selection approach of reverse logistics provider through a practical case
Wei and Chai (2007)	Initiated a selection and evaluation system for long-term partnerships with logistics providers
Hamdan and Rogers (2008)	Proposed DEA method to assess the efficiency of 3PL warehouse logistics tasks
Choy *et al.* (2008)	Suggested an intelligent performance measurement system to evaluate 3PL providers' performance and their upstream and downstream supply chain partners
Efendigil *et al.* (2008)	Proposed an integrated artificial neural networks and fuzzy logic method for 3PRLP selection
Kannan *et al.* (2009)	Developed a fuzzy multi-criteria group decision-making model for 3PRLP selection
Perçin (2009)	Used a two-phase AHP and TOPSIS methodology for 3PL provider evaluation
Liu and Wang (2009)	Presented an integrated fuzzy linear assignment approach for 3PL providers evaluation and selection
Farzipoor Saen (2009)	Provided a method to select the best 3PL provider in existence of both cardinal and ordinal data

(*continued*)

Table II.
Summary of articles related to 3PL provider selection and evaluation

References	Article abstract
Farzipoor Saen (2010)	Depicted 3PL provider selection process using a DEA model, and considered incorporation of multiple dual-role factors
Azadi and Farzipoor Saen (2011)	Proposed a new CCDEA approach for 3PRLP selection and considered dual-role factors and stochastic data
Kayakutlu and Buyukozkan (2011)	Defined an ANP model to analyze the effectiveness of criteria which connect strategic and operational performance factors for 3PL
Rajesh *et al.* (2012)	Proposed a set of strategies based on four balanced score cards (BSC) aspects for different functions of 3PL service providers
Li *et al.* (2012)	Proposed a fuzzy method based on synthesis effect for 3PL provider selection
Govindan *et al.* (2012)	Used ISM method to identify relationship between 3PRLP selection criteria
Hsu *et al.* (2013a)	Developed an integrated DEMATEL and ANP model which was applied to the Taiwanese airline case
Colicchia *et al.* (2013)	Provided the consequences of an empirical study on the implementation of environmental initiatives in logistics service providers companies and considered the metrics, barriers and drivers used for environmental performance measurement
Perçin and Min (2013)	Integrated quality function deployment (QFD), fuzzy linear regression and multi-objective programming methods for 3PL selection in Turkish auto part manufacturers
Jiang *et al.* (2014)	Investigated decision and coordination in a supply chain system consisting of a manufacturer, a 3PL provider, and two competing retailers
Aguezzoul (2014)	Reviewed 67 papers published within 1994-2013 period and provided a literature review on 3PL selection in terms of criteria and methods
Li and Wan (2014)	Combined LINMAP and TOPSIS to propose a new fuzzy linear programming method to outsource IT tasks
Jie *et al.* (2015)	Proposed a triadic model which included e-retailers, product delivery service providers and customers and identified the relationship between selection of product delivery service providers and customer satisfaction in Chinese e-retailers
Yayla *et al.* (2015)	Presented a hybrid fuzzy AHP and TOPSIS methodology for 3PL provider evaluation in a confectionary company
Wan *et al.* (2015)	Proposed a new intuitionistic fuzzy linear programming method for solving logistics outsourcing provider selection as a kind of group decision making
Sahu *et al.* (2015)	Proposed a fuzzy-based method for evaluation and selection of 3PL providers in an Indian automobile part manufacturing company
Momeni *et al.* (2015)	Proposed a multi-objective additive network DEA model to select the most appropriate 3PL providers
Garg *et al.* (2015)	Proposed a fuzzy bi-objective mixed integer linear programming problem to minimize cost and maximize performance of outsourced services to 3PL providers in a real case study
Shi *et al.* (2015)	Presented a real-life third-party purchase (3PP) service model to illustrate 3PP's innovative aspect and then developed a conceptual model. They applied structural equation modeling to test their model based on the survey data from 245 Chinese 3PL providers

Table II.

and intangibles, and found that the role of IT is important when shippers utilized 3PL providers. Wei and Chai (2007) proposed a framework for 3PL provider selection and evaluation and for enhancing long-term partnerships. The most important 3PL provider selection criteria which have been discussed in the literature are presented in Table III. According to Table III the most important measures for 3PL provider selection are service quality, price, and delivery performance.

References	3PL provider selection criteria
Zhang *et al.* (2006)	Price, financial ability, experience in the same industry, location, international horizon, information systems and technology capabilities, customer service, flexibility to deal with unique necessities, reaction to unforeseen difficulties, ability to meet orders, service quality and performance (like six sigma, ISO 9000), commitment to continuous enhancement, human resource policies, accessibility to qualified talent
Bottani and Rizzi (2006)	Transportation, warehousing, inventory management, packaging, reverse logistics, business experience, compatibility, financial performance, flexibility of service, performance, price, management of information systems, quality, strategic viewpoint, trust and fairness
Aguezzoul *et al.* (2006)	Price, reliability, service quality, on time performance, cost reduction, flexibility and innovation, quality management, location, customer service, order cycle time, customer support, vendor reputation, technical competence, special expertise, system capabilities, services variety, personal relationship, early notification of disruptions, increased competition, global capabilities
Power *et al.* (2007)	Customer satisfaction, inventory control, capacity management, productivity, service quality, flexibility, sales growth, net profit, cycle times, cash flow, backlog management and transportation, cost management
Jharkharia and Shankar (2007)	Compatibility, cost of services, quality of services, company's reputation, long-term relationship, performance evaluation, readiness to use logistics manpower, flexibility in billing and payment, information sharing and mutual trust, operational performance, information technology capability, size and quality of fixed assets, delivery performance, employee satisfaction, financial performance, market share, geographical location, risk management, flexibility in operation and delivery
Efendigil *et al.* (2008)	On time delivery, confirmed fill rate, service quality, unit operation cost, total order cycle time, system flexibility index, research and development, environmental costs, customer satisfaction index
Liu and Wang (2009)	Price, experience in similar industry, location, asset ownership, growth forecast, market share, logistics equipment, optimization capabilities, logistics information system, electronic data interchange capacity, customer services, on time shipment and delivery, requirement, responsiveness, service quality, continuous improvement, value added services, key performance indicator (KPI) measurement, cultural fitness, general reputation, human resource policies, availability of qualified talent
Kannan (2009)	Warehouse management, inventory replenishment, shipment consolidation, direct transportation services, communication, service enhancement, cost reduction, quality, cost, flexibility, time, customer satisfaction, service, order management, shipment and tracking, supply chain planning, freight payment
Jayaram and Tan (2010)	Commitment to quality, ability to meet unforeseen orders, financial stability, scope of resources, ability to meet delivery due dates, on time delivery, quick response time in emergencies, service level, communication skill/systems
Aktas *et al.* (2011)	Cost, market, speed, service quality, flexibility, wide range of services, financial status, size/turnover, reputation, geographical location, cultural and management philosophy, technological level
Perçin and Min (2013)	Cost, timeless, service quality, flexibility, and reputation
Aguezzoul (2014)	Costs, relationships, services, quality, information and equipment system, flexibility, delivery, professionalism, financial position, location, reputation
Li and Wan (2014)	Management, economics, strategy, technology, quality
Liao and Kao (2014)	Just-in-time, forecasting methods, information technology, information sharing and trust, service quality, long-term trade relationship, order picking performance, warehouses lay-out performance, customer relationship management, risk management, customer relationship management
Guarnieri *et al.* (2015)	Logistics, financial, capacity/infrastructure, value added services to customers, alliances with suppliers, environmental practices
Jie *et al.* (2015)	Soft infrastructure, hard infrastructure, flexibility, customer satisfaction

Table III.
The most important criteria for 3PL provider selection

2.3 Grey systems theory

To deal with uncertainty of human subjective judgments, both fuzzy set theory, which is on the basis of fuzzy mathematics, and grey systems theory can be utilized. There are many differences between fuzzy mathematics and grey systems (see Table IV). In Table IV a comparison between grey systems theory, probability statistics and fuzzy mathematics is shown (Liu and Lin, 2006).

Grey systems theory can be used to handle the ambiguity in decision-making problems with discrete data and incomplete information is utilized (Deng, 1989). Each grey system is defined by grey numbers, grey equations and grey matrices; grey numbers are like atoms and cells of this system. According to Table IV, the main advantage of grey systems theory is the ability to generate satisfactory results using a relatively small amount of data (Tseng, 2009; Fu *et al.*, 2012; Bai and Sarkis, 2013). Grey numbers are usually characterized as numbers with incomplete information. For instance, the prioritization of criteria in one decision-making problem is expressed as linguistic variables that can be stated as number intervals which include uncertain information (Li *et al.*, 2007). Also, it can be said that the exact value of a grey number is unknown, but the interval that includes its value is known. Recently, a grey systems theory has been efficiently used in many research areas such as the automotive industry, business processes, outsourcing logistic activities, supplier selection, project risks management, insurance industry, and information technology selection (Zavadskas *et al.*, 2010; Saeedpoor *et al.*, 2012; Hsu *et al.*, 2013a; Bai and Sarkis, 2013; Liu and Qiao, 2014; Oztaysi, 2014; Rajesh and Ravi, 2015a, b; Xia *et al.*, 2015; Vafadarnikjoo *et al.*, 2015).

A grey number, $\otimes X$, can be characterized as an interval with known upper and lower bounds, but unknown distribution information for X (Deng, 1989). In the following equation, $\underline{X}$ and $\overline{X}$ are the lower and upper bounds of $\otimes X$, respectively (Vafadarnikjoo *et al.*, 2015):

$$\otimes X = \left[\underline{X}, \overline{X}\right] = \left[X' \in \otimes X \middle| \underline{X} \leqslant X' \leqslant \overline{X}\right] \tag{1}$$

In the following equations, four basic grey number mathematical operations are represented (Liu and Lin, 2006):

$$\otimes X_1 + \otimes X_2 = \left[\underline{X_1} + \underline{X_2}, \overline{X_1} + \overline{X_2}\right] \tag{2}$$

$$\otimes X_1 - \otimes X_2 = \left[\underline{X_1} - \overline{X_2}, \overline{X_1} - \underline{X_2}\right] \tag{3}$$

$$\otimes X_1 \times \otimes X_2 = \left[\min.\left(\underline{X_1 X_2}, \underline{X_1}\overline{X_2}, \overline{X_1}\underline{X_2}, \overline{X_1 X_2}\right),\right.$$

	Grey systems theory	Probability statistics	Fuzzy mathematics
Objects of study	Poor information uncertainty	Stochastic uncertainty	Cognitive uncertainty
Basic sets	Grey hazy sets	Cantor sets	Fuzzy sets
Methods	Information coverage	Probability distribution	Function of affiliation
Requirement	Any distribution	Typical distribution	Experience
Objective	Laws of reality	Laws of statistics	Cognitive expression
Characteristics	Small samples	Large samples	Experience

Source: Liu and Lin (2006)

Table IV. A comparison between grey systems theory, probability statistics, and fuzzy mathematics

$$\max\left(\underline{X_1}\underline{X_2}, \underline{X_1}\overline{X_2}, \overline{X_1}\underline{X_2}, \overline{X_1}\overline{X_2}\right)\Big] \tag{4}$$

$$\otimes X_1 \div \otimes X_2 = \left[\underline{X}_1, \overline{X_1}\right] \times \left[\frac{1}{\overline{X_2}}, \frac{1}{\underline{X_2}}\right] \tag{5}$$

So as to arrive at a crisp number, grey aggregation methods are needed. In this research, a de-greying tool is a modification of a de-fuzzification method, namely, converting fuzzy data into crisp scores (CFCS) is applied (Opricovic and Tzeng, 2003; Dou *et al.*, 2014). The $\otimes X_{ij}^{p}$ is defined as the grey number for a specialist p, who will evaluate the impact of risk i on a risk j. The $\underline{X}_{ij}^{p}$ and $\overline{X}_{ij}^{p}$ are the lower and upper grey values of the grey number $\otimes X_{ij}^{p}$, respectively (Vafadarnikjoo *et al.*, 2015). That is:

$$\otimes X_{ij}^{p} = \left[\underline{X}_{ij}^{p}, \overline{X}_{ij}^{p}\right] \tag{6}$$

The modified CFCS method includes three steps as explained below.

Step 1: normalization:

$$\underline{\tilde{X}}_{ij}^{p} = \left(\underline{X}_{ij}^{p} - \min_j \underline{X}_{ij}^{p}\right) / \Delta_{\min}^{\max} \tag{7}$$

$$\tilde{\overline{X}}_{ij}^{p} = \left(\overline{X}_{ij}^{p} - \min_j \overline{X}_{ij}^{p}\right) / \Delta_{\min}^{\max} \tag{8}$$

where:

$$\Delta_{\min}^{\max} = \max_j \overline{X}_{ij}^{p} - \min_j \underline{X}_{ij}^{p} \tag{9}$$

Step 2: calculate total normalized crisp value:

$$Y_{ij}^{p} = \frac{\left(\underline{\tilde{X}}_{ij}^{p}\left(1 - \underline{\tilde{X}}_{ij}^{p}\right) + \left(\tilde{\overline{X}}_{ij}^{p} \times \tilde{\overline{X}}_{ij}^{p}\right)\right)}{\left(1 - \underline{\tilde{X}}_{ij}^{p} + \tilde{\overline{X}}_{ij}^{p}\right)} \tag{10}$$

Step 3: calculate crisp values:

$$Z_{ij}^{p} = \min_j \underline{X}_{ij}^{p} + Y_{ij}^{p} \Delta_{\min}^{\max} \tag{11}$$

2.4 DEMATEL method

DEMATEL is a comprehensive method to construct a structural model, including causal relationships between complicated items. DEMATEL was introduced by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976 and has been used to solve a group of complex problems (Hsu *et al.*, 2013b). DEMATEL is capable of categorizing whole factors as either cause or effect group. This categorization results in a realization of the system's components and eventually makes available solutions to resolve complicated issues. In this paper

DEMATEL is applied to create a causal diagram of interdependent criteria. The use of the DEMATEL method provides some advantages for this study. First, it allows decision makers to find causal relations between the 3PL selection criteria, to consider the relationships between criteria, and to rank them according to the type of relations and severity of their influences on each other. The other advantages are that the outputs of the DEMATEL method show that 3PL provider selection criteria can be classified into cause and effect groups through a causal diagram. The DEMATEL methodology consists of the following five steps (Gabus and Fontela, 1972, 1973; Fontela and Gabus, 1976; Wang and Chuu, 2004; Nikjoo and Saeedpoor, 2014):

(1) Generating the direct-relation matrix. Five scales are utilized to measure the relation between criteria: 0 (no influence), 1 (very low influence), 2 (low influence), 3 (high influence), and 4 (very high influence).

Experts are asked to make pair-wise comparisons and as a result the direct-relation matrix $A_{n\times n}$ (there are n criteria) will be produced. Each element of matrix $A_{n\times n}$ which is shown by a_{ij}^{k} is a number that shows the influence degree of criterion i on j by expert k. The average matrix for the whole expert opinions (H is the number of experts) would be generated using the following equation in which $\overline{a}_{ij}$ represents each element of the average matrix:

$$\overline{a}_{ij} = \frac{\sum_{k=1}^{H} a_{ij}^{k}}{H} \tag{12}$$

The relationship between two selection criteria means how they can influence each other. The influence of the criterion i on criterion j means how an increase/decrease in i can increase/decrease j. The influences scores are represented in terms of values between 0 and 4. For example, the influence of service quality (C1) over customer service (C5) is 3 which is a high influence, while on the other hand the influence of customer service (C5) over service quality (C1) is 1 which represents the very low influence.

(2) Normalizing the direct-relation matrix. A normalized matrix of initial relationships can be obtained through the following equations:

$$X = k \times A \tag{13}$$

$$k = \frac{1}{\max \sum_{j=1}^{n} a_{ij}} \quad 1 \leqslant i \leqslant n \tag{14}$$

(3) Calculating the total relation matrix. The total relation matrix (T) can be computed by the following equation where I represent an $n\times n$ identity matrix:

$$T = X(I-X)^{-1} \tag{15}$$

(4) Generating a causal diagram. D and R are denoted as a sum of rows and sum of columns, respectively, and can be calculated utilizing the following equations:

$$T = \left[t_{ij}\right]_{n\times n} \quad i,j = 1, 2, \ldots, n \tag{16}$$

$$R = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} = \left[t_{.j}\right]_{1\times n} \tag{17}$$

$$D = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = [t_{i.}]_{n\times 1} \tag{18}$$

The relative significance of each criterion can be determined by horizontal axis vector $(D+R)$ which is named "Prominence." The "Relation" vector is $(D-R)$ and makes the vertical axis by subtracting R from D. Overall, a criterion is a member of the cause category, while $(D-R)$ value is positive; when it is negative, the corresponding criterion attributes to the effect category.

(5) Obtaining the inner dependence matrix. With the help of normalization method, the summation of each column in total relation matrix would be equal to 1, and eventually the inner dependence matrix could be achieved.

2.5 Gap analysis and research highlights

After a thorough investigation of the 3PL provider selection literature, it is concluded that there was no prior study that has applied the hybrid method of grey DEMATEL. This method can consider both poor information uncertainty of decision makers' subjective judgments and the causal relationships between 3PL provider selection criteria. It is clear from our review of the current literature that only a few papers have elucidated 3PL in the Iranian automotive industry. The automotive industry in Iran, a developing country, is considered as the second largest industry; it accounts for 10 percent of Iran's Gross Domestic Product (GDP) and 4 percent of the workforce (nearly 700,000 employees). However, 3PL is a new and growing domain in Iran and logistics managers are trying to outsource their logistics activities. It would be highly significant to know which criteria are more important in the 3PL provider selection process to gain a greater competitive advantage. The combination of grey systems theory and DEMATEL is not totally a new methodology, but its relevance to the current study (3PL provider selection in Iran), in addition to our applying sensitivity analysis to investigate the validity of our results, constitutes our paper's key differences as compared to prior studies. The sensitivity analysis of importance weights of experts was not very common in prior methodological uses of grey DEMATEL; only a few studies applied sensitivity analysis with grey DEMATEL in their studies which can verify the robustness of the results. Hence, to fill this gap with the aid of the grey DEMATEL method, this research will investigate the 3PL provider selection criteria in Iran as a developing country. This paper features some highlights as follows:

- Proposes the grey system to examine the condition of fuzziness and to avoid the limitations of fuzzy set theory.
- Proposes an integrated grey DEMATEL method to consider interdependent relationships among the 3PL provider selection criteria. This method divides a set of complex criteria into cause and effect groups through a causal diagram. Therefore, decision makers comprehend the complexity of a problem and can make wise decisions.
- This will be one of the first studies to consider 3PL provider selection in a developing country such as Iran. The paper's results would assist managers of automotive industries to outsource logistic activities to 3PL providers and create a significant competitive advantage.

3. Methodology

In this study a grey DEMATEL method is utilized in order to choose 3PL providers. This approach considers the causal influences between criteria and it is capable of taking into account direct and indirect relations of various factors in the 3PL provider selection process (Chang *et al.*, 2011). In prior studies, the integration approach of grey systems theory and DEMATEL technique has been used in a few number of studies such as SWOT (strengths, weaknesses, opportunities, threats) matrix analysis in insurance industry (Saeedpoor *et al.*, 2012), project risks management (Vafadarnikjoo *et al.*, 2015), evaluating green supplier development programs (Fu *et al.*, 2012), internal barriers analysis in automotive industry (Xia *et al.*, 2015), business process management (Bai and Sarkis, 2013), agent service quality expectation ranking (Tseng, 2009), grey multi-attribute group decision making (Yan *et al.*, 2009) and strategy prioritization and selection (Ozdemir and Tuysuz, 2015).

3.1 The methodological steps of the grey DEMATEL method

Step 1: developing direct-relation matrix.

In this stage, the experts define the relations between criteria using five scales in each pair-wise comparison: 0 (no influence), 1 (very low influence), 2 (low influence), 3 (high influence) and 4 (very high influence).

In order to deal with human's subjective judgments, this study uses grey numbers according to the linguistic variables of Table VII to substitute the influence scores of linguistic information in the direct-relation matrix. To be prepared for DEMATEL technique, these grey numbers are converted to crisp values using the modified CFCS method and Equations (7)-(11).

Step 2: transforming the linguistic information into grey linguistic scale.

Each expert was given a 12×12 linguistic direct-relation matrix to evaluate the interrelationship of each criterion of the 3PL provider selection criteria. The averages of experts' opinions were computed according to Equation (12). Accordingly, the initial direct-relation matrix will be achieved.

Step 3: obtaining the cause and effect diagram.

The normalized initial direct-relation matrix was calculated using Equations (13) and (14). The total relation matrix was calculated using Equation (15). The prominence and relation axes for cause and effect groups were computed using Equations (16)-(18). Thus, with the usage of $(D+R, D-R)$ data set, the causal diagram can be depicted.

In summary in order to justify the assessments of experts the simple average method is utilized as shown in Equation (12) to obtain the aggregated opinions of all experts then they are replaced with equivalent grey numbers to handle the ambiguity of experts' subjective assessments before applying the modified CFCS method (Equations (7)-(11)) to acquire converted crisp values to use in DEMATEL method. Also, a sensitivity analysis in Section 6 was conducted by altering the importance weight of each expert to ensure the robustness of results.

4. Application of the method in a real case

Iran has a high potential to be an industrial and logistic hub across the Middle East and to meet all industrial and logistics business demands for local and regional companies. Iran has logistic advantages such as the premium location close to the seaports and airports, extensive land and maritime borders, and its common border with 13 countries. Also, the country is situated in the Middle East between international transportation corridors. The country boasts considerable natural resources, a well-educated workforce, and a diversified manufacturing base. Third party service providers locate a logistics hub for operating their tasks. The future success of logistics hubs depend on successful performance of 3PL providers. 3PL ability to act as a world-class transportation provider can contribute to the market share of 3PLs and assist the country in acting as a major international hub. However, the 3PL selection is a critical decision in the outsourcing process of companies (https://en.wikipedia.org/wiki/North%E2%80%93South_Transport_Corridor; http://supply-chain-management.persianblog.ir/post/86).

Iran's automotive industry is the country's second largest industry, accounting for 10 percent of Iran's GDP and 4 percent of the workforce (nearly 700,000 employees). The industry experienced 53 percent total vehicles production growth from 736,948 total vehicles in 2013 to 1,130,164 in 2014 (www.washingtoninstitute.org/policy-analysis). The Iranian automotive market for passenger cars is dominated by local companies, including Iran Khodro and SAIPA. In this section, a real case is presented for application of the grey DEMATEL method in SAIPA automobile manufacturing company in Iran. SAIPA was founded in 1966 as the Citroën Production Association in Iran, and in 1968 began to manufacture the Citroën Dyane model. SAIPA has accomplished joint partnership with Korean, French and Japanese auto-makers during recent years. SAIPA produces a variety of vehicles including passenger cars, pickups, 4WDs, minibuses and buses in various production sites. In 2011 SAIPA fabricated approximately 760,000 automobiles and arranged to push up its annual capacity to 980,000 per year (www.fa.iaiic.com/my_doc/irankhodro/Saipa.pdf). In 2013, SAIPA proved to be the dominant player on the Iranian passenger vehicle sales market and got a market share of nearly 40 percent (www.businessmonitor.com/autos/iran).

The company has launched production plants in other countries such as Iraq, Venezuela, and Syria to get regional and overseas benefits. Azerbaijan, Iraq, Egypt, Syria, and Sudan were the SAIPA's main export destinations (www.businessmonitor.com/autos/iran).

SAIPA's core competition is on products, not on the logistics industry which causes the weakness of logistics tasks against its rivals. Hence, SAIPA is going to outsource logistics activities by selecting a 3PL provider to decrease the operation cost and increase its focus on the core competencies to compete with rivals. SAIPA intends to outsource inbound and outbound logistics activities including logistics planning, cross-dock operations, transportation, and the distribution of automobiles to clients located in different cities in Iran and export them to other countries. The reasons include large workforces and huge investments which need to take care of logistics activities itself, pay high attention to core business activities by forming long-term relationships with 3PLs, attain cost-efficiency and adapt to the competitive global market. Also, the company emphasizes environmental protection and aims to decrease their fuel consumption and hazardous emission during the delivery process. The company is going to collaborate with a 3PL provider, which can provide logistics and transportation activities with low cost, high quality, short lead time, and with environmental responsibility to reduce air pollution and produces less carbon emissions. Thus, developing the 3PL provider selection criteria is a vital task for this company. The details of the methodology to develop 3PL provider selection criteria and facilitate the provider selection procedure for the case company are elaborated in Sections 4.1 and 4.2.

4.1 Identification of the most important criteria for 3PL provider selection

The criteria of the 3PL provider selection process have been extensively discussed in the literature. More than 40 papers in the 3PL provider selection and evaluation field were reviewed. A summary of these papers is provided in Table II. In Table III the most important measures for 3PL provider selection are presented. A team of experts in the realm of supply chain and logistics management were invited to form the group decision and rate the criteria. The linguistic variables for the significance and weight of the criteria are presented in Table V. The 12 most important criteria were selected according to experts' opinions. Table VI presented the definition of these criteria. The team consists of managers and experts from logistics, production, supplier management, and customer service departments. These experts were selected on the basis of their experience in the automotive supply chain and their contributions in the realm of logistics and supply chain in SAIPA. These experts have an extensive logistics and supply chain management knowledge with valuable working experience of five

Linguistic variable	Fuzzy numbers
Very low (VL)	(0, 0.1, 0.3)
Low (L)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
High (H)	(0.5, 0.7, 0.9)
Very high (VH)	(0.7, 0.9, 1)

Table V. Linguistic variable for relative importance weight of experts

Criterion number	Criterion	Definition
C1	Service quality	Refers to 3PL provider ability, accuracy, quality awareness, inspection methods, minimum loss of goods during delivery, aaccuracy of order fulfillment, and commitment to continuous improvement
C2	On time delivery performance	Refers to 3PL capability to meet delivery schedules. It includes flexibility, speed and reliability of delivery, distribution capacity, lead time, order fulfill rate
C3	Flexibility in operation	Refers to ability to accommodate special or non-routine request, provides quick response to customers in emergency needs, and responds to unforeseen demands
C4	Cost of services	Minimization of logistics outsourcing costs, cost reduction program
C5	Customer service	Customer satisfaction, customer complaint rate, service improvement, response to complaints, communication system
C6	Logistics information system	It refers to provider's capabilities in decreasing uncertainties and inventory level, its application for order management, warehouse management, and shipment planning and tracking
C7	Financial stability	A perfect financial performance confirms continuity of services and ordinary improving of logistics equipment and services
C8	Reputation	Refers to people's opinion about satisfying customers' needs
C9	Geographic location	Wide geographic distribution of services (local, regional, domestic, international) which are offered by provider. This criterion is very important when logistics costs (packaging, handling and storage) are high
C10	Technological capability	Refers to availability of technical manpower, modern reprocessing technology, research and development programs, modern logistics equipment, and capability of tracking goods
C11	Performance history	Experience in similar industry, technical and academic certificates in logistics services
C12	Human resource policies	Employee satisfaction level, availability of qualified talents, employee training and employee performance

Table VI. 3PL provider selection criteria and their definitions to ten years. Four senior managers of the firm were invited to answer questionnaires to estimate the interrelationship of each criterion using a five-point linguistic rating scale mentioning the effect of each measure on others (i.e. 0 = no influence, 1 = very low influence, 2 = low influence, 3 = high influence, and 4 = very high influence). The collected data and experts' opinions were examined using the methodology of grey DEMATEL. We used the DEMATEL method to build the influence map in line with actual condition in which criteria should be interdependent.

4.2 The computation steps of the grey DEMATEL method

Step 1: developing direct-relation matrix.

In this stage, the experts define the relations between criteria using five scales in each pair-wise comparison: 0 (no influence), 1 (very low influence), 2 (low influence), 3 (high influence) and 4 (very high influence).

In order to deal with human's subjective judgments, this study uses grey numbers according to the linguistic variables of Table VII to substitute the influence scores of linguistic information in the direct-relation matrix. To be prepared for DEMATEL technique, these grey numbers are converted to crisp values using the modified CFCS method and Equations (7)-(11).

Step 2: transforming the linguistic information into grey linguistic scale.

Each expert was given a 12 × 12 linguistic direct-relation matrix to assess the interrelationship of each criterion of the 3PL provider selection criteria. The averages of experts' opinions were computed on the basis of Equation (12). Accordingly, the initial direct-relation matrix will be achieved. The initial direct-relation matrix from the data collected is presented in Table VIII.

Step 3: obtaining the cause and effect diagram.

Table VII. The grey linguistic rating

Linguistic variable	Influence score	Grey numbers
No influence (No)	0	[0, 0]
Very low influence (VL)	1	[0, 0.25]
Low influence (L)	2	[0.25, 0.5]
High influence (H)	3	[0.5, 0.75]
Very high influence (VH)	4	[0.75, 1]

Table VIII. Direct-relation matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0	1	1	3	3	1	0	4	0	4	3	0
C2	1	0	4	1	3	3	1	1	2	3	0	1
C3	1	1	0	1	3	1	1	2	0	3	2	1
C4	3	1	1	0	1	1	1	0	3	1	2	1
C5	1	1	2	1	0	0	1	4	1	2	3	3
C6	1	3	2	1	3	0	1	0	0	3	1	0
C7	1	1	1	1	1	2	0	1	0	3	2	3
C8	1	0	1	0	1	0	0	0	0	0	3	0
C9	0	2	2	3	3	0	0	2	0	0	1	0
C10	4	2	1	3	2	2	1	1	0	0	1	1
C11	1	0	1	1	1	0	1	2	0	1	0	1
C12	2	1	2	2	3	1	0	2	0	3	3	0

The normalized initial direct-relation matrix was calculated using Equations (13) and (14). The total relation matrix was generated using Equation (15) as presented in Table IX. The prominence and relation axes for cause and effect groups were computed using Equations (16)-(18) and shown in Tables X-XII. Thus, with the usage of

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0.1664	0.0761	0.1019	0.2829	0.3058	0.0691	0.0242	0.4160	0.0591	0.3744	0.3683	0.0732
C2	0.1629	0.1017	0.3562	0.1528	0.3895	0.2278	0.0393	0.2268	0.1275	0.3830	0.2078	0.1009
C3	0.1239	0.0627	0.0705	0.1056	0.2782	0.0592	0.0321	0.2353	0.0271	0.2837	0.2374	0.0784
C4	0.2420	0.0642	0.0866	0.1115	0.1537	0.0481	0.0286	0.1519	0.1986	0.1410	0.2206	0.0558
C5	0.1209	0.0530	0.1577	0.1063	0.1378	0.0394	0.0294	0.3752	0.0371	0.2196	0.3356	0.2045
C6	0.1478	0.2343	0.2145	0.1286	0.3464	0.0809	0.0377	0.1762	0.0469	0.3520	0.1819	0.0792
C7	0.1517	0.0841	0.1044	0.1322	0.1788	0.1469	0.0184	0.1581	0.0323	0.3282	0.2429	0.2180
C8	0.0312	0.0051	0.0278	0.0161	0.0371	0.0048	0.0057	0.0413	0.0037	0.0245	0.1973	0.0122
C9	0.0930	0.1300	0.1790	0.2358	0.2890	0.0426	0.0176	0.2339	0.0555	0.1278	0.1724	0.0633
C10	0.3616	0.1531	0.1199	0.2883	0.2727	0.1459	0.0335	0.2152	0.0664	0.2084	0.2133	0.0779
C11	0.0534	0.0124	0.0409	0.0485	0.0593	0.0126	0.0254	0.1472	0.0102	0.0630	0.0621	0.0385
C12	0.2436	0.0779	0.1843	0.2227	0.3368	0.0714	0.0249	0.3060	0.0493	0.3449	0.3790	0.0785

Table IX.
Total relation matrix

Rank	Criteria	*D*	Rank	Criteria	*R*
1	C2	2.4762	1	C10	2.8503
2	C12	2.3193	2	C11	2.8187
3	C1	2.3174	3	C5	2.7850
4	C10	2.1561	4	C8	2.6831
5	C6	2.0264	5	C1	1.8985
6	C5	1.8165	6	C4	1.8311
7	C7	1.7960	7	C3	1.6438
8	C9	1.6397	8	C12	1.0802
9	C3	1.5940	9	C2	1.0546
10	C4	1.5024	10	C6	0.9485
11	C11	0.5735	11	C9	0.7137
12	C8	0.4068	12	C7	0.3166

Table X.
The degree of influential impact (*D*) and the degree of influenced impact (*R*)

Rank	Criteria	$D+R$
1	C10	5.0064
2	C5	4.6015
3	C1	4.2159
4	C2	3.5308
5	C12	3.3995
6	C11	3.3922
7	C4	3.3335
8	C3	3.2378
9	C8	3.0899
10	C6	2.9749
11	C9	2.3534
12	C7	2.1126

Table XI.
The prominence vector ($D+R$)

Table XII.
The relation vector ($D-R$)

Rank	Cause group	$D-R$
1	C7	1.4793
2	C2	1.4215
3	C12	1.2390
4	C6	1.0779
5	C9	0.9260
6	C1	0.4189
Rank	Effect group	$D-R$
1	C8	−2.2762
2	C11	−2.2452
3	C5	−0.9686
4	C10	−0.6943
5	C4	−0.3287
6	C3	−0.0497

($D+R$, $D-R$) data set, the causal diagram can be depicted, which is shown in Figure 1. This diagram can provide us with specific views into the realization of all the systems and can allow us to recognize noteworthy criteria in addition to the comprehension of the criteria which have more influence on the system.

5. Results analysis

The causal diagram is studied and findings are represented as follows. Financial stability (C7), on time delivery performance (C2), human resource policies (C12), logistics information system (C6), geographic location (C9) and service quality (C1) as shown in Table XII are grouped into cause criteria category. Effect criteria group includes reputation (C8), performance history (C11), customer service (C5), technological capability (C10), cost of services (C4) and flexibility in operation (C3) which are tended to be influenced. The causal diagram shown in Figure 1 confirms that financial stability (C7) and on time delivery performance (C2) are the most influential criteria.

($D+R$) score represents the relative significance of each criterion; as a result criteria with higher ($D+R$) scores should be significantly considered in the criteria ranking process. Technological capability (C10) has the highest ($D+R$) value (see Table XI). Cause criteria influence on all the system and their performance can affect the overall aim.

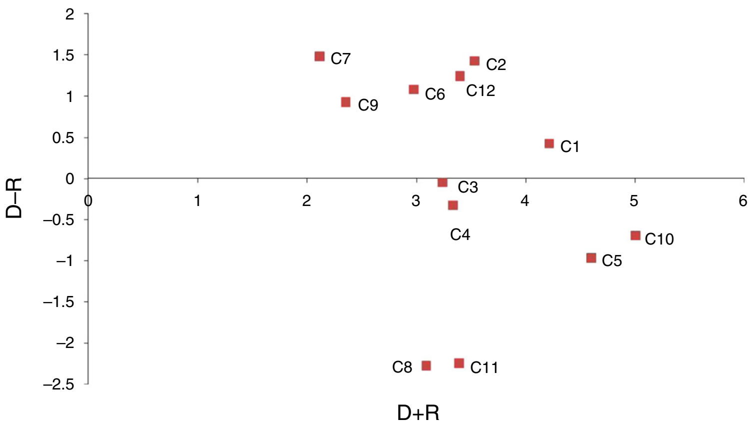

Figure 1.
Cause and effect diagram

Hence, elements of cause criteria group should be paid more attention because their $(D-R)$ score is positive and it means the score of influential impact (D) is greater than the score of influenced impact (R). Financial stability (C7) in the cause group gets first rank with a score of 1.4793 (see Table XII). Customer service (C5), service quality (C1), on time delivery performance (C2), and human resource policies (C12) are other important criteria according to $(D+R)$ score which stands after Technological capability (C10) (see Table XI). Among nine best criteria according to their $(D+R)$ score, only service quality (C1), on time delivery performance (C2), and human resource policies (C12) are in cause group. Thus, on time delivery performance (C2) is preferred to service quality (C1) because they rank 2 and 6 in $(D-R)$ ranking and 4 and 3 in $(D+R)$ ranking, respectively, and as it can be seen the priority of (C2) in $(D-R)$ ranking is much greater than the priority of (C1) in $(D+R)$ ranking. The criterion on time delivery performance (C2) has priority over the criterion human resource policies (C12) in both $(D-R)$ and $(D+R)$ rankings as well. As a result considering both the cause group (Table XII) and the prominence group (Table XI) ranking with more emphasis on cause criteria, the most important criteria for 3PL providers selection is on time delivery performance (C2) followed by technological capability (C10), financial stability (C7), human resource policies (C12), service quality (C1), and customer service (C5), respectively. In fact, based on the analyses among 12 criteria, the six most significant criteria are selected and presented in Table XIII.

The companies' experts agree with the results and findings of this study. They mentioned delivery performance and technological capability as the most important criteria for 3PL provider selection. Delivery performance refers to issues such as ability to meet delivery due dates, delivery capacity, optimum distance traveled, fleet capacity (number of vehicles used in logistics), efficiency of the vehicle drivers. They mentioned transportation capacity and shipping cars by trucks and train, is crucial to an automobile manufacturing company's long-term success. According to the Federal Railroad Administration, railroads are up to four times more fuel efficient than trucks depending on the commodity carried and the length of the transportation (www.fra.dot.gov, 2012). Hence, experts suggested increasing auto transportation by train to decrease fuel consumption and enhancing environmentally friendly freight transportation. They also suggest using convertible and multilevel auto decks which can be adjusted for two and three levels depending on the size of vehicles being shipped as a means to expand distribution capacity and delivery speed. Technological capability mentions modern reprocessing technology, research and development facilities, modern logistic equipment and tracking capability. The experts argue technological capability (especially information technology) is a strategic resource for 3PL and has a key role in integration of supply chain. Advanced technological capability and using information technology can assist 3PL

Criteria	Cause group rank	Prominence rank	Final rank
On time delivery performance (C2)	2	4	1
Technological capability (C10)	na[a]	1	2
Financial stability (C7)	1	12	3
Human resource policies (C12)	3	5	4
Service quality (C1)	6	3	5
Customer service (C5)	na	2	6

Note: [a]na means the criterion belongs to effect group, thus no ranking in cause group

Table XIII. The six most important criteria and their rankings providers in monitoring inventory status, enhancing utilization of vehicles and warehouses and completing delivery tasks efficiently, which may lead to a decline in fuel consumption and air pollution (Shi *et al.*, 2015). The experts suggest using wireless technology such as radio frequency identification (RFID) technology and track and trace system to strengthen information and transportation management systems.

Managers argued logistics services coordination is a main problem in the company. They ask 3PLs to implement an online platform to organize logistics services. An online platform which merges comprehensive information would ease the rapid identification of goods. Managers asserted 3PLs should implement advanced information technology. Also, technological capabilities such as RFID, tracking and tracing systems and warehouse management technologies including automated storage and retrieval systems are necessary to perform online platform. The results of this study are aligned with managers' opinion for selecting 3PLs. Managers believe that technological capabilities including information technology play a vital role in the selection process. According to 18th annual 3PL study shippers still rank 3PL IT capabilities including network modeling and optimization, electronic data interchange, order tracking and inventory management. This study followed a measurable distinction between shipper's ideas on whether they think IT is an essential component of 3PLs expertise, and if they are convinced of their 3PLs' IT capabilities (www.capgemini.com/resource-file-access/resource/pdf/3plstudyreportwebversion.pdf). Managers would like to decrease the IT gap between shippers and 3PLs and select 3PLs with advanced technological capabilities.

6. Sensitivity analysis of results

Sensitivity analysis of grey DEMATEL method for 3PL provider selection is provided in this section. The sensitivity analysis allows experts to consider the robustness of their decisions. Five scenarios determining the sensitivity of results in the case of alterations to experts' relative importance weights are explored because the expertise, experience and responsibility of experts are not really equal. In this sensitivity analysis, it focussed on the weights given by expert 1 from the logistics department. Different importance weights are assigned to the opinions of expert 1; these weights can be seen in Table XIV. Scenario 1 is the initial weights which have been considered in the previous section.

A weighted average is applied in order to compute direct-relation matrices. In scenarios 1-3 there are no changes in the final results and the total relation matrices are the same (see Figure 2). In scenario 4, "customer service" (C5) and in scenario 5, "technological capability" (C10) have the highest $(D+R)$ score as can be seen in Figures 3 and 4. The most significant criteria in scenarios 4 and 5 are the same as in scenarios 1-3. These criteria are C1, C5, C7, C10, C2 and C12, but in both scenarios 4 and 5 the most important criterion is service quality (C1) compared to "on time delivery performance" (C2) from scenarios 1-3.

Table XIV. Importance weights of experts

Experts	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Expert 1 (logistic department)	1	0.1	0.5	5	7
Expert 2 (production dep.)	1	1	1	1	1
Expert 3 (supplier management dep.)	1	1	1	1	1
Expert 4 (customer service dep.)	1	1	1	1	1

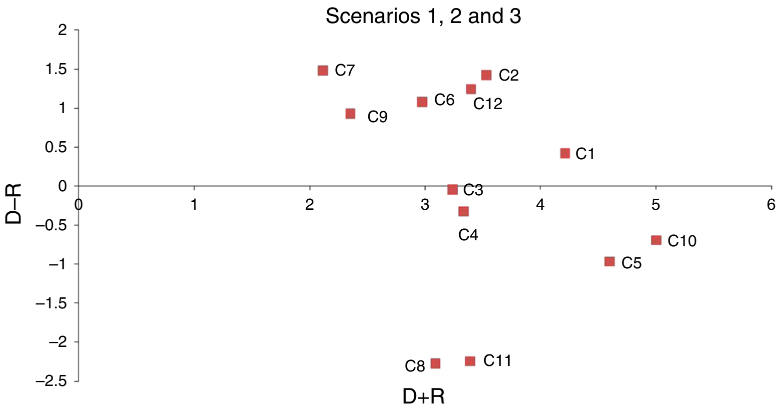

Figure 2.
Sensitivity analysis causal diagram for scenarios 1, 2 and 3

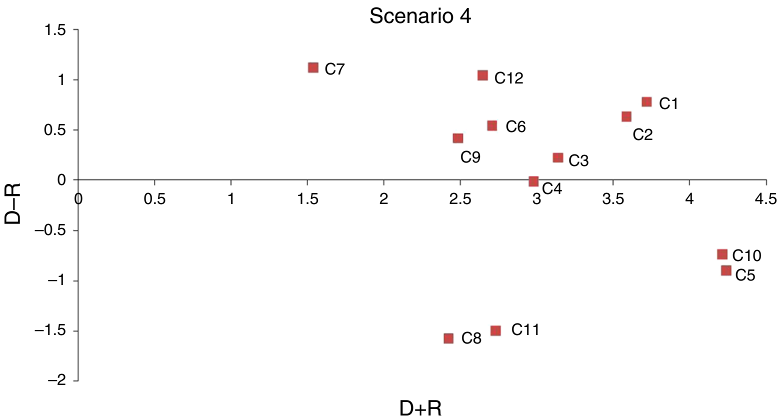

Figure 3.
Sensitivity analysis causal diagram for scenario 4

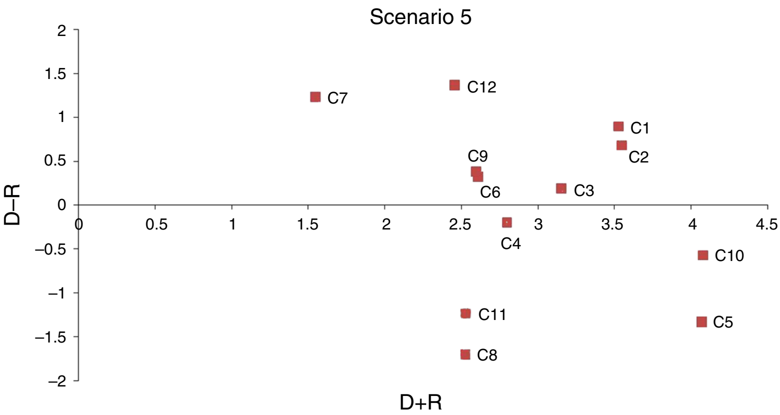

Figure 4.
Sensitivity analysis causal diagram for scenario 5

Criteria C5, C8, C10 and C11 and C4 are common in the effect group of all scenarios, but we have, in addition, flexibility in operation (C3) for scenarios 1-3.

Overall, it seems six most important criteria are not sensitive to importance weights variations of expert 1 because in all scenarios six most important criteria are the same. But, it appears that the most crucial criterion is sensitive to the importance weights variations of expert 1 because the most critical criterion in scenarios 1-3 is C2 and the one for scenarios 4 and 5 is C1 with a slight priority compared to C2. The main reason is giving very high weights to opinions of expert 1 in scenarios 4 and 5. In initial condition, the experts' weights are equal given that experts have equal expertise. The sensitivity analysis showed determining the most important criterion is sensitive to expert 1's importance weight.

7. Managerial implications

This study uses empirical data to consider interdependent relationships among the 3PL provider selection criteria. Managers should make wise decision and outsource their logistics activities to 3PL providers to maintain competitive performance. Managers can reduce the average logistics cost; the average inventory cost and the average fixed logistics cost when outsourcing logistics tasks to a 3PL provider. Managers understand that setting up the long-term relations between shippers and 3PL providers is a critical factor to implement the 3PL provider system and to select the best 3PL provider. Decision support methods like grey DEMATEL provide significant information which can be utilized by managing directors to make strategic or operational decisions. Furthermore, many managerial implications are realized based on the paper's results. It is necessary to concentrate on the cause group criteria because of their influences on the effect group criteria (Fontela and Gabus, 1976). The impact that effect group criteria receive from other criteria (*R*) is higher than their influential impact (*D*) on others (Table XII). In the effect group, the reputation (C8) criterion gets first rank that means for 3PL provider selection, reputation (C8) criterion has higher influenced impact (*R*) than influential impact (*D*) but it does not mean reputation (C8) criterion has the highest degree of influenced impact (*R*) because technological capability (C10) has the highest degree of influenced impact (*R*) according to Table X. This outcome is in line with the Jharkharia and Shankar (2007) study in which the most critical determinants in a provider selection were compatibility, cost, reputation and quality. Also, some results of this study are aligned with the key finding of Jie *et al.* (2015). Managers should invest in technology and technology-related resources (e.g. RFID and global positioning system). These technologies may facilitate both the horizontal and vertical flow of information in supply chain. Managers should coordinate new technology with human-related resources. The company may recruit new technical staffs or train employees how to effectively use this new technology.

Managers should emphasize criterion C2 (on time delivery performance) for 3PL provider selection because it has the highest degree of influential impact (*D*) on other criteria as shown in Table X and could directly or indirectly influence other criteria. In other words, managers who choose 3PL providers should first consider on time delivery performance (C2), then technological capability (C10), financial stability (C7), human resource policies (C12), service quality (C1) and customer service (C5). The practical implications of sensitivity analysis may provide insights into which criteria play key roles in 3PL evaluation and may guide managers to focus on various criteria in their analysis. For instance, if some criteria provide greater sensitivity to 3PL selection, these criteria should be put under detailed examination and may require more careful evaluation. Our findings are consistent with managers' opinion in selecting 3PL providers. Apart from basic criteria such as price, quality and delivery, managers also believe that technology capability (e.g. infrastructure) and financial stability play an important role in the selection process. Financial stability is the third most important criteria for 3PL. managers should note that supply chain financing is a relatively new and innovative method for supply chain improvement. Hence there is a significant relationship between financial stability and 3PL service (Shi *et al.*, 2015). Hence, managers should support 3PL providers to solve unpredicted financial problems and ask them to borrow bank loans to handle their financial restrictions. Furthermore, large 3PL providers, which have strong financial ability, are more confident about the financial returns in offering logistics services. Also, large 3PL providers, which often have extensive logistics networks, advanced technological equipments, integrated information technologies; financial strengths and large customer services are the ideal beginner to start logistics service. Last but not the least, 3PLs are able to change the structure of the traditional supply chain to a more efficient one that reaches higher service levels, enhances operations efficiency and decreases carbon footprints at the same time.

In this paper a comprehensive list of important criteria for 3PL provider selection is provided by reviewing related literature and more than 40 papers. These findings provide significant insights for 3PL provider to manage their business activities. It is essential for 3PL to evaluate their own strengths and weaknesses to satisfy their customers' expectations successfully. The 3PL provider managers should pay high attention to customer services. It is necessary to improve customer satisfaction and keep customers' loyalty that contributes to increased market share and additional profits. Customers' satisfaction includes fulfillment on the purchased product and the delivery service they met. The delivery service plays an important role on the customer satisfactions. Managers should notice an improved customer services needs to provide teaching for employees and keep experienced staff (Ellinger *et al.*, 2010; Jie *et al.*, 2015).

8. Conclusion and future research

Outsourcing is a common activity in many industries, especially in logistics and supply chain management. Currently, a rising number of companies are outsourcing their logistics tasks. Selecting an appropriate 3PL provider is a strategic decision and plays a substantial role in establishing long-term relations between providers and outsourcing firms. In this study, an overview of the literature regarding 3PL provider selection and evaluation decision was provided. The literature review indicated that this decision is of a complicated nature because it needs to explore several conflicting and interdependent criteria. Furthermore, 3PL provider selection involves uncertain, imprecise, and subjective judgments to determine the importance and influence rate of evaluation criteria. For this reason a grey DEMATEL method which can handle complicated problems and determine the causal relationships between assessment criteria and effectively avoid vague and imprecise judgments was presented. Then, a practical case study of grey DEMATEL method to develop 3PL provider selection criteria in an automobile manufacturing company in Iran was introduced. The DEMATEL findings revealed the structure and interrelationships between criteria and identified the main criteria for 3PL provider selection. The causal diagram results divided the criteria into two cause and effect groups. "Financial stability" (C7) indicates sound financial performance of providers, "on time delivery performance" (C2) refers to 3PL ability to meet delivery schedules, "human resource policies" (C12) such as employee satisfaction level, availability of qualified talents and employee training, "logistics information system" (C6) refers to provider's capability to reduce uncertainties and inventory level, "geographic location" (C9) means extensive geographic range of services offered by providers, "service quality" (C1) such as 3PL provider ability, accuracy, quality awareness and inspection methods belong to the cause group which should be paid more consideration. "Reputation" (C8) indicates customers' opinion about satisfying their needs, "performance history" (C11) refers to experience in similar industry, "customer service" (C5) includes customer satisfaction, customer complaint rate and service improvement, "technological capability" (C10) considers the availability of technical manpower, modern reprocessing technology, research and development facilities, "cost of services" (C4) is the total cost of logistics outsourcing and "flexibility in operation" (C3) refers to the capability of accommodating special or non-routine request all are in the effect group which should be improved. Results indicated that "on time delivery performance" (C2) is the most important criterion for 3PL provider selection. Other important criteria are "technological capability" (C10), "financial stability" (C7), "human resource policies" (C12), "service quality" (C1) and "customer service" (C5), respectively. The findings represented that "financial stability" (C7) has the highest influence on other criteria. The results are useful for firms to identify the suppliers' weaknesses. Additionally, the results assist firms in reducing costs, concentrating on core competencies, and lowering the risk of selecting an inappropriate logistics provider.

This study, like many other studies, is unlikely to be flawless and it suffers from some limitations which can be investigated in future research. For example, one limitation was the "importance" assessment of each criterion which was based on the level of each criterion's influence on each other. Hence, criteria which do not have a strong causal relationship with others are not sufficiently captured by this method. Integrating of other ranking methodologies (like ANP or rough set theory) may provide comparatively more reliable methodologies to remove this drawback. While environmental concerns have been growing rapidly, companies should take environmental criteria into account in a 3PL provider selection process and utilize 3PRLP which can be considered for future research explorations.

Moreover, it seems that a few number of studies developed balanced scorecard strategies, SCOR (supply chain operations reference-model), hybrid MCDM methods and SWOT analysis for 3PL service providers which can be developed as future works. To deal with human's subjective judgments, other concepts such as intuitionistic fuzzy set theory can be applied and it would be attractive to compare the results with the outcomes of the methodology. Due to increasing environmental concerns and development of reverse logistics activities, selection of reverse logistics providers becomes a more significant topic. Thus, developing criteria to select 3PRLP using DEMATEL method can be examined as another future research topic. Finally, the outcome of this study is exclusively determined by four experts from the realms of logistics and supply chain management. To build a more generalized model to develop 3PL provider selection criteria and to ensure the validity of the research, it would be cogent to extend the number of experts in the study. As 4PL can manage the supply chain and logistics process, it has attracted more and more attention in many industries. Hence, using MCDM methods to develop 4PL provider selection criteria can be considered as future research.

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