Integrated DANP and Binary Goal Programming Model in Generating Joint-Decision Making for Packaging Postponement and Supplier Selection

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Abstract

This article explores the application of goal programming (GP) for improving tactical decision-making in supply chains. GP demonstrates flexibility to be integrated with other Multi-Criteria Decision Making (MCDM) methods such as Decision-Making Trial Evaluation and Laboratory (DEMATEL)-based Analytic Network Process (ANP) (DANP) to support better business decisions. Joint-decision making of packaging postponement and supplier selection involving two business functions: logistics and purchasing, effectively reduce the supply chain cost. This research proposes integrating the DANP and binary goal programming (BGP) model to generate optimal joint decision-making of packaging postponement and supplier selection. Based on a case of a shoe company in Indonesia, this research identifies the optimal trade-off between packaging and transportation costs. The findings show that the company needs to apply the packaging postponement to all distribution centres to minimize total cost. The sensitivity analysis illustrates that the decision remains until the packaging cost at the main factory is reduced by 50% or the packaging cost at the distribution centre (DC) is increased by 50%. The optimal solution shows the reduction of average logistics cost by 12.64%. This article provides a practical approach for managers to negotiate packaging prices with suppliers by considering transportation costs.

Keywords: Analytic Network Process; Binary goal programming; Joint decision-making; Packaging postponement; Supplier Selection

1. INTRODUCTION

Due to its role in cost minimization, efficient product packaging has become a critical success factor in supply chain management (Regattieri & Santarelli, 2013). Products with low-profit margins, such as food commodities, are often shipped in bulk or unpackaged to reduce transportation costs. Packaging postponement is a concept that integrates packaging and the supply chain. It is a strategy in supply chain management that delays packaging to a certain point that can reduce product distribution costs (Twede et al., 2000). This particular point can refer to a specific location or final shape of a product. It is not a type of packaging intended to facilitate distribution, product handling, and product protection from damage. Instead, the implementation is for retail or consumer packaging when the demand arises. Packaging postponement is considered successful in minimising costs if products are delivered in a standard and compact format before specific packaging is applied. Products in retail packaging will experience an increase in volume and weight, so the delivery of products in the shortest possible way will increase the volume of product shipments so that the cost is lower.

One of the global success stories of the packaging postponement implementation is the Hewlett-Packard (HP) printer division. HP sends printers in generic packaging and then makes differentiation when an order comes in (Venkatesh & Swaminathan, 2004; B. Yang & Burns, 2003). This strategy decreases the inventory levels and lowers the logistics costs because more printers (in a smaller size) can be shipped (Twede et al., 2000). HP's success in implementing packaging postponement has spurred research projects on packaging postponement. A Taiwan survey shows that the postponement strategy reduces logistics costs significantly in information technology companies due to their roles in the Original Equipment Manufacturer (OEM) market (Chiou et al., 2002). In California, a mathematical model was developed to see the effect of the postponement strategy on the wine industry's profitability. The results showed that labelling and packaging postponement could significantly increase profits (Cholette, 2009). In India, packaging postponement has increased the sanitary pad industry's supply chain responsiveness (Seth & Panigrahi, 2015). Another exploratory study on the cleaning equipment industry suggested the application of packaging postponement by considering various technical factors (Graman & Magazine, 2006). The positive findings of packaging postponement in various industrial sectors form the basis of the hypothesis in this study.

One crucial aspect of packaging postponement implementation is determining the timing of the primary packaging. Order penetration point (OPP) and decoupling point (DP) are the last points in a supply chain, where the product will undergo customization based on customer demand (Zinn, 2019). However, this concept may not apply in industries that implement a push supply chain system because it requires integration between push-pull systems (Olhager, 2010). Total operating costs need to be considered when postponing product packaging in industries that implement a push system. One component of operating costs is logistics. If products are packaged before distribution, transportation costs will increase because the number of products shipped is lower. Without primary packaging, the number of products sent can be optimized. The trade-off is the increasing packaging cost. If the packaging is purchased centrally in large quantities (centralized ordering), the packaging cost will be lower. On the other hand, if the purchase is decentralized to accommodate packaging postponement, the prices offered by local suppliers could be higher. Therefore, it is crucial to know when primary packaging needs to be done and how to select suppliers to achieve optimal operating costs.

The supplier selection process is complex and needs to consider quality, delivery, and environmental issues—making it a multi-criteria decision-making (Kilic & Yalcin, 2020). Previous studies have not discussed joint decision-making in supply chain management involving supplier selection. Most research focuses on methods and techniques for solving multi-criteria decision-making problems (Cano & Ayala, 2019). Supplier selection is an important decision in supply chain management to save costs and minimize risk (Cano & Ayala, 2019; Naqvi &

Amin, 2021). Research has shown a strong relationship between supplier selection and carrier selection (Ghorbani & Ramezanian, 2020) or the lot-sizing problem (Cárdenas-Barrón et al., 2021). However, to the best of our knowledge, there have been no studies combining packaging postponement and supplier selection to minimize operating costs. The cost minimization could be even more effective by combining these two functions in a supply chain tactical decision. Therefore, this study proposes a relevant mathematical model. The hypothesis is that the integration model can effectively reduce costs and improve supply chain performance.

The mathematical model is developed using a binary goal programming (BGP) approach. BGP is an extension of linear programming (LP), which accommodates multiple objective functions with binary decision variables. The objective is to minimize costs and select the best supplier by considering the supplier assessment score. The weight of each supplier selection criteria will be assessed using the Decision-Making Trial Evaluation and Laboratory (DEMATEL)-based Analytic Network Process (ANP) (DANP). The weights obtained from the DANP will be the parameters of the BGP model.

The integration of ANP and GP has been used in past studies, such as project selection modelling (Nesticò et al., 2020; Chang et al., 2009; Ravi et al., 2008; Wey & Wu, 2007) and worker scheduling (Özder et al., 2019; Polat et al., 2017). In supplier selection, previous studies involving ANP and GP have solved supplier selection and order allocation issues (Aouadni et al., 2013). In the current study, the integration of DANP and BGP seeks to facilitate joint decision-making to determine the primary packaging timing and the supplier. DANP is used to analyse causal effects and their influence from a holistic point of view. It involves a network structure that can accommodate the interaction and interdependence of elements between levels. The network structure allows relationships to spread in all directions and involve cycles between clusters, as well as loops within the same cluster. One axiom in DANP that can be integrated with BGP is the priority or weight—a value of relative dominance (Niemira & Saaty, 2004). Problem-solving with the GP model can be categorized as pre-emptive and non-pre-emptive. Pre-emptive programming solves problems in a stratified manner according to the priority of the objective function. After the priority is solved, the next priority must be solved without changing the optimal solution of the previous priority. Mathematically, the priority solution will be a constraint for the next priority. In contrast, non-pre-emptive programming completes all goals simultaneously without any prioritisation. This pre-emptive and non-pre-emptive concept allows a more flexible problem solving using the GP approach.

This model is applied to solve a case study in a shoe company in East Java, Indonesia. The country has the highest logistics costs in Asia (23% of the gross domestic product). A critical component of logistics costs is transportation costs, so minimizing it will significantly impact the industry. Shoe companies can provide retail packaging (shoeboxes) at the factory or the distribution centre. If the final packaging is at the distribution centre, the company needs to select a new packaging supplier to supply shoeboxes to the distribution centre. The proposed model will help find an optimal solution for joint decision-making between packaging postponement and supplier selection.

2. Literature Review

Postponement, a supply chain strategy to anticipate demand uncertainty, has been implemented in various industries and positively impacted inventory management. A postponement strategy considers the operating characteristics, including technological, process, product, and market characteristics (van Hoek, 2001). Postponement strategies are classified into three main types: time, place, and form (Bagchi & Gaur, 2018). Time postponement is delaying the movement of inventory. Then, place postponement is maintaining inventory in a specific location. Form postponement includes manufacturing, assembly, labelling, and packaging delays. Other postponement strategies—such as upstream, downstream, distribution (Waller et al., 2000), purchasing, and product development postponement (B. Yang & Burns, 2003)—are adjustments of the time, place, and form postponement. Studies on postponement have continued to grow since Alderson (1950) proposed it because it needs to consider many aspects.

From the literature search results on the recent postponement strategy-related studies, 22 articles were found. The research focuses on the postponement area is diverse: product modularity (Bagchi & Gaur, 2018; Xiong et al., 2018), sustainability (Budiman & Rau, 2019; Mukherjee, 2017; Kühle et al., 2019), supply chain complexity (Chiu et al., 2019; Choi et al., 2019; Geetha & Prabha, 2021; Ngniatedema et al., 2018; Chiu et al., 2020), supply and demand uncertainty (Carbonara & Pellegrino, 2018; Herbon, 2018; Kouvelis et al., 2021; Wang et al., 2022; Weskamp et al., 2019), decoupling point (Aktan & Akyuz, 2017; Oey & Nitihardjo, 2016), product shelf life (Bandaly & Hassan, 2020), labelling postponement (Varas et al., 2018), packaging postponement (Prataviera et al., 2022), and product recall (Gunawan et al., 2022). The postponement strategies cover not limited to product form but include price (Herbon, 2018; Kouvelis et al., 2021), labelling (Varas et al., 2018), and service (Wang et al., 2022).

The most widely used postponement modelling approach is algebraic (Bagchi & Gaur, 2018; Carbonara & Pellegrino, 2018; Chiu et al., 2019; Choi et al., 2019; Geetha & Prabha, 2021; Herbon, 2018; Kouvelis et al., 2021; Ngniatedema et al., 2018; Prataviera et al., 2022; Chiu et al., 2020). Some studies seek optimization through stochastic programming (Varas et al., 2018; Weskamp et al., 2019), game theory (Wang et al., 2022; Xiong et al., 2018), mixed-integer programming (Budiman & Rau, 2019; Gunawan et al., 2022), and dynamic programming (Bandaly & Hassan, 2020). Several other studies utilized hybrid multi-criteria decision-making (MCDM) methods such as Intuitionistic Fuzzy Analytic Hierarchy (IFAHP)-Multi-Objective Genetic Algorithm (MOGA) (Mukherjee, 2017) and AHP - Technique for Others Reference by Similarity to Ideal Solution (TOPSIS) (Oey & Nitihardjo, 2016). Statistical analysis methods such as Structural Equation Modelling (SEM) have also been used in the postponement research area (Saghiri & Barnes, 2016).

Almost all research in the postponement area involves specific case studies. Various case studies highlight the distinctive characteristics of manufacturing products (Budiman & Rau, 2019; Choi et al., 2019; Herbon, 2018; Ngniatedema et al., 2018; Oey & Nitihardjo, 2016; Varas et al., 2018; Weskamp et al., 2019;

Xiong et al., 2018; Kühle et al., 2019) to agricultural products (Bandaly & Hassan, 2020; Gunawan et al., 2022; Kouvelis et al., 2021; Prataviera et al., 2022) have been reviewed in the postponement area. Specific case examples of postponement models enhance the understanding of the model application and managerial implications of the research.

Furthermore, a review of research on supplier selection area shows that the development of mathematical modelling revolves around the development of multi-criteria decision-making solutions involving new criteria such as green (Alimohammadlou & Bonyani, 2021; Banaeian et al., 2018; Chen et al., 2019; Haeri & Rezaei, 2019; Hosseini & Barker, 2016; Kilic & Yalcin, 2020; Yazdani et al., 2019; Yu & Hou, 2016), resilient (Alimohammadlou & Bonyani, 2021; Cavalcante et al., 2019; Hosseini & Khaled, 2019), green and resilient (Hosseini & Barker, 2016), sustainable (Durmić, 2019; N. Jain & Singh, 2020; Kannan et al., 2020; Luthra et al., 2017; Mukherjee, 2017; Stević et al., 2020; Tirkolaee et al., 2020; Wu et al., 2021), corporate social responsibility (Govindan et al., 2018), and lean-agile (Li et al., 2020). In addition to criteria development, research streams in the supplier selection area combine supplier selection with other concepts such as the six sigma (Chen et al., 2019). The integration of supplier selection and postponement has been carried out by Mukherjee (2017) on the assemble-to-order production system and Saghiri and Barnes (2016), whose research focuses on the effect of supplier flexibility criteria on the postponement strategy. However, these studies have not explicitly modelled supplier selection process.

Literature review in the supplier selection area also shows that researchers had a higher interest in using hybrid MCDM approach such as DEMATEL-ANP- Preference Ranking Organizational Method for Enrichment Evaluation (PROMETHEE) (Govindan et al., 2018), Logistic regression-Classification and Regression Tree (CART)-Neural network-ANP (Hosseini & Khaled, 2019), AHP-ViseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Luthra et al., 2017), Full Consistency Method (FUCOM)- Rough Simple Additive Weighting (RSAW) (Durmić et al., 2020). The fuzzy logic approach in the development of supplier selection methods is also growing rapidly (Banaeian et al., 2018; Haeri & Rezaei, 2019; N. Jain & Singh, 2020; V. Jain et al., 2018; Kannan et al., 2020; Polat et al., 2017; Wu et al., 2021). Some previous studies also used the DANP and Goal Programming (GP) integration methods but were limited to supplier selection (Alimohammadlou & Bonyani, 2021; Chauhan & Singh, 2021; Sarkar et al., 2018; Tirkolaee et al., 2020) or decoupling point position (Aktan & Akyuz, 2017). This is different from the use of DANP-BGP proposed in this study, which aims to get the best supplier and determine the decoupling point of packaging postponement.

DEMATEL and ANP are integrated into DANP to overcome the weakness of ANP in determining the degree of dependency between criteria. Then the results are used to normalize the unweighted supermatrix in ANP. By employing DEMATEL technique, this degree of interdependency does not have a reciprocal value and thus is closer to the real condition (Büyüközkan & Güleryüz, 2016).

GP is a very popular approach in multi-objective optimisation as it provides simplicity, tractability and diversity of applications (Colapinto et al., 2020). GP is capable of producing optimal solutions for conflicting objective functions. Applying GP in supplier selection aims to obtain the optimal decision from many conflicting supplier selection criteria. Although the integration of DANP and GP is widely used in supplier selection, various previous studies have shown the flexibility of using DANP-GP in various cases such as sustainable infrastructure projects (Yang et al., 2016), green management strategies (Lee et al., 2018), marketing strategy selection (Cahyadi & Anna, 2019), information system strategies (C.-H. Yang, Lee, Tsai, et al., 2020), intelligent building management systems (Yang et al., 2020), and smart healthcare management systems (Yang et al., 2022). This study employs the binary goal programming (BGP), where the decision variables are limited to binary values. In other studies it can be called zero-one goal programming (ZOGP). Thus far, no proposed DANP-BGP has been developed considering the integration of packaging postponement and supplier selection (see Figure 1). The rationale is that when packaging postponement is implemented, the next decision is how to choose a supplier to meet the needs of the auxiliary component whose application is postponed. Therefore, this study aims to fill this research gap.

Table 1. Review of related past studies on postponement, supplier selection, and DANP-GP

No.	Author(s)	Research focus	Case selection	Modelling approach	Journal
1	Aktan & Akyuz (2017)	Decoupling point position	Not specified	DANP and GP	Int. J. Productivity and Quality Management
2	Alimohammadlou & Bonyani (2021)	Resilient supplier selection under a fuzzy environment	Electronic industry	DANP and GP	Modern Research in Decision Making
3	Badi et al. (2020)	Supplier selection	Iron and steel industry	Grey theory and MARCOS	Decision Making: Applications in Management and Engineering
4	Bagchi & Gaur (2018)	Modular product design	Not specified	Algebraic	Journal of Global Operations and Strategic Sourcing
5	Banaeian et al. (2018)	Green supplier selection	Agri-food industry	Fuzzy TOPSIS, Fuzzy VIKOR and Fuzzy GRA	Computers & Operations Research
6	Bandaly & Hassan (2020)	Product deterioration	Apple juice	DP	Production Planning & Control
7	Budiman & Rau (2019)	Environmental issue	Notebook computer	MIP	Computers & Industrial Engineering
8	Cahyadi & Anna (2019)	Marketing strategy selection	Batik	DANP and GP	International Journal of Advances in Scientific Research and Engineering
9	Carbonara & Pellegrino (2018)	Supply and demand disruption	Not specified	Algebraic	International Journal of Production Research
10	Chauhan & Singh (2021)	Selection waste management service provider	Healthcare	DANP and GP	Journal of Environmental Management
11	Cavalcante et al. (2019)	Resilient supplier selection	Digital manufacturing	Simulation and Machine learning	International Journal of Information Management
12	Chen et al. (2019)	Green supplier selection model using six sigma quality indices	Electronic industry	Fuzzy logic	International Journal of Production Economics
13	Chiu et al. (2019)	Multi-item two-stage production process	Not specified	Algebraic	Jordan Journal of Mechanical and Industrial Engineering
14	Chiu et al. (2020)	Multi-product fabrication and shipment problem	Not specified	Algebraic	Journal of Applied Research and Technology
15	Choi et al. (2019)	Online-offline franchise business	Fashion products	Algebraic	International Journal of Production Economics
16	Durmić et al. (2019)	Sustainable supplier selection	Not specified	FUCOM and Rough SAW	Reports in Mechanical Engineering
17	Dweiri et al. (2016)	Supplier selection	Automotive industry	AHP	Expert Systems with Applications
18	Geetha & Prabha (2021)	Fuzzy cost in inventory management	Not specified	Algebraic	Journal of Management Analytics
19	Govindan et al. (2018)	Supplier selection based on corporate social responsibility practices	Access control hardware industry	DANP and PROMETHEE	Int. J. Production Economics
20	Gunawan et al. (2022)	Product recall	Edible oil	MIP	Journal of Food Engineering

No.	Author(s)	Research focus	Case selection	Modelling approach	Journal
21	Haeri & Rezaei (2019)	Green supplier selection	Automotive industry	BWM, FGCM and Improved GRA	Journal of Cleaner Production
22	Herbon (2018)	Ordering and pricing postponement for seasonal product	Fashion jeans	Algebraic	Decision Sciences
23	Hosseini & Al Khaled (2019)	Resilient supplier selection	Plastic pipe industry	Logistic regression, CART, Neural network, and AHP	J. Intell. Manuf.
24	Hosseini & Barker (2016)	Green and resilient supplier selection	Not specified	Bayesian network	Intern. Journal of Production Economics
25	Jain & Singh (2020)	Sustainable Supplier Selection	Iron and steel industry	Fuzzy kano and Fuzzy inference system	Journal of Cleaner Production
26	Jain et al. (2018)	Supplier selection	Automotive industry	Fuzzy AHP and TOPSIS	Neural Computing & Applications
27	Kannan et al. (2020)	Sustainable circular supplier selection	Wire-and-cable industry	Fuzzy BWM and Interval VIKOR	Science of the Total Environment
28	Kilic & Yalcin (2020)	green supplier selection	Air filter industry	Fuzzy GP and IF-TOPSIS	Applied Soft Computing Journal
29	Kouvelis et al. (2021)	Pricing postponement under crop random yield	Agricultural products	Algebraic	Management Science
30	Kühle et al. (2019)	Sustainable value creation of hardwood product	Furniture industry	LP	Cogent Business & Management
31	Lee et al. (2018)	Green management strategy selection	Aviation industry	DANP and GP	Journal of Air Transport Management
32	Li et al. (2020)	Legile supplier selection	Textile industry	DEMATEL	Annals of Operations Research
33	Luthra et al. (2017)	Sustainable supplier selection	Automotive industry	AHP and VIKOR	Journal of Cleaner Production
34	Mukherjee (2017)	Sustainable procurement and procurement postponement	Not specified	IF-AHP and MOGA	Production
35	Ngniatedema et al. (2018)	Global supply chain complexities	HP desk jet printer	Algebraic	Int. J. Business Performance and Supply Chain Modelling
36	Oey & Nitihardjo (2016)	Postponement center selection	Pharmaceutical industry	PESTLE, AHP, and TOPSIS	Global Business Review
37	Polat et al. (2017)	Supplier selection	Rail supplier	Fuzzy AHP and Fuzzy TOPSIS	Journal of Civil Engineering and Management

No.	Author(s)	Research focus	Case selection	Modelling approach	Journal
38	Prataviera et al. (2022)	Comparing global logistics postponement and global packaging postponement	Edible oil	Algebraic	The International Journal of Logistics Management
39	Saghiri & Barnes (2016)	The relationship of supplier flexibility on postponement strategy	Not specified	SEM	Intern. Journal of Production Economics
40	Sarkar et al. (2018)	Supplier selection with qualitative and quantitative criteria	Welding	DANP and GP	Journal of Manufacturing Systems
41	Stević et al. (2020)	Sustainable supplier selection	Healthcare industry	MARCOS	Computers & Industrial Engineering
42	Tirkolaee et al. (2020)	Sustainable-reliable supplier selection in two-echelon supply chain	Not specified	DANP and GP	Journal of Cleaner Production
43	Varas et al. (2018)	Labelling postponement	Wine industry	Stochastic programming	International Journal of Production Research
44	Wang et al. (2022)	Matching supply and demand in service industries	Service	Game theory	Omega
45	Weskamp et al. (2019)	Uncertain demand	Apparel industry	Stochastic programming	Omega
46	Wu et al. (2021)	Sustainable Supplier Selection	Chemical industry	Fuzzy GRA, FMEA, cloud computing-EWM, and DEMATEL	Expert Systems with Applications
47	Xiong et al. (2018)	Modular product design	Laser printer	Game theory	International Journal of Production Economics
48	Yang et al. (2016)	Sustainable infrastructure project	Public transport	DANP and GP	Journal of Cleaner Production
49	Yang et al. (2020a)	Information system portfolio strategy for sustainability	Healthcare	DANP and GP	Sustainability
50	Yang et al. (2020b)	Intelligent building management system portofolio	Semiconductor industry	DANP and GP	Sustainable Cities and Society
51	C.H. Yang et al. (2022)	Smart healthcare management system portofolio	Public medical center	DANP and GP	Socio-Economic Planning Sciences
52	Yazdani et al. (2017)	Green supplier selection	Dairy company	DEMATEL, QFD, COPRAS, and MOORA	Journal of Cleaner Production
53	Yazdani et al. (2019)	Supplier selection	Construction management	DEMATEL, BWM, and CoCoSo-G	Journal of Civil Engineering and Management
54	Yu & Hou (2016)	Green supplier selection	Automotive industry	MMAHP	Kybernetes

- Notes for the abbreviations: MARCOS (Measurement of Alternatives and Ranking According to the Compromise Solution), TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), GRA (Grey Relational Analysis), BWM (Best-Worst Method), FGCM (Fuzzy Grey Cognitive Map), FMEA (Failure Mode Effect Analysis), EWM (Entropy Weight Method), QFD (Quality Function Deployment), COPRAS (Complex Proportional Assessment), MOORA (Multi-Objective Optimization on the Basis of Ratio Analysis), CoCoSo-G (Combined Compromise Solution Method with Grey Numbers), MMAHP (Modified Multiplicative Analytic Hierarchy Process)

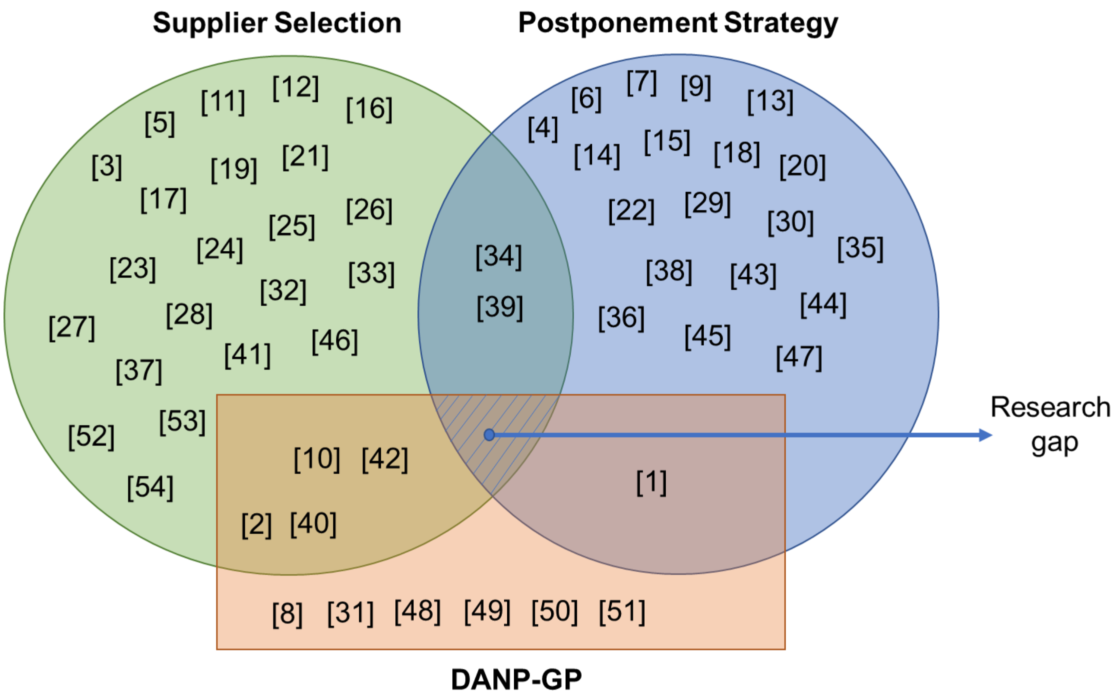

Figure 1. The Intended Research Gap

3. METHOD

The research method is described in two parts. The first part is the BGP model development, and the second part is the supplier assessment model development.

3.1. The BGP Model Development for Joint-Decision Making

GP is a multi-criteria decision analysis branch with a long development history. Charnes et al. introduced GP in 1955, and it developed rapidly in the 1970s (Tamiz et al., 1995). Therefore, GP is the oldest multiple objective programming (Orumie & Ebong, 2014). Supply chain management has become a new business management perspective that improves effectiveness and efficiency better than common management. This research explores the application of the GP to generate optimal tactical decisions in supply chain management. BGP is a variant of GP with binary decision variables used to generate optimal joint-decision between packaging postponement and supplier selection. The general equation of lexicographic GP is as follows

$$Minimize\ Z = \sum_{i}^{m} P_i(d_i^- + d_i^+) \tag{1}$$

subject to

$$\sum_j^n a_{ij}x_j + d_i^- - d_i^+ = b_i \quad \text{(i=1, 2, …, m)} \tag{2}$$

$$d_i^+, d_i^- \geq 0 \text{ for } \forall_i \tag{3}$$

$$x_j \geq 0 \text{ for } \forall_j \tag{4}$$

Equation (1) is the objective function to minimize Z which is the sum of the deviation from m desired goals. P_i is a pre-emptive priority ($P_1 > P_2 > P_3 >>> P_m$) for goal m. d_i^+ and d_i^- are the positive or negative deviation variables for the selection criterion i. Equation (2) shows that a given target value or goal (b_i) needs to be achieved. The undesired deviations d_i^+ and d_i^- from the given set of targets (b_i) are minimized using an objective function (Z). a_{ij} is the decision parameter j of selection resource i and x_j is the binary selection variable. Equation (3) and (4) are the non-negative constraints.

The general transformation of the GP lexicographic model into a BGP model for specific cases follows the modelling-validation process (Landry et al., 1983). Figure 2 shows the steps involved in building the mathematical model, starting by describing the problem situation. The data were collected from observations and unstructured interviews. After that, a conceptual model was built as the basis for developing a formal model and the verification. The formal model is a translation of the conceptual model into mathematical symbols. In this research, the formal model is a BGP-based optimization model. The formal model is declared valid if it follows the conceptual model (logical validity) and produces a verifiable solution (experimental validity). The solution in this research was solved using Lingo 11 software.

The solution search technique applied to the model generates an optimisation model. This is the solution model that becomes the basis for submitting recommendations and testing the model's validity (validation by results). The validation procedure used is a prediction experiment using a real case example.

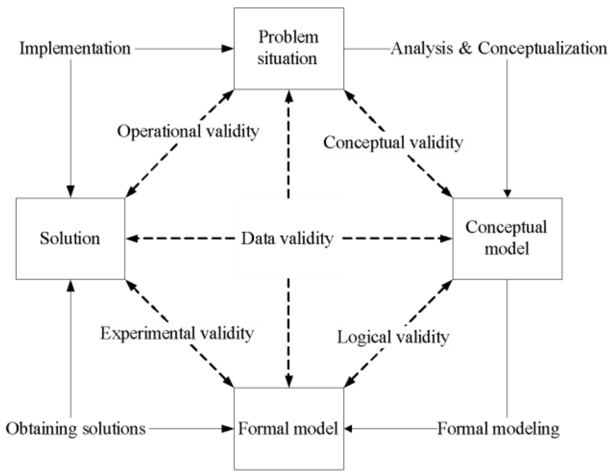

Figure 2. The Modelling-Validation Process Cycle

3.2. The Supplier Assessment Model Development

Suppliers are selected by assessing the offers against a supplier assessment model. The development of the model starts from the identification and determination of the criteria and sub-criteria. This process includes a literature review and unstructured interviews with company representatives. The relationship between the sub-criteria was determined using a pairwise comparison questionnaire adopted from the DEMATEL approach. The questionnaire uses a Likert scale of 0 to 4, with the number 0 indicating no relationship and the number 4 indicating a very strong relationship. This step aims to build a network model in ANP. Therefore, it can be called DEMATEL-based ANP or DANP.

The ANP questionnaire was prepared based on predetermined sub-criteria. Therefore, this paired comparison questionnaire is different from the previous questionnaire. The ANP questionnaire uses a Likert scale with a range of 1 to 9, with a scale of 1 indicating that both elements have significant influence and a scale of 9 indicating one element is more important than the others. The two questionnaires were distributed to respondents categorized as experts in the industry.

The DEMATEL procedure begins by processing the questionnaire results on the relationship between the sub-criteria to compile a relationship matrix (Matrix A). If the number of experts is more than one, the matrix will be filled with the average value of all experts' assessments. Each expert (k) will produce non-negative matrices $X^k = [x_{ij}^k]_{nxn}$, with $1 \leq k \leq H$. Then, the mean is calculated to accommodate all experts' opinions using Equation (5).

$$A = [a_{ij}]_{nxn} = \frac{1}{H}\sum_{k=1}^{H}[x_{ij}^k]_{nxn} \quad (5)$$

After the relationship matrix between sub-criteria is formed, then the matrix is normalised using Equation (6). Finally, the normalized matrix (Matrix G) is processed into a total relationship matrix (matrix T) using Equation (7), where I is the identity matrix.

$$G = \frac{1}{\sum_{j=1}^{n} a_{ij}} A, i, j = 1, \dots, n \quad (6)$$

$$T = G(IG)^{-1} \quad (7)$$

The next step is to calculate the threshold from the average value in the T matrix, which is then tested with a threshold value. Suppose the value of the relationship in the matrix T (t_{ij}) is greater than the threshold value; in that case, it means that the respondents agree that the relationship between the two sub-criteria is significant. A relationship model between the sub-criteria is formed from the T matrix that is used in the ANP. After obtaining the criteria and sub-criteria relationship model, the data processing follows the ANP procedure.

The ANP questionnaire that the expert has filled in is also arranged into a pairwise comparison matrix. The value in the pairwise comparison matrix is obtained from the geometric mean of the expert's answers. The next step is to sum up, according to the number of columns, dividing each component element by the total amount to find the eigenvector value. To get the maximum lambda value, the eigenvector value is multiplied by the total number of columns.

This process is followed by consistency checking. Inconsistency may occur because the data are qualitative based on human perception. Therefore, the Consistency Index (CI) and Consistency Ratio (CR) were calculated to determine the consistency of each input. Suppose the CR value > 0.1, the data taken is inconsistent and needs to be reassessed. After that, the data were arranged into a super matrix composed of relative-importance weight vectors. There are three super matrix stages: unweighted, weighted, and limit. The value of the unweighted super matrix is derived from the eigenvector of each sub-criterion. The value of the weighted super matrix is obtained from the multiplication of the unweighted super matrix with the weight of each criterion (cluster matrix). After that, each value in the matrix was normalised. The limit matrix is obtained by powering the weighted super matrix until stable. When all rows in the super matrix have the same value, then the super matrix is declared stable. The final weight calculation in the ANP method uses the normalized super matrix limit results. The weights generated can show the essential sub-criteria. The results from the sub-criteria weights are used as weights in the BGP model.

4. RESULTS AND DISCUSSION

4.1. The Supplier Assessment Model

This research begins with the development of criteria and sub-criteria as assessment indicators in the supplier selection process at each distribution centre. Then, the supplier is selected by evaluating offers against the criteria and sub-criteria. Five criteria and 12 sub-criteria were established through a literature study and in-depth interviews with the purchasing team—from purchasing staff to the heads of purchasing and the warehouse. Afterwards, a questionnaire adapted from the DEMATEL method was used to determine the relationship between the criteria and sub-criteria. Five respondents, i.e., the head of the production department, the head of production planning and inventory control department, the head of the quality control department, the head of purchasing department, and the head of the warehouse, filled out the questionnaire. Figure 3 shows the criteria and sub-criteria used in the model and the relationship between criteria in the packaging supplier selection. The service criteria have no inner dependence (interaction with itself) or a reciprocal relationship between price and quality criteria. In comparison, the other criteria have a reciprocal relationship. Additionally, the relationship between sub-criteria was established, as shown in Table 2.

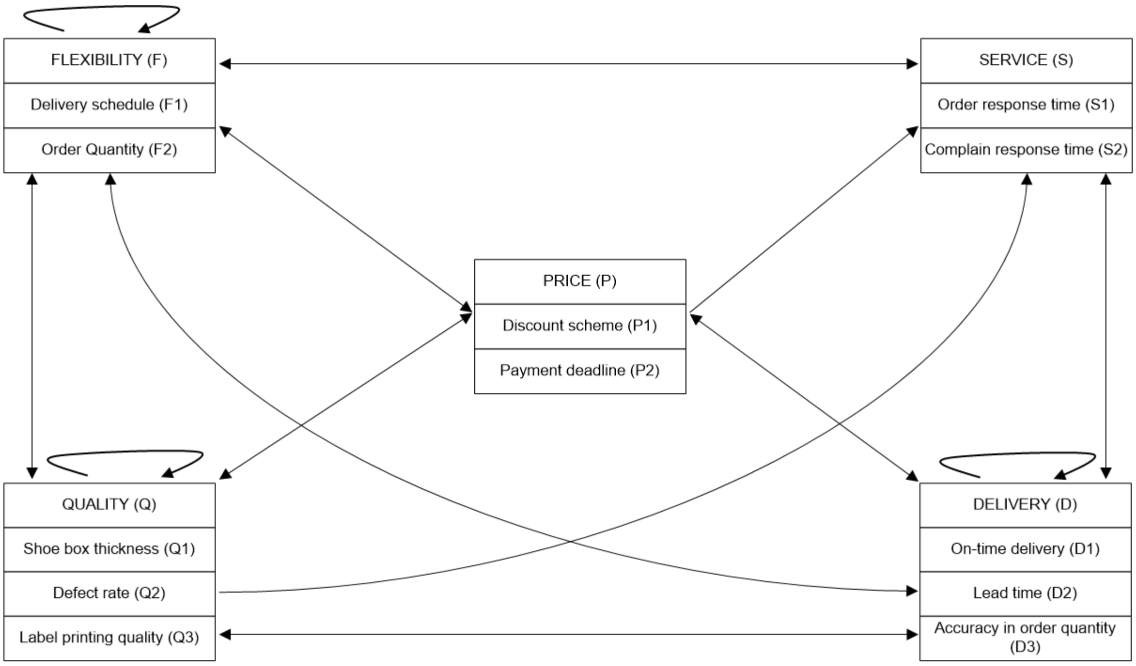

Figure 3. The Relationship between Supplier Selection Criteria

Table 2. The Relationship between Supplier Selection Sub-Criteria

	P1	P2	Q1	Q2	Q3	D1	D2	D3	S1	S2	F1	F2
P1		√	√	√	√	√	√	√				√
P2	√					√	√	√			√	
Q1	√			√	√							
Q2	√	√	√		√	√						
Q3	√			√		√	√					√
D1	√	√	√	√	√		√		√	√	√	√
D2			√					√	√	√	√	√
D3	√		√	√	√					√	√	√
S1						√	√				√	√
S2	√		√	√	√	√		√				√
F1		√	√	√	√	√	√	√	√	√		√
F2	√	√				√	√	√	√	√	√	

After that, the weight for each sub-criterion was calculated, which would be used as model parameters. Among the identified sub-criteria, the three highest sub-criteria are label printing quality, discount scheme, and order quantity flexibility.

Table 3. Supplier Assessment

Criteria	**Sub-criteria**	**Weight (W_I)**				**Score (S_I)**			
Price	Discount scheme	0.1207	(Very unsuitable)	1	2	3	4	5	(Very suitable)
	Payment deadline	0.0868	(Very unsuitable)	1	2	3	4	5	(Very suitable)

	Shoebox thickness	0.1033	(Very unsuitable)	1	2	3	4	5	(Very suitable)
Quality	Defect rate	0.0546	(Very unsuitable)	1	2	3	4	5	(Very suitable)
	Label printing quality	0.1230	(Very unsuitable)	1	2	3	4	5	(Very suitable)
	On-time delivery	0.0571	(Very unsuitable)	1	2	3	4	5	(Very suitable)
Delivery	Lead time	0.0920	(Very unsuitable)	1	2	3	4	5	(Very suitable)
	Accuracy of order quantity	0.0879	(Very unsuitable)	1	2	3	4	5	(Very suitable)
Service	Order response time	0.0373	(Very unsuitable)	1	2	3	4	5	(Very suitable)
	Complain response time	0.0774	(Very unsuitable)	1	2	3	4	5	(Very suitable)
Flexibility	Delivery schedule	0.0527	(Very unsuitable)	1	2	3	4	5	(Very suitable)
	Order quantity	0.1074	(Very unsuitable)	1	2	3	4	5	(Very suitable)

- Score information:
  1: Very unsuitable
  2: Not suitable
  3: Less suitable
  4: Suitable
  5: Very suitable

Table 3 is the reference for the distribution centres to conduct supplier assessments. The supplier assessment uses a Likert scale of 1 to 5 for each sub-criterion compared with the company's requirements.

4.2. Packaging Postponement and Supplier Selection

4.2.1. Model Formulation

Indices:

i = Distribution centre, $i = 1, 2, 3, \ldots, N$

j = Packaging alternative, $j = 0$: without packaging, 1: with packaging

k = Distribution centre candidate supplier, $k = 1, 2, 3, \ldots, R$; $k = 0$: factory supplier

l = Sub-criteria, $l = 1, 2, 3, \ldots, T$

Parameters:

T_i = Transportation cost to distribution centre i (IDR/trip)

Q_{ij} = Number of products shipped to distribution centre i with packaging decision j (pairs)

P_{ik} = Packaging cost in distribution centre i proposed by supplier k (IDR/pair)

w_l = Weight of sub-criteria l

s_{lk} = The score of sub-criteria l for candidate supplier k

Variables:

X_{ijk} = 1 if the products are shipped to distribution centre i with j packaging decision using supplier k.

0 otherwise.

Objective functions:

$$Min\ C = \sum_{i \in N} \sum_{j \in [0,1]} \sum_{k \in R} x_{ijk} (T_i / Q_{ij} + P_{ik}) \tag{8}$$

$$Max\ S = \sum_{i \in N} \sum_{j=0} \sum_{k \in R} \sum_{l \in T} x_{ijk} (w_l s_{lk}) \tag{9}$$

subject to

$$\sum_{j \in [0,1]} \sum_{k \in R} x_{ijk} = 1, \forall i \in N \tag{10}$$

$$x_{ijk} \in \{1,0\} \tag{11}$$

The developed mathematical model consists of objective functions (8) and (9). The objective function in Equation (8) aims to minimise transportation costs and packaging costs per unit of product (C). Meanwhile, the objective function in Equation (9) aims to select the best supplier from the model's highest assessment score (S). Then, Equation (10) ensures a single decision for each delivery to the distribution centre. Equation (11) provides the decision variable to produce a binary value. The binary linear programming (BLP) equation with the two objective functions is then transformed into the BGP Equation as follows:

Objective function:

$$Min\ Z = P_1 d_1^+ + P_2 d_2^- \tag{12}$$

subject to

$$\sum_{i \in N} \sum_{j \in [0,1]} \sum_{k \in R} x_{ijk} (T_i / Q_{ij} + P_{ik)} + d_1^- - d_1^+ = 0 \tag{13}$$

$$\sum_{i \in N} \sum_{k \in R} \sum_{l \in T} x_{ijk} (w_l s_{lk}) + d_2^- - d_2^+ = N \cdot 5, \quad \forall \, j = 0 \tag{14}$$

$$\sum_{j \in [0,1]} \sum_{k \in R} x_{ijk} = 1, \forall i \in N \tag{15}$$

$$x_{ijk} \in \{1.0\} \tag{16}$$

$$d_1^+, d_1^-, d_2^+, d_2^- \geq 0 \tag{17}$$

The difference between mathematical formulas in the BLP and BGP models lies in the objective function. The BGP model always minimises the deviational variables. The objective function in LP model creates a goal constraint for the BGP model with the addition of two non-negative deviation variables: d_i^+ and d_i^- in Equations 13 and 14. In Equation 13, variables d_1^+ demonstrate the advantages, whereas d_1^- shows shortcomings from the target cost of 0. Supplier selection for each distribution centre is carried out only under conditions of packaging postponement (shipping products without packaging), in which j = 0. In Equation 14, the variable d_2^+ shows the advantages and d_2^- shows the shortcomings of the target score N (the number of distribution centres) multiplied by 5 (highest score). Furthermore, Equations 15 and 16 have the same function as Equations 10 and 11. Finally, Equation 17 guarantees that the deviational variables are positive.

In this study, the programming was pre-emptive or solving stratified problems starting from the top-priority goals. After the top priority is resolved, the next priority is determined without changing the optimal solution from the previous priority solution. Therefore, the solution of the top priority goal becomes a constraint for the next priority's problem solution. In this case, minimising logistics costs has a higher priority than supplier selection. Thus, the first solution sought is minimising logistics costs.

4.2.2. Model Assumptions

In the developed model, several assumptions used are as follows:

1. Delivery is carried out in full truck load (FTL) $Q_{ij} = Truck\ capacity$
2. Shipping costs are set per trip according to the vehicle capacity
3. The vehicle capacity used for each distribution centre is fixed
4. Only a single supplier is assigned to each distribution centre
5. The supplier is equal to the demand of each distribution centre
6. The labour costs for packaging at the factory and the distribution centre are the same
7. There is no damaged product

4.3. The Case Study

Model validation was carried out by applying and analysing the model's implications in case study of a shoe company in East Java, Indonesia. The company has a factory with six distribution centres spread across East Java. Currently, the shoe factory sends products to each distribution centre with complete packaging, and the factory has a main shoebox supplier. The company intends to postpone the primary packaging by transferring the final process to the distribution centre. The company has conducted an assessment of each potential supplier at its distribution centre (see Table 6). The distribution centres have independently assessed the supplier using the assessment instrument. The data for the model parameters are shown in Table 4, Table 5, and Table 6. In Table 4, the capacity for transporting products with primary packaging is around 80% of the capacity without primary packaging.

Table 4. Data on Transportation Costs and Delivery Capacity Per Truck

		Distribution Centre (i)					
		1	**2**	**3**	**4**	**5**	**6**
	T_i (IDR/trip)	9,800,000	6,300,000	10,200,000	8,900,000	14,500,000	8,250,000
Capacity (pairs)	**Without postponement**	2,000	1,280	1,600	1,280	2,000	1,600
	Postponement	2,500	1,600	2,000	1,600	2,500	2,000

Table 5. Main Supplier Price and Price Offers for each Supplier Distribution Centre (IDR/shoebox)

Supplier	**Distribution Centre**					
	1	**2**	**3**	**4**	**5**	**6**
0	1,500	1,500	1,500	1,500	1,500	1,500
1	1,800	1,870	1,800	1,850	1,650	1,800
2	1,650	1,730	1,800	1,900	1,750	1,800
3	1,750	1,850	1,800	1,850	1,800	1,830
4	1,800	1,750	1,800	1,800	1,650	
5	1,650	1,750	1,800	1,850	1,650	

Table 6. Total Score Data from the Supplier Assessment for each Potential Distribution Centre

Supplier	**Distribution Centre**					
	1	**2**	**3**	**4**	**5**	**6**
1	4.2155	4.3076	4.2155	4.2682	3.7910	4.3076
2	4.0301	3.8566	3.7358	4.5628	3.7358	3.7904

3	4.0301	4.3076	3.8753	3.8753	4.3512	3.9299
4	4.3076	4.3076	4.2330	3.9609	3.9611	
5	3.8318	4.0466	4.0466	4.0466	3.7746	

Distribution centres 1 to 5 have assessed proposals from five potential suppliers, and distribution centre 6 has received offers from three potential suppliers. Table 3 shows that the main suppliers provide the lowest prices compared to price offers from potential suppliers at each distribution centre. Table 4 shows the total score of each potential supplier in each distribution centre. The model calculates the trade-off between the decreasing shipping capacity due to primary packaging and the increase in packaging prices from potential suppliers in each distribution centre.

This research applied pre-emptive programming or solving stratified problems starting from the top-priority goals. After the main priority goal is resolved, the next priority is determined without changing the optimal solution from the previous priority solution. Therefore, the solution of the top priority becomes a constraint for finding solutions to the next priority. In this case, minimizing logistics costs has a higher priority than supplier selection. Thus, minimizing logistics costs' solution first. Completing the model with pre-emptive programming implies that the effect of the second objective function work on potential suppliers which offer the same lowest price at each distribution centre. The solutions generated by the model can be seen in Table 7 and Figure 4. As a result, packaging postponement was chosen as a strategy for product delivery to all distribution centres. In Table 7, it can be seen that suppliers selected in distribution centres 1 to 6 are supplier 2, supplier 2, supplier 4, supplier 4, supplier 4, and supplier 1.

Table 7. Optimal Solutions for the Integrated Model between Postponement Packaging and Supplier Selection

DC (i)				**1**		
Supplier (k)	**0**	**1**	**2**	**3**	**4**	**5**
Solution	-	-	√	-	-	-
DC (i)				**2**		
Supplier (k)	**0**	**1**	**2**	**3**	**4**	**5**
Solution	-	-	√	-	-	-
DC (i)				**3**		
Supplier (k)	**0**	**1**	**2**	**3**	**4**	**5**
Solution	-	-	-	-	√	-
DC (i)				**4**		

Supplier (k)	0	1	2	3	4	5
Solution	-	-	-	-	√	-
DC (i)			5			
Supplier (k)	0	1	2	3	4	5
Solution	-	-	-	-	√	-
DC (i)		6				
Supplier (k)	0	1	2	3		
Solution	-	√	-	-		

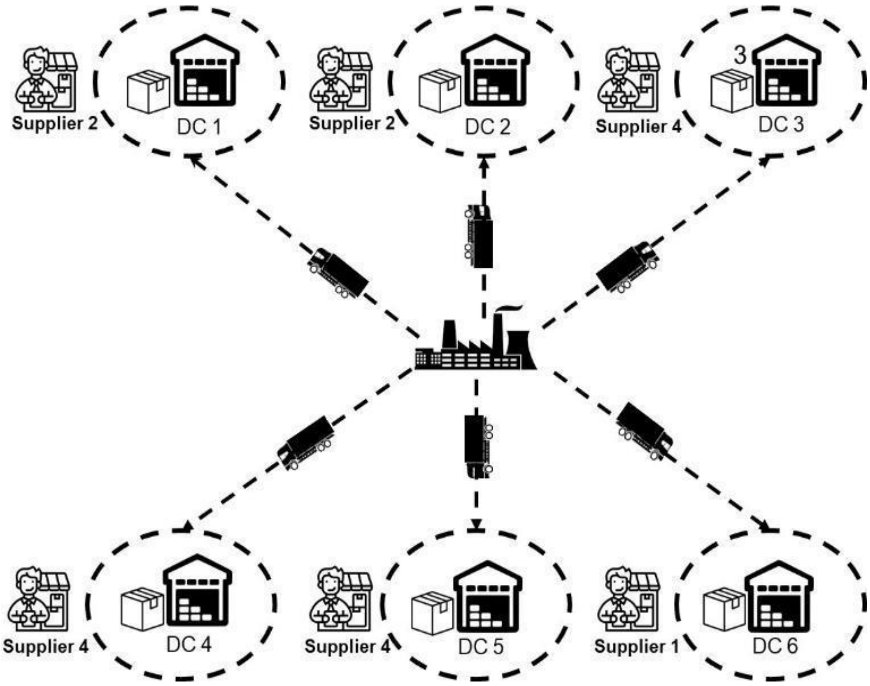

Figure 4. The Packaging Postponement and the Supplier Selection Decision

4.4. A Sensitivity Analysis

A sensitivity analysis is performed to see the effect of price changes from the main supplier (see Table 8). At a price reduction of up to 40%, the model still suggests packaging postponement to all distribution centres. When the main supplier's price is reduced by 50%, the model suggests packaging postponement being applied to distribution centres 1 to 5. In the case of decreasing the supplier's price to 60%, the model recommends that packaging postponement be implemented to distribution centres 3, 4, and 5 only. When the price reduction is down by 70%, the remaining two distribution centres are recommended to apply packaging postponement. The model recommends that packaging is done at the factory (the existing state) if the main supplier can reduce prices by > 70%. This sensitivity analysis shows that, under the assumption of reduced capacity used, the difference in packaging prices between the main supplier and the potential supplier for the distribution centre must be significant. Otherwise, complete packaging at the factory becomes non-feasible, so it needs to be decentralized.

Table 8. The Effect of Changes in Factory Supplier Prices on Packaging Postponement Decision

Discount on Packaging Prices from Factory Suppliers	Number of DCs Implements Packaging Postponement	DC					
		1	2	3	4	5	6
90%	0						
80%	0						
70%	2				√	√	
60%	3			√	√	√	
50%	5	√	√	√	√	√	
40%	6	√	√	√	√	√	√
30%	6	√	√	√	√	√	√
20%	6	√	√	√	√	√	√
10%	6	√	√	√	√	√	√
0%	6	√	√	√	√	√	√

Another sensitivity analysis was performed by considering the price changes from potential suppliers for each distribution centre when prices from the main supplier are fixed (see Table 9). It was found that when the price from the potential new suppliers increases by 40%, the packaging postponement decision does not change. The change occurs when the potential supplier raises the price up to 50%. At this point, the packaging postponement decision applies to distribution centres 1, 3, 4, and 5. Meanwhile, a 60% price increase suggests packaging postponement decision in distribution centres 4 and 5; and a price increase of 70% suggests postponement being applied at the distribution centre 5. Finally, packaging done in the factory (the existing state) becomes feasible if the packaging price reaches more than 70%.

Table 9. The Effects of Price Distribution Changes on Packaging Postponement

The Increase of Price by DC Packaging Suppliers	Number of DCs Implements Packaging Postponement	DC					
		1	2	3	4	5	6
10%	6	√	√	√	√	√	√
20%	6	√	√	√	√	√	√
30%	6	√	√	√	√	√	√
40%	6	√	√	√	√	√	√
50%	4	√		√	√	√	
60%	2				√	√	
70%	1					√	
80%	0						
90%	0						
100%	0						

4.5. Discussion

Integrating decisions in the internal supply chain positively influence management performance. The supply chain functions that have not been widely reviewed are the collaboration of logistics and purchasing functions (Breitling, 2019; Fabbe-Costes & Nollet, 2015). The two main perspectives to studying the decision-making of logistics and purchasing functions are competition and collaboration. From the competition perspective, logistics and purchasing will make decisions independently to exercise their strategic role in a company. However, logistics and purchasing share many similarities, so collaboration should be straightforward (Fabbe-Costes & Nollet, 2015). Research has highlighted the need to integrate purchasing and logistics functions (Ashenbaum & Terpend, 2010) because they can positively impact.

An integrated decision-making model involving logistics and purchasing functions can provide evidence of the positive impact. Packaging postponement is a strategy that has been proven to improve logistics performance (Simão et al., 2016) by minimising costs (Prataviera et al., 2022). In the application, packaging postponement needs to determine when and where the final packaging should take place. These decisions then require the determination of when and from whom packaging purchases should be made. This leads to the selection of a new supplier at the point where the final packaging is done. This is a critical decision because it can reduce costs throughout the supply chain (Pal et al., 2013). A multi-objective decision model is appropriate to make an informed decision. This study employs BGP as the preferred mathematical modelling to integrate packaging postponement and supplier selection decisions.

The collaboration should be followed by inter-functional coordination that aligns the operational activities (Breitling, 2019). The integration model requires the purchasing function to transfer its decision-making authority to other units in a decentralized manner (McCue & Pitzer, 2000). Thus, to maintain the supplier selection process's quality, the purchasing department's role is to establish a supplier assessment model and train assessors. The following process relies on the model to be effective. Suppose the decision is to implement packaging postponement, then the supplier selection should be decided based on the optimality, which is synonymous to cost reduction.

This research proposed the integration model of packaging postponement and supplier selection. This model proves that the collaboration between logistics and purchasing functions can reduce costs without compromising the quality of the selected supplier. The integrated model can produce an optimal solution that reduces the unit cost by 12.64%. The cost reduction of the optimal solution can be seen in Table 10.

Table 10. Cost Reduction (IDR) based on Packaging Supplier Decisions at Each Distribution Centre

Distribution Centre					
1	**2**	**3**	**4**	**5**	6
830	754,375	975	1,090,625	1,300	731.25

In the real case under study, the company considers the price the most important decision, so pre-emptive programming is used. This means supplier assessment becomes the second priority. This condition has implications; supplier assessment will work if a supplier offers the same price at a distribution centre. If the supplier's price and the price offered at the distribution centre can be aligned, minor modifications to the model must be made. First, it is necessary to consider using non-pre-emptive programming and normalizing the rating score and prices to make an equivalent comparison.

5. THEORETICAL AND MANAGERIAL IMPLICATIONS

This study fills a research gap in logistics and purchasing by integrating packaging postponement and supplier selection models. This model completes the diversity of literature in multi-objective business decision-making. The result supports the applicability of the BGP in business decision-making, i.e., utilising the DANP-BGP approach in producing an optimised inter-functional joint decision-making model. The findings of this study form the basis of a theory that supports joint decision making in supply chain inter-functions: logistics and purchasing. The findings of this study are also in line with the past literature review. Joint decisions significantly impact the supply chain effectiveness more than decisions that promote departmental vested interest. In particular, this study provides a potential research guide to develop models for other postponement strategies that consider each industry's operating characteristics and supporting functions.

The managerial implication is that the study results can be directly used by the company involved in a real case example. Other companies can adopt the developed model with or without minor modifications. Minor modifications are required if there are differences in operating characteristics. Additionally, the findings from the model provide insight for policymakers to make more informed decisions related to inter-functional coordination and collaboration. The results of the model support tactical decision-making to improve business efficiency.

6. CONCLUSIONS, LIMITATIONS, AND FUTURE DIRECTIONS

This paper proposes an DANP-BGP integration model for joint decision-making regarding packaging postponement and supplier selection. The rationale for incorporating supplier selection decisions with packaging postponement is because supplier selection decisions directly influence packaging postponement decisions. Although companies can get discounts or cheaper prices when buying large quantities of packaging from the same supplier, shipping transportation costs is a trade-off. The model can find the optimal trade-off between packaging prices and transportation costs. Since packaging postponement and supplier selection come from different business functions, inter-functional collaboration and coordination are needed to execute the decisions generated by the model. Therefore, strategic policy-making needs to be involved.

The developed model has been successfully validated using a real case study. Packaging postponement was chosen as the strategy for product delivery to all distribution centres. Then, the suppliers selected in distribution centres 1 to 6 are supplier 2, supplier 2, supplier 4, supplier 4, supplier 4, and supplier 1. The packaging postponement and supplier selection model has reduced unit costs by 12.64%. The sensitivity analysis shows the role of the price offered by each supplier on the packaging postponement decision. In this case, the price reduction of less than 50% for the main and DC suppliers did not affect the postponement decision.

The limitation in the supplier assessment model is the lack of a supplier assessment rubric. A supplier assessment rubric with quantitative indicators needs to be made for each distribution centre to reduce the subjectivity of the assessors. The limitation of the mathematical models is that it was solved only with pre-emptive programming because it adjusts the company's characteristics, as observed in this study. The development of a model with a non-pre-emptive program and modifications need to be considered for industries that intend to see a trade-off between the price offered by suppliers and supplier selection criteria. Future research can examine model development involving transportation mode selection and order allocation quantity. This model can also be developed by releasing the assumptions used in this study. Model objectives that involve economic, social, and environmental aspects related to sustainability can be a further direction for developing an integrated model of packaging postponement and supplier selection (Nesticò, et al., 2020). Besides, the long solving time in large and complex real cases requires further research to develop heuristic or metaheuristic approaches to overcome them.

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