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A Hybrid Goal Programming, AHP, and ANP Approach for Multi-Criteria Decision-Making: Application to Supply Chain Management Optimization

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Abstract

Goal Programming (GP) is perhaps the most widely used multi-criteria decision-making (MCDM) technique that addresses complex decision problems involving multiple, conflicting objectives. However, GP has inherent limitations, particularly in handling subjective preferences and trade-offs decision criteria. This paper proposes a hybrid approach, combining Goal Programming (GP) with the Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) to overcome these limitations. The integration of AHP and ANP with GP allows for better prioritization of decision criteria and trade-offs among them. The main contribution of this paper is to propose this unique AHP-ANP-GP methodology as a robust solution to multi-objective decision problems, enhancing decision-making accuracy and flexibility. Finally, the paper demonstrates the application of the proposed model to an important Supply Chain Management (SCM) problem: optimizing the trade-off between transportation and inventory costs.

Keywords
Goal Programming, Analytic Hierarchy Process, Analytic Network Process, Supply Chain Management

Introduction
Decision-making in complex environments, where multiple objectives and constraints must be simultaneously addressed, poses significant challenges for decision-makers. Goal Programming (GP) has proven to be a powerful multi-criteria decision-making (MCDM) tool for tackling such problems. By optimizing a set of predefined goals while satisfying various constraints, GP allows decision-makers to find optimal solutions in scenarios involving conflicting objectives. However, while GP excels in handling quantitative goals and constraints, it faces notable limitations when it comes to dealing with subjective preferences and interdependencies between decision criteria.

This paper proposes an integrated approach that combines Goal Programming (GP) with the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) to overcome these shortcomings. AHP provides a structured framework for ranking decision criteria based on pairwise comparisons, helping decision-makers prioritize goals. ANP extends AHP by modelling the complex interdependencies among criteria, thereby offering a more comprehensive representation of the decision environment. By combining these techniques, the proposed methodology enhances the ability of GP to incorporate both ranking and trade-offs.

The main contribution of this paper is to demonstrate how integrating AHP and ANP with GP can significantly improve decision-making in complex multi-objective problems. The paper highlights the strengths of this hybrid approach and its ability to address the limitations of traditional GP models. To illustrate the practical application of the proposed methodology, we apply the combined GP-AHP-ANP model to solve a typical Supply Chain Management (SCM) problem: optimizing the trade-off between transportation and inventory costs. This example serves as a demonstration of how the hybrid methodology can be used to balance competing objectives, taking both quantitative and qualitative factors into account.

2. Goal Programming (GP) in Multi-Criteria Decision-Making

Goal Programming (GP) is a mathematical optimization technique that is widely used for solving problems with multiple, often conflicting, objectives. GP aims to minimize the deviation from predefined goals, providing decision-makers with a way to balance trade-offs among conflicting objectives (Gupta & Maranas 2003). In preemptive Goal Programming (PGP) the goals are prioritized and are placed in different priority levels. The most important goals (in the highest priority level) are considered first. However, in weighted goal programming (WGP) all the goals are in the same priority level and are assigned weights, based on their importance. In the suggested methodology, ANP is used for identifying the priorities for PGP and, within each priority level, AHP is used to determine the weights for criteria.

GP is particularly useful when decision-makers must prioritize goals, but it has some limitations. One such limitation is that GP models often assume that the decision criteria are independent and do not consider the interrelationships between them.Recent work has sought to address these limitations by integrating GP with other MCDM techniques. For instance, Yoon and Kim (2015) used a hybrid AHP and GP approach to select suppliers in global supply chains, where the criteria such as cost, quality, and delivery time were conflicting. The combination of AHP and GP allows for the optimization of these criteria while also addressing interdependencies.

Moreover, research by Melnyk, Davis, and Spekman (2014) explored fuzzy AHP models to incorporate uncertainty into GP-based models. This illustrates that while GP can optimize goals, its ability to model uncertainty and complex interdependencies between criteria is limited. This gap can be bridged by integrating AHP and ANP with GP.

3. The Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP)

AHP, developed by Saaty (1980), is a structured technique used to prioritize decision criteria through pairwise comparisons. It is widely used in multi-criteria decision-making because it provides a clear, hierarchical structure for decision problems. AHP helps decision-makers break down complex problems into manageable parts, allowing for a systematic evaluation of alternatives based on their relative importance.

However, AHP does not explicitly account for interdependencies between criteria, which can be a critical issue in real-world decision-making scenarios. To address this, ANP was introduced as a more generalized form of AHP, allowing for the modelling of complex interdependencies and feedback loops between criteria (Saaty & Vargas, 2006). ANP is particularly useful when the criteria are not independent, as it provides a more flexible structure for decision-making.

Liu, Wei, and Xu (2013) demonstrate the integration of ANP with GP for optimizing supply chain decisions. Their work highlights the power of the combined approach in handling both hierarchical and interdependent relationships in complex decision-making environments.

4. Combining GP, AHP, and ANP: A Hybrid Approach

This paper proposes integrating GP with AHP and ANP in the following manner:

- **a)** Initially use ANP to identify priorities for the alternatives (i.e., which alternatives have the highest priority, which alternatives have the next priority, and so on).
- **b)** For each priority level identified in (a), determine the criteria that falls in that category/level.
- **c)** For the criteria specified in (b), use AHP to determine their relative weights.
- **d)** Using the information obtained from ANP and AHP, construct a PGP model to determine the amount of resources that should be allocated to each alternative.

The integration of GP with AHP and ANP offers several advantages. While GP is effective in solving optimization problems, it does not handle interdependencies well. By integrating AHP or ANP, we can model the relationships between criteria, which enhances the decision-making process. This hybrid approach provides a comprehensive framework for solving complex, multi-criteria problems.

As Tzeng and Huang (2011) note, integrating multiple decision-making methods can improve the robustness of models and address the limitations inherent in individual techniques. The combination of GP, AHP, and ANP allows for the optimization of both independent and interdependent criteria, providing decision-makers with more accurate and effective solutions.
Xu, Zhang, and Chen (2012) explored the combination of AHP and GP in a supply chain context, demonstrating how this hybrid approach can optimize decision-making when both hierarchical structures and interdependencies are present. The integration of ANP further enhances this by modeling complex feedback relationships between decision criteria.

5. Application to Supply Chain Management (SCM): Transportation vs. Inventory

To illustrate the effectiveness of the proposed hybrid methodology, we apply it to a typical SCM problem: balancing transportation and inventory costs. Transportation and inventory management are two critical aspects of SCM that often conflict with each other. While reducing transportation costs may require consolidating shipments, it can increase inventory holding costs. On the other hand, reducing inventory holding costs may require more frequent shipments, increasing transportation costs.

By integrating GP, AHP, and ANP, we can optimize this trade-off and find the best solution. For example, using AHP, decision-makers can evaluate the relative importance of transportation and inventory costs. ANP can model the interdependencies between these criteria, and GP can then be used to optimize the solution.Recent work by Zandieh and Moghaddam (2021) has applied a hybrid AHP-GP model to supply chain optimization, while Wang and Zhang (2023) demonstrated the use of ANP-GP integration in supply chain risk management. These studies highlight the potential of the hybrid approach for solving SCM problems that involve conflicting objectives.

Based on the proposed hybrid model, initially ANP is used to determine the priority level for transportation and inventory. Within each priority level, different criteria or alternatives and ranked and assigned weights, using AHP. The objective function for PGP will be as follows:

$$Min: \quad P_{Transportation}^{ANP}(W_i^{AHP}[T_i^- - T_i^+]), \qquad P_{Inventory}^{ANP}(W_j^{AHP}[I_j^- - I_j^+])$$

Where $P_{Transportation}^{ANP}$ and $P_{Inventory}^{ANP}$ are the priority levels for transportation and inventory respectively.

Within the transportation component of the above objective function, the decision maker initially identifies the alternatives modes of transportation and the aspiration level for each, then, using AHP determines the weight for each alternative, denoted by W_i^{AHP}. T_i^- *and* T_i^+ are the under-achievement and over-achievement of the target levels for the goals in the transportation category. Considering the inventory component of the objective function, the decision maker initially identifies the alternatives levels of inventory and safety stocks (e.g., high, medium, low) and the aspiration level for each, then, using AHP determines the weight for each alternative inventory level, denoted by W_j^{AHP}. I_j^- *and* I_j^+ are the under-achievement and over-achievement of the target levels for the goals in the inventory category. Thus, the constraints, among other constraints, should include a series of constraints for transportation and other series for inventory.

6. Conclusion

This paper has proposed a hybrid approach combining Goal Programming, AHP, and ANP to address the limitations of GP in multi-criteria decision-making. By incorporating AHP and ANP, we can model interdependencies between decision criteria, providing a more robust and flexible decision-making framework. The paper illustrates the application of this hybrid methodology through a typical SCM problem, balancing transportation and inventory costs. The future work should use numerical example to show that this integrated approach offers an effective solution to complex, multi-objective problems.

Future research could explore further applications of the hybrid GP-AHP-ANP approach in other industries, such as energy management, healthcare, and finance, to enhance decision-making under uncertainty and interdependency.

References

Khorramshahgol, Y., & Ignizio, J. P. , Goal programming and the analytic hierarchy process: A combined approach for multi-objective decision making. *Advances in Management Studies*, 3, 145-155, (1984). .

Saaty, T. L. , *The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation*. McGraw-Hill., (1980).

Gupta, S. M., & Maranas, C. D. , Goal programming models for integrated production planning in supply chains. *Computers & Operations Research*, 30(11), 1733-1750,(2003). .

Melnyk, S. A., Davis, E. W., & Spekman, R. E. , Fuzzy AHP models for risk management in supply chains. *International Journal of Production Research*, 52(17), 5227-5245, (2014). .

Yoon, H., & Kim, Y. , Hybrid AHP and ANP approaches for supplier selection in global supply chains. *Journal of Manufacturing Science and Engineering*, 137(8), 841-849,(2015). .

Liu, J., Wei, W., & Xu, Y. , A hybrid analytic network process approach for facility location selection. *International Journal of Production Economics*, 146(1), 142-150, (2013). .

Cheng, E. W., & Li, H. , Application of the analytic hierarchy process in supplier selection: A case study of an electronic manufacturing company. *Journal of Supply Chain Management*, 45(3), 1-14, (2009).

Saaty, T. L., & Vargas, L. G. , *Decision Making with the Analytic Network Process: Economic, Political, Social and Technological Applications with Benefits, Opportunities, Costs, and Risks*. Springer Science & Business Media, (2006). .

Xu, L., Zhang, X., & Chen, L., An integrated AHP-GP approach for multi-objective supply chain optimization. *International Journal of Production Economics*, 139(1), 85-94, 2012. .

Kuo, Y. F., & Liang, H. , Application of fuzzy AHP and fuzzy GPA to evaluation of the energy efficiency of logistics systems. *Expert Systems with Applications*, 37(4), 2952-2960,2010 .

Tzeng, G. H., & Huang, J. J. , *Multiple Attribute Decision Making: Methods and Applications*. CRC Press, (2011). .

Zandieh, M., & Moghaddam, M. , Hybrid goal programming and multi-criteria decision-making for sustainable supply chain optimization. *Sustainable Operations and Computers*, 2(4), 289-301,2021 .

Madadi, M., & Nazari, K. , Multi-objective optimization of the supply chain using goal programming and AHP: A case study of a food company. *Journal of Manufacturing Processes*, 59, 86-98, 2020 .

Wang, H., & Zhang, L. , Goal programming-based hybrid decision-making approach for supply chain risk management. *Journal of Business Research*, 155, 12-22, (2023). .

Lee, S. M., & Lee, J. Y. , Decision-making in supply chain networks using integrated AHP-GP and ANP approaches. *International Journal of Logistics Management*, 32(1), 39-61, (2021). .

Liu, S., Xu, W., & Wang, F. , A hybrid approach of ANP and goal programming for supply chain sustainability optimization. *Journal of Cleaner Production*, 348, 131317, (2022). .

Wang, H., Liu, X., & Chen, Y. , A hybrid multi-criteria decision-making model based on AHP, ANP, and goal programming for supplier selection in a competitive market. *Decision Support Systems*, 130, 113226,2020 .

Zhang, H., & Lee, J. K. , Integrated multi-objective decision-making for sustainable supply chain management: A hybrid AHP-GP-ANP approach. *Sustainability*, 16(1), 18, (2024).

Zhan, S., & Wang, C. , A hybrid approach of AHP and goal programming for demand-supply imbalance in global supply chains. *International Journal of Production Economics*, 245, 108404, (2023).

Tabares, M., & Soto, M., The use of goal programming in optimizing supplier selection with environmental concerns: A hybrid AHP and ANP approach. *Environmental Modeling & Assessment*, 27, 405-417,(2022).