

THE TRANSPORTATION PROBLEM APPLIED TO TOURISM UNDER RISK AND UNCERTAINTY

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Abstract

The transportation problem applied to tourism is a quantitative approach to optimizing tourist movements from points of departure to tourism destinations, by minimizing total costs and maximizing efficiency. This paper examines how classic transportation-problem models can be adapted to tourism activities such as airport transfers, sightseeing tours, and tour-operator packages. In addition, we introduce elements of risk and uncertainty by using scenario-based costs. The sources discussed are defined as airports, while destinations include hotels, resorts, or tourist attractions. Costs may reflect ticket prices, travel time, or service quality and may vary due to fuel price differences, traffic congestion, and operational disruptions. The paper presents the theoretical foundations of the transportation problem, its mathematical formulation, solution methods, and a detailed numerical example solved step by step, including the computation of expected costs and the full application of Vogel's Approximation Method (VAM).

Keywords: tourism, transportation problem, risk, uncertainty, scenario analysis

JEL classification: C61, L83, R41

1. Introduction

Tourism is one of the most dynamic and interesting sectors of the global economy, generating jobs, income, and highly important regional development. Transport plays a fundamental role in tourism, as it connects tourists to destinations and directly influences both costs and the quality of services provided by travel agencies. Tour operators and travel agencies must organize transfers between airports, hotels, and tourist attractions in an efficient, reliable, and economically sustainable way. They must consider many aspects—economic, geographic, climatic, and even political. Inefficient planning and a lack of attention to transport details can lead to increased operating costs, delays, and tourist dissatisfaction. Therefore, special attention should be given to this topic in order to achieve the most favorable outcomes.

In this context, quantitative methods can support decision-making in tourism management. One of the most widely used models in operations research is the transportation problem, a special case of linear programming designed to optimize distribution activities. Although it was originally developed for the transport of goods, this model can be successfully adapted to tourism logistics by interpreting flows as tourists and routes as transport links.

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Unlike the classic deterministic framework, real-world tourism transport is influenced by risk and uncertainty. Costs may change due to fuel price volatility, traffic congestion, weather conditions, or operational disruptions (e.g., delays), or even for socio-political reasons (e.g., airport staff strikes). Therefore, extending the transportation problem by incorporating uncertainty leads to more realistic and more resilient allocation plans and is an interesting topic.

The objective of this paper is to analyze the transportation problem and to demonstrate its applicability in tourism, including a scenario-based extension under uncertainty. The paper is structured as follows: Section 2 presents the theoretical framework, Section 3 introduces the mathematical formulation, Section 4 provides a step-by-step numerical example, Section 5 discusses solution methods and software tools, and Section 6 presents the conclusions.

2. The transportation problem in economic theory and tourism

The transportation problem is a classic and particularly interesting optimization model within linear programming. It aims to determine the optimal allocation of a homogeneous flow from multiple sources to multiple destinations so that total transportation cost is minimized. Each source has a fixed supply, each destination has a given demand, and the unit transportation cost between each source–destination pair is known.

The simplicity of the transportation problem makes it especially attractive in practical applications. The model has been used in logistics, supply chain management, industrial planning, and public policy. Another situation in which this problem is applied is the diet problem. In tourism, the same logic applies by replacing goods with tourists and transport routes with travel connections.

When adapted to tourism, sources may represent departure cities or airports or ports, and destinations include hotels, resorts, tourist attractions, or cruise terminals. Supply corresponds to the number of tourists available at a source, while demand reflects accommodation capacity or planned flows. Costs can be expressed in monetary units, travel time, comfort level, or reliability.

To link the model to risk and uncertainty, these costs may vary across scenarios that represent different operating conditions (e.g., normal conditions versus adverse conditions).

3. Mathematical formulation of the transportation problem

We consider m sources and n destinations. Let s_i denote the supply (number of tourists) at source i and d_j the demand at destination j . Let c_{ij} denote the unit cost of transporting a tourist from source i to destination j . The decision variable x_{ij} represents the number of tourists allocated from i to j .

The objective function is to minimize total transportation cost:

$$\text{Min } Z = \sum_i \sum_j x_{ij} c_{ij}$$

subject to the following constraints:

$$\sum_j x_{ij} = s_i, \text{ for all sources } i$$

$$\sum_i x_{ij} = d_j \text{ for all destinations } j$$

$$x_{ij} \geq 0, \text{ for any } i \text{ and } j$$

If total supply equals total demand, the problem is balanced. Otherwise, a dummy source or a dummy destination is introduced to transform the problem into a balanced one; therefore, there is no point in discussing an unbalanced problem here.

Under uncertainty, a practical approach is scenario analysis. If $\hat{c}_{ij}(k)$ is the unit cost in scenario k with probability p_k , then the expected cost is computed as $E(c_{ij}) = \sum_k p_k \hat{c}_{ij}(k)$, and the problem is solved using the matrix $E(c_{ij})$.

4. Numerical example applied to tourism under risk and uncertainty

Sources: Airport A with a supply of 1200 tourists; Airport B with a supply of 800 tourists.

Destinations: Hotel 1 demand 700 tourists; Hotel 2 demand 600 tourists; Hotel 3 demand 700 tourists.

Total supply equals total demand (2000 tourists), so the problem is balanced.

4.1. Defining the scenarios

Two scenarios are considered:

- Scenario 1 (under normal conditions): the probability for this scenario is $p_1 = 0.7$
- Scenario 2 (under adverse conditions): the probability for this scenario is $p_2 = 0.3$

The probabilities used in these calculations are obtained from statistical data.

The cost matrix in Scenario 1 (monetary units per tourist) is presented in the following table:

	Hotel 1	Hotel 2	Hotel 3	Supply
Airport A	10	12	9	1200
Airport B	11	8	14	800
Demand	700	600	700	2000

The cost matrix in Scenario 2 (monetary units per tourist):

	Hotel 1	Hotel 2	Hotel 3	Supply
Airport A	13	15	11	1200
Airport B	14	11	18	800
Demand	700	600	700	2000

4.2. Expected cost matrix (complete calculation)

Expected costs are computed as: $E(c_{ij}) = 0.7 \cdot \hat{c}_{ij}(1) + 0.3 \cdot \hat{c}_{ij}(2)$.

Calculation for each route:

$$E(c_{A1}) = 0.7 \cdot 10 + 0.3 \cdot 13 = 7 + 3.9 = 10.9$$

$$E(c_{A2}) = 0.7 \cdot 12 + 0.3 \cdot 15 = 8.4 + 4.5 = 12.9$$

$$E(c_{A3}) = 0.7 \cdot 9 + 0.3 \cdot 11 = 6.3 + 3.3 = 9.6$$

$$E(c_{B1}) = 0.7 \cdot 11 + 0.3 \cdot 14 = 7.7 + 4.2 = 11.9$$

$$E(c_{B2}) = 0.7 \cdot 8 + 0.3 \cdot 11 = 5.6 + 3.3 = 8.9$$

$$E(c_{B3}) = 0.7 \cdot 14 + 0.3 \cdot 18 = 9.8 + 5.4 = 15.2$$

The resulting expected-cost matrix:

	Hotel 1	Hotel 2	Hotel 3	Supply
Airport A	10.9	12.9	9.6	1200
Airport B	11.9	8.9	15.2	800
Demand	700	600	700	2000

4.3. Solving with Vogel's Approximation Method (VAM) – step by step

VAM penalties are computed as the difference between the two smallest costs in each row and column.

Step 1 – penalties on the full expected-cost table:

Row penalties:

- Airport A: the smallest costs are 9.6 and 10.9 $\rightarrow$ penalty = $10.9 - 9.6 = 1.3$
- Airport B: the smallest costs are 8.9 and 11.9 $\rightarrow$ penalty = $11.9 - 8.9 = 3.0$

Column penalties:

- Hotel 1: 10.9 and 11.9 $\rightarrow$ penalty = $11.9 - 10.9 = 1.0$
- Hotel 2: 8.9 and 12.9 $\rightarrow$ penalty = $12.9 - 8.9 = 4.0$
- Hotel 3: 9.6 and 15.2 $\rightarrow$ penalty = $15.2 - 9.6 = 5.6$

The maximum penalty is for Hotel 3 (5.6). Allocate in the cell with the minimum cost in the Hotel 3 column: Airport A $\rightarrow$ Hotel 3 (cost 9.6).

Allocation: $x_{A3} = \min(s_A = 1200, d_3 = 700) = 700$.

Update: s_A becomes 500; d_3 becomes 0 (Hotel 3 satisfied).

Step 2 – reduced table (Hotel 1 and Hotel 2 remain):

	Hotel 1	Hotel 2	Supply
Airport A	10.9	12.9	500
Airport B	11.9	8.9	800
Demand	700	600	1300

Recompute penalties:

Row penalties:

- Airport A: $12.9 - 10.9 = 2.0$
- Airport B: $11.9 - 8.9 = 3.0$

Column penalties:

- Hotel 1: $11.9 - 10.9 = 1.0$
- Hotel 2: $12.9 - 8.9 = 4.0$

The maximum penalty is for Hotel 2 (4.0). Allocate in the cell with the minimum cost: Airport B $\rightarrow$ Hotel 2 (cost 8.9).

Allocation: $x_{B2} = \min(s_B=800, d_2=600) = 600$.

Update: s_B becomes 200; d_2 becomes 0 (Hotel 2 satisfied).

Step 3 – final allocations (only Hotel 1 remains with demand 700):

Remaining supplies: $s_A = 500$, $s_B = 200$.

Therefore: $x_{A1} = 500$ and $x_{B1} = 200$. All supplies and demands are satisfied.

4.4. Final allocation and total expected cost (complete calculation)

Final allocation:

Route	Tourists
Airport A $\rightarrow$ Hotel 3	700
Airport B $\rightarrow$ Hotel 2	600
Airport A $\rightarrow$ Hotel 1	500
Airport B $\rightarrow$ Hotel 1	200

Total expected cost:

$$Z = 700 \cdot 9.6 + 600 \cdot 8.9 + 500 \cdot 10.9 + 200 \cdot 11.9$$

$$Z = 6720 + 5340 + 5450 + 2380 = 19890 \text{ monetary units.}$$

5. Analysis of results

The numerical example highlights how incorporating risk and uncertainty into the transportation problem influences decisions in tourism-agency plans. By considering two scenarios with different cost structures and different associated probabilities, the model captures the variability of transportation costs generated by external factors such as fuel volatility, traffic congestion, and operational disruptions.

Computing expected costs transforms the stochastic problem into a deterministic equivalent that can be solved with classic methods. Applying

Vogel's Approximation Method to the expected-cost matrix provides a structured and transparent allocation process. The step-by-step computation of penalties and allocations highlights the trade-offs between alternative routes and the importance of cost differences under uncertainty.

Compared with a purely deterministic approach, the risk-sensitive model provides a more realistic estimate of total transportation cost, reducing the tendency to underestimate operational expenses. From a managerial perspective, this can improve transfer reliability and tourist satisfaction, as the plan anticipates adverse conditions with a non-zero probability.

However, optimization based on expected value targets average performance, not necessarily protection against extreme scenarios. In situations with strict service-level requirements (e.g., limits on delays), extensions such as robust optimization or explicit risk penalties may be needed.

6. Conclusions

The transportation problem provides a powerful analytical framework for optimizing tourist movements. By adapting classic linear-programming models to tourism-specific conditions and by incorporating risk and uncertainty through scenario-based costs, agencies and tour operators can reduce expected costs, improve resource allocation, and increase tourist satisfaction.

The numerical example demonstrates, step by step, how uncertain costs can be integrated through expected values and how Vogel's Approximation Method can be applied to obtain an efficient allocation plan. The computed total expected cost (19890 monetary units) highlights the practical impact of uncertainty on planning results. In practice, software tools such as Excel Solver can be used to obtain optimal solutions and to test multiple scenarios, providing decision support for more robust planning.

Bibliography

1. Despa, R., Vișan, C., Pricina, C. (2005). Applied Mathematics in Economics. Editura Universitară.
2. Dantzig, G. (1963). Linear Programming and Extensions. Princeton University Press.
3. Hillier, F., Lieberman, G. (2015). Introduction to Operations Research. McGraw-Hill.
4. Cooper, C. et al. (2008). Tourism: Principles and Practice. Pearson Education.