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（都市間旅客交通のためのマルチモーダル計画モデル）
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論 文 内 容 要 旨

Chapter 1: Background and Objective

Planning, development and operational responsibility for various pieces of the intercity transport network (ITN) are usually divided among different institutions in developing countries. Efforts of these various agencies do not always add up to an efficient, seamless system and a holistic approach is needed when designing long term strategic ITN. Additionally, goal of achieving a well-functioning network is exacerbated by the substitutive or complementary effects in a network which means that new links may compete with or support other links in the network. So, efficient ITNs can only be designed after understanding these interactions by using a computer model which can deal with the combinatorial problem and also multimodality. That model should consider profitable operating conditions from the viewpoint of operators in order to achieve reasonable solutions. Consequently, the objective of this dissertation is to propose a multimodal transport planning model for intercity passenger transport to be used by national transport planners in order to analyze and understand behavior of the networks. This study is concerned with long term network design issues such as probing transport network effects, understanding importance of multimodal connections and analyzing impact of low-carbon targets on the network. By the help of this model, we hope that transport planners can simulate different scenarios, be able to design better performing transport networks and achieve long term policy targets.

Chapter 2: Model Proposal

Proposed model addresses the long term network design problem which tries to construct a network that optimizes the objective function while considering limitations which can come from resource constraints or specific problem requirements. Our model tries to find multimodal route traffic flows for given OD demand, rail, bus, air existence and frequencies of links which optimize the design criteria (minimizing total social cost). Objective function, variables, parameters and constraints are given in Figure 1.

Objective Function

$$\min(GC+TOC) \qquad GC = v*\left(\sum_{ij}\sum_{m} t_{ij}^{m} X_{ij}^{km} + \sum_{n}\sum_{mm'} \tau_{n}^{mm'} Y_{n}^{kmm'}\right) \qquad TOC = \sum_{ij}\sum_{m} f_{ij}^{m}\left(e_{ij}^{m} F_{ij}^{m} + d_{ij}^{m} Z_{ij}^{m}\right)$$

Variables and Parameters:

X_{ij}^{km} : Traffic amount on a link *ij* originated from node *k* by mode *m*,

$Y_n^{kmm'}$: Transit passengers between mode *m* to *m`* at node *n,* originated from node k

A_n^{km}, B_k^{m}: Ended trips and originated trips at node *k* using mode *m*

Z_{ij}^{m}, F_{ij}^{m}: *Existence variable (0-1) and frequency of a service on link ij* for mode *m*

T_{kn}: *Total OD demand between k and n*

t_{ij}^{m}, $\tau^{mm'}$: Link travel time and transfer time

h^m, g^m: Seat capacity and max. operable frequency of mode m

d_{ij}^{m}, e_{ij}^{m}: Fixed and variable cost of maintaining service on a link

v : value of time

Constraints:

$$\sum_{i\in N^-(n)} X_{in}^{km} = A_n^{km} + \sum_{m'\in M} Y_n^{kmm'}, \quad \sum_{m} A_n^{km} = T_{kn}, \quad B_n^{m} + \sum_{m'\in M} Y_n^{km'm} = \sum_{j\in N^+(n)} X_{nj}^{km}, \quad \sum_{l\in K} T_{nl} = \sum_{m\in M} B_n^{m}$$

$$F_{ij}^{m} \le g^{m} Z_{ij}^{m}, \quad \sum_{i\in N^-(n)} F_{in}^{m} = \sum_{j\in N^+(n)} F_{nj}^{m}, \quad \sum_{k} X_{ij}^{km} \le h^{m} F_{ij}^{m}, \quad \sum_{k} X_{ij}^{km} \ge d_{ij}^{m} Z_{ij}^{m} + e_{ij}^{m} F_{ij}^{m}$$

Figure 1: Model Structure

Chapter 3: Network Effect Analysis

In this chapter, an analysis of 5 HSR projects in Turkish intercity transport network was conducted using the proposed model for demonstration of transport network effects (TNEs). TNEs are defined as the impact of a change in one link that occurs at other links of the network due to the complementary of substitutive interaction between links. They are measured as the difference between project impacts when projects are realized individually and in combination. In this study, TNEs were detected for Ankara-Eskisehir HSR project. It was shown that network effects were significant enough to affect funding decision. Results indicate the importance and necessity of TNEs consideration in project evaluation process. It was also shown that the proposed model makes it possible to measure TNEs which otherwise would be impossible due to the complex interaction of links in the network.

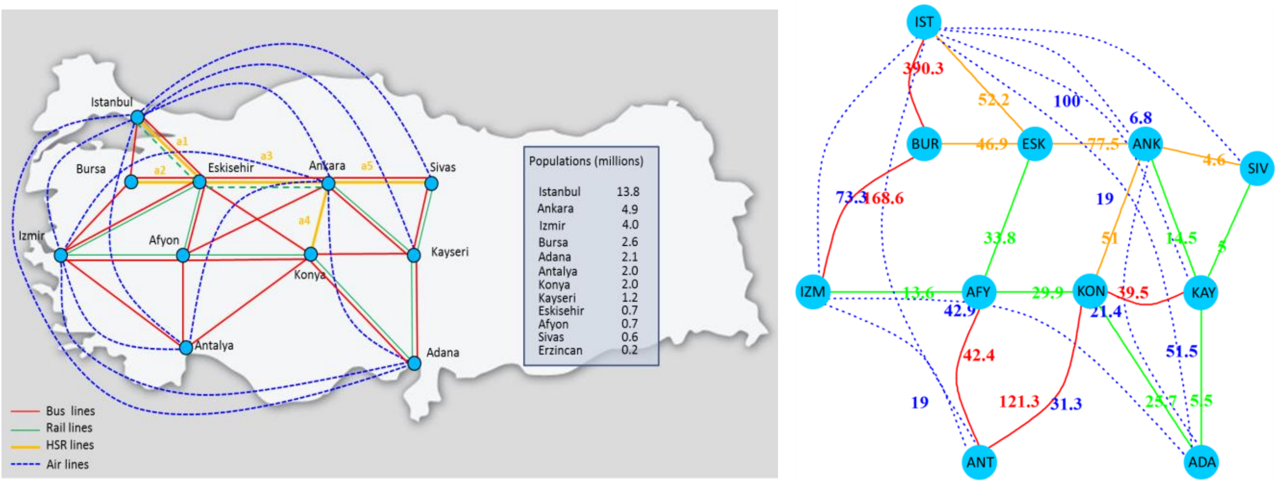
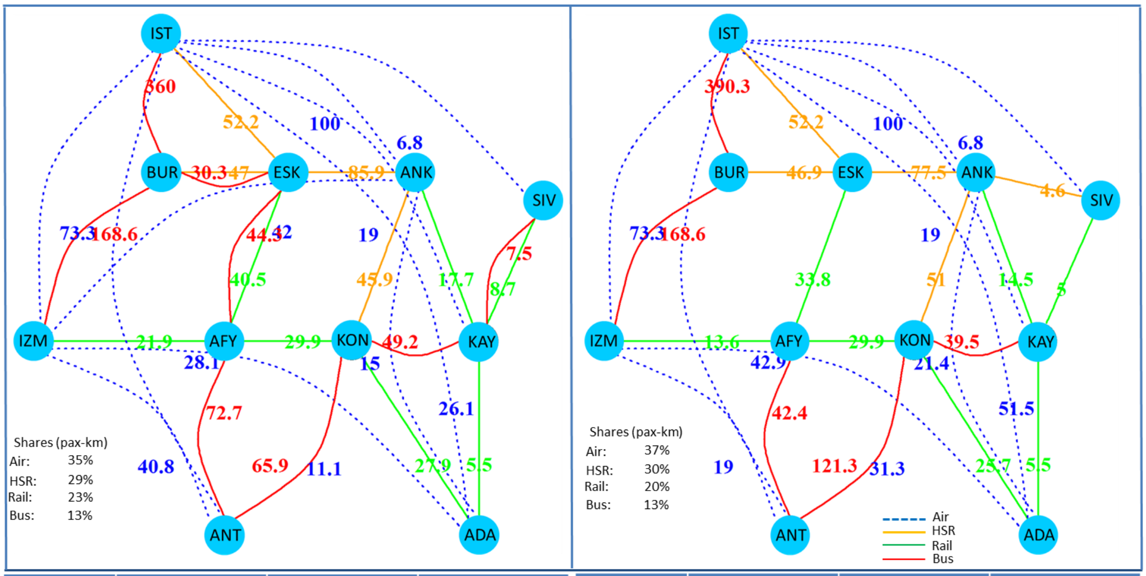


Figure 2: Turkish Intercity Network (left) and optimal solution with link frequencies (right)

Chapter 4: Improvement of Multimodal Transfers

In this chapter, importance of multimodal connections was explained and effects of multimodal transfers were analyzed on the study network. Results show that enabling multimodal transfers is likely to increase network performance because they enlarge the choice set of passengers assuming operators cooperate. It also helps to some extent shifting passengers from road to rail and HSR which is one of the 2023 targets of Turkey for sustainable transport. Next, priority analysis is carried out for the improvement of transfer facilities which could help the decision of improvement projects with a limited budget. Analysis shows that, unlike the general view, it is not necessarily the largest city that will get more benefits from multimodal transfers but rather the central cities in the network.



Travel Time (hours)	Operators Cost (million$)	Social Cost (million$)	CO2 Emissions (tons)
1,073,999	3.661	8.488	2,337

Travel Time (hours)	Operators Cost (million$)	Social Cost (million$)	CO2 Emissions (tons)
1,051,871	3.466	8.193	2,387

Figure 3: Comparison of networks with (left) and without (right) enabling multimodal transfers

Chapter 5: Low-Carbon Network Design

In this chapter, proposed multimodal planning model is extended to analyze impact of low-carbon limit on the ITN of Turkey. In order to find out impact of possible climate change tackles, different levels of CO_2 emissions limits were applied and resulting networks were assessed. Moreover, accessibility changes for each node caused by different CO_2 limits are also analyzed. It is found that, tightening CO_2 threshold in order to achieve a carbon-efficient network increases total travel time and so total social cost. On the other hand, operators cost decreases due to the shift from air to bus and rail. Interestingly, at some steps, there might be some unexpected situations such as an increase in the air passengers or appearance of a new bus service due to the need of compensation of a terminated link or congestion. By these calculations, it can be implied that setting though CO_2 emissions levels cause the present network structure lose some critical links, diminishing its performance and then, we must endure inconvenient and ineffective network structure. Therefore, it is necessary to analyze all possible scenarios, considering interactions between modes in order to achieve a well-balanced network to satisfy both social cost and low-carbon criteria.

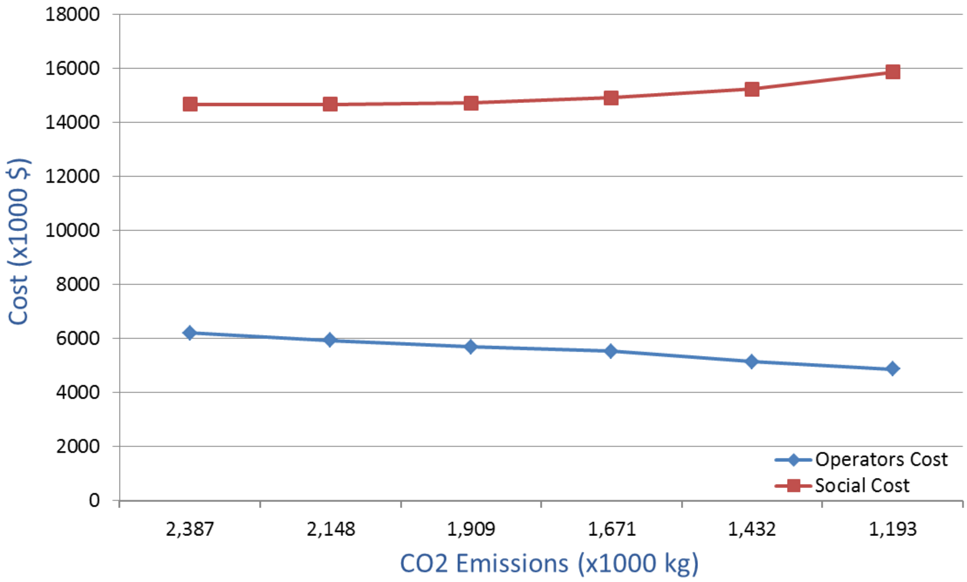


Figure 4: Effects of tightening CO_2 threshold on operators cost and social cost

Chapter 6: Conclusion

In this dissertation, a new multimodal planning model for intercity passenger transport is proposed. The model framework is developed from the viewpoint of planning authorities to achieve a system-optimized network. The model is formulated as a linear programming model which is easy to solve by available computer tools. Then, the model was applied to Turkish intercity network in order to evaluate issues related with long term strategic network design. First, transport network effects were analyzed and it is found that they might affect the funding decision of a project. Therefore, they need to be taken into account at the design process. Second, improvement of multimodal transfers was analyzed. It was found that, they can help to improve performance of the network in general. But, impact in each node is different according to the geographical position. Third, impact of setting a CO_2 limit to tackle climate change was analyzed. It was found that, for the small values of threshold, network behaves as expected. But, for the stricter values, structural change occurs such as lose of critical links, harming the network performance severely. Therefore, detailed analysis is recommended before applying low-carbon policies.