Analysis of Potential Multimodal Connections in Intercity Network of Turkey

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Abstract: In recent years, Turkey has started a development thrust to improve its scarce transport infrastructure by several highway, railway and airport projects throughout the country. Still, it will take years to build a complete and well-functioning network due to time consuming and costly nature of transport projects. Meanwhile, using existing networks in multimodal solutions may be useful to increase network efficiency and to alleviate current congestion problems. Object of this study is to analyze potential multimodal connections that can be realized by small-scale projects using existing infrastructure. Optimal modal-mix planning model was applied to Turkish intercity network to find out optimal link frequencies considering minimum generalized cost to passengers as objective function.

Keywords: multimodal, intercity passenger, network analysis, MILP

1. INTRODUCTION

In recent years, Turkey has started a development thrust to improve its scarce transport infrastructure in line with the ambitious vision of 2023, the centennial founding of the Republic. Several highway, railway and airport projects were commenced or planned throughout the country and majority of these projects are related with passenger transport aiming to create well balanced and sustainable network (TMCT, 2011). Still, it will take years to build a complete and well-functioning network due to time consuming and costly nature of transport projects. Meanwhile, using existing networks in multimodal solutions may be useful to increase network efficiency and to alleviate current congestion problems. They may also lead to less CO_2 emissions by shifting passengers from road to rail (Muller et al. 2004). In fact, necessary multimodal connections are also lacking in many cities. However, they can be realized in relatively shorter times and with smaller budgets. In consideration of the foregoing, object of this study is to analyze the effects of potential multimodal connections on the network performance which can be realized by small-scale projects using existing infrastructure. Total travel time, total user cost and total CO_2 emissions were selected as indicators of network performance. Optimal modal-mix planning model was applied to Turkish intercity network to find out optimal link frequencies and passenger numbers on each link considering minimum generalized cost to passengers as the objective function.

The paper is organized as follows. In section 2 optimal modal-mix planning model is explained. In section 3, study network and used data are explained. Effects of multimodal connections are analyzed using several constraints on the model and results are discussed in section 4.

2. MODEL

Total travel time, total user cost, generalized cost and total CO_2 emissions were used as indicators of network performance. Link frequencies and passenger numbers on each link were necessary for calculating performance indicators. Therefore, optimal modal-mix planning model, developed by Okumura et al. (2012) was used to find out optimal link frequencies and passenger numbers. It is formulated as a MILP (mixed integer linear programming) model which tries to minimize a linear function subject to several linear constraints similar to Chang et al. (2000). Although, the original model permits more than one objective function, minimizing total generalized cost to users was considered as the only objective function in this study. It is the summation of link cost, link travel time and transfer time as expressed in Equation (1). Equations (2)-(5) show the constraints to preserve the traffic amount while Equations (6)-(8) show the constraints for incoming and outgoing frequencies to prevent exceeding link users than link capacity. Equation (9) is the sustainability condition and it states that in order to provide a service on a link, certain number of passengers are necessary to cover operating costs. Resulting MILP model is given following equations and variables are explained in Table 1. This model was constructed and solved by R using lpSolve package, an open source mixed integer programming tool.

Objective function:

$$\min_{X,Y,B,A,Z,F} \sum_{ij} \sum_{m} (c_{ij}^{m} + v t_{ij}^{m} + v \tau_{n}^{mm`}) \quad (1)$$

Constraints:

$$\sum_{i \in N^{-}(n)} X_{in}^{km} = A_{n}^{km} + \sum_{m' \in M} Y_{n}^{kmm'} \quad (2)$$

$$\sum_{m} A_{n}^{km} = T_{kn} \quad (3)$$

$$B_{n}^{m} + \sum_{m' \in M} Y_{n}^{km'm} = \sum_{j \in N^{+}(n)} X_{nj}^{km} \quad (4)$$

$$\sum_{l \in K} T_{nl} = \sum_{m \in M} B_{n}^{m} \quad (5)$$

$$F_{ij}^{m} \leq g^{m} Z_{ij}^{m} \quad (6)$$

$$\sum_{i \in N^{-}(n)} F_{in}^{m} = \sum_{j \in N^{+}(n)} F_{nj}^{m} \quad (7)$$

$$\sum_{k} X_{ij}^{km} \leq h^{m} F_{ij}^{m} \quad (8)$$

$$\sum_{k} X_{ij}^{km} \geq d_{ij}^{m} Z_{ij}^{m} + e_{ij}^{m} F_{ij}^{m} \quad (9)$$

Table 1. Model variables

Variable	Explanation
X_{ij}^{km}	Traffic amount originated from node k on a link between nodes i, j by mode m
$Y_n^{kmm'}$	Amount of passengers coming from origin node k, transferring from mode m to m` at node n
B_k^m	Trips originated from node k using firstly mode m
A_n^{km}	OD trips between k and n lastly using mode m to reach node n
T_{kn}	Total OD demand from nodes k to node n
Z_{ij}^m	Binary value {0,1} for existence of service on a link between nodes i, j for mode m
F_{ij}^m	Frequency on a link between nodes i, j for mode m
h^m, g^m	Seat capacity and max. operable frequency of mode m
d_{ij}^m, e_{ij}^m	Number of required passenger numbers covering the fixed and variable cost of maintaining service on an link between nodes i, j
c_{ij}^m	Link fare between nodes i, j for mode m
v	Value of time
t_{ij}^m	Link travel time between nodes i, j for mode m
$\tau_n^{mm`}$	Transfer time at node n between modes m and m`

3. STUDY NETWORK

3.1 Existing Intercity Network of Turkey

Study network is limited to 11 cities in the central region of Turkey but covers most of the main transport arteries and majority of the intercity passenger traffic. 4 public transport modes (air, HSR, rail and bus) were considered for the analysis. There are 50 links in the network as shown in Figure 1 with city populations. HSR links between Bursa-Eskisehir, Eskisehir-Istanbul and Ankara-Sivas are still under construction but they were included in the analysis because they are expected to be operational by the end of 2013.

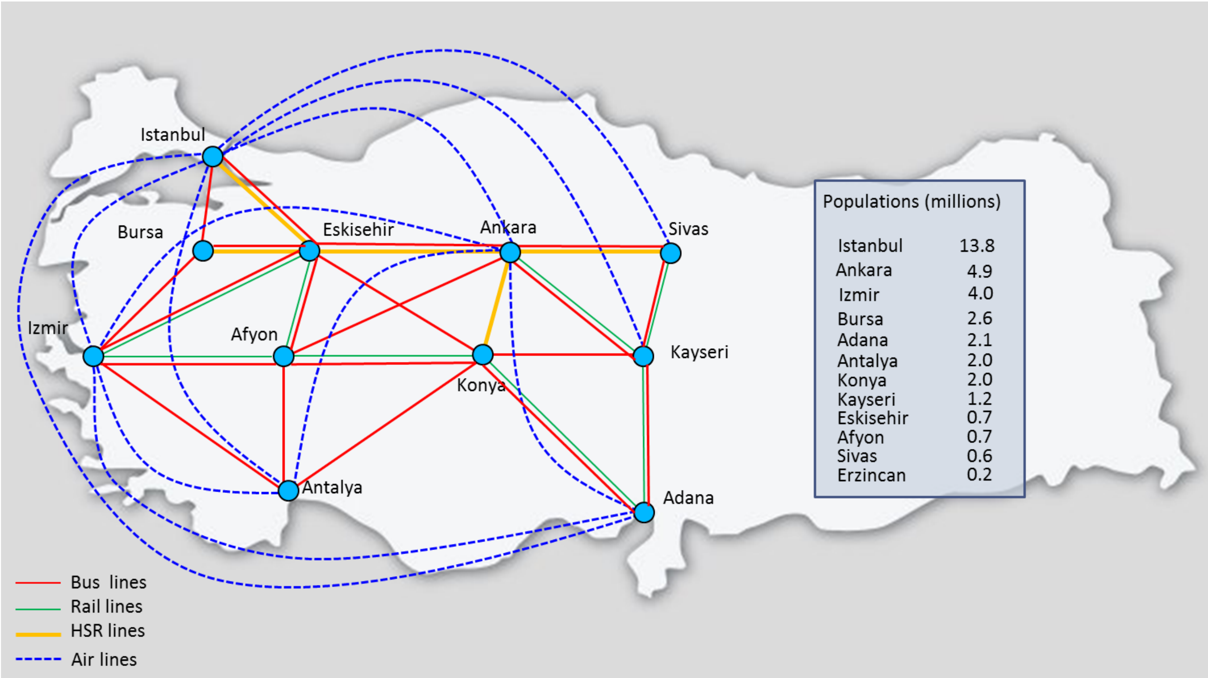

Figure 1. Study network and city populations

3.2 Data

Because of the fact that there was not any available observation data for OD traffic in Turkey at the time of study, artificially generated data by gravity model using city populations and distance between cities were used for the analysis. Link distances, travel times and fares are taken from actual data for the year 2012. Some generalizations were necessary for simplicity at the vehicle seat capacities and maximum link frequencies. CO_2 emission values for were taken from CO_2 Emissions Report for Turkey (Hotinli, 2008). OD data, mode attributes and line parameters are given in Figure 2, Table 2 and Table 3, respectively. Average value of time for Turkey is taken from a recent study (Dogan, 2012) as 5.36 $/hour.

O/D	Istanbul	Bursa	Izmir	Eskisehir	Afyon	Antalya	Ankara	Konya	Sivas	Kayseri	Adana	Total
Istanbul	0	16560	11415	7425	3480	4035	21705	4770	810	2175	2475	74850
Bursa	16560	0	7755	7095	1860	1395	6765	1755	180	525	600	44490
Izmir	11415	7755	0	1380	2010	3135	4380	2055	180	495	780	33585
Eskisehir	7425	7095	1380	0	1935	645	5355	1080	75	240	255	25485
Afyon	3480	1860	2010	1935	0	1305	3930	2175	60	225	7710	24690
Antalya	4035	1395	3135	645	1305	0	2550	3030	135	465	1050	17745
Ankara	21705	6765	4380	5355	3930	2550	0	9885	1185	4590	3255	63600
Konya	4770	1755	2055	1080	2175	3030	9885	0	345	1815	2580	29490
Sivas	810	180	180	75	60	135	1185	345	0	1590	390	4950
Kayseri	2175	525	495	240	225	465	4590	1815	1590	0	1815	13935
Adana	2475	600	780	255	7710	1050	3255	2580	390	1815	0	20910
Total	74850	44490	33585	25485	24690	17745	63600	29490	4950	13935	20910	353730

Figure 2. OD Data

Table 2. Mode attributes

Modes	Transfer times (min)	Modes	Vehicle Capacities (passengers)	CO_2 Emissions ($grCO_2$/pass-km)
Rail(HSR) to Rail	10	Rail	400	5
Rail(HSR) to Air	60	HSR	400	3.9
Rail(HSR) to Bus	20	Air	165	34
Air to Air	40	Bus	54	9
Air to Bus	60			
Bus to Bus	10			

Table 3. Line parameters

Links	Travel Time (min)				Fare ($)			
	Rail	Bus	Air	HSR	Rail	Bus	Air	HSR
Istanbul-Eskisehir	209	283	-	91	13	29	-	36
Istanbul-Bursa	-	208	-	-	-	21	-	-
Bursa-Eskisehir	138	128	-	62	8	20	-	26
Bursa-Izmir	-	275	-	-	-	28	-	-
Izmir-Eskisehir	381	353	-	-	24	36	-	-
Izmir-Afyon	281	277	-	-	17	28	-	-
Izmir-Antalya	-	380	-	-	-	40	-	-
Eskisehir-Ankara	169	200	-	69	10	21	-	26
Eskisehir-Konya	-	287	-	-	-	67	-	-
Eskisehir-Afyon	108	125	-	-	8	16	-	-
Afyon-Ankara	-	220	-	-	-	23	-	-
Afyon-Konya	181	191	-	-	12	20	-	-
Afyon-Antalya	-	247	-	-	-	26	-	-
Antalya-Konya	-	277	-	-	-	29	-	-
Ankara-Sivas	402	380	-	118	25	40	-	46
Ankara-Kayseri	254	273	-	-	16	28	-	-
Ankara-Konya	141	221	-	64	9	23	-	26
Konya-Kayseri	-	280	-	-	-	29	-	-
Konya-Adana	247	305	-	-	16	32	-	-
Sivas-Kayseri	149	166	-	-	9	17	-	-
Kayseri-Adana	216	285	-	-	13	30	-	-
Istanbul-Adana	-	-	120	-	-	-	60	-
Istanbul-Izmir	-	-	70	-	-	-	53	-
Istanbul-Antalya	-	-	65	-	-	-	53	-
Istanbul-Ankara	-	-	90	-	-	-	53	-
Istanbul-Kayseri	-	-	80	-	-	-	60	-
Istanbul-Sivas	-	-	95	-	-	-	53	-
Izmir-Ankara	-	-	75	-	-	-	53	-
Izmir-Adana	-	-	85	-	-	-	60	-
Izmir-Antalya	-	-	65	-	-	-	53	-
Ankara-Antalya	-	-	70	-	-	-	53	-
Ankara-Adana	-	-	60	-	-	-	53	-

4. ANALYSIS

4.1 Effect of Enabling Transfers

In order to analyze the effects of multimodal transfers we compare two cases: one network without any transfers between modes (except rail vs HSR) as similar to the current situation, and one network with possible transfers between modes hypothesizing that all necessary infrastructures and facilities are completed for each city. In the second network, transfer times between modes are considered same at all cities for simplicity as 60 min between air and rail/bus, 20 min between rail and bus. It is also assumed that operators of different modes cooperates to ease multimodal transfers by making arrangements in timetables, ticket sales, luggage transfers, information share etc. which are prerequisites for passengers` multimodal choice.

We applied the optimal modal-mix planning model to these networks to find out optimal frequencies and link passengers. Total travel time, total user cost, total CO_2 emissions and shares of modes were calculated to measure network performance. Resulting networks are shown in Figure 3-4 and related data are given in Table 3.

Table 3. Performance parameters for two cases

Parameter	without transfers	with transfers
Total Travel Time (hours)	1.135.178	1.113.399
Total User Cost (million$)	5,398	5,364
Total Generalized Cost (million$)	11,490	11,339
Total CO_2 Emissions (tons)	1.757	1.738
Share of Rail (% pass-km)	23	24
Share of HSR (% pass-km)	36	38
Share of Air (% pass-km)	23	23
Share of Bus (% pass-km)	18	16

Main difference in two networks is that, there are less bus routes at the second network at which bus users transferred to better modes (rail or HSR) when it is possible. Total travel time, total user cost and CO_2 emission levels are also decreased in the second case. Thus, results show that enabling transfers improved the network performance considerably. This is an expected result because it is apparent that enabling transfers between modes with short waiting times make the choice set of passengers larger by including other (sometimes better) alternatives.

Shares of rail and HSR are also increased with intermodal transfers to the detriment of bus mode. This is a desired situation considering adverse effects of current dominant bus share (around 90%) such as congested roads; high number of accidents, high CO_2 emissions etc. It is also in consistent with the sustainable transport strategy of Turkey (TMCT, 2011) to shift passengers from roads to green modes.

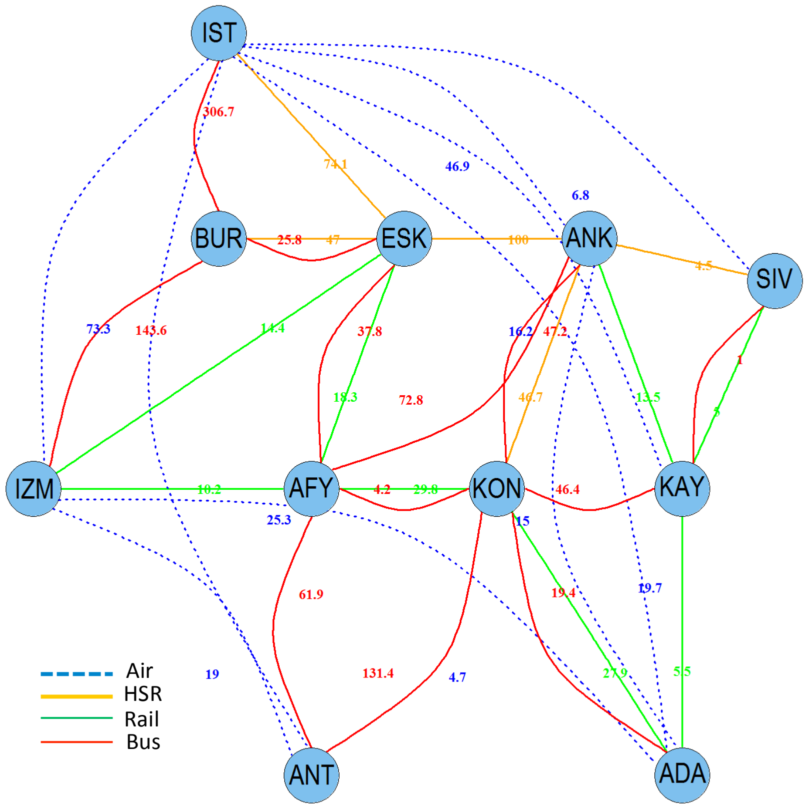

Figure 3. Optimal network shape and link frequencies for min. tot. gen. cost without transfers

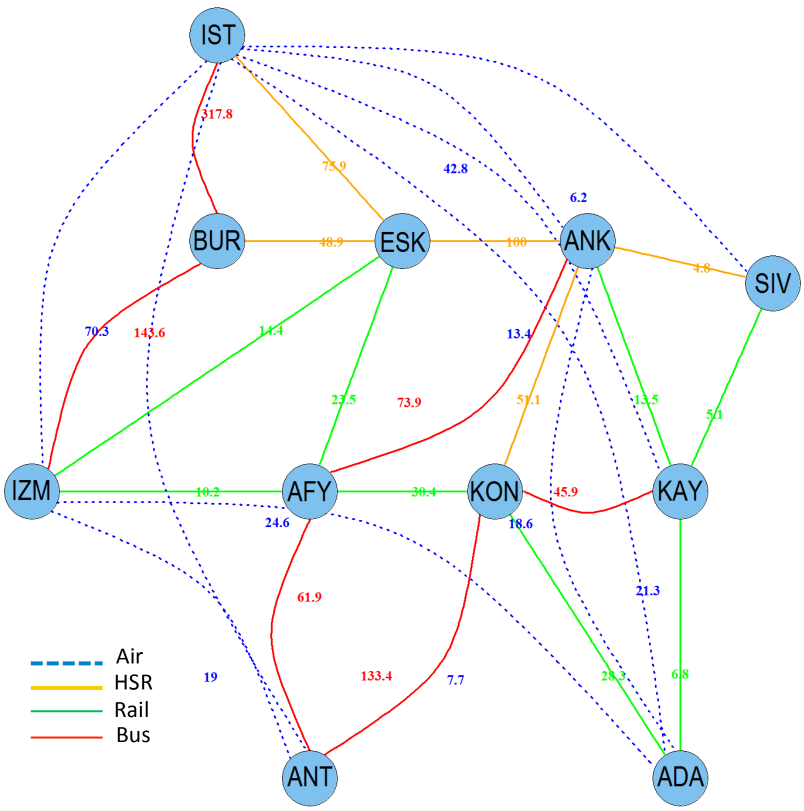

Figure 4. Optimal network shape and link frequencies for min. tot. gen. cost with transfers

4.2 Prioritizing of Necessary Improvements

Next analysis is related with the priorities of necessary infrastructure improvements to enable intermodal transfers. It is evident that effect of improvements will be different at each node according to the position in the network, availability of all modes and populations. Moreover, it may not be possible to carry out all infrastructure projects at once. Therefore, ranking of those improvements can be useful to some extent to prioritize investment projects taking into account a limited budget.

Importance of the improvements can be evaluated by comparing the performance parameters for each case. Therefore, we analyzed 11 cases that transfers were enabled at only one node at each time and compared number of total transfers. Results are given in Table 4. The best, second and third values for each column were colored in red, green and blue, respectively.

Table 4. Ranking of transfer improvements

Nodes	Originated Traffic	Travel Time (h)	User Cost (million$)	Gen. Cost (million$)	CO_2 (tons)	Total Transfers
Konya	29.490	1.121.074	5,397	11,413	1.737	7872
Istanbul	74.850	1.118.116	5.460	11,460	1.833	5790
Afyon	24.690	1.126.980	5,392	11,439	1.754	4127
Eskisehir	25.485	1.333.644	5,406	11,490	1.756	2790
Ankara	63.600	1.128.929	5,418	11,476	1.774	1877
Izmir	33.585	1.135.338	5,392	11,485	1.774	1200
Adana	20.910	1.138.256	5,375	11,484	1.740	990
Kayseri	13.935	1.135.148	5,398	11,490	1.757	47
Bursa	44.490	1.135.178	5,398	11,490	1.757	0
Antalya	17.745	1.135.178	5,398	11,490	1.757	0
Sivas	4.950	1.135.178	5,398	11,490	1.757	0

Some may expect that improvements in larger cities would have more benefits but, results show that Konya is the highest ranked city according to generalized cost, CO_2 emissions and number of transfers in spite of it is only 5^{th} largest city according to originated traffic in the study network. Apparent reason is that Konya is placed at the very center of the network and hence witnesses more transfer users. Istanbul is ranked 2^{nd} according to transfers and 3^{rd} for the generalized cost reduction despite its edge position, probably due to its hub function for air traffic. Its first rank for travel time and worst for reductions of user cost and CO_2 emissions also support that suggestion. 3^{rd} ranked city according to transfer users, reductions of CO_2 emissions and travel time is Afyon, which is also placed at the center of the network and has high rankings (2^{nd}) for user cost reduction and generalized cost reduction, too. On the other hand, Adana which is ranked 7^{th} according to transfer users, has high rankings for user cost (1^{st}) and CO_2 emissions (2^{nd}) reductions probably because it is the node that most transfers are from air to rail or bus.

Another interesting result is that some cities did not have any transit users, mostly because they are placed at the edge points. This is important because it means that multimodal transfer facilities may not give desired effects always and those effects depend on cities location in the network and availability of several alternative modes.

It can be seen that rankings become different according to selected criteria. Optimal modal-mix planning model makes it possible to do this kind analysis which otherwise would be difficult to estimate.

5. CONCLUSION

In conclusion, we studied the effects of multimodal transfers on the study network similar to the existing situation in Turkey. 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 to shift passengers from road to rail and HSR by improving transfer facilities which is one of the 2023 targets of Turkey for sustainable transport.

We also did priority analysis for the improvement of transit 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 city in the network is.

We had to use hypothetical data due to the lack or inaccessibility of real data in this study. However, results above reflect the suitability of the model and we think that it is possible to do realistic analysis using optimal modal-mix planning model and real data.

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