PRIORITIZATION OF KOREAN RAIL INVESTMENTS UTILIZING EXTENDED CAPITAL BUDGETING PROBLEM

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Abstract

Constructing a railroad network includes a process of selecting projects that will form the railroad network based on efficiency measures. Such a selection process has many difficulties, since it is usually made under budget constraints and those projects are not mutually independent. In many applications, however, Capital Budgeting Problem (CBP) models have been used under an assumption that alternative projects are mutually independent to maximize NPV. Accordingly, the configuration of long-term railroad networks in application of these models will likely to produce differences according to the interdependency between projects. To overcome this shortcoming of CBP, extended forms of CBP have been utilized. This paper analyzes the difference in long-term railroad network configurations from applications of CBP and some Extended CBP under budget constraints for Korea's actual case. The resulting long-term network configurations from CBP and Extended CBP are compared that from the network design problem which explicitly considers projects interdependency. Configurations from CBP, Extended CBP and NDP application show noticeable differences. The desirability of these configurations is compared with additional measure of effectiveness. CPU times and computing resources relating to the creation of models and the solution of problems are also discussed.

Keywords: Rail network; Capital budgeting problem; Extended CBP; NDP
Topic Area: E1 Assessment and Appraisal Method w.r.t. Transport Infrastructure Projects and Transport Activities

1. Introduction

From the standpoint of a government, the government must consider proper allocation of investment budget to each transport modes and each projects as well as the allocation of its national budget to each industrial sector. The problem of budget allocation to each project within a mode is a process to establish the priority order of investment for those projects, which is relatively easier than other problems of intermodal comparison. If these target projects are mutually independent without any budget restraint, then selecting all projects having a positive NPV(net present value) may maximize the social efficiency. In cases with budget restraints, it becomes a knapsack problem. This knapsack problem, sometimes in this case called capital budgeting problem (CBP), is practically applied in many cases.

However, each alternative composing transportation networks is difficult to be assumed independent, and, especially for railroad networks, they seem to have high interdependency each other. In this case, a series of processes to select an optimum alternative firstly and a second best alternative among from those left under the condition that the first optimum alternative is put in operation, and then verify a third most appropriate alternative after the first and the second alternatives are enforced, should be repeated over and over until the budget restraint totally vanish. Such problem has been traditionally modeled as Network Design Problem, widely used in many applications up to now (Magnanti and Wang, 1984).

The problem of CBP has an advantage of simple applications. However, the interrelationship between projects is disregarded in this case. Therefore, the difference in rail network configurations will be conspicuous if the interrelationship between projects is considered. To make the application of CBP more realistic, various forms of Extended CBP are being utilized. Concerns whether the NDP approach or Extended CBP should be utilized over the simple application of CBP due to a significant difference in results are also important issues for further development process of rail networks.

This paper conducted a case study on the configuration of railroad networks in Korea to answer these questions. Suh and Cho (2004) compared network configuration with CBP and NDP application. This paper builds on it, and tries to identify whether there are significant differences among network configuration with CBP and Extended CBP. It also tries to identify that whether Extended CBP resolves the wide gap between CBP and NDP results. Toward that end, the long-term railroad networks are developed applying CBP, Extended CBP and NDP approaches and efficiency of resulting networks are compared along with computational complexity. In this paper, the efficiency of each railroad network configurations is compared following the procedure in the Korean railroad evaluation manual (KNR, 2001), and the performance of each network is measured. Lastly, the summary of research and concluding remarks for future research directions are also provided.

2. Major related studies

There are many different approaches possible in developing long term railroad networks. For modeling approaches, this paper considers basically NDP and CBP approaches. Extended CBP models are outgrowth of simple CBP modes to make the models more realistic by considering real budget allocation/use pattern and other policy considerations.

There are numerous literatures about the problem of NDP, and it is easy to find papers on algorithms (e.g. Magnanti and Wong, 1984). Even though it has excellent theoretical superiority, however, a need for large computing resources commonly appears as a problem for easy practical application. This is because of the characteristic of the problem itself that accompanies a geometrically increasing degree of computing resources as the number of variables increase. A nonlinear 0-1 programming problem is created usually, taking into consideration of the congestion on links. Generally, a variety of algorithms are used based on branch-and-bound method (Steenbrink, 1974).

With regard to the problem of constructing a railroad network with budget constraints, a combination of projects having a maximum NPV can be obtained by solving knapsack problem under the assumption that alternative projects are independent each other. The knapsack problem is also called as CBP in this case (e.g. Stevens, 1979). In HDM-3 (World Bank, 1987), the priority order of projects for investment is determined by using a multi-period, multi-constraint problem. These problems are presented under the name of EBM(expenditure budgeting model) to which a budget is the constraint. To solve the EBM problem, full enumeration, heuristic method, and dynamic programming applicable for mainframe computers are proposed. In addition, if the objective function under the single budget constraint is convex in relation to each alternative, a method using incremental NPV/C ratios for the selection is also applicable. In HDM-4, the same problem is solved by using full enumeration and incremental NPV/C ratios. Petersen (2002) reports India's 3,000 kilometers (1864 mile) long national road network plan with a dynamic programming method.

Stevens (1979) also summarizes various forms of Extended Capital Budgeting Problem. Extended CBP forms utilized in this paper are from Stevens (1979).

The excellent theory of NDP accompanies computational difficulties in applying it to a real size network. The applying CBP is relatively easy, but it ignores the interdependency of each project and come with the assumption that those projects are independent each other. Recently, Suh and Cho (2004) compared long-term rail networks resulting from NDP and CBP and reported marked differences. Comparing results from Extended CBP and those from the simple CBP are not explicitly done in their work. Given these points and the fact that there are few researches on the comparing difference of transportation networks form CBP and Extended CBP, especially railroad networks, according to the selection of projects, the subject of this study is important.

3. Creation of models for application

To verify the difference of railroad networks based on project selection methods, a clear study model must be established, the data used for analysis should be realistic, and the calculation procedure must have a consistency. NPV values of alternatives are available from KMOCT (1994), those were calculated utilizing multimodal assignment of total origin/destination demands on highway and railway networks. They were based on the differences of vehicle-kilometers and vehicle-hours from do-alternative and do-nothing cases.

A full enumeration method was used for solution of CBP problem, which resulted in the base network configuration in this study. CBP model utilized is as follow;

$$\max Z = \sum_{i=1}^{n} (NPV)_i \cdot X_i$$

$$\text{s.t.} \quad \sum_{i=1}^{n} P_i X_i \le B$$

$$X_i = 0 \text{ or } 1$$

where, NPV : NPV for Alt i

P_i : Cost for Alt i

X_i : Variable for Alt i

B : Budget constrain

n : Number of alternative

Four Extended CBP models utilized are as follow;

1) Budget constraints are multi year: In this Extended model, budget constraint becomes,

$$\sum_{j} PjtXj \le Bt$$

where t is for time period. This constraint replaces that of the original CBP problem.

2) Unused yearly budget is allowed to be carried over to the next time period: When budget is not all used up in the time period, it is allowed to be carried over to the next time period. This can be modeled with the modification of the budget constraints as follow;

$$\sum_{j}\sum_{t=0}^{n} KjtXj \leq \sum_{t=0}^{n} Bt$$

Again this constraint replaces the original constraint.

3) Considering Mutually Exclusive Alternatives: When there are mutually exclusive alternatives, only one investment alternative can be selected over the others. This can be modeled with the following additional constraints to the original CBP model;

$$\sum_{j} Xj \leq 1$$

where j represents mutually exclusive alternatives. This constraint is in addition to the existing CBP constraint(s).

4) Considering Project Precedence: In certain case, one project should be invested before other project can be implemented. This is about project precedence. When selection of project m is contingent on the selection of the project n, this can be modeled with the following additional constraint;

$$Xm \leq Xn$$

This condition does not necessary assume selection of the project n. Again, this constraint is in addition to the existing CBP constraint(s).

The problem of NDP is formulated minimize the total transport costs. Thus, its objective function must include linearized marginal cost functions. The same model was utilized in Suh and Cho (2004), and included here for the sake of completeness;

$$\min \sum_{i,j \in L} m_{ij} \times X_{ij} - \sum_{i,j \in E} m_{ij} \times K_{ij} \times X_{ij}$$

$$\text{s.t.} \quad \sum_{K \in A_j} {}^{S}X_{jk} - \sum_{i \in B_j} {}^{S}X_{ij} = {}^{S}D_j$$

$$\sum X_{ij} - \sum_{S} {}^{S}X_{ij} = 0$$

$$0 \leq X_{ij} \leq Cap_{ij} + AddCap_{ij} \times K_{ij}$$

$$\sum P_{ij} \times K_{ij} \leq B$$

$$K_{ij} = 0 \text{ or } 1$$

where, $AddCap_{ij}$: Add capacity for link i, j

P_{ij} : Improvement cost for link i, j

B : Budget constraint

m_{ij} : Linearized marginal cost for link i, j

L : All link set

E : Improvement link set

4. Case study

4.1 Development of configurations

Actual data of railroad networks in Korea (KNR, 2001) is used to secure reliable data. The basic network has 132 O/D pairs, 283 nodes, and 710 links, and a total number of 41 investment alternatives are proposed. Figure 1 shows the railroad network including investment alternatives, and Table 1 presents the investment cost, NPVs of each alternative projects. Numbers are used for easy identification of investment alternatives. Network configurations for one budget are identified with budget level of 12 billion dollars. The total O/D volume of each year's is provided in Table 2. Solutions of each model are obtained by using Lingo 7 (Lindo, 2002), and a PC with Pentium-4 1GHz CPU and the main memory of 1GB is used for the process.

As for CBP, alternatives are selected by applying full enumeration and incremental NPV/C ratio method. Full enumeration method was implemented with the same software, with 41 integer variables, and took 0.5 seconds. Incremental NPV/C ratio method was carried with Excel spreadsheet. Projects were ranked with descending order of NPV/C ratio and were selected until the budget is exhausted. Extended CBP problems required about 1-3 seconds with Lingo. In comparison, the given NDP model took about 3 hours and 20 minutes by using Lingo under the Dual Pentium-4 2.4 GHz Xeon with main memory of 3.2 GB PC environment.

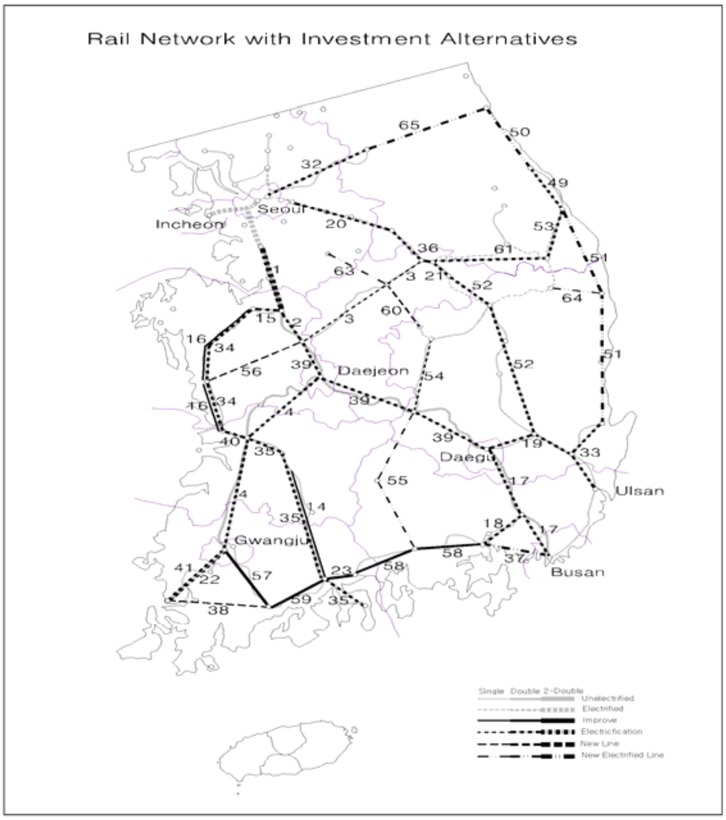

FIGURE 1 Rail Network with Investment Alternatives

TABLE 1 Investment Alternatives

No	Line	Characteristics	Length(mile) (Kilometer)	Financial Cost (million $)	NPV (million $)	NPV/C
1	Gyeongbu	2-double electrification	35(55.6)	803	210	0.29
2	Gyeongbu	electrification	20(32.7)	79	77	1.08
3	Chungbuk	electrification	71(115)	244	206	0.94
4	Honam	electrification	112(70.6)	433	273	0.70
14	Jeolla	improvement	76(122.6)	1008	199	0.22
15	Janghang	Double electrification	10(16.5)	395	252	0.71
16	Janghang	improvement	58(93.4)	1676	452	0.30
17	Gyeongbu	electrification	73(117.4)	434	246	0.63
18	Gyeongjeon	Double electrification	15(23.8)	412	185	0.50
19	Daegu	Double electrification	44(70.2)	1202	0	0.00
20	Jungang	Double electrification	48(76.8)	1562	-42	-0.03
21	Jungang	Double electrification	10(16.4)	214	149	0.77
22	Honam	electrification	44(180)	170	162	1.06
23	Gyeongjeon	improvement double	6(9.3)	132	130	1.10
32	Gyeongchun	Double electrification	54(86.3)	2146	19	0.01
33	Danghaenambu	Double electrification	44(70.3)	1137	102	0.10
34	Janghang	Double electrification	79(126.6)	1087	-205	-0.21
35	Jeolla	Double electrification	121(194.9)	1519	14	0.01
36	Jungang	Double electrification	26(41.1)	734	502	0.76
37	Gyeongjeon	double electric railway	31(50.1)	843	182	0.24
38	Gyeongjeon	single track railway	45(72.3)	1020	487	0.53
39	Gyeongbu	electrification	123(197.3)	687	433	0.70
40	Gunsan	Double electrification	14(23)	381	226	0.66
41	Hanam	Double	44(70.6)	618	234	0.42
49	Donghae	Double electrification	36(57.5)	830	209	0.28
50	Donghae	double electric railway	36(57.2)	909	384	0.47
51	Donghae	double electric railway	106(171.3)	3053	-1099	-0.40
52	Jungang	Double electrification	102(164)	2369	-618	-0.29
53	YeongDong	Double electrification	33(53.8)	1324	60	0.05
54	Gyeongbuk	Double electrification	37(60)	845	-46	-0.06
55	Gimcheon-Jinju	single electric railway	72(115.6)	1173	74	0.07
56	Boryeong-Jochiwon	single track railway	55(88.9)	1029	241	0.26
57	Gyeongjeon	improvement double	38(60.6)	889	912	1.14
58	Gyeongjeon	improvement double	66(106.7)	1696	-244	-0.16
59	Gyeongjeon	improvement double	31(49.1)	712	199	0.31
60	Chungju-Mungyeong	single track railway	24(39)	405	269	0.74
61	Taebaek	Double electrification	60(96.8)	1824	-164	-0.10
62	East-West Industrial	single track railway	61(98.4)	1030	334	0.36
63	Icheon- Chungju	single electric railway	38(61)	843	356	0.47
64	buncheon-Uljin	single electric railway	21(34)	554	329	0.66
65	Chuncheon-Sokcho	double electric railway	67(108)	2364	-277	-0.13

TABLE 2 O/D Volumes for Each Years

(unit: passenger/yr)

Year	2001	2006	2011	2016	2021
Total OD	6,523,983	8,176,822	10,182,910	12,576,300	15,432,090

4.2 Comparison of railroad network configurations

Projects selected by these three approaches are compared and summarized in Table 3 and Figure 2. The result is significantly different in railroad networks solved by either CBP or NDP. The railroad network by NDP tends to have more concentrated tracks and have more network connections (Suh and Cho, 2004). For example improvement to connect from the West to the East in Korea is much need, and NDP solution includes improvement of Gyungjeon line which connects western and eastern part of the country. On top of that, projects having a negative NPV are basically excluded from the selection in case of CBP, but some negative NPV projects are seen in the NDP case due to their level of contribution to the entire railroad network. This means that the negative NPV of such projects at the original Do-Nothing status has changed.

Extended CBP also produced different network configuration. Specific configurations are different depending on the scenarios employed. For example, Table 3 summarizes links included in the network configuration when the simple CBP, multi-period budgeting, and the budget carry-over were permitted. Figure 2 compares these links on the map. Links represented with black dotted line are those not chosen by multi-period method. Broken black lines represent links chosen only by the simple CBP. We can see that network configuration did not show marked difference as with CBP and NDP methods.

TABLE 3 Links Chosen by Different CBP Formulation

	CBP	Multi-Period	Carry-Over
Links Chosen	1,2,3,4,14,15,16,17, 18,19,21,22,23,32, 33,35,36,37,38,39,40 ,41,49,50,53,55, 56,57,59,60,62,63,64	2,3,4,14,15,16,17, 21,22,23,33,35,36 ,37,38,39,40,41,4 9,50,53,55,56,57, 59,60, 62,63,64,	1,2,3,4,14,15,16,17, 18,21,22,23,33,35,36 ,37,38,39,40,41,49,5 0,53,55,56,57,59,60, 62,63,64,

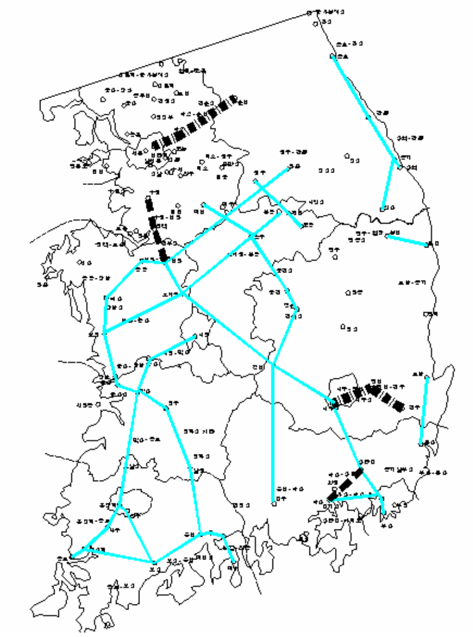

Figure 2 Network Configuration of CBP and Extended CBP Formulation

Some of the alternatives are mutually exclusive. For example, electrification and double track alternative are mutually exclusive on some links. When we impose the mutually exclusive constraint in the model, the model ensures that only one of these alternatives is chosen. Also project precedence is also analyzed. These two Extended CBP problems are depending how you impose constraints, and those constraints should be provided exogenously.

4.3 Evaluation of alternative configurations

Network configurations from CBP and Extended CBP models show different characteristics in terms of the national rail network. However, an additional analysis is necessary for an objective evaluation on these railroad networks. With regard to the completed railroad networks, their ultimate efficiencies with considerations of road and railroad networks and distribution by means were verified pursuant to the procedure provided in the Korean railroad investment evaluation manual (KNR, 2001). Network analysis was done with the software called TRANPLAN(Urbansys, 1999). This is to objectively compare those configurations by applying a standard procedure. Table 4 compares the performance of each railroad network by using some important measure of effectiveness. For comparison purpose, the railroad network based on NDP is also included. Generally Extended CBP formulation showed higher efficiency level than other networks, as expected.

TABLE 4 Comparison of Rail Networks Performances

	CBP	Multi Period Budgeting	Budget Carry-Over
Passenger-km (daily)	5,867,317	5,855,706	5,843,477
Passenger-hour (daily)	62,909	62,456	62,373
NPV billion dollars	16.35	17.25	18.55

Remark: Passenger-km and Passenger-hour are based on 65,000 rail passenger Trip/day
NPV is calculated for the period of 37 years

5. Summary

In theory, it is generally advised to use a NDP formulation in solving project selection problem to construct transportation networks such as railroad networks with budget constraints, because of the interrelationship among alternative projects. Due to complexity of applying NDP, knapsack problems (CBP) that maximize NPV under a budget constraint by assuming each alternative project is independent are often used. Although the assumption of independency may make the overall solving process of the problem easy, but the railroads designed by using the assumption will be likely to differ from those developed in consideration of the interdependency of projects in network. Extended CBP can be also utilized to make the selection process more realistic and overcome deficiency of the simple CBP.

To identify such points, railroad networks are created with the CBP and Extended CBP utilizing the actual data utilized in real railroad network plans in Korea for the comparison purposes. Commercial software is used for the case study to objectively verify the result. The railroad network used in this study has 132 O/Ds, 710 links, and 283 nodes. The problem of CBP was solved with full enumeration and also with a heuristic approach of incremental NPV/C ratios. Four Extended CBP formulations were developed and solved with a standard 0-1 integer programming program.

According to the resulting configuration, these methods showed some differences, and Extended CBP permits analysts to test various polity constraints. CBP problem only selects projects with positive NPV. This seems to be a result of the correlation of projects. Performance of each rail network configurations was evaluated utilizing a standard multimodal evaluation manual. The configuration from Extended CBP showed best performance as expected. Those efficiency gains are relatively small compared to those can be obtained by applying NDP as was shown in Suh and Cho (2004).

Minimal additional computational requirement in applying Extended CBP, it can be safely said that application of Extended CBP is always desirable over the simple CBP. Extended CBP models are more flexible in representing real-life policy environment.

Even though, we can have some efficiency gain with Extended CBP, it is no match to that can be achievable by applying NDP formulation. It is therefore recommended that to use NDP concept in formulating long-term national rail network configuration.

References

Federal Ministry of Transportation, 1992. Federal Transport Investment Plan, Germany.

E.R. Petersen, 2002. A highway corridor planning model: QROAD, Transportation Research A, 36, 107-125.

Korean Ministry of Construction and Transport, 1994. National Arterial Transport Network(in Korean).

Magnanti, T.L. and R.T. Wong, 1984. Network Design and Transportation Planning: Models and Algorithms, Transportation Science 18(4), 362-384.

World Bank, The Highway Design and Maintenance Standards Model, 1987. The Johns Hopkins University Press.

World Road Association and the World Bank, 2000. HDM-4, Highway Development and Management.

Lindo, 2002. LINGO 7, Users Manual.

Korean National Railway, 2001. Railroad Investment Evaluation Manual (in Korean.

Groninger, K.L, 1971. An Algorithm for Synthesizing Optimal Transportation Networks, Dissertation, Cornell University

Steenbrink, P.A. 1974. Optimization of Transport Networks, John Wiley and Sons.

Dantzig G, R. Harvey, Z. Lansdowne, D. Robinson, and S. Maier, 1979. Formulating and Solving the Network Design Problem by Decomposition, Transportation Research 13B, 5-17.

Teng, J-Y and G-H Tzeng, 1996. A Multiobjective Programming Approach for Selecting Non-Independent Transportation Investment Alternatives, Transportation Research B, 30(4), 291-307.

LeBlanc, L.J. 1988. Transit System Network Design, Transportation Research B, 22B(5), 383-390.

Stevens Jr., G.T. 1979. Economic and Financial Analysis of Capital Investment, John Wiley and Sons.

Urbansys, 1998. User Manuals for TRANPLAN and NIS.

Suh, SD and Cho S.H. 2004. A Comparison of Rail Network Configurations Considering Project Interdependency: A Case Study of Korea, Submitted to Transportation.