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# DEVELOPMENT OF REGIONAL RAILROAD LINE CAPACITY CALCULATION PROCEDURE FOR PLANNING PURPOSE IN KOREAN CONTEXT

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**Abstract**: In the planning process, reliable capacity figures for rail link have vital importance. Rail capacity calculation procedures being utilized by many rail operators or standard procedures usually require extensive information infrastructure, technical and operation aspects, such as, signaling, control system, which are not usually available in the planning stage. For example, in a feasibility study stage, information on rail configuration and system should be designed with demand level and economic criteria. Factors shaping up rail capacity are not decided in this stage of the project. Those factors are usually decided at later stage of the project, such as preliminary design or detailed design stage. Still aggregate capacity figures are necessary even at the early stage of a project, such as feasibility study stage. Therefore it is necessary to develop procedures to reliably estimate regional railway capacity using data typically available to planners. The technique is based upon a theoretical approach or standard frameworks. Developed procedure is checked with the Korean environment for the applicability in the planning stage based on a rail capacity simulator.

**Key Words:** Rail Capacity, Planning Purpose, Rail Capacity Simulator, Korean Railroad.

# 1. INTRODUCTION

Reliable capacity figures for rail line have vital importance in operation planning and capacity addition feasibility study. Rail capacity calculation procedures being utilized by many rail operators or standard procedures, for example, such as Rail Transit Capacity (TCRP, 1996) and Transit Capacity and Service Quality Manual (TCRP, 2004), usually require extensive information infrastructure, technical and operation aspects, such as, signaling, control system, which are not usually available in the planning stage. In regional railroad setting, additional aspects, such as train mix, are of importance but not explicit in planning stage.

For example, in a feasibility study stage, information on rail configuration and system should be designed with demand level and economic criteria. Factors shaping up rail capacity, such as listed above, are not decided in this stage of the project. Those factors are usually decided at later stage of the project, such as at a preliminary design or detailed design stage. Capacity figures, even in aggregate manner, are still necessary even at the early stage of a project. To develop rail system capacity figures without utilizing full operational details is necessary. One approach might be to suggest some defaults values which represent average conditions of the project or to provide aggregate values of factors to be used in the capacity calculation procedures.

Similar situation, for example, arises in highway engineering too. The Highway Capacity Manual (TRB, 2000) or local equivalents, is the most generally accepted method for estimating capacity. Its procedures, however, require a great deal of data not readily available to planning practice. Aggregated approaches for planning purposes are introduced in the HCM, or agencies develop more aggregated estimating procedures for their own purpose.

Therefore it is necessary to develop procedures to reliably estimate regional railway capacity using data typically available to planners or at the planning stages. The techniques are based upon a theoretical approach or standard frameworks presented in the Rail Transit Capacity (TCRP, 1996), Transit Capacity and Service Quality Manual (TCRP, 2004), UIC capacity calculation approach, and that utilized at Korean National Railroad, substituting defaults for some of the more difficult to obtain input data for the above said methods. Developed procedures are checked with the Korean environment for the applicability in the planning stage utilizing rail capacity simulators and actual field data.

# 2. RAIL CAPACITY

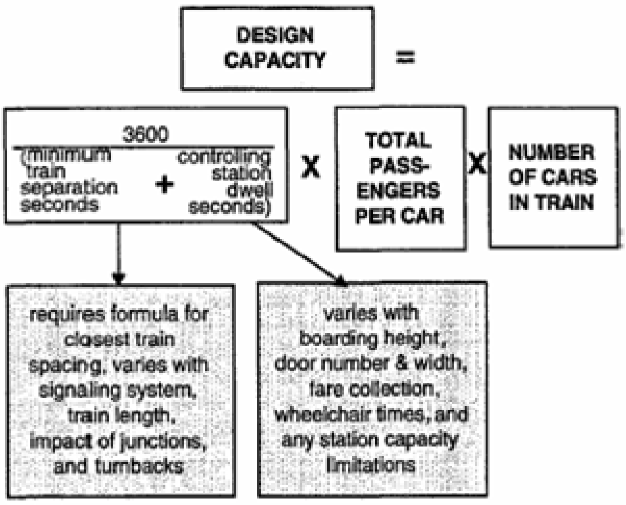
## 2.1 Definitions

In operation and planning stage alike, decision makers have keen interests in knowing how much one rail line can transport people and freight. The concept of capacity, as in highway, has been employed to address these questions.

Two concepts of rail capacity are widely used, design capacity and achievable capacity. Design capacity is defined as, "*The maximum number of passenger spaces past a single point in an hour, in one direction on a single track"(TCRP, 1966)*". Design capacity is similar to, or the same as, *maximum capacity, theoretical capacity or theoretical maximum capacity*— expressions used in other work. Achievable capacity is similar to the concept of practical capacity, and takes into account that demand fluctuates over the peak hour and that not all trains—or all cars of a train—are equally and uniformly full of passengers. Achievable capacity is defined as, "*The maximum number of passengers that can be carried in an hour in one direction on a single track allowing for the diversity of demand (TCRP, 1996).* Figure 1 shows the concept of design capacity. First part of the figure is called line capacity and the next two parts in the rectangular designate train capacity, or vehicle capacity. The basics of rail capacity are very simple—the product of how many trains can be operated in the peak hour and by the number of passengers that will fit on those trains. Trains usually have multiple cars, and number of cars per train is constrained by platform length.

Design (minimum) train operating headway is a function of signaling system type and characteristics, including block lengths and separation; operating speed at station approaches and exits or other bottlenecks such as junctions; train length; and station dwells (TCRP, 1996). *Achievable headway* must account for additional factors that can affect the separation of individual trains such as, operator performance, vehicle performance, external interference, and schedule recovery.

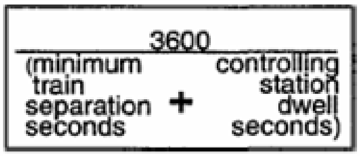
Determining how many passengers will fit on a train is a policy issue subject to significant economic constraints. This encompasses the concept of level of service, which is called 'Quality of Service' in the Transit Capacity and Quality of Service Manual (TCRP, 2004). Actual level of service utilized varies depending on the countries and region the rail operates. This is not the focal issue of this paper, while the line capacity is.




Source: TCRP, 1996
Figure 1. Concept of Design Capacity

Line capacity can be express as in Figure 2. The first item in denominator is called minimum line headway, and the second minimum station headway. Usually, the larger number of these headways in second is called controlling, design, minimum headway, and used to calculate frequency of trains per hour, but can be added as in the figure to provide overall minimum headway over line segment and station. For the regional railroad, station dwell time is usually not a controlling factor in determining minimum headway of a rail line. The number of trains per hour that is theoretically possible is dependent on the different signaling systems including conventional block signaling, cab signaling, and communication- or transmission-based signaling systems with moving blocks. TCRP (1996) lists design headway for different signaling system along others.

In the regional rail setting, when daily capacity figure is desired, usually headway is expressed in minutes, and hours of train operations are considered explicitly with the concept of line utilization ratio. The concept, however, is same for rail transit and regional rail.




Source: TCRP, 1996
Figure 2. Line Capacity

## 2.2 Korean Practices

Korean regional rail operator is Korea Railroad, which used to be the Korean National Railroad. It utilizes several line capacity equation based on number of tracks, signaling systems (Kim, 1997).

For Double Track,

$$N = \frac{f \bullet T}{h(v' + \sum v - \sum w) + \sum wd} \qquad (1)$$
$$d = \frac{p}{2q}(t'_m - t_m) + \gamma + \mu - (1 - \frac{p}{2q})(s' - s)$$

For Single Track,

$$N = \frac{f \times T}{t + c} \qquad (2)$$

Where, N : Number of Trains
f : Line Utilization Ratio
T : 1,440.
t :average travel time of train between stations
c : required time for block operation (1.5 for automatic blocking system)

Kim(1997) and KNR(2004) reports discrepancies between capacity results from these equations and actual line capacity utilized in operation. Biggest contributing factors for the discrepancies are line utilization ratio and the ratio between fast and slow trains. Based on this observation, Kim (1997) proposed to use the line capacity procedure proposed by UIC (Union International de Chemin de Fer).

The procedure adopted by UIC is

$$C = T/(t_{fm} + t_r + t_{zu}) \qquad (3)$$

Where, C: Capacity (Number of Trains)
T: 1440 minutes (for one day)
$t_{fm}$ : Average of minimum train headways

$t_r$ : Extra Time Margin
$t_{zu}$ : Additional Time

Kim(1997) applied the procedures and come up with capacity which is 5-10% higher that those from KNR approach. The capacity from UIC approach represented real rail operation numbers more closely.

More recently, KNR (2004) developed a simulation program for calculating line capacity. The simulator is based on concept adopted by the UIC approach, and can accommodate schedule disturbance and other features common to simulation approaches for line capacity. The base formula used in the simulator is,

$$TimePeriod(T) / Headway(H) = (24hour - HoursNotUsed) / (SafeHeadway + NoOfSection\delta 1 + \delta 2) \times \gamma \tag{4}$$

Where delta, and gamma are parameters to represent realistic headway. KNR (2004) reports development efforts and major findings of the study.

### 2.3 Issues for Planning Applications

The above procedures require detailed information, among other things, about number of trains and sequence of operation for each speed classes. The information is not available in planning phase, where total number of required operations is only available. One might decide hypothetically the sequence of train operation, but the assumed operation can not be guaranteed in the operation stage.

Therefore one should develop a new procedure for line capacity calculation, or provide ways to aggregate data requirements of the procedure to represent planning stage. Fransoo and Bertrand (2000) address the issue based on the first approach. The latter approaches were taken in this paper. The theoretical relationship between headway and frequency, and the base equation from UIC approach provide the platform for the railroad line capacity calculation procedure for planning stage in Korean context. The calculated number and value of parameters were tested with the results from the line capacity simulator (KNR, 2004).

## 3. RAIL LINE CAPACITY FOR PLANNING CONTEXT

The procedure which has been utilized by Korea Railroad requires large input data, and resulting capacity number is somewhat low compared to the actual train operations. Therefore, we decided not to follow the current practice. Instead, we start from the theoretical relationship for line capacity, which is

$$LineCapacty(C) = TimePeriod(T) / MinimumHeadway(h\min) \tag{5}$$

Time period is simply 24 hours minus the hours unusable for train operation for such as maintenance activities or arrival/departure time window restriction. The term line utilization ratio is used to denote the how many hours are usable for train operation per day. Line utilization ratio is simply,

$$LineUtilizationRatio(f) = TimePeriod(T)/24 \quad (6)$$

The usual range is 0.6 to 0.75 in Korea, giving 14.4 hours to 18 hours of operation. Traditionally Korea Railroad used 0.6, which might give somewhat conservative line capacity figures.

Biggest challenge is how to come up with reliable minimum headway for the line segment in question. When different classes of trains are being operated, which is general practice for regional railroad, and many intermediate stations, schedule recovery situation, and so on, it is not straightforward to calculate minimum headway, even though the concept is simple.

The approach taken in this paper is based on UIC formula, while value for variables are localized based on Korean context, for planning stage, and acquired from the line capacity simulator (KNR, 2004). The initial formula to start is one suggested by UIC as,

$$C = T/(t_{fm} + t_r + t_{zu}) \quad (7)$$

Where, C: Capacity (Number of Trains)

T: 1440 minutes (for one day)

$t_{fm}$ : Average of minimum train headways

$t_r$ : Extra Time Margin

$t_{zu}$ : Additional Time

Exact calculation of $t_{fm}$ per UIC approach requires detailed train operation time schedule, which include order of dispatch of fast/slow trains. These information are not available at the planning stage, therefore one can calculate it assuming that headways between successive trains are distributed in random pattern. Only information necessary under this assumption is number of trains per different service classes. This number can be calculated based on demand forecast and basic operation plan in a planning stage.

$$t_{fm} = \sum n_i \times n_j \times t_{fij} / (\sum n_i \times n_j) \quad (8)$$

Where: $i$ : leading train,

$j$ : following train,

$n_i$ : number of trains

$n_j$ : number of trains

$t_{fij}$ : minimum train headway between classes

Minimum headway for double track section is calculated as,

$$starthead = \frac{0.06 \times (N_2 \bullet signaldist + trainlength + insulation)}{fasttrainspeed} + timecross \quad (9)$$

$$arrivehead = \frac{0.06 \times (N_1 \bullet signaldist + trainlength + sigconfdist + insulation)}{fasttrainspeed} + timecross$$

Where *starthead* is minimum headway for start(in minutes), N2, N1: number of blocks (4,3 for 5phase signal, 2,2 for 3phase signal), *signaldist* is average distance between signal(in meter), *trainlength* is length of train(in meter), *insulation* is track insulation distance(in meter), *timecross* is time required for interlocking(0.3 minutes for large station), *fasttrainspeed* is speed of fast trains (in kph).

The extra time margin, $t_r$ , can be regarded as breathing space between train headway to reduce train delays. This has something to do with level of train operation, and related to the length of section, train operation speed, and train minimum headway. UIC proposed two numbers for this,

$t_r = 0.67 \times t_{fm}$, when utilization is 0.6
$t_r = 0.33 \times t_{fm}$, when utilization is 0.75

Additional time, $t_{zu}$ , is added to attain certain level of service. When the number of sections increases, the capacity decreases in general. It can be calculated as,

$t_{zu} = 0.25 \times a$
Where, $a$ is number of segments.

The next step is to review these recommended procedures and value for the parameters regarding Korean context and planning stage. To this end, results from KNR (2004) are utilized with 10 minutes of schedule disturbance. The established procedure requires,

1) Add station dwell time to the segment travel time to get total travel time in the segment. Total time is expanded 1.06 times to allow for delay schedule recovery. This expanded travel time is used to calculate train speeds in the segment.
2) Identify number of train operation for each class.
3) Calculation of $t_{fm}$ based on planned number of trains per classes with random approach utilizing, $t_{fm} = \sum n_i \times n_j \times t_{fij} / (\sum n_i \times n_j)$
4) $t_r = 0.67 \times t_{fm}$
5) $t_{zu} = 0.25 \times a$

## 4. SOME CASE STUDIES

We applied the developed procedure to the line segments in Seoul-Busan rail line. Three segments are selected based on the capacity number availability from previous studies. Three segments are Seoul-Siheung, Daejeon Yard-Okcheon, and Sindong-Dong Daegu sections. Currently, freight train, trains for two conventional passenger services and KTX (high speed rail service) trains are in operation in these segments.

Table 1 shows input variables for these segments. Travel time can be obtained with train performance simulation. Station dwell time can also be estimated based on experience on similar stations. Factor of 1.06 is applied to get adjusted travel time. This factor is added to allow some margin for travel time.

Utilizing data in Table 1, departure headway, arrival headway, $t_{fm}$, $t_r$, $t_{zu}$ are calculated as shown Table 2. Table 2 also compares line capacities from the proposed method with those reported by KNR (2004). The line capacity between Yard-Okcheon shows some discrepancy, but other section show lightly high number. The reason the proposed method gives higher

Table 1. Data for Case Study Segments
(unit: time in min. length in meter otherwise noted)

| | Train type | time (min) | dwell time | train | adj time | spd kph | L | B | a | dist (km) | t | C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| seoul-sihung | | | | 97 | | | | 600 | 4 | 3.3 | 53 | 600 |
| | KTX | 2.4 | 0 | 59 | 2.5 | 78.9 | 400 | | | | | |
| | saemaeul | 3.3 | 1 | 13 | 4.6 | 43.4 | 200 | | | | | |
| | mugung | 3.3 | 1.1 | 21 | 4.7 | 42.2 | 200 | | | | | |
| | freight | 3.5 | 3 | 4 | 6.9 | 28.7 | 250 | | | | | |
| yard-okcheon | | | | 125 | | | | 600 | 3 | 4.7 | 76 | 650 |
| | KTX | 2.9 | 1.8 | 68 | 4.9 | 40.2 | 400 | | | | | |
| | saemaeul | 3.3 | 1.9 | 11 | 5.5 | 35.8 | 200 | | | | | |
| | mugung | 3.4 | 2 | 26 | 5.7 | 34.7 | 200 | | | | | |
| | freight | 4.7 | 3 | 20 | 8.1 | 24.4 | 250 | | | | | |
| sindong-ddaegu | | | | 106 | | | | 600 | 3 | 3.2 | 70 | 720 |
| | KTX | 2.8 | 0 | 58 | 3.0 | 67.1 | 400 | | | | | |
| | saemaeul | 3.1 | 0.9 | 10 | 4.2 | 46.9 | 200 | | | | | |
| | mugung | 3.3 | 1 | 19 | 4.6 | 43.1 | 200 | | | | | |
| | freight | 4.1 | 1 | 19 | 5.4 | 36.5 | 250 | | | | | |

Note: L-train length, B-block length, a-number of section, t-track insulation length, C-signal confirmation distance

numbers might be because that random distribution of different classes of trains has been used. In actual train operation, one has to follow certain train dispatching rules. This might further constraint total number of trains usable on line section.

Table 2. Comparison of Capacity Results with Those from Simulator
(unit: minutes, trains/day)

| | | depart h | arrive h | tfm | tr | Tzu | tmin | Capacity | Simulator |
|---|---|---|---|---|---|---|---|---|---|
| seoul-sihung | | 3.0758 | 4.228 | 4.228 | 2.833 | 1 | 8.1 | 179 | 175 |
| yard-okcheon | | 4.0178 | 6.025 | 6.025 | 4.037 | 0.75 | 11 | 133 | 149 |
| sindong-ddaegu | | 3.8082 | 5.284 | 5.284 | 3.54 | 0.75 | 9.6 | 150 | 149 |

## 5. CONCLULSION

It is necessary to develop procedures to reliably estimate regional railway capacity using data typically available to planners. A procedure based on the concept proposed by UIC was adopted to Korean context to calculate line capacity for planning purpose. Developed procedure is checked with the Korean environment for the applicability in the planning stage based on a rail capacity simulator. One three section tested, one section give somewhat lower number, while in other two section, higher capacities compared with those from simulator were observed.

In planning stage, detailed train operation schedule is not available. Therefore, in calculating minimum safe separation time, trains of different classes are assumed to randomly distributed. In actual situation, there will some train dispatching rules to follow. This might be the reason that the proposed procedure gives a little bit higher capacity figures.

Theoretically the proposed procedure has not abnormalities. But, some input variables should be check with more diverse situation. Also those numbers from the procedures have to be checked against the actual operation and/or official capacity figures of Korea Railroad. To make the result more concrete, additional case studies on section with various signaling, track structure, and physical/operational factors are advisable.

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