Chapter (1)
Literature Review

1-1 Classical method (A.M. Wellington, 1887)

The basic criteria for railroad alignment comparison and route selection stem largely from the classic text by A.M. Wellington titled "Economic Theory of the Location of Railways" that describes the ideal railway as that taking the flattest, straightest and shortest route between two points.

This method discusses the problem of minimizing grades and curves on a transcontinental scale.

1-2 MATRIX ANALYSIS APPROACH

(C.Tyler Dick, 2008)

The matrix analysis approach is used to compare multiple alignment alternatives under consideration for a railroad project. The alignment alternatives are selected such that they represent distinct routes with differing horizontal layouts. However, it is possible for alignment alternatives to have common segments, particularly near start and end points. The analysis does not require that the alignment alternatives have common start or end points. This is useful when studying a line into a new industrial plant where there are several possible locations to tie the line to an existing mainline.

1-2-1 Modern engineers often find themselves working on a less grand scale with shorter projects such as industrial spur build-ins and urban by-passes, and needing to consider a host of engineering and environmental factors other than railway geometry to complete a modern railway alignment study.

1-2-2 Remote sensing and computer design programs allow multiple alignment alternatives to be generated in a fraction of the time it took classical method to develop a single route.

This method describes alignment analysis and comparison techniques that have been used successfully in the development of preferred railway geometry for such projects ranging from 8 to 80 km in length.

1-2-3 Two main techniques are highlighted:

First technique: The matrix approach to alignment analysis and comparison.

It allows a particular alignment to be evaluated on the basis of multiple criteria, each considering several factors. Each alignment alternative is judged relative to several evaluation categories.

a- These evaluation categories are subdivided into multiple decision criteria against which the alignments are scored.

b- The individual scores for each criteria are weighted and summed to produce a category score.

c- These category scores are then weighted again and summed to produce a total score for the alternative.

d-The total score derived through this "double weighting" system provides a means to directly compare the overall performance of each alternative relative to the various decision factors deemed important by the client.

The following steps summarize this approach:

Step (1): Each evaluation area is given a weight in advance of the study by the owner.

Step (2): The evaluation is made in the form of a score, including those criteria and factors where the observed data is qualitative and not quantitative in nature. This score is determined, typically on a scale of zero to five, with zero being the least optimal and five being the most optimal.

Step (3): The individual alignment scores are then multiplied by the weights to form an overall alignment score.

Step (4): This overall score can be directly compared to that of other alignments to make decisions regarding a preferred alignment and a final recommendation to the owner.

An example of an evaluation matrix is shown in table (1-1). The evaluation matrix also shows the relative weights of each decision criteria and of the evaluation categories.
This double weighting system is used to convert the individual decision criteria scores (ranging between zero and five) into a total alignment alternative score (ranging between zero and 500). The final result of the scoring procedure is a summary matrix of scores with evaluation categories (and the total score) as rows and each alternative as a column.

Table (1-1); Evaluation matix

Category	Weight	Alternative		
		A	B	C
Operational Efficiency, Mobility and Safety Effects (25% of total)				
Operational Efficiency of the Railroad	50%	4	4	3
Number of At-Grade Railroad/Roadway Crossings Added	10%	2	2	2
Levels of Service at Grade Crossings	10%	4	4	4
Railroad Freight Safety	15%	3	3	3
Public Safety	15%	3	3	3
Cost-Effectiveness (30% of total)				
Total Project Cost	50%	3	3	4
Railroad Operating and Maintenance Cost	25%	4	4	3
Roadway Operating and Maintenance Cost	10%	3	3	3
Ease of Implementation	15%	3	3	4
Social and Economic Effects (20% of total)				
Number of Properties Affected	35%	2	2	5
Change in Property Values	50%	3	3	4
Compatibility with Regional Plans and Planned/Existing Development	15%	4	4	5
Environmental Effects (15% of total)				
Number of Potential Noise and Vibration-Sensitive Receptors Affected	15%	5	5	5
Concentrations of Minority and Low-Income Populations within Corridor	10%	4	4	4
Number of Parklands, Historical, Cultural, and Archaeological Resources Affected	10%	3	4	3
Presence of Regulated Material Sites, Mines, Brownfields, and Landfills	10%	5	5	5
Effect on Waters of the US, Including Wetlands Areas	15%	3	4	4
Proximity to Floodplain	10%	4	4	4
Effects to Prime Farmlands	15%	1	2	1
Effects to Endangered Species and Wildlife Habitats	15%	2	3	2
Public and Agency Support (10% of total)				
Level of Public Support	35%	2	2	4
Level of Agency Support	35%	3	3	3
Schedule	30%	3	3	4

An example of a summary matrix is shown in Table (1-2). In this example, alignment alternative C has the highest total score and is selected as the preferred alignment for further study and detailed design. In addition to comparing the total scores for competing alignments, displaying the data in this matrix format and grouping various decision criteria into broad evaluation categories via the double weighting system permits evaluation category scores to be readily compared between categories and between alignments. This allows the design engineer to determine which of the evaluation categories are driving the decision between alignments and examine the sensitivity of the total scores to changes in scoring in specific categories. It also aids the design engineer in identifying potential trade-offs between the various evaluation categories. For example, if Alignment A had a higher score than Alignment B due to scoring poorly in the environmental effects category but was an attractive option otherwise, the design engineer could go back and possibly adjust the design of Alignment A to eliminate some of the environmental impact. This may come at the expense of a lower score elsewhere but ideally the change could be made such that these decreases would be isolated to lightly weighted categories, resulting in an increased overall score and making the alternative more attractive.

Table (1-2); Summery matrix

Category	Alternative A	Alternative B	Alternative C
Operational Efficiency, Mobility and Safety Effects			
Category Score	3.5	3.5	3.0
Weight	25	25	25
Weighted Category Score	**88**	**88**	75
Cost-Effectiveness			
Category Score	3.3	3.3	3.7
Weight	30	30	30
Weighted Category Score	98	98	**110**
Social and Economic Effects			
Category Score	2.8	2.8	4.5
Weight	20	20	20
Weighted Category Score	56	56	**90**
Environmental Effects			
Category Score	3.3	3.8	3.4
Weight	15	15	15
Weighted Category Score	49	**57**	51
Public and Agency Support			
Category Score	2.7	2.7	3.7
Weight	10	10	10
Weighted Category Score	27	27	**37**
Total Scores			
Total Score	316	325	**362**

<u>Second technique:</u> Indexes for comparing grades and curves on short alignments.

One of the more highly weighted decision criteria is the operational efficiency of the proposed railroad. For a major railroad project, train performance calculators or other simulation software are often used to model alignment alternatives and compare running times and fuel consumption. For a smaller railroad project, often such detailed analysis is too time consuming for the desired schedule or is outside the scope and budget of the study. In these instances, a simplified method of estimating which alignment alternative best minimizes length, grades and curves is needed. While measures of alignment length are straightforward, two indexes have been developed to meet the need for curves and grades.

<u>First index</u> is Curve Index (I_c):

A commonly used measure of total curvature is the total degrees of central angle of curvature for the entire alignment alternative. This value is calculated by summing the defection angle (or central sweep angle delta) for every curve along the alignment alternative. In this manner, the total degrees of central angle provides a measure of how much curvature each alignment contains. By dividing by 360 degrees, the number of complete circles of curvature can be compared between alignment alternatives.
However, the total degrees of central angle does not provide a measure of the tightness of these curves and it is the tightness of these curves that determines:

a- Allowable train speed.
b- Train resistance.
c- Impacts rail wear.
d- Required maintenance activity.

So curve index is the sum of the product of the deflection angle (or central angle) and degree of curvature for each curve along the alignment alternative:

$$I_C = \sum \Delta D \quad (1\text{-}1)$$

Where I_C = curve index

Δ = deflection angle or central angle

D = degree of curvature

With this form, tighter curves (higher degree of curvature curves) are weighted more heavily in the curve index calculation. The heaviest curve index penalty is assigned to those curves which have both a large central angle and a tight degree of curve.

Figure (1-1) illustrates a hypothetical situation where curve index can distinguish between horizontal alignment alternatives that have equal values for tightest curve and total degrees central angle of curvature. In this case, the alignment with the broad larger radius (smaller degree) curves has a lower curve index value and, on the basis of curvature, is a more attractive alternative in terms of operating efficiency.

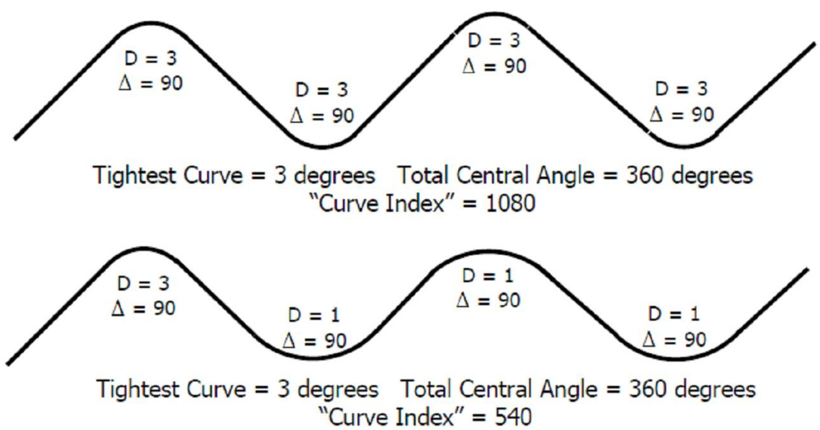

Figure (1-1); curve index comparison

<u>Second index</u> is Grade Index (I_G):

The simplest measure of gradient on a particular alignment alternative is the ruling grade or the segment with the steepest uphill gradient. Although the ruling grade has operational implications in determining maximum train length for a given locomotive, it does not give any indication regarding the number or severity of other grades on the alignment alternative. Ruling grade is often supplemented by measures of rise and fall. For the purposes or this discussion, rise and fall is defined as the sum of the absolute value of the total vertical elevation change over each segment of constant grade:

$$Z = \sum | GL | \qquad (1\text{-}2)$$

Where: Z = rise and fall

G = percent grade

L = length of constant grade segment (in feet)

The calculated value of rise and fall provides a good measure of the amount of undulation on a particular alignment alternative. This helps to give the engineer an idea of the fuel consumption, running time and train handling requirements of the alignment alternative. However, rise and fall does not give an indication of how steep the grades are that result from the undulation. It is the combination of the steepness of the grades and the total rise and fall that provides the engineer with the best picture of the efficiency of the vertical alignment.

To measure the combination of these effects, the value of grade index is calculated for each alignment alternative as follows:

$$I_G = \sum G^2 L \qquad (1\text{-}3)$$

Where: I_G = grade index

G = percent grade

L = length of constant grade segment (in feet)

The calculated value of grade index provides a measure of undulation with segments on steeper grades weighted more heavily than those on less severe grades. The resulting high grade index value for alignment alternatives with rapidly undulating steep grades reflects the difficulties encountered in handling trains over such territory.

Figure (1-2); illustrates a situation where two alignment alternatives have different profiles but have equal ruling grades and rise and fall. The grade index, however, can distinguish between the two alternatives with the alternative featuring longer but less severe grades being the more attractive option in terms of vertical alignment.
Once length, curve index and grade index are determined for a particular alignment alternative, they can be compared against other alignments to allow the engineer to gauge the relative efficiency of each alignment alternative and score them appropriately.

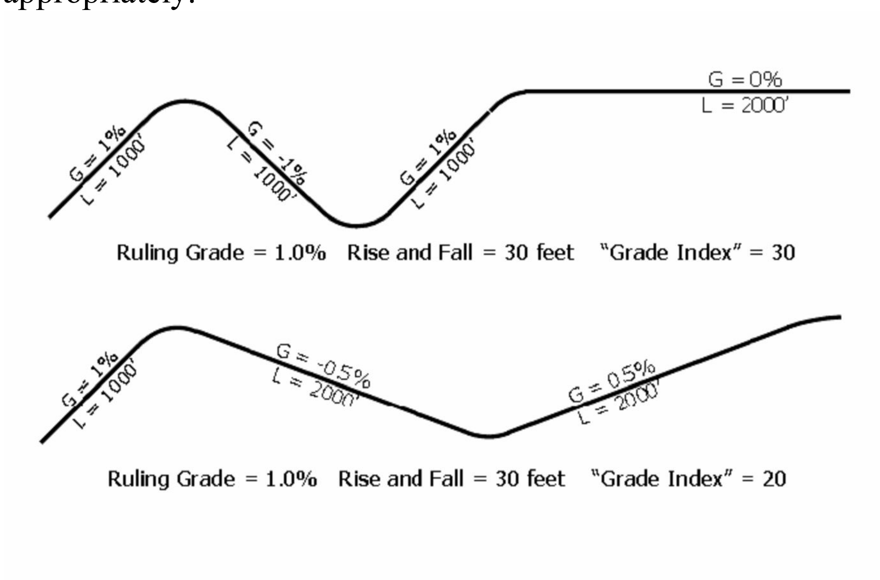

Figure (1-2); Grade index comparison

1-3 <u>Zigzag Broken line Methodology:</u> (Riad, 1984)

To connect two given sites with each other by railway line the following methodology is proposed either using digital topography map or contour map with scale 1: 25000. the suitable path can be selected taking into consideration the minimum earthwork, grades, horizontal curves, length, and avoiding level crossings with roads, channels, important buildings,..etc. More than two paths must be studied; the lowest cost one is the best to be carried out:

Step (1) Draw Zigzag line which indicates the path with no earth work and has a constant gradient (g); where g can be calculated from the formula

$$‰\ g = \frac{\text{(level difference between the two sites (start and end) in meter)}}{\text{(horizontal staight line distance between the two sites in km)}} \tag{1-4}$$

With a radius r on the contour map one can obtain zigzag line as shown in figure (1-3)

Where $r = \dfrac{\text{contour interval } (h_{i+1} - h_i) \text{in meter}}{g‰} = r \text{ in } km$ (1-5)

Step (2) Change Zigzag line to broken line as shown in figure (1-4)

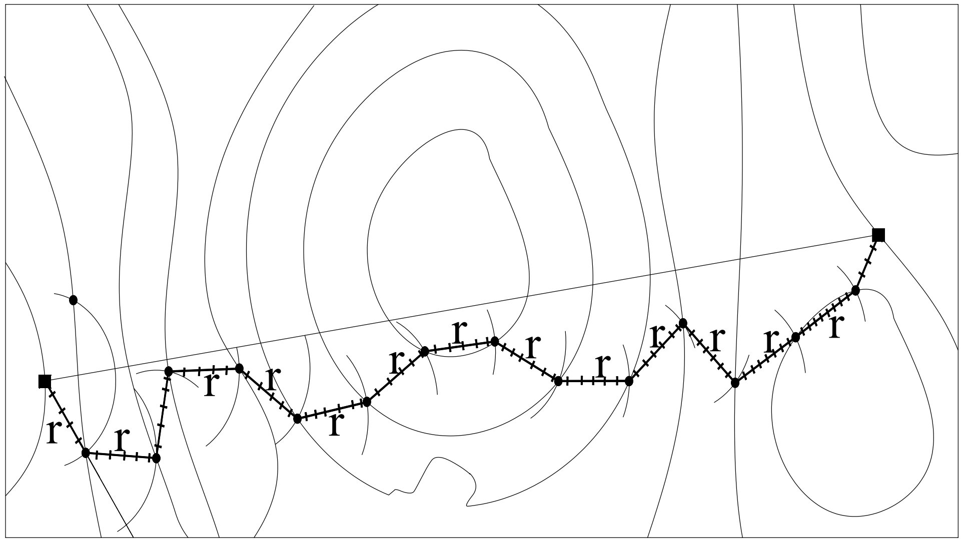

Fig. (1-3); zigzag line in plan   scale 1:25000

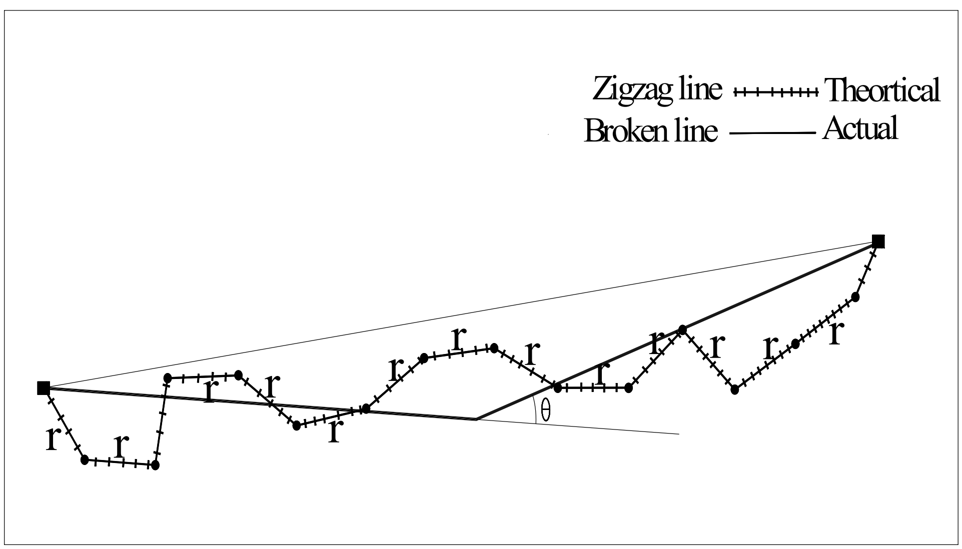

Fig. (1-4); broken line in plan scale 1:25000

Step (3) For the chosen broken line, draw the ground land level corresponding to this path which has a zigzag line in elevation (or longitudinal section) as shown in figure (1-5), then raw the broken line which represents the track level.

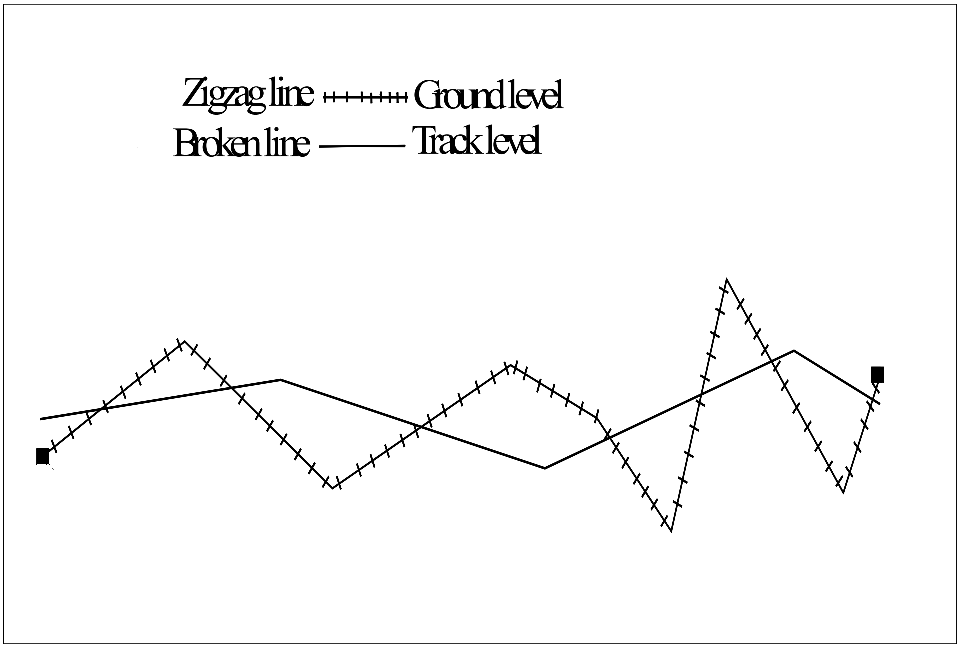

Fig. (1-5); zigzag and broken lines in elevation (longitudinal section)

Step (4) Calculate the earth work (cut & fill) and determine the track type (single or double) according to the required daily capacity and the proposed signal system, calculate also ROW.

Step (5) By the use of railway dynamics studies, the suitable time table can be proposed (graphically), stations and yards can be designed, turnaround time of rolling stock can be estimated.

Step (6) Calculate the estimated cost of each path to select the lowest cost one. The estimated cost is function of the annual traffic demand which can be indicated by passenger.km (for passenger trains) and ton.km (for freight trains).

Table (1-3) gives the relationship between the annual traffic demand and the operating units for both passenger and freight trains

Table (1-3) mathematical models to calculate the operating units for both passenger and freight traffic. (ECOGIM, 1991)

Operating units for passenger traffic in pass. km	**Operating units for freight traffic in ton. km**
Train. Km=2.34x10^{-3} (Pass. Km)	Train. Km=3x10^{-3} (ton . km)+1605.8
Car. Km=9x10^{-3} (Pass. Km)+170096	Car. Km=38x10^{-3}(ton . km)
Ton . km=0.904(Pass. Km)	Ton (Load+empty).km=1.71(ton . km)
Car Trip=0.177x10^{-3} (Pass. Km)	Car Trip=0.183x10^{-3} (ton. km)

The total cost for passenger and freight traffic can be calculated according the empirical Egyptian Railway equation in thousand Egyptian pounds as a function of the general inflation rate which has a number 100 on year 1966 according to Egyptian central authority for accounts.

For passenger traffic:

$$\text{Cost}=[2.872 \times 10^{-3} (\text{Car Trip})^2 + 1.85 \times 10^{-11} (\text{ton.km})^2 + 5.01 \times 10^{-7}(\text{Car km})^2 + 0.215 (\text{Car km}) +39135] \times (\text{Inflation Rate}) \quad (1\text{-}6)$$

Where, Inflation Rate = 0.212 + 1.812 x10^{-3} x General Inflation Rate

For freight traffic:

Cost=[5.45x10^{-6} (Train.km)^2 + 0.178 (Train.km) + 19.7x10^{-4}(ton.km) + 8.679(Car Trip) + 0.2454(Car.km) +20044]x (Inflation Rate) (1-7)

<u>Where</u>, Inflation Rate = 0.196 + 1.755 x10^{-3} x General Inflation Rate

Step (7) Feasibility study for the selected path can be estimated using the following equation

$$r = \frac{R - E_O}{E_C} \qquad (1\text{-}8)$$

<u>Where</u>, r; expected annual interest

R; required revenue (LE/ year)

E_O; operating cost + replacement value of rolling stock (LE/ year).

E_C; capital cost for rolling stock, track, and other infrastructure (LE).

Replacement value of rolling stock cost can be calculated by the use of the equation (1-9)

Replacement value of rolling stock cost = rolling stock * price (LE/ unit)*A (1-9)

Where A≡ replacement value which can be calculated by equation(1-10)

$$A = \frac{0.9\bar{r}}{\left[1 - \left(1 + \bar{r}\right)^{-n}\right]} + 0.1\bar{r} \qquad \text{(1-10) (NIDCO, 1982)}$$

<u>Where</u>, n ;life time & ŕ ; the bank rate of interest (current interest)

Rolling stock can also be estimated by the use of equation(1-11)

$$\text{Rolling stock} = \frac{\text{Annual traffic demand} * \text{Turnaround time}}{365(\text{day/year}) * \text{load/unit} * (1 - \%\text{maintenance})} \qquad (1\text{-}11)$$

The project is feasible if r expected is equal or bigger than ŕ (the bank rate of interest announced by the central bank).