Design of Track Alignment Using Building Information Modeling

Shih-Fang Huang[1]; Chun-Sung Chen[2]; and Ren-Jye Dzeng[3]

Abstract: In recent decades, the spreadsheet and computer-aided mapping are the major tools for track alignment design. These traditional methods can meet the design criteria, but when the design factors and the change order must be satisfied at the same time, the process is always complicated and redundant. Building information modeling (BIM) is mainly applied on the generation and management of building data. It utilizes the object-oriented concept to increase the efficiency of information management in the building life cycle. The track-alignment data also have topographic relation that is similar to the building. There is a much closer relation between the topological, sharp, and position of track entities than that of the building components. This paper discusses the feasibility of applying a real-time, dynamic, three-dimensional building information model to design the alignment; compares the traditional alignment method with the BIM alignment method to find out the differences; and analyzes the precision by using alignment data of east and west main tracks of Qidu Switchyard of Taiwan Railways Administration. Moreover, the paper proves that the BIM can simplify track-alignment design, increases the abilities of computer-aided design and automation, and greatly shortens the design period. **DOI:** **10.1061/(ASCE)TE.1943-5436.0000287.** © *2011 American Society of Civil Engineers.*

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Introduction

Building information modeling (BIM) is a process of generating and managing building data during the building's life cycle (Holness 2008). Typically, BIM uses three-dimensional (3D), real-time, and dynamic building modeling software to increase productivity in building design and construction (Lee et al. 2006). The process generates the BIM with building geometry, spatial relation, geographic information, as well as the quantities and properties of building components.

The track alignment is the train route, including horizontal and vertical sections. Multiple factors, such as speed, radius, arc length, superelevation, gradient, length of route, building line, platform clearance, and passenger comfort, need to be considered at the same time. The factors are usually interactive, so any change in one factor influences the other factors. On highly urbanized land, the design of the track alignment faces limited road corridors, more facilities, and viaduct or underground gradient. Thus, meeting the operating requirements for safety, comfort, convenience, and design criteria for less demolition, low noise, energy-saving features, and environmental protection are the primary goals of track-alignment design (Huang 1993).

The design and construction of infrastructure usually depends on the drawings and documents, and the approved drawings are regarded as a part of the contract documents. The drawings and documents are utilized as the database of subsequent facility management. However, the traditional two-dimensional (2D) drawings cannot fully describe the 3D object of building, and they are likely to result in errors and omissions. On the other hand, the points, lines, surfaces, and characters in drawings cannot be interpreted by the computer directly and need to be identified by professional personnel, where manual identification will obstruct automation.

BIM uses entities to compose the track design, makes the entities intelligent by parameters, and defines the relationships among entities. Therefore, when an entity changes, the adjacent entities are reconstructed according to the embedded parameter. For example, when a wall moves, the adjacent window, door, and doorknob are also moved automatically, and the material amount is renewed automatically, too.

The track alignment is a 3D continuous line segment. It is composed of straight lines, curves, and spirals, like a building is composed of columns, beams, and walls. The components are correlated with one another through specific parameters; for example, the running speed influences the curve radius, superelevation, and spiral length at the same time, and any curve radius change will influence the subsequent full-stake mileage and coordinates, etc.

In traditional track-alignment design, the alignment is evaluated in the map. Designers have to calculate details such as the design speed, radius of curve, superelevation, arc length, tangent length, and middle ordinate. When the parameters of curves are designed, the spreadsheet is utilized for calculating the main stakes, the point from tangent to spiral (TS), point from spiral to curve (SC), point from curve to spiral (CS), the point from spiral to tangent (ST), and full-stake coordinates. Finally, AutoCAD is used for drawing. When the designer changes any entity or parameter, the same steps

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must be repeated for reviewing the clearance of topography and surface features, so it is time- and labor-consuming. But BIM can parameterize the track design entities, and embed the design criteria and standards in the model. For the modification of any entity or parameter, the computer can update the adjacent entities automatically and examine whether the new parameter coincides with the relevant design criteria; hence, the work of traditional alignment design is reduced greatly by BIM.

Importance of Track-Alignment Design

The track alignment is the train running route. Its design aims to satisfy convenience, safety, comfort, and multiple external factors (Huang 2007). The factors can be classified into five major types, as seen in Table 1.

Table 1 shows that many factors need to be satisfied in the alignment design and the factors are usually interactive to one another. For example, the improvement of vehicle performance will influence the train speed, which is limited to the longitudinal gradient, radius, and superelevation. The change in radius may invade the boundary line of construction and thus, in turn, influence the ground object demolition and compensation cost. It is impossible for the alignment design to satisfy all factors. Hence, how to obtain a balance of all factors is a big challenge to designers.

This paper refers to the process of traditional track-alignment design and the relevance among track-alignment components, using AutoCAD Civil 3D software to build parameterized track entities conforming to local criteria, and discusses the feasibility of automatic track-alignment design.

Table 1. Track-Alignment Design Factors

Type	Factor
Vehicle	Running speed
	Vehicle performance
	Track live load
	Vehicle scheduling
	Vehicle relief track
Civil work	Civil structure
	Construction difficulty
	Earthwork balance
Geometric	Superelevation
	Curve
	Speed restricted at curve
	Transition curve
	Longitudinal gradient
	Boundary line of construction
Environmental	Environmental impact
	Noise vibration
	Geologic conditions
	Demolition
Cost	Demolition compensation
	Land cost
	Construction cost
	Maintenance cost
	Operational cost
Other	Combination of bad route conditions

Traditional Track-Alignment Design

The track-alignment design process includes collecting topographic atlases, planning on maps, surveying in the field, and determining the design speed, curve radius, superelevation, spiral type, and the minimum spiral length. Then the coordinates and mileage of the main stakes (TS, SC, CS, and ST) are calculated. Finally the mileage of full stakes (per 10 m), profile and cross profiles, curve tables, and coordinate table of main stakes and full stakes are finished. The track-alignment design process is shown in Fig. 1 (Yao 2006). However, the track alignment has an important succession character: any modification of parameter, tangent angle, or superelevation may influence the mileage and coordinates of all subsequent main stakes and full stakes. In such cases, reviewing and redrawing as well as identifying shall be carried out again and again, until the alignment meets all design criteria. Therefore, the traditional design method has the following shortcomings.

1. The alignment design requirements should be identified manually one by one. When the route is long and the workload increases, it is likely to result in human error.
2. When there is no dynamic link in design data, all the spreadsheets, drawings, outcome tables, or coordinates shall be modified step by step. This is likely to cause inconsistency between graphs and illustrations.
3. The alignment and profile cannot be considered at the same time, which is sure to cause conflict between them.
4. There is no graphic user interface, so it is difficult to align the layout.

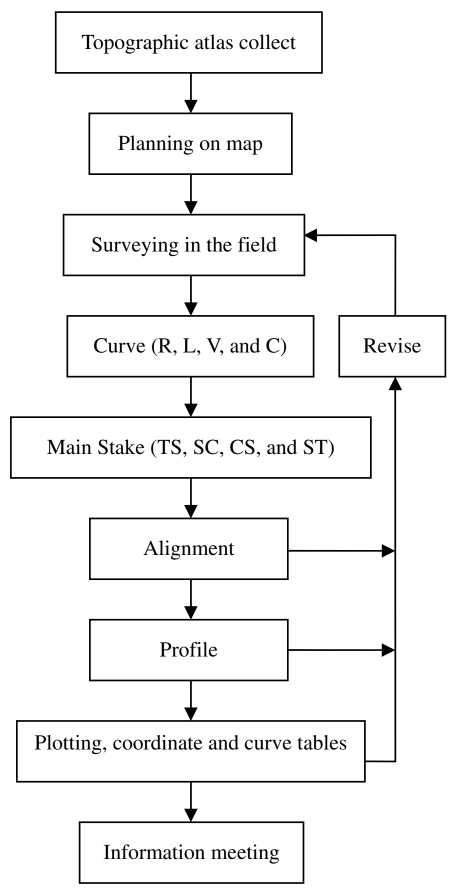

Fig. 1. Traditional alignment design flow chart

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Data Exchange Structure of BIM

BIM software can set up, update, integrate, exchange, and reuse building information in the life cycle of buildings. BIM utilizes information technology, object-oriented concepts, and professional engineer knowledge base to build the model. The model can satisfy the requirements of design, construction, and maintenance. Differing from traditional computer-aided systems, the data of points, lines, surfaces, and notes must be transformed into information manually. BIM can obtain information (e.g., window materials, size, and total quantity) from computerized interpretation in the model. The computerized interpretation can increase the functions of the system, shorten the period of the process, and improve the quantity of information.

To exchange information effectively at each stage, there must be an information exchange standard for BIM. Currently, the accepted standards of BIM are Standard for the Exchange of Product Model Data (STEP), Industry Foundation Classes (IFC), and CIMSTEEL Integration Standards Release 2 (CIS/2). AutoCAD Civil 3D supports the IFC information exchange standard.

The IFC is an information exchange standard designed for the Architectural, Engineering, Construction and Facility Management (AEC/FM) industry. It is maintained by the International Alliance for Interoperability (IAI). It will enable various systems to establish building information by the same standard during the building's life cycle, and improve the exchangeability and reusability of information.

IFC is based on STEP and is an object-oriented information exchange standard. The structure of IFC is divided into four layers from bottom to top; they are resource layer, core layer, interoperability layer, and domain layer. Each layer defines different classes of data type and entity, and only the class of the same layer or the lower layer can be inherited (Fan 2006).

Alignment Design Using BIM

Differing from traditional alignment design, BIM using criteria-based alignment design can create the local standards in a custom design criteria file beforehand. For example, the minimum radius of a curve at a given design speed, the superelevation attainment method, the superelevation rate at a given radius, and minimum transition length at a given radius can be contained in the design criteria file. When a designer plans the alignment, proper parameters are automatically suggested. Thus, the designer can select the suggestions of the system or type in any specific value, so as to ensure that the design values meet the local design standards. AutoCad Civil 3D with the support of BIM has the following characteristics.

Parameterized Entities

BIM classifies parameterized entities into three types: fixed entity, floating entity, and free entity.

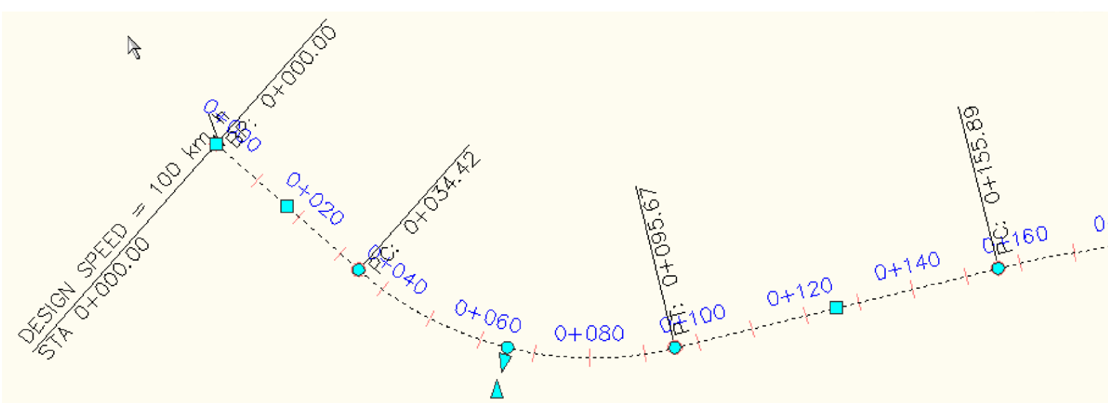
1. The position of the fixed entity is defined by specific parameters, and the parameters can be modified by the designer only. Its topological relation or tangency would not change under the effect of other entities, but its length would vary with its adjacent entities.
2. The floating entity is tangential to its adjacent entity automatically, so its topological relation is defined by the tangency of the adjacent entity.
3. The free entity is tangential to its adjacent entities, so the topological relation of the free entity is defined by the adjacent entities.

The BIM maintains the tangency of alignment automatically by three types of parameterized intelligent entities, so the planner can pay more attention to other factors that influence the alignment. Take Fig. 2 as an example: regardless of how the planner modifies the alignment, PC and TC would be tangential to all straight entities automatically.

Automation Design Standard and Inspection

The method of BIM using criteria-based characteristic design ensures that the alignment design meets the local standards. For example, the designer can define the minimum design criteria of the alignment in a design criteria file beforehand. The design criteria file contains four design criteria as follows:

1. Minimum radius at a given speed
2. Superelevation attainment method
3. Superelevation rate at a design speed
4. Minimum transition length at a given radius



No.	Type	Constraint1	Constraint2	Length	Radius	Start Sta...	End Station	Chord length
1	Line	Fixed	Two points	34.417m		0+000.00m	0+034.42m	
2	Curve	Free	Radius	61.251m	63.606m	0+034.42m	0+095.67m	58.912m
3	Line	Fixed	Two points	60.227m		0+095.67m	0+155.89m	
4	Curve	Free	Radius	77.598m	200.000m	0+155.89m	0+233.49m	77.112m

Fig. 2. Schematic diagram of track alignment

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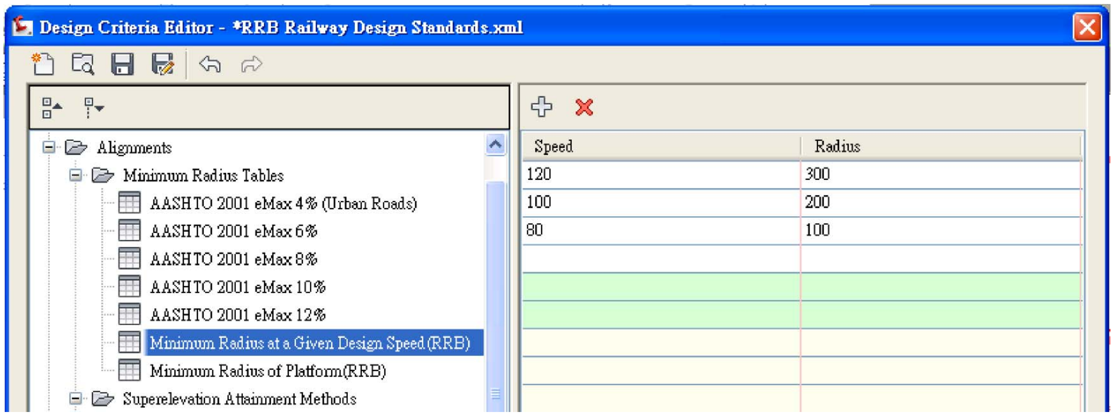

Fig. 3. Minimum radius at a given design speed (Taiwan Railway)

These four design criteria contain most of the alignment design criteria. While the other design criteria are not included in the design criteria file, the designer can create design checks in a design check set. The predefined design criteria and design check set are helpful in the automatic inspection of design achievements. For example, in Fig. 3, when the design speed is 120 km/h, the program would automatically check whether all the radii are larger than 300 m.

Application of Warning Symbol

When the design parameters of alignment entities violate the predefined design criteria or design check, the program would display warning symbols on both the drawing window and the alignment entities table to remind the designer that the alignment has failed to meet the design criteria. For example, Fig. 4 shows radius shortage and insufficient length of transition on both sides.

Link between Tables and Entities

BIM (IFC standard) is composed of many schemas, according to object-oriented concept that can be divided into four types. Following the reference and succession relations, a structure of four concept layers is formed. This strict ladder reference principle creates a dynamic link between tables and entities. When the designer modifies any parameter in the drawing window or data table, the entire real-time data model updates all related information. As shown in Fig. 5, when the curve radius changes, the curve length, alignment length, and main stake are updated automatically and immediately.

Multiple Data Updating Modes

The modification of the traditional alignment design needs to use a spreadsheet, alignment calculation program, and AutoCAD drawing step by step; the process is complicated and redundant. BIM makes the data updating more flexible and efficient because of the dynamic link between tables and entities. Take Fig. 6 as an example: the designer can update the radius in the data table directly and prove its position in the drawing window or modify the curve in the drawing window and make sure the radius meets the design criteria in the data table at the same time.

Dynamic Figure Modification

The BIM creates an alignment as a combination of parameterized intelligent entities. When any parameter in the alignment is edited, the changes are automatically reflected in any related entities and the topological relation is displayed on the drawing window immediately. Take Fig. 7 as an example: when the straight segment of the original route shifts for a distance, the curves ahead and

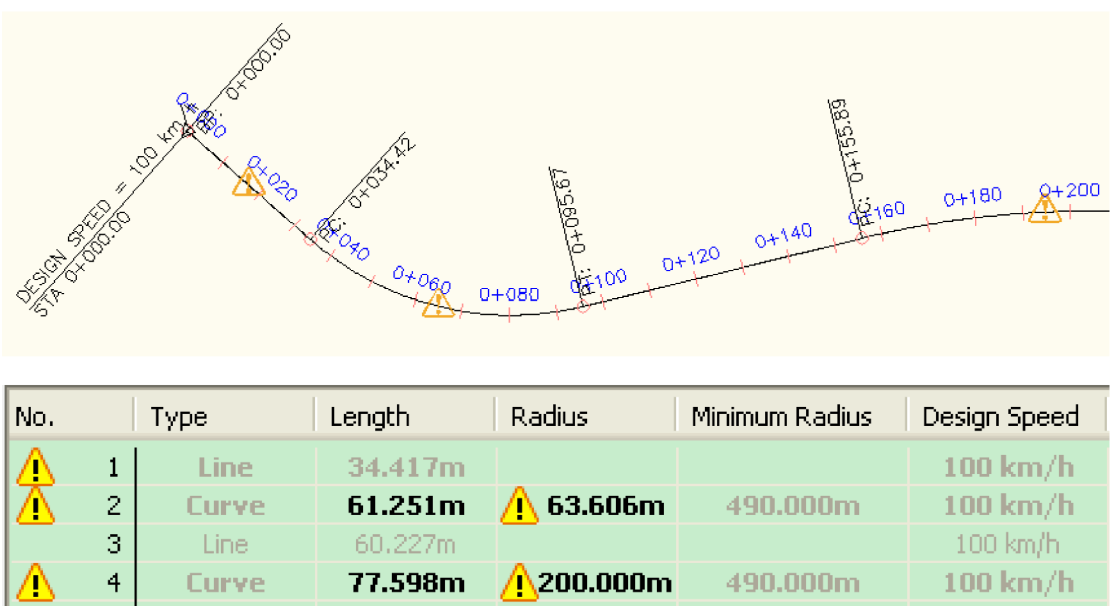

Fig. 4. Warning symbols of radius shortage and spiral length shortage

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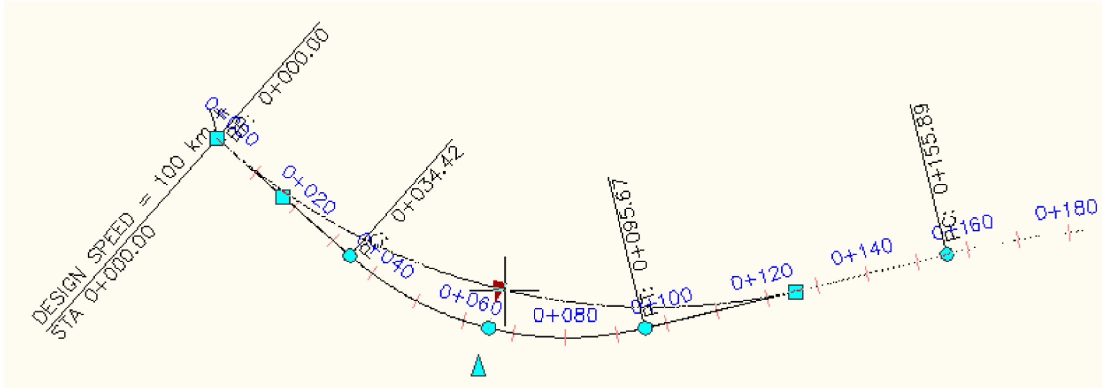
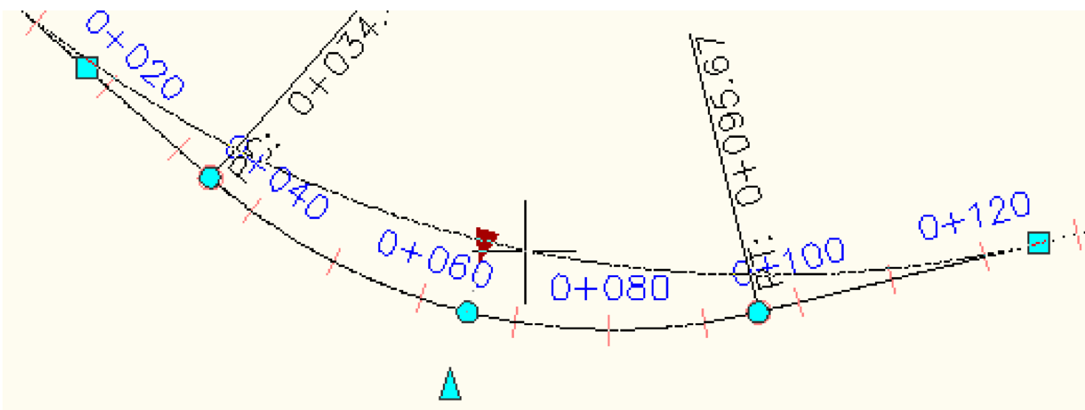


No.	Type	Constraint1	Constraint2	Length	Radius	Start Sta...	End Station
1	Line	Fixed	Two points	34.417m		0+000.00m	0+034.42m
2	Curve	Free	Radius	61.251m	63.606m	0+034.42m	0+095.67m
3	Line	Fixed	Two points	60.227m		0+095.67m	0+155.89m
4	Curve	Free	Radius	77.598m	200.000m	0+155.89m	0+233.49m

No.	Type	Constraint1	Constraint2	Length	Radius	Start Sta...	End Station
1	Line	Fixed	Two points	2.229m		0+000.00m	0+002.23m
2	Curve	Free	Radius	120.575m	125.211m	0+002.23m	0+122.80m
3	Line	Fixed	Two points	28.038m		0+122.80m	0+150.84m
4	Curve	Free	Radius	77.598m	200.000m	0+150.84m	0+228.44m

Fig. 5. Schematic diagram of dynamic link between tables and entities



No.	Type	Constraint1	Constraint2	Length	Radius	Start Sta...	End Station
1	Line	Fixed	Two points	34.417m		0+000.00m	0+034.42m
2	Curve	Free	Radius	61.251m	63.606m	0+034.42m	0+095.67m
3	Line	Fixed	Two points	60.227m		0+095.67m	0+155.89m
4	Curve	Free	Radius	77.598m	200.000m	0+155.89m	0+233.49m

Fig. 6. Schematic diagram of multiple data updating

behind adjust the curve lengths automatically and maintain tangency to the straight line. The original route is indicated by a dotted line, and the changed route is indicated by a solid line. It is easy for the designer to identify the effects of modification from the drawing window.

Comparison between Traditional and BIM Method

The traditional alignment design adopts a mathematical method and spreadsheet or program language to calculate alignment coordinates. Then, the alignment is displayed in the mapping software.

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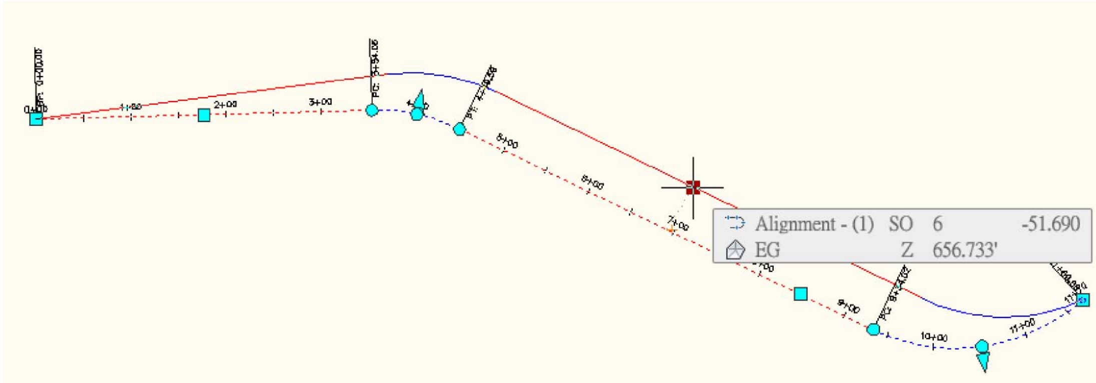

Fig. 7. Schematic diagram of dynamic figure modification

Finally, the topological relations are proved manually. The same process is repeated until the alignment meets the design criteria; strictly speaking, the traditional alignment design is only a computer-aided mapping system. The BIM method defines the alignment calculation as a background operation; the designer only needs to create design criteria and set up relevant entity parameters, and the system will automatically generate the alignment conforming to the local standard. The system does real-time calculations and updates any modification so that the designer only focuses on the selection of design factors. This is a true computer-aided design system. The differences between BIM and traditional design systems are presented in Table 2.

Table 2. Comparison between Traditional and BIM Track Design

Characteristics	Traditional	BIM
Precise alignment	Precise	Precise
Computer-aided mapping	Yes	Yes
Computer-aided design	No	Yes
Automatic inspection of design criteria	No	Yes
Dynamic link of data	No	Yes
Object-oriented concept	No	Yes
Parameterized entity	No	Yes
Design period	Long	Short

Precision Analysis

According to the east/west line of Qidu Switchyard of Taiwan, the BIM tool has been validated against usual practices. The results obtained are presented in Tables 3 and 4. The studied track was about 14.5 km, including 28 curve entities. A cubic parabola spiral was set between the curve entity and the straight entity. The track lengths, the mileages of the main stakes, and the full stakes coordinates per 10 m were compared as follows:

1. The total length of the east main track was 7 km + 200.923 m as calculated by the traditional alignment method, and the total length was 7 km + 200.925 m by the BIM alignment method. The bias between them was 2 mm. The total length of the west main track was 7 km + 297.191 m as calculated by the traditional alignment method, and the total length was 7 km + 297.190 m by the BIM alignment method. The bias between them was 1 mm.
2. Table 3 shows the biases among 14 curve sections of the east main track. The mean bias in the mileage of TS and ST points was only 2 to 3 mm; the maximum bias was 14 mm. Most of the biases were less than 3 mm, whereas the mean bias in the mileage of SC and CS points was 44 cm, and most of the biases were larger than 1 m.
3. Table 4 shows the biases among 14 curve sections of the west main track. Similar to the east main track, the mean bias in the

Table 3. Biases among Main Stakes Mileages of the East Main Track

	Point of tangent spiral (TS)			Point of spiral curve (SC)			Point of curve spiral (CS)			Point of spiral tangent (ST)			
No.	Traditional (m)	BIM (m)	Bias (m)	Traditional (m)	BIM (m)	Bias (m)	Traditional (m)	BIM (m)	Bias (m)	Traditional (m)	BIM (m)	Bias (m)	Radius (m)
1	4,385.856	4,385.857	−0.001	4,410.857	4,410.847	0.010	4,437.977	4,437.987	−0.010	4,462.977	4,462.977	0.000	800
2	4,527.632	4,527.639	−0.007	4,602.632	4,601.570	1.062	4,779.442	4,780.504	−1.062	4,854.442	4,854.435	0.007	400
3	5,132.158	5,132.158	0.000	5,192.158	5,192.072	0.086	5,260.681	5,260.767	−0.086	5,320.681	5,320.681	0.000	1,000
4	5,349.783	5,349.783	0.000	5,389.783	5,389.772	0.011	5,412.171	5,412.183	−0.012	5,452.171	5,452.171	0.000	1,500
5	5,707.944	5,707.944	0.000	5,747.944	5,747.933	0.011	5,832.727	5,832.739	−0.012	5,872.727	5,872.727	0.000	1,500
6	6,185.730	6,185.731	−0.001	6,255.730	6,255.405	0.325	6,282.572	6,282.897	−0.325	6,352.571	6,352.571	0.000	650
7	6,668.831	6,668.832	−0.001	6,728.831	6,728.481	0.350	7,132.610	7,132.961	−0.351	7,192.610	7,192.610	0.000	497
8	7,321.820	7,321.828	−0.008	7,381.820	7,380.853	0.967	7,463.931	7,464.899	−0.968	7,523.931	7,523.924	0.007	300
9	7,861.125	7,861.129	−0.004	7,911.125	7,910.567	0.558	7,994.272	7,994.831	−0.559	8,044.272	8,044.270	0.002	300
10	8,087.031	8,087.032	−0.001	8,127.031	8,126.913	0.118	8,221.127	8,221.246	−0.119	8,261.127	8,261.128	−0.001	465
11	8,438.209	8,438.210	−0.001	8,478.209	8,478.185	0.024	8,545.333	8,545.359	−0.026	8,585.333	8,585.334	−0.001	1,000
12	8,848.130	8,848.144	−0.014	8,928.130	8,926.662	1.468	9,110.093	9,111.564	−1.471	9,190.093	9,190.082	0.011	375
13	9,809.829	9,809.830	−0.001	9,874.829	9,874.778	0.051	9,904.616	9,904.670	−0.054	9,969.616	9,969.618	−0.002	1,450
14	10,452.427	10,452.435	−0.008	10,552.427	10,551.312	1.115	11,010.466	11,011.585	−1.119	11,110.466	11,110.462	0.004	600
Mean bias			−0.003			0.440			−0.441			0.002	

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Table 4. Biases among Main Stakes Mileages of the West Main Track

	Point of Tangent Spiral (TS)			Point of Spiral Curve (SC)			Point of Curve Spiral (CS)			Point of Spiral Tangent (ST)			
No.	Traditional (m)	BIM (m)	Bias (m)	Traditional (m)	BIM (m)	Bias (m)	Traditional (m)	BIM (m)	Bias (m)	Traditional (m)	BIM (m)	Bias (m)	Radius (m)
1	4,364.072	4,364.072	0.000	4,404.072	4,404.047	0.025	4,445.880	4,445.906	−0.026	4,485.880	4,485.880	0.000	1,000
2	4,523.503	4,523.513	−0.010	4,603.503	4,602.213	1.290	4,775.155	4,776.446	−1.291	4,855.155	4,855.146	0.009	400
3	5,129.378	5,129.379	−0.001	5,189.378	5,189.292	0.086	5,257.901	5,257.988	−0.087	5,317.901	5,317.901	0.000	1,000
4	5,347.177	5,347.178	−0.001	5,387.177	5,387.166	0.011	5,409.565	5,409.577	−0.012	5,449.565	5,449.566	−0.001	1,500
5	5,705.088	5,705.089	−0.001	5,745.088	5,745.077	0.011	5,829.872	5,829.884	−0.012	5,869.872	5,869.872	0.000	1,500
6	6,177.031	6,177.033	−0.002	6,247.031	6,246.707	0.324	6,273.873	6,274.199	−0.326	6,343.873	6,343.873	0.000	650
7	6,644.472	6,644.483	−0.011	6,744.472	6,742.877	1.595	7,131.079	7,131.421	−0.342	7,191.079	7,191.078	0.001	502
8	7,322.243	7,322.252	−0.009	7,382.243	7,381.277	0.966	7,463.344	7,464.314	−0.970	7,523.344	7,523.338	0.006	300
9	7,858.086	7,858.090	−0.004	7,908.086	7,907.529	0.557	7,991.232	7,991.792	−0.560	8,041.232	8,041.231	0.001	300
10	8,082.779	8,082.780	−0.001	8,122.779	8,122.662	0.117	8,216.875	8,216.995	−0.120	8,256.875	8,256.876	−0.001	465
11	8,437.872	8,437.874	−0.002	8,472.872	8,472.855	0.017	8,540.715	8,540.735	−0.020	8,575.715	8,575.716	−0.001	960
12	8,841.872	8,841.887	−0.015	8,921.872	8,920.404	1.468	9,103.836	9,105.307	−1.471	9,183.835	9,183.825	0.010	375
13	9,802.202	9,802.205	−0.003	9,867.202	9,867.152	0.050	9,896.990	9,897.044	−0.054	9,961.990	9,961.992	−0.002	1,450
14	10,449.120	10,449.126	−0.006	10,539.120	10,538.322	0.798	11,012.031	11,012.834	−0.803	11,102.031	11,102.030	0.001	605
Mean bias (m)			−0.005			0.522			−0.435			0.002	

mileage of TS and ST points was about 2 to 5 mm, the maximum bias was 15 mm, and most of the biases were less than 3 mm. The mean bias in the mileage of SC and CS points was about 50 cm, and most of the biases were greater than 1 m.

4. The comparison results of the biases of northing (N) and easting (E) coordinates of the full stakes per 300 m in the east main track are shown in Table 5. The mean N and E coordinate bias of the east main track were 0.1 and 0.8 mm, and the maximum N and E coordinate biases were 1.7 and 1.8 mm, respectively. The mean N and E coordinate biases of the west main track were 0.3 and 1.2 mm, and the maximum N and E coordinate biases were 4.2 and 6.1 mm, respectively.

The comparison between traditional and BIM methods showed that the topographical relations, coordinates, and total length of

Table 5. The East Main Track

	Traditional			BIM		
Station (m)	Northing (m)	Easting (m)	Direction	Northing (m)	Easting (m)	Direction
4 + 300.000	2,777,697.83520	322,345.19097	N 193 41′ 46″	2,777,697.83520	322,345.19097	N 193 41′ 46″
4 + 600.000	2,777,410.10722	322,261.11799	N 202 28′ 54″	2,777,410.10700	322,261.11860	N 202 28′ 51″
4 + 900.000	2,777,191.52481	322,062.64697	N 233 36′ 07″	2,777,191.52503	322,062.64728	N 233 36′ 07″
5 + 200.000	2,777,012.81505	321,821.69552	N 231 25′ 55″	2,777,012.81528	321,821.69582	N 231 25′ 55″
5 + 500.000	2,776,811.49324	321,599.39032	N 228 37′ 05″	2,776,811.49349	321,599.39060	N 228 37′ 05″
5 + 800.000	2,776,614.52083	321,373.14196	N 231 22′ 14″	2,776,614.52107	321,373.14225	N 231 22′ 14″
6 + 100.000	2,776,434.81618	321,132.93248	N 233 23′ 05″	2,776,434.81640	321,132.93278	N 233 23′ 05″
6 + 400.000	2,776,272.25991	320,881.50717	N 241 56′ 25″	2,776,272.26009	320,881.50750	N 241 56′ 25″
6 + 700.000	2,776,130.99275	320,616.85056	N 241 00′ 09″	2,776,130.99295	320,616.85089	N 241 00′ 09″
7 + 000.000	2,775,920.19110	320,409.75129	N 207 14′ 31″	2,775,920.19150	320,409.75142	N 207 14′ 31″
7 + 300.000	2,775,630.28875	320,339.44644	N 188 30′ 03″	2,775,630.28918	320,339.44650	N 188 30′ 03″
7 + 600.000	2,775,362.36590	320,216.66225	N 215 46′ 05″	2,775,362.36648	320,216.66267	N 215 46′ 05″
7 + 900.000	2,775,119.34230	320,040.78183	N 218 40′ 59″	2,775,119.34277	320,040.78240	N 218 40′ 57″
8 + 200.000	2,774,964.31976	319,787.92283	N 252 43′ 46″	2,774,964.32000	319,787.92361	N 252 43′ 46″
8 + 500.000	2,774,898.10732	319,495.37557	N 255 24′ 25″	2,774,898.10752	319,495.37636	N 255 24′ 25″
8 + 800.000	2,774,805.83000	319,209.96063	N 251 39′ 47″	2,774,805.83025	319,209.96140	N 251 39′ 47″
9 + 100.000	2,774,771.20828	318,917.17241	N 284 06′ 40″	2,774,771.20655	318,917.17357	N 284 06′ 39″
9 + 400.000	2,774,878.94165	318,637.33429	N 291 50′ 29″	2,774,878.94104	318,637.33582	N 291 50′ 29″
9 + 700.000	2,774,990.55349	318,358.86921	N 291 50′ 29″	2,774,990.55287	318,358.87075	N 291 50′ 29″
10 + 000.000	2,775,095.40273	318,077.90366	N 288 05′ 41″	2,775,095.40186	318,077.90523	N 288 05′ 41″
10 + 300.000	2,775,188.57844	317,792.74061	N 288 05′ 41″	2,775,188.57793	317,792.74174	N 288 05′ 41″
10 + 600.000	2,775,273.37736	317,505.30872	N 278 44′ 28″	2,775,273.37763	317,505.31050	N 278 44′ 28″
10 + 900.000	2,775,244.49438	317,209.83227	N 250 05′ 35″	2,775,244.49557	317,209.83396	N 250 05′ 36″
11 + 200.000	2,775,090.45626	316,953.69437	N 234 44′ 01″	2,775,090.45749	316,953.69609	N 234 44′ 01″
11 + 500.000	2,774,917.24293	316,708.75123	N 234 44′ 01″	2,774,917.24415	316,708.75296	N 234 44′ 01″
11 + 600.925	2,774,858.97217	316,626.34982	N 234 44′ 01″	2,774,858.97230	316,626.35000	N 234 44′ 01″

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alignment were consistent, but the start and end of curves were different.

According to the data of the east and west main tracks of the Qidu Switchyard of Taiwan Railway Administration, there was no geometric bias between alignments calculated using the traditional and BIM methods; but the mileages of SC and CS had biases greater than 1 m. The typical cubic parabola spiral equation is written as Eq. (1) (Deng 1991)

$$y = \frac{x^3}{6A^2} \tag{1}$$

These two alignment methods adopted the same equation for the calculation of coordinates; therefore, the two alignment methods had consistent topographic relationships under the same curvature rate (A).

The curvature rate of the traditional alignment method was defined as Eq. (2),

$$A = \sqrt{R * X * (1 + \tan \theta^2)^{\frac{3}{2}}} \tag{2}$$

in which θ = angle of tangent. The curvature rate of the BIM alignment method was defined as Eq. (3):

$$A = \sqrt{R * L} \tag{3}$$

in which L = length of spiral.

The two alignment methods had different definitions of curvature rate (A), which caused the difference in spiral lengths. When the radius (R) is large ($X \approx L$), the mileage biases between SC and CS would only be several centimeters. When the radius (R) is small ($X \neq L$), there will be large biases between SC and CS mileages. Tables 3 and 4 indicate that if the curvature radius is small, the bias between SC and CS mileages will be large.

To simplify the calculation, the BIM alignment method assumed that the length of the spiral was indicated by its projection on X-axis. The assumption was reasonable only when the radius of the curve was greater than 1,000 m. The mileage bias in curves was about 1 m if the radius was less than 500 m, but the topological relation of alignment was not affected.

Conclusion

A total of 29 km were examined. The bias of total length between the two alignment methods was 2 mm, and the maximum bias of coordinates for each 10 m full stakes (including the curve segment) was only 2 mm, too. These findings show that the precision of the traditional alignment method was identical to that of the BIM alignment method. But the biases in mileages of SC and CS in the curve segment were relatively larger, mostly greater than 1 m. The reason for these biases in mileage was the curvature rate (A). Under the same curvature rate, the cubic parabola spiral lengths calculated by the two alignment methods resulted in the mileage difference.

BIM used parameterized intelligent entities to adjust topographic relations automatically. In the traditional alignment design, all alignment entities were independent of one another; hence, the topographic relations among entities should be reviewed and recalculated individually for any modification. On the other hand, BIM shortened the time for alignment modification and adjustment effectively, so that the realignment becomes easier, and the requirements for change order are reduced.

Because BIM utilized a criteria-based characteristic design and a design check and warning symbols, the automatic design criteria inspection of track alignment became feasible. The errors in artificial interpretation could be avoided, and the track-alignment design could be accelerated.

Multiple data updating and dynamic figure modification helped the designer modify alignment on the drawing window directly, so that the overall design could be reviewed simultaneously. The result of modification on the field could be evaluated immediately, and the track alignment could closely coincide with actual needs.

AutoCAD Civil 3D applied BIM to alignment design, focused on the alignment design of highways. The built-in alignment design criterion was the AASHTO green book for highways (2001). If the track design criteria and relevant parameterized entities could be constructed, such as turnouts, fastenings, elastic mat, sleepers, and road bed types, the application of BIM to the alignment design of tracks could be accelerated.

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