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Use of Civil 3D and InfraWorks for Optimising Highway Design

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Abstract
The geometric design of road networks is a vital aspect of sustainable transportation infrastructure, influencing safety, efficiency, and overall user experience. This study presents the geometric design and visualization of the Al Dhaid road, Sharjah, U.A.E., following the Geometric Design Manual of Roads (GDM) for Dubai. The work demonstrates how Autodesk Civil 3D and InfraWorks can be used together to achieve design precision, model visualization, and enhanced multidisciplinary collaboration in large-scale highway projects. The methodology covers horizontal and vertical alignment creation, design-speed selection, minimum curve-radius computation, superelevation, transition lengths, and stopping sight distance (SSD), in accordance with GDM Chapter 4. Typical cross-sections, interchange configurations, and corridor modelling were developed in Civil 3D, after which the model was imported into InfraWorks for visualization, clash detection, and drive-through simulation. Results show that the integrated BIM-based workflow improves geometric consistency, reduces earthwork through alignment optimization, and enhances stakeholder communication compared with conventional two-dimensional drafting methods.
Keywords: *Civil 3D, InfraWorks, highway geometric design, BIM, corridor modelling, superelevation, sight distance, GDM Dubai, alignment optimization*

I. Introduction

The integration of Autodesk Civil 3D and InfraWorks has redefined contemporary highway design practice. InfraWorks accelerates BIM-centric conceptual design and stakeholder engagement, while Civil 3D delivers the precision, parametric control, and documentation required for detailed design and construction. Combined with optimization concepts such as genetic algorithms and particle-swarm variants, this toolset enables data-driven route selection, earthwork minimization, and safety-centric profile refinement.

InfraWorks is a conceptual planning tool that combines GIS data, terrain models, satellite imagery, and survey data to build intelligent 3-D context models for feasibility studies and master planning. Civil 3D, in contrast, is a detailed engineering and documentation platform built on a dynamic, model-based environment in which alignments, profiles, corridors, surfaces, and pipe networks are interrelated, so that any modification automatically propagates through the model.

A. Challenges in Conventional Highway Design

Conventional highway design relies on manual calculations, two-dimensional drafting, and separated workflows for alignment, profile, and cross-section design. This approach is time-consuming when design changes occur, provides limited visualization of terrain interaction, complicates alignment optimization, and increases the likelihood of human error in chainage, superelevation, and quantity estimation. Coordination among disciplines such as drainage, structures, and utilities is also difficult when each uses separate data sources, often resulting in design conflicts that are discovered only at construction stage.

B. Aim and Objectives

The aim of this study is to demonstrate how Autodesk Civil 3D and InfraWorks can be used together to optimize highway geometric design, improve terrain analysis, and enhance visualization. The specific objectives include studying the limitations of conventional design methods, applying Civil 3D for corridor development and quantity estimation, applying InfraWorks for conceptual planning and visualization, and comparing the digital workflow with traditional drafting in terms of accuracy, efficiency, and coordination.

C. Scope and Limitations

The scope of the study is limited to geometric design, corridor modelling, and visualization of the Al Dhaid road corridor. Detailed structural design of bridges, pavement material design, traffic-signal design, and hydrological analysis are outside the scope. The accuracy of the outputs depends on the quality of the survey data used, and findings are based on a single case-study corridor in Sharjah, U.A.E., so conclusions may not generalize to all highway project types.

II. Literature Review

Transportation infrastructure is a key driver of economic growth, and highway networks support passenger movement, freight transport, and regional connectivity. Traditional planning relied on manual surveying, 2-D drafting, and empirical calculations, which often produced lengthy design cycles, coordination difficulties, and limited visualization. The advancement of Building Information Modelling (BIM) and three-dimensional simulation has transformed highway engineering by enabling intelligent terrain models, multiple alignment alternatives, and traffic and geometric analysis within a unified digital environment.

A. Design Speed

Design speed is the controlling parameter for curve radius, sight distance, superelevation, and gradient. The minimum horizontal curve radius is given by $R = V^2/127(e+f)$, where R is the curve radius in metres, V is the design speed in km/h, e is the superelevation rate, and f is the side-friction coefficient. The Dubai GDM classifies roads into freeway, arterial, collector, and local categories, with recommended design speeds ranging from 30–50 km/h for local streets up to 100–120 km/h for urban freeways.

B. Sight Distance

Stopping sight distance (SSD) is computed as $SSD = 0.278Vt + V^2/254f$, combining the lag distance travelled during driver reaction time and the braking distance. Overtaking sight distance (OSD), intermediate sight distance (ISD), and decision sight distance are additional criteria applied at intersections, interchanges, and two-lane sections.

C. Horizontal and Vertical Alignment

Horizontal alignment consists of tangents, circular curves, and transition curves, with curve radius governed by design speed, superelevation, and side friction. Vertical alignment comprises gradients, summit curves, and valley curves; summit curves are governed mainly by sight distance, while valley curves consider driver comfort, headlight sight distance, and drainage.

D. Superelevation

Superelevation counteracts centrifugal force on curved paths and is expressed as $e + f = V^2/127R$. Adequate superelevation improves vehicle stability and driver comfort, while improper design can cause drainage problems and unsafe operation.

E. Cross-Sectional Elements

Cross-sectional elements include carriageway width, shoulders, medians, kerbs, footpaths, cycle tracks, and side drains. These elements are dimensioned according to traffic volume, vehicle type, and roadway classification, and significantly affect safety, capacity, and maintenance requirements.

F. Importance of Geometric Design Optimization

Optimization aims to minimize earthwork, reduce construction cost, balance cut and fill, and improve traffic safety. Digital platforms allow engineers to generate multiple alignment alternatives, analyse terrain interaction, estimate earthwork, and evaluate traffic operations within a BIM-based workflow, improving accuracy and reducing design conflicts compared with conventional methods.

III. Study Area and Data Collection

The project is located at Al Dhaid, Emirate of Sharjah, U.A.E. The scope of work comprises a grade separator over a proposed lagoon and a ring road around the lagoon site, including service roads, on-street parking, cycle tracks, and sidewalks. This study focuses on optimizing the design of the main road with the grade separator connecting to Al Dhaid Municipality.

A. Topography and Road Classification

Topographic survey data was collected and used directly for design. The road network was classified into primary arterial, secondary arterial, and collector categories, with rights-of-way varying from 18.29 m to 110 m depending on hierarchy.

B. Design Criteria

Design criteria were derived from the Geometric Design Manual for Dubai Roads (GDM, 2017 edition), AASHTO Geometric Design of Highways and Streets (6th edition, 2011), and associated RTA manuals for traffic control devices, access management, and pedestrian/cyclist facilities. The design speed for the grade separator/bridge was set at 110 km/h, ramps at 50 km/h, and the lagoon outer/connecting roads at 40 km/h. Passenger car, single-unit truck, and WB-15 semi-trailer were adopted as design vehicles. Lane width was fixed at 3.65 m per lane, with a 5 m service-road lane width. Minimum gradients of 0.337% (bridge) and 0.2% (other roads) were applied, with a maximum gradient of 3.02% on the main bridge and 6.00% on the truck-entry ramp. Crest and sag vertical-curve K-values were taken from both GDM and AASHTO tables for design speeds between 40 and 110 km/h.

C. Software and Hardware Requirements

The study used Autodesk InfraWorks for conceptual planning, terrain modelling, and visualization; Autodesk Civil 3D for detailed geometric design, corridor modelling, and quantity estimation; Autodesk Navisworks for 3-D review and clash detection; AutoCAD for drawing preparation; and Google Earth Pro for satellite imagery and preliminary route assessment. High-performance computing resources were required to handle large terrain datasets, corridor models, and rendering workloads.

IV. Methodology and Modelling

The overall workflow began with selection of the project corridor, followed by collection of topographic, survey, traffic, and imagery data. This data was imported into InfraWorks to create the existing terrain model, after which a preliminary highway alignment was developed. Design parameters such as design speed, lane width, gradient, curve radius, and superelevation were defined, multiple design alternatives were generated, and each was evaluated through traffic and geometric analysis. Optimization targeted reduced earthwork, improved safety, minimized construction cost, and enhanced traffic efficiency. The preferred alternative was visualized and simulated in InfraWorks before being exported to Civil 3D for detailed design and preparation of final drawings and reports.

A. Terrain Modelling in InfraWorks

Survey points and figures were imported into Civil 3D to generate a Triangulated Irregular Network (TIN) surface saved as the Existing Ground (EG) surface. The surface was reviewed for inconsistent data prior to import into InfraWorks. In InfraWorks, a model was created using Model Builder for project areas under 200 km², or via the New Model dialog for larger areas, with the coordinate system set to UTM WGS84 Zone 40N and the AASHTO_Metric_2011 design kit applied. The Civil 3D surface was then exported in IMX format and imported into InfraWorks to generate the terrain model, which was reviewed for elevation, contour, and slope accuracy before aerial imagery and GIS context layers were applied.

B. Preliminary Corridor Development

Existing site conditions were studied using the terrain model, satellite imagery, and survey information to identify steep slopes, drainage paths, existing roads, and utility corridors. Two alternative alignments were developed: the first prioritized full geometric standards and two-level interchanges while minimizing land acquisition; the second followed natural contours to reduce earthwork at the cost of a slightly longer route. Preliminary geometric parameters, terrain interaction, and earthwork were assessed for each alternative, and three-dimensional visualization and drive-through review supported a comparative evaluation based on alignment length, earthwork, terrain compatibility, constructability, and compliance with GDM standards. The alignment offering the best balance of safety, constructability, and cost was selected for detailed design.

V. Highway Design and Modelling in Civil 3D

Detailed design began with project setup, including templates, coordinate systems, and design standards. The Existing Ground surface was generated from survey points as a TIN surface and validated by removing irregular triangles and spikes. The horizontal alignment was refined using tangents, circular curves, and transition curves in compliance with design speed, minimum curve radius, and sight-distance requirements. The vertical alignment was then developed from the EG surface, incorporating vertical curves for smooth grade transitions while satisfying drainage and gradient constraints.

Roadway assemblies representing the carriageway, shoulders, median, kerbs, and side slopes were created and combined with the alignment and profile to generate the three-dimensional corridor model. A proposed finished-ground surface was then extracted from the corridor, and cross-sections were generated at regular intervals to verify roadway geometry and cut-and-fill requirements. Earthwork was estimated by comparing the Existing Ground and Proposed Finished Ground surfaces, and the alignment or profile was iteratively refined wherever excessive cut or fill was identified. Final outputs included plan and profile drawings, cross-sections, corridor and surface models, and earthwork reports.

VI. Visualization and Analysis

The completed Civil 3D corridor model was exported into InfraWorks and integrated with the terrain, imagery, and existing infrastructure to produce a realistic three-dimensional representation of the proposed highway, including pavement structure, embankments, cut slopes, and bridge and drainage locations. Rendering techniques, including surface materials, markings, vegetation, and lighting, were applied to verify that the design blended naturally with the surrounding landscape.

Drive-through simulation enabled assessment of horizontal and vertical alignment smoothness, driver visibility around curves, grade transitions, and overall driving comfort from a road-user perspective. Three-dimensional review also identified design conflicts not readily apparent in 2-D drawings, such as excessive cut/fill sections, abrupt slope transitions, drainage issues, and conflicts with existing roads, allowing corrective measures to be applied before finalizing construction drawings.

A. Comparative Analysis

Compared with conventional drafting, in which plans, profiles, cross-sections, and quantities are prepared independently and require manual updates across multiple drawings, the integrated Civil 3D–InfraWorks workflow keeps all design elements dynamically linked, so that any modification automatically propagates throughout the model. This reduced manual effort, improved coordination, and enabled more efficient evaluation of design alternatives, while three-dimensional visualization enhanced both design verification and stakeholder communication.

VII. Conclusion and Future Scope

This study demonstrated the application of Autodesk Civil 3D and Autodesk InfraWorks for the planning, design, modelling, and visualization of the Al Dhaid road corridor in Sharjah, U.A.E. The integrated BIM-based workflow improved alignment selection through evaluation of multiple corridor alternatives, supported earthwork optimization through iterative comparison of existing and proposed surfaces, and enhanced design verification and stakeholder communication through three-dimensional visualization and drive-through simulation. Compared with conventional two-dimensional drafting, the digital workflow reduced manual effort, improved coordination between design elements, and enabled more efficient identification of design conflicts.

The study was limited to geometric design and visualization; structural design, traffic-capacity analysis, and construction-stage planning were outside its scope, and outputs depended on the resolution of available survey data. Future work may integrate traffic simulation software to evaluate operational performance, incorporate LiDAR or drone survey data to improve terrain accuracy, apply artificial-intelligence techniques for automated alignment optimization and earthwork balancing, and explore Digital Twin and cloud-based BIM collaboration platforms for long-term infrastructure management. The methodology developed here can also be extended to larger and more complex projects such as expressways, urban road networks, and grade-separated interchanges.

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