

# Integrating Production Planning into Road Corridor Evaluation Using ETL

Jan Krantz<sup>1</sup>, Tim Johansson<sup>2</sup>

1) Ph.D. Candidate, Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, Luleå, Sweden. Email: [jan.krantz@ltu.se](mailto:jan.krantz@ltu.se)

2) Ph.D. Candidate, Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, Luleå, Sweden. Email: [tim.johansson@ltu.se](mailto:tim.johansson@ltu.se)

## Abstract:

Complex road projects, particularly near sensitive locations, often have substantial effects on humans and the environment caused by construction, production processes and the use phase. Before a road alignment is determined, several road corridors are identified and evaluated during early planning stages. Oftentimes this evaluation focuses on impacts of the finished road whereas construction and production processes frequently are ignored, risking viable corridors to be discarded before having been sufficiently evaluated. Existing IT-systems enables modeling of relevant aspects such as road corridors, noise, pollution, production and construction, but there is often a lack of interoperability between these systems. Interoperability problems can be faced with Extract Transform Load (ETL) tools but this has not been adequately examined regarding infrastructure projects. Our study presents a novel method for evaluating road corridors that includes production aspects, which are visualized and analyzed in 3D. By using ETL technology to handle interoperability problems, existing tools for road corridor planning, production planning and 3D visualization are used to demonstrate the method. The findings indicate that large scale production aspects related to road corridors can be modeled, analyzed and visualized in 3D, which can benefit stakeholders in making decisions.

**Keywords:** Buildability, 3D visualization, Mass-haul optimization, Line-of-balance

## 1. INTRODUCTION

During construction as well as during the usage phase, roads cause significant impact on humans and the environment. Road infrastructure is, among other things, a main cause for degradation of natural habitat (Geneletti, 2003), greenhouse gas (GHG) emissions (Cass & Mukherjee, 2011), health detrimental noise (Bodin et al., 2009) and air pollution (Hoek et al., 2002). It is critical that these types of impacts are carefully evaluated already during the planning stage (Rebolj, 1998). If sufficient attention is given to these types of aspects and constraints, the project can reduce its harmful impacts (Loro et al., 2014). Moreover, if conducted early on in the project, the resulting benefit can be orders of magnitude greater than if conducted later (Paulson, 1976).

Road corridors, which represent rough locations of road alignments, are typically identified and analyzed in early planning stages of road projects. This can often be a costly and time consuming process (Kim et al., 2014). One method for this is the least-cost path analysis (LCPA) algorithm which is used for finding the “cheapest way” to connect two points on a so called “cost surface” which is often defined as a raster (Bagli et al., 2011). Each point in the cost surface is valued based several criteria. While the perceived importance of each criterion directly affects the location of the road corridor, the relative importance of each criterion needs to be determined. This is a procedure that can be conducted through a Multi Criteria Analysis (MCA) (Atkinson et al., 2005). Two dimensional Geographic Information Systems (GIS) are commonly used for these types of computations (Collischonn & Pilar, 2000; Yu et al., 2003) and has widespread use in urban planning and environmental decision making (Yu et al., 2012). Some types of data and criterion are better visualized and analyzed in 3D (Brooks & Whalley, 2008), thus cost surfaces will not fully reflect the effects. For instance noise propagation to certain locations depends on their distances from the source (Easa et al., 2002) and air pollution concentrations, which can be predicted in 3D (Sarasua et al., 2000). Many analysis tools exist as isolated systems (Easa et al., 2002), hence, to combine several systems of this sort, achieving interoperability can be a major challenge (Karabegovic & Ponjavic, 2010). In the Architecture, Engineering and Construction (AEC) industry, ETL has been used to solve interoperability problems (Grilo & Jardim-Goncalves, 2010). ETL tools are particularly suitable for integrating data models (Cerovsek, 2011) and can aid the creation of a seamless information flow to support design and construction in infrastructure projects (Karan & Irizarry, 2015; Gökçe & Gökçe, 2014).

After a road corridor has been selected, its alignment and design is planned in greater detail, commonly by using 3D-based geometric design tools (Easa et al., 2002). Buildability aspects, which tries to ensure smooth and efficient construction and production processes (Pheng & Abeyegoonasekera, 2001), are generally considered just prior to, and throughout the construction phase. Mass haul optimization and time-location scheduling, which both can improve buildability, have been integrated into commercial software such as TILOS and DynaRoad

(Shah & Dawood, 2011). Recent research by Kim et al. (2014) has connected road corridor evaluation in 3D with buildability of construction and production aspects such as earthworks quantities and project duration. However it does not account for borrow pits, disposal areas or material production plants, e.g. crushing plants, or the mass hauls between these, all of which can have severe environmental impacts and costs (Hajji & Lewis, 2013).

Our study provides an innovative method for integrating production planning and mass haul optimization with road corridor evaluation and 3D impact modeling and visualization. We present and demonstrate a framework which achieves this through the use of ETL technology and software used for road corridor planning, production planning and 3D visualization. The findings indicate that road corridor evaluation can be combined with production planning aspects that are visualized in 3D, which can provide stakeholders with more comprehensive knowledge for decision making.

## 2. METHODS

LCPA is the process of finding the least cost path through a rasterized cost surface using an algorithm that searches the cells with the lowest cost between a start and a finish cell (Bagli et al., 2011). This process can be applied on road construction to give an idea of low cost road alignments or corridors. However, roads are complex and require considerable earthworks and specific geometric properties. Therefore, our study uses a specific software for this purpose called Quantm (Trimble, 2012). Quantm uses vector based cost surfaces and accounts for mass balances, bridges, tunnels and specific geometric properties. Further details of costs and properties can be seen in Table 1.

Table 1. Costs and properties accounted for in our study.

Area costs	Volume costs	Fixed costs	Geometric properties
Used area	Template materials	Environmental consultants	Grade
Town	– <i>Pavement</i>	Traffic control	Horizontal curve radius
Nature reserve	– <i>Subgrade 1</i>		Vertical curve radius
Bridges	– <i>Subgrade 2</i>		– <i>Crest</i>
– <i>Cable stayed</i>	Earthworks		– <i>Sag</i>
– <i>Standard bridge</i>	– <i>Topsoil</i>		
– <i>Concrete arch structure</i>	– <i>Soil</i>		
Private properties	– <i>Broken rock</i>		
– <i>Clip distance</i>	– <i>Dump</i>		
– <i>Clip cost</i>	– <i>Borrow</i>		
– <i>Full cost</i>	– <i>Fill</i>		
	– <i>Haul / km</i>		

Cost and geometric properties are not sufficient for analyzing the buildability since it doesn't model construction, production, constraints, scheduling or mass hauls along the network of the road project, disposal areas and crushing plants. DynaRoad software, which specifically accounts for both mass hauls in a road project and scheduling, can be used to model these sorts of aspects (DynaRoad, 2015). Using a linear programming algorithm the software cost optimizes the mass hauls according to predefined hauling costs. Project managers often depend on the subjective decisions for resources allocation and progress monitoring from location aspects. This causes uncertainties in planning and scheduling which results in delays and cost overruns (Shah & Dawood, 2011). Location-based scheduling is therefore suitable to use to analyze buildability from a location standpoint. To schedule linear construction projects, such as roads, linear scheduling methods are useful (Liu & Wang, 2012). One such method called line-of-balance (LOB) is particularly useful in balancing operations so that construction is performed continuously (Arditi et al., 2002). DynaRoad software, which enable both LOB scheduling and traditional Gantt chart scheduling, was used in this study.

3D models are a valuable supplement to LOB as it provides quick and clear insight of the spatial configuration of building projects (Jongeling & Olofsson, 2007). By visualizing construction in 3D, stakeholders can increase their understanding of a project and thereby make better decisions (Kamat & Martinez, 2001). InfraWorks (Autodesk Inc., 2012) software was selected to model our project in 3D. However, interoperability between Quantm and DynaRoad to InfraWorks is weak, therefore an ETL software called Feature Manipulation Engine (FME) (Safe Software Inc., 2015) was used to mitigate this problem, but also to create additional data. ETL technology has also been applied in disciplines such as business intelligence to manage big sets of data sources in different data formats and models (Kimball & Caserta, 2004; Bimonte et al., 2014). ETL tools are generally

used for repeatable processes involving multiple heterogeneous data sources starting with data extraction, transforming the extracted data and finally loading the data in a given structure to a target application or database. This process corrects errant and missing data, provides documented measures of confidence in the data, captures the flow of transactional data for safekeeping, adapts data from multiple sources to be used together and structures data to be usable by end-user tools (Kimball & Caserta, 2004). Within this process, the extracted and imported data goes through a series of steps which transforms it from being heterogeneous in terms of semantics, constraints, formats, and coding into a homogenous result (Bédard & Han, 2009). The transformation steps include a variety of cleansing activities, filters, sorters, groupers, etc., organized in a work flow (Karagiannis et al., 2013).

### 3. RESULTS

#### 3.1 Framework

To include production aspects into the evaluation of road corridors, we propose a framework which can be seen in Figure 1. In the first step of implementing the framework a set of road corridors are determined and evaluated. This is done using cost surfaces and linear obstacles as well as basic earthworks costs associated with alignments that form the basis for the road corridor. In the next step each alignment is production planned and mass haul optimized. In this step crushing plants, asphalt plants, borrow pits, disposal areas and required hauling roads are included. Each alignment is scheduled using a line-of-balance scheduling method. This allows for more realistic data output and can furthermore aid in the discovery of possible constraints that can arise during construction and that can pose significant added costs. In the next step the production of each alignment is visualized in 3D. By including 3D visualization the effects of construction, such as noise, traffic disturbances, pollution etc. can be assessed and visualized for stakeholders to make their decisions. With the given knowledge, new corridors can be determined and analyzed, or existing corridors can be selected for further planning.

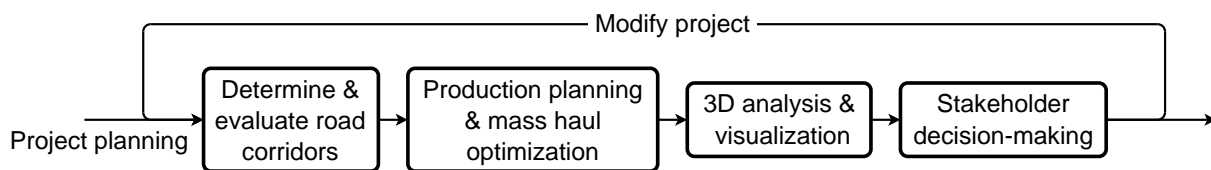


Figure 1. The proposed framework.

#### 3.2 Demonstration

To demonstrate the proposed framework it is applied on a road project around a generic town. The area contains hills, streams, a nature reserve, a railroad, and private properties etc. The road corridor planning is performed using Quantm software by Trimble (2012). In the software a Digital Terrain Model (DTM) is imported, start and finish locations are set, and cost parameters, such as surfaces and linear features, are defined. The alignments in the software can be automatically generated, manually inserted or imported. Figure 2 shows three road alignments, manually inserted, each representing a corridor. Beside the cost parameters for passage through surfaces and across linear features, each alignment has costs associated with earthworks (cut, fill and hauling), as well as fixed costs. Given the standard cost and geometric properties in Quantm, Alignment 1, which passes north of the town partly through the nature reserve, has slightly lower costs than Alignment 2 which in turn has slightly lower costs than Alignment 3. The quantities of each alignment are imported to DynaRoad software (DynaRoad, 2015) to create more detailed production plans where the masses, crushing plants, borrow pits and disposal areas are included. The location of these can impact the hauling distances and the need for new hauling routes. Figure 3 shows the locations of the disposal area, quarry and crushing plant and how they can connect to Alignment 1. Given the fact that there are considerable amounts of excess masses in Alignment 1, these will have to be disposed at the disposal area, unless there are better options available. Excess masses can partly be hauled on the existing road network, but the last stretch of the hauling route needs to be constructed. Part of the excess masses can be used for this construction. These can be accounted for in DynaRoad by placing a fill on the affected stretch of the hauling road. Next, the alignments are scheduled in DynaRoad using line-of-balance. By making a rough schedule, the project duration, realistic hauling distances and associated costs can be estimated. The schedule can also provide details of the duration and quantity of mass flows, such as hauls of excess masses from Alignment 1 to the disposal area as seen in Figure 3. Considering the quantity of the masses and that these are hauled through the town, these impacts are interesting to examine further. If the impacts are deemed too severe, perhaps Alignment 2 or 3, which don't have similar impacts would be better to select for further study.

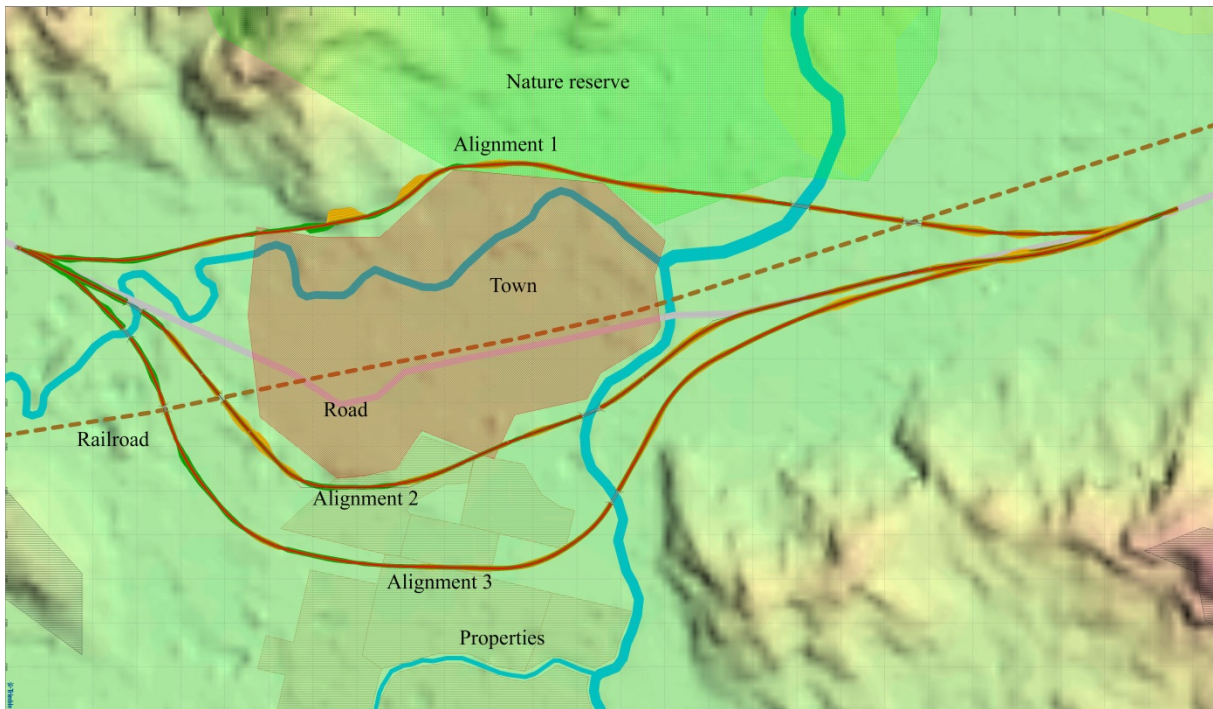


Figure 2. Three road alignments created in Quantm software.

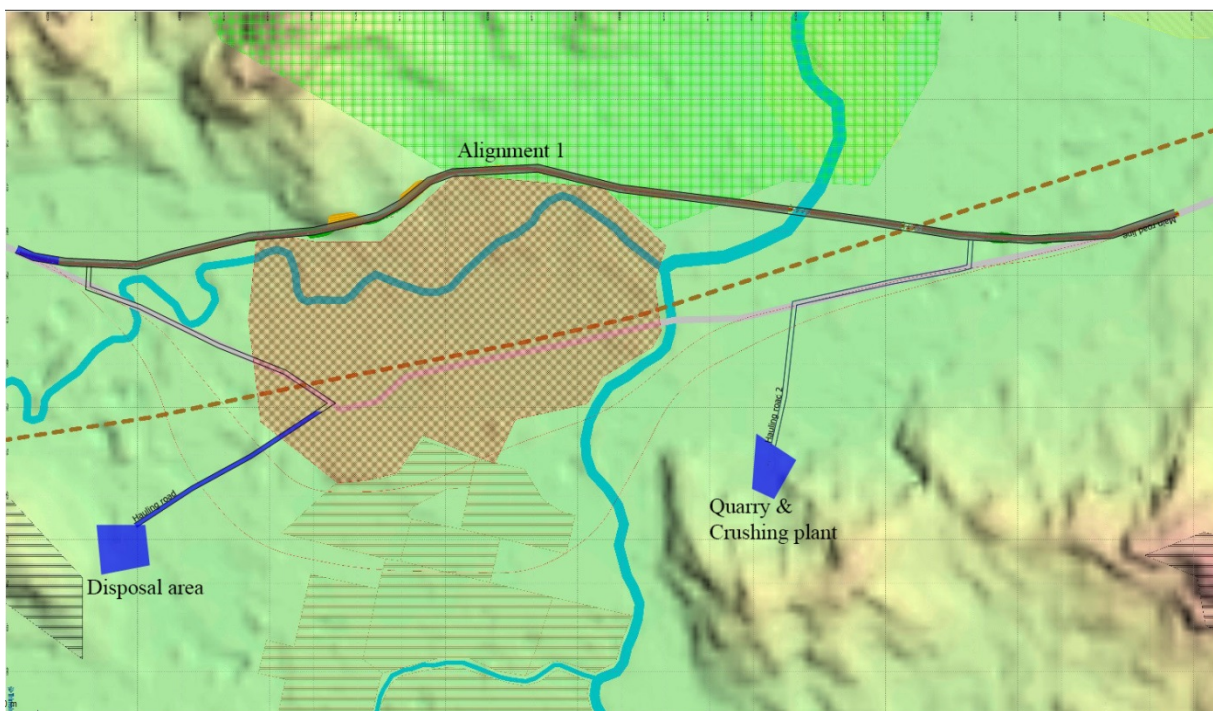


Figure 3. Alignment 1 worked in DynaRoad and the planned hauling routes from the disposal area and the quarry and crushing plant locations.

The alignments and cost surfaces from Quantm and the hauling routes from DynaRoad were analyzed and exported with FME. In this way we created a repeatable process to update the 3D model in InfraWorks. The process of moving data to InfraWorks included transformers such as offsetters, re-projectors, image rasterizers, attribute mappers and neighbor finders. To enable a good functionality of the information exchange, some specific file formats and data structures had to be selected. The data is thereby adapted to 3D visualization/analysis tools so that the impacts of the hauls can be shown to stakeholders. In Figure 4, the hauling

road from the disposal area to Alignment 1 is shown as it passes through the town. The sharp increase of heavy traffic will impact the traffic and the nearby buildings. The color of the buildings depends on their distances from the road and visualizes which buildings are affected and to what degree. This could act as an initial approximation of impacts such as noise and air pollution. Further analysis of these types of aspects can be made with other software but are not elaborated on further in our study. With these types of visualizations however, stakeholders can get an idea of the impacts and think of possible solutions, other options, hauling road locations, or new road corridors.

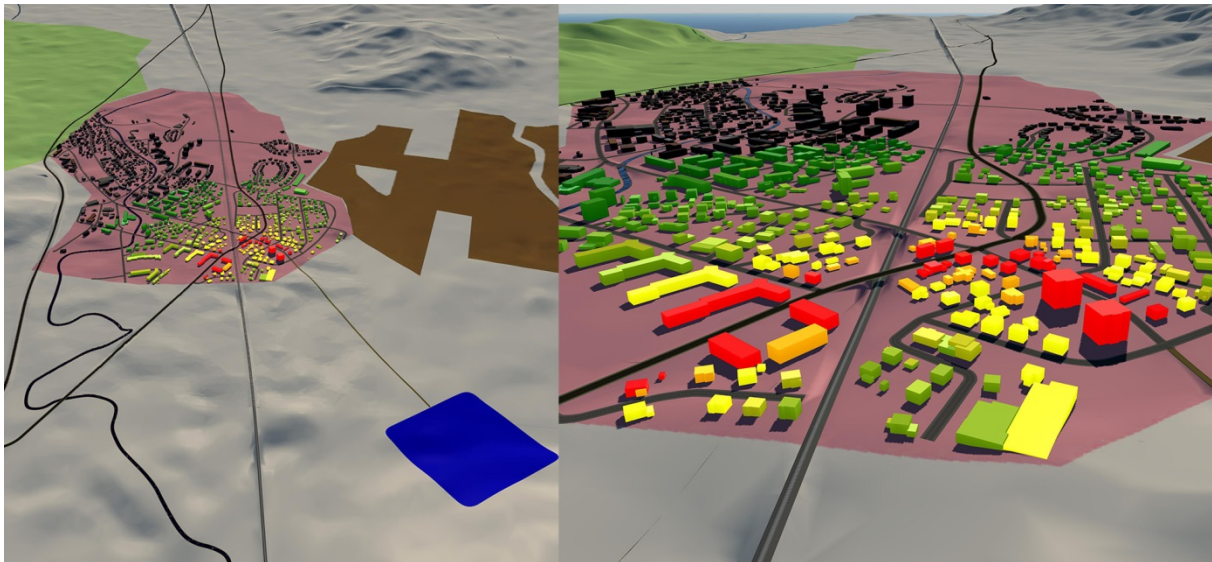


Figure 4. 3D visualization of buildings affected by the hauling road, red indicates high impact and green indicates low impact.

#### 4. CONCLUSIONS

Our study has integrated tools for road corridor planning, production planning, 3D visualization and analysis using ETL to overcome interoperability problems. ETL was a crucial tool when building the demonstration as it allowed exchange, re-structuring and analysis of Quantm and Dynaroad data to InfraWorks. production and buildability aspects, which are commonly considered in later stages, have been successfully incorporated as factors that can be considered when determining, evaluating and selecting corridors. Through a study of relevant literature a rough framework was proposed that show how our method can be used. It is a method that combines algorithms and tools that automates much of the work and could be incorporated into the conventional project planning process. The method was demonstrated through examples of relevant knowledge that was encountered in the process. The presented method can be seen as a stepping stone towards expanding, both the scope and the detail, of factors considered in the early project stages. A strong basis for decision making in early project stages is important as was implied by Paulson (1976), who showed that investments, decisions and commitments conducted at early project stages can have orders of magnitude greater impact compared to if they are conducted at later stages.

It must be stressed, however, that our study is of exploratory nature, the demonstration is not based on a real project and it does not present actual costs. As a result, definitive and far-reaching conclusions cannot be drawn and further research into the topic is needed. Another topic for further research deals with how to involve more complex analysis tools regarding e.g. noise, air pollution and traffic disturbances resulting from construction and production processes. Whether or not there other tools that in combination could work better for our stated aim is also a possible topic for further study. In sum, our study has shown how road corridors can be evaluated from more perspectives than what is commonly done and this can give stakeholders a stronger basis for their decision making.

#### ACKNOWLEDGMENTS

The authors would gratefully like to acknowledge the Swedish Research Council for Environment, Agricultural Sciences, and Spatial Planning (FORMAS), and Sweden's innovation agency, VINNOVA, for their financial support.

## REFERENCES

- Arditi, D., Tokdemir, O., and Suh, K. (2002). Challenges in Line-of-Balance Scheduling, *Journal of Construction Engineering and Management*, 128 (6), [http://dx.doi.org/10.1061/\(ASCE\)0733-9364\(2002\)128:6\(545\)](http://dx.doi.org/10.1061/(ASCE)0733-9364(2002)128:6(545)), 545-556.
- Atkinson, D. M., Deadman, P., Dudycha, D., and Traynor, S. (2005). Multi-criteria evaluation and least cost path analysis for an arctic all-weather road, *Applied Geography*, 25 (4), <http://dx.doi.org/10.1016/j.apgeog.2005.08.001>, 287-307.
- Autodesk Inc. (2012). *Autodesk Infraworks Training Guide*, John Wiley & Sons Inc., Hoboken, New Jersey, USA.
- Bagli, S., Geneletti, D., and Orsi, F. (2011). Routeing of power lines through least-cost path analysis and multicriteria evaluation to minimise environmental impacts, *Environmental Impact Assessment Review*, 31 (3), <http://dx.doi.org/10.1016/j.eiar.2010.10.003>, 234-239.
- Bédard, Y., and Han, J. (2009). *Fundamentals of spatial data warehousing for geographic knowledge discovery, Geographic data mining and knowledge discovery*. Taylor & Francis Group, Boca Raton, FL, USA, 45-68.
- Bimonte, S., Boucelma, O., Machabert, O., and Sellami, S. (2014). *From Volunteered Geographic Information to Volunteered Geographic OLAP: A VGI Data Quality-Based Approach*, Springer International Publishing, Cham, Switzerland., 69-80.
- Bodin, T., Albin, M., Ardo, J., Stroh, E., Ostergren, P., and Bjork, J. (2009). Road traffic noise and hypertension: results from a cross-sectional public health survey in southern Sweden, *Environmental Health*, 8 (1), <http://dx.doi.org/10.1186/1476-069X-8-38>, 38-47.
- Brooks, S., and Whalley, J. L. (2008). Multilayer hybrid visualizations to support 3D GIS, *Computers, Environment and Urban Systems*, 32 (4), <http://dx.doi.org/10.1016/j.compenvurbsys.2007.11.001>, 278-292.
- Cass, D., and Mukherjee, A. (2011). Calculation of Greenhouse Gas Emissions for Highway Construction Operations by Using a Hybrid Life-Cycle Assessment Approach: Case Study for Pavement Operations, *Journal of Construction Engineering and Management*, 137 (11), [http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000349](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000349), 1015-1025.
- Cerovsek, T. (2011). A review and outlook for a 'Building Information Model' (BIM): A multi-standpoint framework for technological development, *Advanced Engineering Informatics*, 25 (2), <http://dx.doi.org/10.1016/j.aei.2010.06.003>, 224-244.
- Collischonn, W., and Pilar, J. V. (2000). A direction dependent least-cost-path algorithm for roads and canals, *International Journal of Geographical Information Science*, 14 (4), <http://dx.doi.org/10.1080/13658810050024304>, 397-406.
- DynaRoad. (2015). *DynaRoad Manual Release 5.4.1*, DynaRoad Oy, Helsinki, Finland.
- Easa, S., Strauss, T., Hassan, Y., and Souleyrette, R. (2002). Three-Dimensional Transportation Analysis: Planning and Design, *Journal of Transportation Engineering*, 128 (3), [http://dx.doi.org/10.1061/\(ASCE\)0733-947X\(2002\)128:3\(250\)](http://dx.doi.org/10.1061/(ASCE)0733-947X(2002)128:3(250)), 250-258.
- Geneletti, D. (2003). Biodiversity Impact Assessment of roads: an approach based on ecosystem rarity, *Environmental Impact Assessment Review*, 23 (3), [http://dx.doi.org/10.1016/S0195-9255\(02\)00099-9](http://dx.doi.org/10.1016/S0195-9255(02)00099-9), 343-365.
- Gökçe, H. U., and Gökçe, K. U. (2014). Multi dimensional energy monitoring, analysis and optimization system for energy efficient building operations, *Sustainable Cities and Society*, 10 <http://dx.doi.org/10.1016/j.scs.2013.08.004>, 161-173.
- Grilo, A., and Jardim-Goncalves, R. (2010). Value proposition on interoperability of BIM and collaborative working environments, *Automation in Construction*, 19 (5), <http://dx.doi.org/10.1016/j.autcon.2009.11.003>, 522-530.
- Hajji, A., and Lewis, P. (2013). Development of productivity-based estimating tool for energy and air emissions from earthwork construction activities, *Smart and Sustainable Built Environment*, 2 (1), <http://dx.doi.org/10.1108/20466091311325863>, 84-100.
- Hoek, G., Brunekreef, B., Goldbohm, S., Fischer, P., and van den Brandt, P. A. (2002). Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study, *The Lancet*, 360 (9341), [http://dx.doi.org/10.1016/S0140-6736\(02\)11280-3](http://dx.doi.org/10.1016/S0140-6736(02)11280-3), 1203-1209.
- Jongeling, R., and Olofsson, T. (2007). A method for planning of work-flow by combined use of location-based scheduling and 4D CAD, *Automation in Construction*, 16 (2), <http://dx.doi.org/10.1016/j.autcon.2006.04.001>, 189-198.
- Kamat, V., and Martinez, J. (2001). Visualizing Simulated Construction Operations in 3D, *Journal of Computing in Civil Engineering*, 15 (4), [http://dx.doi.org/10.1061/\(ASCE\)0887-3801\(2001\)15:4\(329\)](http://dx.doi.org/10.1061/(ASCE)0887-3801(2001)15:4(329)), 329-337.
- Karabegovic, A., and Ponjavic, M. (2010). Integration and interoperability of spatial data in spatial decision

- support system environment, *MIPRO, 2010 Proceedings of the 33rd International Convention*, 1266-1271.
- Karagiannis, A., Vassiliadis, P., and Simitis, A. (2013). Scheduling strategies for efficient ETL execution, *Information Systems*, 38 (6), <http://dx.doi.org/10.1016/j.is.2012.12.001>, 927-945.
- Karan, E. P., and Irizarry, J. (2015). Extending BIM interoperability to preconstruction operations using geospatial analyses and semantic web services, *Automation in Construction*, 53 <http://dx.doi.org/10.1016/j.autcon.2015.02.012>, 1-12.
- Kim, H., Orr, K., Shen, Z., Moon, H., Ju, K., and Choi, W. (2014). Highway Alignment Construction Comparison Using Object-Oriented 3D Visualization Modeling, *Journal of Construction Engineering and Management*, 140 (10), [http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000898](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000898), 05014008.
- Kimball, R., and Caserta, J. (2004). *The data warehouse ETL toolkit*. John Wiley & Sons Inc., Hoboken, New Jersey, USA.
- Liu, S., and Wang, C. (2012). Optimizing linear project scheduling with multi-skilled crews, *Automation in Construction*, 24 <http://dx.doi.org/10.1016/j.autcon.2011.12.009>, 16-23.
- Loro, M., Arce, R. M., Ortega, E., and Martín, B. (2014). Road-corridor planning in the EIA procedure in Spain. A review of case studies, *Environmental Impact Assessment Review*, 44 <http://dx.doi.org/10.1016/j.eiar.2013.08.005>, 11-21.
- Paulson, B. C. (1976). Designing to reduce construction costs, *Journal of the Construction Division*, 102 (4), 587-592.
- Pheng, L. S., and Abeyegoonasekera, B. (2001). Integrating buildability in ISO 9000 quality management systems: case study of a condominium project, *Building and Environment*, 36 (3), [http://dx.doi.org/10.1016/S0360-1323\(00\)00004-4](http://dx.doi.org/10.1016/S0360-1323(00)00004-4), 299-312.
- Rebolj, D. (1998). Integrated Information System Supporting Road Design, Evaluation, and Construction, *Computer-Aided Civil and Infrastructure Engineering*, 13 (3), <http://dx.doi.org/10.1111/0885-9507.00097>, 179-187.
- Safe Software Inc. (2015). *FME Desktop Manual*, Safe Software Inc., Surrey, British Columbia, Canada.
- Sarasua, W., Hallmark, S., and Bachman, W. (2000). Environmental assessment of transportation-related air quality, 197-213.
- Shah, R. K., and Dawood, N. (2011). An innovative approach for generation of a time location plan in road construction projects, *Construction Management and Economics*, 29 (5), <http://dx.doi.org/10.1080/01446193.2011.563785>, 435-448.
- Trimble. (2012). *User Guide Quantm Software*, Trimble Navigation Limited., Melbourne, Australia.
- Yu, C., Lee, J., and Munro-Stasiuk, M. (2003). Research Article: Extensions to least-cost path algorithms for roadway planning, *International Journal of Geographical Information Science*, 17 (4), <http://dx.doi.org/10.1080/1365881031000072645>, 361-376.
- Yu, L., Sun, D., Peng, Z., and Zhang, J. (2012). A Hybrid System of Expanding 2D GIS into 3D Space, *Cartography and Geographic Information Science*, 39 (3), <http://dx.doi.org/10.1559/15230406393140>, 140-153.