Road Planning and Route Alignment Selection Criteria in the Norwegian Context

Citation for the original published paper (version of record):
Booto, G., Born, R., Ebrahimi, B. et al (2019). Road Planning and Route Alignment Selection Criteria in the Norwegian Context. IOP Conference Series: Materials Science and Engineering, 471(6). http://dx.doi.org/10.1088/1757-899X/471/6/062007

(article starts on next page)

IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Road Planning and Route Alignment Selection Criteria in the Norwegian Context

To cite this article: Gaylord K. Booto *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 062007

Road Planning and Route Alignment Selection Criteria in the Norwegian Context

Gaylord K. Booto [1], Reyn O Born [2], Babak Ebrahimi [3], Hrefna R. Vignisdottir [1], Helge Brattebo [1], Kelly Pittera [1], Holger Wallbaum [3], Rolf A. Bohne [1].

[1] Norwegian University of Science and Technology, Høgskoleringen 7a, 7491 Trondheim, Norway
[2] University of Agder, Jon Lilletuns vei 9, 4979 Grimstad, Norway
[3] Chalmers University of Technology, SE-412 96 Gothenburg, Sweden

gaylord.booto@ntnu.no

Abstract. This paper reveals the main factors that guide road alignment design process in Norway. The goal is to discover what constitutes the main priorities for road planners, how these priorities are ranked when it comes to alignment selection, and how they are related to guiding factors identified in official planning documents and government transport plans throughout the life cycle of a road. This is done through a comprehensive literature and data search, involving published academic research in the road alignment design field, and by exploring Norwegian road planning documents and guidelines. Examples from a recently implemented road project are also included as a way to illustrate alignment priorities in theory versus how alignment decisions are made in practice. Particular attention is paid to how key factors influence environmental and social dimensions and how much importance these dimensions are given in the overall decision-making process. The focus on the Norwegian case is relevant in that it will identify which knowledge gaps need to be filled based on actual practices in the Norwegian road sector. The results of this study found that the dominating factors in road planning and alignment selection are the user cost and the environmental and socio-economic as they are directly related to the main national transport strategy of developing a carbon-neutral and resilient transport system. These results can be used to reinforce and amplify existing road planning strategies and to understand where challenges for environmental and social responsible road planning and alignment selection are found.

1. Introduction

The increase in highway traffic and the related safety concerns often prompt the need for new highway infrastructure or the expansion, if not the adjustment, of existing routes. This happens to be the case in Norway, a country where positive economic growth boosts industrial development and trade in almost all sectors of the economy nationwide, there is a prescient need for new and upgraded roads [1]. To help cope with the situation, the government has initiated several large projects and mobilized resources to adequately respond. As a logical consequence, the Norwegian highway network is currently undergoing massive upgrading – with an unprecedented investment from the government – aiming at expanding and modernizing the existing road network in order to meet the expected traffic demand while at the same time complying with current standards [2]. The two main road-planning agencies in Norway – namely the Norwegian Public Roads Administration (NPRA or SVV) and New Roads (Nye Veiger AS) – are tasked with planning, determining and designing new alignments, while construction firms have the responsibility follow designs and construct these planned roads accordingly.

In general, the determination of highway alignment is recognized to be not only a complex but also an intensively iterative process, involving multifarious decisions at multiple levels. The degrees of complexity increase even more when the alignment is to be planned within an area with extremely complicated topographical (i.e. mountainous terrain) and geological (difficult soil conditions) features, as is the case in Norway.

Several relevant factors need to be taken into account during alignment design process. Those factors include among others, the availability of suitable parcels of land, earthworks, maintenance activities, life cycle costs, expected traffic demand, land-use, user trip duration, environmental impacts, safety issues, direct influence on performance of other transportation modes, and collateral effects of the chosen project on regional development [3] . According to Jong and Schonfeld [4] and Jian-xin and Qing [5], these factors will largely influence both the total cost of the project during the implementation phase, and the operating cost of the infrastructure during its lifetime. Therefore it becomes necessary to not only consider those factors but also intelligently incorporate them at an early design stage in order to end up with a more preferable alignment to reduce economic and social costs, improve traffic safety and fluidity, avoid restricted zones, and protect the natural environment [6-8]. Effective alignment is thus critical for a proper operation of the infrastructure in both isolated conditions – taken individually – and within a network.

The present work proposes to identify the most influential factors that guide the process of determining road alignment in Norway. The main goal is to understand both the composition and structure of main cost components used to support the decision regarding how the road must be shaped, when it is to connect a defined point origin O, to another defined point destination D, In that regard, the following points are investigated:

- main priorities for planners with respect to road alignment design in Norway
- factors that embody those priorities
- basis for prioritizing the related factors
- relationship between planners' priorities and factors that symbolize those priorities

2. Studies related to highway alignment design factors

Several studies deal with which factors to consider when designing highway alignment. However, only a select few can be easily identified, as the majority do not explicitly employ the terms "alignment design factors" in their titles. One possible way to identify such studies is to look for expressions such as "highway design models" or "highway alignment modelling", or "highway optimization", in the different databases or search engines. The reason for searching with the suggested key words is that factors are often incorporated into models – developed to assist highway planners and designers in evaluating a finite number of alignment alternatives between any two points – which in most cases appear to be a more suitable term to include in a research title. The term "cost" employed in those studies represents what is understood here as "factor".

The problem of formulating highway design models through a combination of factors and interests was tackled by researchers from two sides [9]. Earlier research focused on cost models aiming at estimating the total cost of alignment from a given set of information [10, 11], while later ones formulated optimization models which relied intensively on computational capabilities of new computers [12, 13].

Recent research concentrates more and more in developing sophisticated and complex models, as well as highly efficient algorithms to solve large-scale alignment design problems within a reasonable time period [14-16]. Several mathematical techniques are employed including calculus of variations [17-20], dynamic programming [21-23], mixed integer programming [24] and linear programming [25, 26].

Another approach makes use of genetic algorithms [3, 5, 27] as a search method, coupling of GA and GIS for simultaneous optimization of alignment with real terrain data [6, 7, 28], and neighbourhood search heuristic with mixed integer programming [29].

More innovative techniques are expected with the use of extension theory to solve contradiction between factors while optimizing highway alignment in a quite complex terrain like the permafrost as a very good example. It should be noted that future works will have to deal simultaneously with computational time, three-dimensional integration of factors of interests, realistic representation of complicated geometrical features, and other technical and engineering issues. The number of factors of interest is also expected to increase and this will need to be reflected in models.

3. Norwegian road sector

3.1. Main stakeholders

Road design and planning in Norway is primarily organized by two main governmental entities: The Norwegian Public Roads Administration (NPRA) and New Roads AS (Nye Veiger). These two entities coordinate communication between stakeholders and government; determine feasible routes, and tender contracts. The stakeholders in road building can be classified between government, planners, road builders and affected parties {table 1}. Each of the stakeholders in the road planning process gives input to how roads are planned and designed from the earliest phases to its completion.

Table 1. Stakeholders and their main roles

Actor	Role
National level NPRA	Determines which routes to focus on for the NTP and develops road construction standards for road builders to follow
National Transportation Plan (NTP)	Assigns main routes to develop, provides provisional budgets, and outlines main national transport goals
National government	Approves NTP routes and overall goals and gives funding to NRPA projects
NPRA Regional/Local offices	Develops local Planning, Municipal and Zoning programs and road designs used in bids
Municipal government	Approves the NPRA Regional plans and budgets for road construction
Contractors and road builders	Bid on the road projects from NPRA tenders and constructs roads
Locally affected parties	Local citizens who voice concerns and give feedback on the road planning process

As demonstrated in Table 1, stakeholders in Norwegian road sector are mostly public actors. The only private party is of the contractors and road builders. This group very important as they deal with the execution and completion of projects. There are many corporations in operation across the country, and their total capacity is more than enough to efficiently absorb any type of road projects nationwide. The most influential among them – based on turnover and workforce – are Veidekke (30,000 MNOK and 7400 emp.), Skanska (13,700 MNOK and 3800 emp.), NCC (8,800 MNOK and 2400 emp.) and Mesta (3608 MNOK and 1334 emp.). Although, this particular stakeholder group fluctuates a lot over the years with companies entering or leaving the industry. Corporations included in this group hold important shares of activities in several other construction sectors such as building, railroad, hydropower, etc.

3.2. Network and Traffic

The Norwegian road network comprises five different categories of roads, which are defined by the Norwegian Public Road Administration. This categorization takes into account a certain number of elements in their definition. Those elements include geographic location, type and size of traffic, degree of importance within the region. The category of the road determines its dimensions and, to a certain extent, fixes some design solutions and engineering requirements to be strictly followed during the design process (e.g. surface type, geometry, materials properties, maximum operating speeds, etc.) [30].

To date a total of 254 468 km of paved and gravelled roads – all categories included – exist in Norway [31].These platforms provide service to some 5,335 076 vehicles of all types, registered nationwide, out of which about 100,000 (i.e. above 1.5% of total fleet) are fully electric [31].

As the status of roads within the network changes quite quickly, numbers presented in **Chyba! Odkaz na záložku nie je platný.** will vary from year over year. Every now and then, a slightly different distribution will arise, correcting for newly built road sections, as well maintained and/or redesigned roads. This will depend largely on traffic behaviour, which constitutes the main reason for road maintenance, redesign or new construction. While detailed road traffic data in Norway presents a less clear pattern, its overall trend remains upward growth, with a relative traffic increase of approximately 1.3% each year, starting from the year 2005. Figure 1 depicts the evolution of road traffic in Norway from 2002 to 2016, for selected types of registered vehicles within the country.

Table 2 shows a distribution of road length [km] within each category and their equivalent share [in percentage]. From the table it reads clearly that private, forest, county and municipal roads constitute the dominant categories within the Norwegian road network.

As the status of roads within the network changes quite quickly, numbers presented in **Chyba! Odkaz na záložku nie je platný.** will vary from year over year. Every now and then, a slightly different distribution will arise, correcting for newly built road sections, as well maintained and/or redesigned roads. This will depend largely on traffic behaviour, which constitutes the main reason for road maintenance, redesign or new construction. While detailed road traffic data in Norway presents a less clear pattern, its overall trend remains upward growth, with a relative traffic increase of approximately 1.3% each year, starting from the year 2005. Figure 1 depicts the evolution of road traffic in Norway from 2002 to 2016, for selected types of registered vehicles within the country.

Table 2. The Norwegian road network distribution [32]

Road category	Total length (km)	Share within the entire network (%)
European road	8 044	3.2
National road	5 075	2.0
County road	49 138	19.3
Municipality road	43 761	17.2
Private road	99 050	38.9
Forest/logging road	49 400	19.4

Examining the road traffic situation as portrayed in Figure 1, it is clear that on average, for the majority of vehicle types, there is an overall upward trend. However, the remarkable reduction of related bus traffic is more pronounced and more noticeable than the average upsurge observed in the other four types. In any event, the total vehicle kilometers travelled by each category were slightly higher in 2016 compared to 2015. The registered overall increase (all motor vehicle) of about 2.2% in 2016 suggests that volume of road traffic in Norway will keep growing rather than shrink.

3.3. Planning process and responsibilities

Road planning in Norway strictly follows the Norwegian Law on Planning and Construction [33], in force since 1985 and last amended in July 2017. This must also be done in accordance with national strategies set forth in the quadrennial National Transport Plans (NTP) issued by the Norwegian Ministry of Transport. The planning is done in five steps as pictured in Figure 2.

The process is quite complex and involves several decision-makers including the Ministry of Transport and Communication (MTC), the NPRA, the regional road authorities, concerned government organizations (GO), land owners (LO), local and national governments (LG, NG), and the local and national parliament (LP, NP). It should be noted that the NTP defines all national transportation strategies i.e. not only for the road sector but also, aviation, maritime and rail transport.

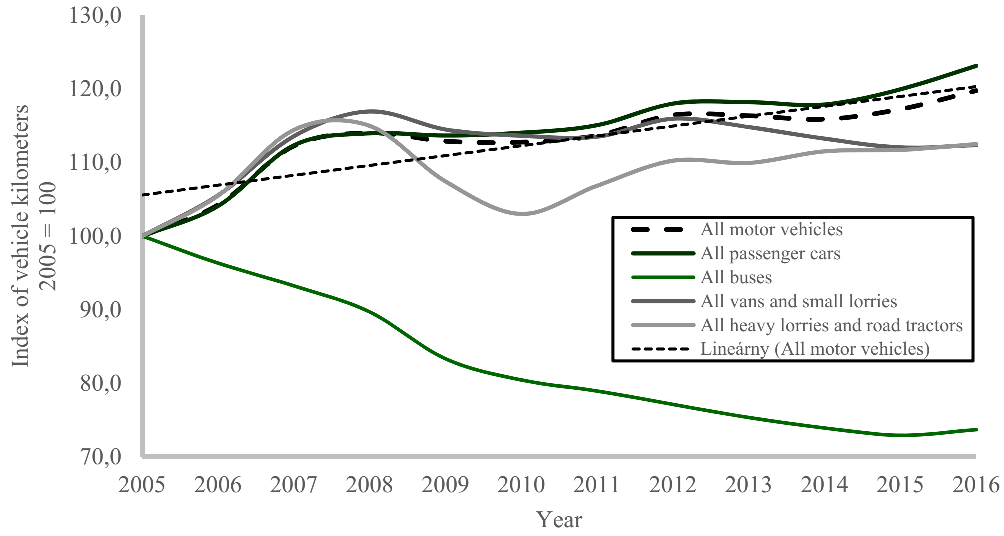

Figure 1. Vehicle kilometres travelled by selected vehicle types in Norway 2005 – *2016*

4. Materials and Method

Data used in this study were collected from two different sources. The one source dealt with published scientific research (i.e. scientific literature or scholarly data) collected from Scopus [35] and Elsevier [36] databases – through the Oria platform [37] – using specific key expressions in the abstract or title. The other source of data involved project reports for a selected highway project that was recently completed in Norway. The analysis conducted here was a qualitative type of analysis, and followed the steps detailed in Figure 3.

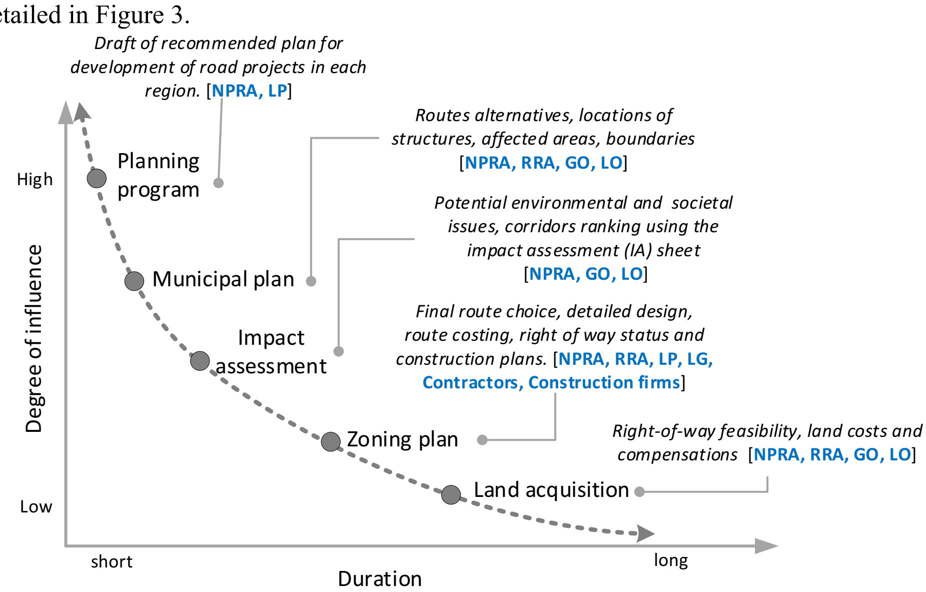

Figure 2. Planning steps, main goals and involved actors (Adapted from [33, 34])

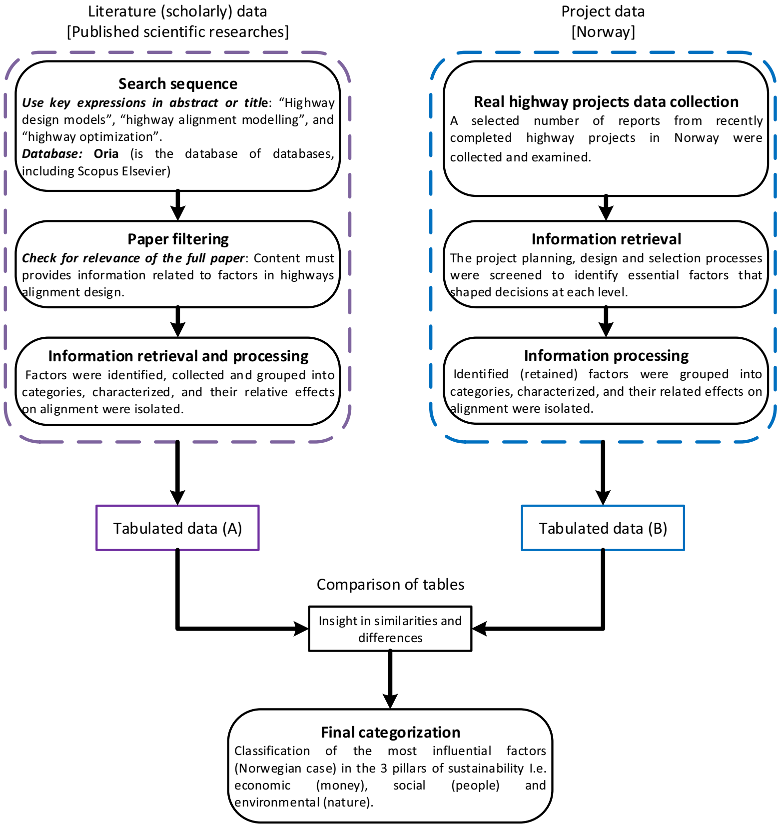

Figure 3. Diagrammatic summary of the study method

First, data from each source were processed and analysed separately before merging them together for comparison and final classification. For each stream, factors connected to alignment design were identified. They were then further compiled, matched and merged, to result in a generic table with the most common factors altering highway alignment's shape. Following, factors' behaviour was examined through simple cause-effect relationship to derive their influence on the overall shape of a given alignment during planning and design phase. Finally, based on the decision process that led to the choice of alignments from the project cases, the most influential factors under the Norwegian case were identified, ranked and classified into economic, social and/or environmental pillars, for final characterization, as was the goal of the work

Table 3. Most usual factors (costs items) for consideration in highway alignment optimization

Category		Included cost items (not exhaustive)	Characterization
Preliminary engineering, administrative, planning and design		Preliminary survey, consulting, supervision, contractor selection, etc.	-
Construction		Earthwork and subgrade formation, site preparation	(a), (c), D, A
		pavement, super and substructures	(b), A
		right-of-way	(c), (a), D, A
		structures,	(d), D, A
		miscellaneous , etc.	-
Maintenance and operation		Reparation, reinforcement, and rehabilitation	(b), (a),
User	vehicle operation	Direct and indirect consumables (including fuels, tires, spare parts, etc.), vehicle depreciation	(b), (c), D, A
	Travel time	Vehicle hours (daily exploitation time duration)	(b), (c), D, A
	accidents	Accident rate, accident occurrence and their related weights	(b), (c), D, A

Environmental and socio-economic	Environmentally sensitive area, historical and cultural patrimonies, Land use changes (LUC), Air and noise pollutions	(c), A (c), A (b), (c), A

Where (a): volume-dependent costs, (b): length-dependent costs, (c): location-dependent costs, (d): structure costs, A: alignment-sensitive costs, D: dominating costs

Table 4. Effects of related cost items on optimized alignment

Item	Action(s) on the alignment
Preliminary survey, consulting, supervision, contractor selection, etc.	Fixed (constant) non-technical effect
Earthwork and subgrade formation, site preparation	Reduces deviation from initial terrain topography; favours introduction of structures (bridges, tunnels)
	Reduces alignment's length
Pavement, super and substructures right-of-way	Induces more circuitous alignment; favours introduction of intersections, overpassing, …
Structures,	Induces circuitous alignment; reduces alignment's length
Miscellaneous , etc.	-
Reparation, reinforcement, and rehabilitation	Reduces alignment's length ;
Direct and indirect consumables (including fuels, tires, spare parts, etc.), vehicle depreciation	Reduces alignment's length; reduces curves and irregularities (i.e. induces more direct and flat alignment)
Vehicle hours (daily exploitation time duration)	Straightening and flattening
Accident rate, accident occurrence and their related weights	Straightening and flattening
Environmentally sensitive areas and cultural heritage	More circuitous alignment (or high socio-environmental cost if violated)
Land use change	More circuitous alignment (or high socio-environmental cost if violated)
Air pollution and noise	Various actions depending on pollutant types, power trains and project phases.

5. Findings

The outcomes of this study are summarized in tables 3 – 5 as follows: Table 3 shows the common factors used in alignment optimization, their characteristics, as well as the items representing those factors. dominating costs

Table *4* informs on possible effects that factors (or cost items) will have on the alignment when forcing them towards their desired extremums.

Table ***5*** exhibits the practice in use in Norway, displaying the factors of most interests, the pillar(s) in which they belong, the metrics used to capture their behaviour, the type of analysis going with those metrics, and the order of significance of those factors.

Table 5. Breakdown of weight for the most influential factors for the Norwegian case. Data are from [38, 39]

Category	Included items	Dimension			Metrics/Analysis	Weight
		Eco.	Soc.	Env.		
Construction	Earthwork and subgrade formation, pavement, and structures			X	NO_x, CO_2 and Energy use / Life Cycle approach (LCa)	**< 10%**
Maintenance	Reparation, reinforcement	X		X	Price, NO_x, CO_2 and Energy use / CBA, LFA	**< 10%**

User	Traffic fuel, accidents, Duration, road tolls		X	X	Non-priced, NO_x, CO_2 and Energy use / CBA, LCa	**65 – 75%**
Environmental and socio-economic	Local landscape, green space, natural areas, resources, cultural heritage, noise		X	X	Non-priced / CBA	**15 – 25%**

6. Discussion

The findings from this study show that the Norwegian highway alignment planning and design process follows a systematic approach, which evaluates several feasible alignment alternatives based on governmental priorities. The decision-makers consider several key factors (Table ***5***), already at earlier stages, to capture those priorities and guide the process. The factors include both dominating and alignment sensitive ones (Table 3), whose overall weight is confronted to the total investment cost of the project. The findings show that key factors do have various effects on the shape of the alignment (dominating costs **Table *4***). The importance of each key factor is captured based on its relative impacts derived by mean of dedicated metrics (Table ***5***). Almost all the key factors (or their components or items) are two-dimensional i.e. of either socio-environmental or economic-environmental types.

The environmental impacts are derived through a life cycle approach using the EFFEKT tool [40], while for social and economic dimensions, a cost benefit analysis (CBA) serves as a basis. It is notable that results from the environmental impacts (i.e. life cycle energy use and emissions) are integrated as environmental costs into a cost benefit analysis [40].

Among the key factors, the user cost appears to be the most important one, representing about three fourths of total weight of all key factors. It is followed by the environmental and socio-economic costs, and by construction and maintenance costs following in importance. The very high importance of the user cost is mostly due to the energy demand and emissions of vehicles during exploitation phase of the infrastructure. In fact, this particular cost is considered as dominant in comparison with road construction, operation, maintenance and end-of-life, especially in dense traffic situation [6, 7, 10, 40, 41]. The relatively high weight of the environmental and socio-economic cost is due to its high social impact, which often constitutes a serious source of conflicts between authorities and local communities [4].

However, this distribution must be regularly revised since it may differ from time to time and terrain to terrain. First, it should be kept in mind that construction cost will be larger if many more complicated structures (tunnels, bridges, etc.) are involved, as they are often energy and material intensive components [40]. Second, development in vehicle technology (powertrain) will probably result in abatement of user cost. Lastly, less dense traffic and lower AADT introduce significant reduction in both energy demand and emissions of vehicle during exploitation, and therefore shift the impact loads to other costs such as construction and / or maintenance.

7. Conclusion

This study showed that planning and design of highway alignment in Norway, is influenced by some key factors that need to be included in the process already at earlier stages. The factors can help materialize decision-makers' priorities, handle both energy demand and emissions issues, with great potential for climate change mitigation and adaptation. This emphasizes on the possibility of developing sophisticated models for intelligent and environmentally optimized highway alignment design, based on those key factors. Such design will contribute to enable a faster transition towards a lower-carbon and carbon-neutral transport goal, fixed by national government.

Acknowledgment(s)
This study was conducted as part of the "Ferry-free E39, Sustainable Infrastructures" project. The authors would like to thank the NPRA for financial support. They also direct special thanks to NTNU (IBM) for all facilities.

References

[1] Statistisk SentralByrå. (2017, September 22). *Road Traffic Volumes*. Available:

http://www.ssb.no/en/klreg

[2] M. o. T. a. Communication. (2017, September 13). *National Transport Plan 2018 - 2029*. Available: https://www.regjeringen.no/contentassets/7c52fd2938ca42209e4286fe86bb28bd/no/pdfs/stm201620170033000dddpdfs.pdf

[3] M.-W. Kang, M. K. Jha, and P. Schonfeld, "Applicability of highway alignment optimization models," *Transportation Research Part C: Emerging Technologies,* vol. 21, no. 1, pp. 257-286, 2012/04/01/ 2012.

[4] J.-C. Jong and P. Schonfeld, "Cost Functions for Optimizing Highway Alignments," *Transportation Research Record: Journal of the Transportation Research Board,* vol. 1659, pp. 58-67, 1999.

[5] C. Jian-xin and L. Qing, "Research on Cost-oriented Modeling and Optimization for Highway Alignment," *Procedia Engineering,* vol. 15, no. Supplement C, pp. 3931-3935, 2011/01/01/ 2011.

[6] M. Jha and P. Schonfeld, "Integrating Genetic Algorithms and Geographic Information System to Optimize Highway Alignments," *Transportation Research Record: Journal of the Transportation Research Board,* vol. 1719, pp. 233-240, 2000.

[7] M. K. Jha and P. Schonfeld, "A highway alignment optimization model using geographic information systems," *Transportation Research Part A: Policy and Practice,* vol. 38, no. 6, pp. 455-481, 2004/07/01/ 2004.

[8] J.-C. Jong and P. Schonfeld, "An evolutionary model for simultaneously optimizing three-dimensional highway alignments," *Transportation Research Part B: Methodological,* vol. 37, no. 2, pp. 107-128, 2003/02/01/ 2003.

[9] M. Jha, P. Schonfeld, J. Jong, and E. Kim, *Interlligent Road Design*. Southampton, Boston: WITpress, 2006.

[10] F. Moavenzadeh and M. Becker, *Highway cost model operating instructions and program documentation* (no. 69). Massachusetts Institute of Technology, 1973.

[11] T. Watanatada, W. Paterson, A. Bhandari, C. Harral, A. Dhareshwar, and K. Tsunokawa, "The highway design and maintenance standards model. volumes 1 and 2," 1987.

[12] G. Athanassoulis and V. Calogero, "Optimal location of a new highway from A to B–A computer technique for route planning," in *PTRC Seminar Proceedings on Cost Models & Optimization in Highway*, 1973, p. 9.

[13] J. Hogan, "Experience with OPTLOC optimum location of highways by computer," in *PTRC Seminar Proceedings on Cost Models and Optimization in Highways (Session L10), London*, 1973.

[14] W. Hare, S. Hossain, Y. Lucet, and F. Rahman, "Models and strategies for efficiently determining an optimal vertical alignment of roads," *Computers & Operations Research,* vol. 44, no. Supplement C, pp. 161-173, 2014/04/01/ 2014.

[15] S. E. Ibrahim, T. Sayed, and K. Ismail, "Methodology for safety optimization of highway cross-sections for horizontal curves with restricted sight distance," *Accident Analysis & Prevention,* vol. 49, no. Supplement C, pp. 476-485, 2012/11/01/ 2012.

[16] P. Saha and K. Ksaibati, "An optimization model for improving highway safety," *Journal of Traffic and Transportation Engineering (English Edition),* vol. 3, no. 6, pp. 549-558, 2016/12/01/ 2016.

[17] B. Howard, Z. Bramnick, and J. Shaw, "Optimum curvature principle in highway routing," 1969.

[18] J. F. Shaw and B. E. Howard, "Expressway route optimization by OCP," *Journal of Transportation Engineering,* vol. 108, no. TE3, 1982.

[19] N. Thomson and J. Sykes, "Route selection through a dynamic ice field using the maximum principle," *Transportation Research Part B: Methodological,* vol. 22, no. 5, pp. 339-356, 1988.

[20] F. Wan, *Introduction to the Calculus of Variations and its Applications*. CRC Press, 1995.

[21] T. Fwa, W. Chan, and Y. Sim, "Optimal vertical alignment analysis for highway design," *Journal of transportation engineering,* vol. 128, no. 5, pp. 395-402, 2002.

[22] M. Gomaa, A. J. Alimin, and K. A. Kamaruddin, "Trade-off between NOx, soot and EGR rates for an IDI diesel engine fuelled with JB5," *Journal of Applied Sciences,* Article vol. 11, no. 11, pp. 1987-1993, 2011.

[23] A. J. Nicholson, D. Elms, and A. Williman, "A variational approach to optimal route location,"

Highway Engineer, vol. 23, no. 3, 1976.

[24] S. M. Easa and A. Mehmood, "Optimizing Design of Highway Horizontal Alignments: New Substantive Safety Approach," *Computer-Aided Civil and Infrastructure Engineering,* vol. 23, no. 7, pp. 560-573, 2008.

[25] S. C. Chapra and R. Canale, *Numerical Methods for Engineers: With Software and Programming Applications*. McGraw-Hill Higher Education, 2001, p. 944.

[26] C. A. Revelle and E. E. Whitlach, *Civil and environmental systems engineering*. Prentice Hall PTR, 1996.

[27] J.-C. Jong, "Optimizing highway alignments with genetic algorithms," research directed by Dept. of Civil Engineering.University of Maryland, College Park, Md., 1998.

[28] M. K. Jha, "A geographic information systems-based model for highway design optimization," 2000.

[29] J.-F. Cheng and Y. Lee, "Model for three-dimensional highway alignment," *Journal of transportation engineering,* vol. 132, no. 12, pp. 913-920, 2006.

[30] H. N. Statens Vegvesen, "Veg- og gateutforming," in "Håndbok," 2014, vol. N100.

[31] Central Vehicle Register. Registered vehicles [Online]. Available: https://www.vegvesen.no/en/vehicles/Buy+and+sell/First+time+registration+in+Norway/Registration

[32] NPRA. Norwegian road network data (road map) [Online]. Available: https://www.vegvesen.no/vegkart/vegkart/#kartlag:geodata/@600000,7225000,3

[33] Lovdata. (2017, August 29). *Norwegian law on planning and construction*. Available: https://lovdata.no/dokument/NL/lov/2008-06-27-71?q=bygningsloven

[34] J. Odeck, "What Determines Decision-Makers' Preferences for Road Investments? Evidence from the Norwegian Road Sector," *Transport Reviews,* vol. 30, no. 4, pp. 473-494, 2010/07/01 2010.

[35] Scopus. Abstract and Citation database of peer-reviewed literature [Online]. Available: https://www.scopus.com/search/form.uri?display=basic

[36] Elsevier. The global leader in Science, Technical and Health publishing [Online]. Available: https://www.elsevier.com/about/this-is-elsevier#data

[37] Bibsys. Oria, the library of databases [Online]. Available: https://bibsys-almaprimo.hosted.exlibrisgroup.com/primo_library/libweb/action/search.do?vid=NTNU_UB&dscnt=0&dstmp=1506964581904&vid=NTNU_UB&backFromPreferences=true

[38] Statens Vegvesen, "Kommunedelplan med konsekvensutredning for E39 Volleberg-Døle route," Bergen 2014, Available: https://www.vegvesen.no/_attachment/760274/binary/1008948?fast_title=Hovedrapport+E39+Volleberg+-+D%C3%B8le+bru.pdf.

[39] Vegdirektoratet, *Impacts analysis (konsekvensanalyser) Håndbok* (Statens vegvesens håndbokserie). Statens vegvesen, 2014.

[40] S. Miliutenko *et al.*, "Consideration of Life Cycle Energy Use and Greenhouse Gas Emissions in Road Infrastructure Planning Processes: Examples of Sweden, Norway, Denmark and The Netherlands," *Journal of Environmental Assessment Policy and Management (JEAPM),* vol. 16, no. 04, pp. 1-26, 2014.

[41] S. Miliutenko, "Life Cycle Impacts of Road Infrastructure Assessment of energy use and greenhouse gas emissions," 2017.