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The Effects of Safety Optimization on Highway Alignment: A Review

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***Abstract*— The study on optimizing the highways alignment has increased during the two past decades. This paper provides an overview of highway optimization models that are being provided in most of the places in the world. It also provides an insight to the related factors for highway alignment optimization, especially with the main focus on the safety characterization. Until now various studies have been performed that are related to the factors leading to an accident. The factors responsible in creating accidents are referred to the environmental, road, drivers, vehicles and traffic factors. Moreover each character is considered to be only in the optimization range of highway alignment with a rational process in this paper. It is also found that more safety parameters in highway optimization should be investigated together before determining the optimal one provided that much research has been carried out in this area, but due to the expansion of human needs it is very important to carry out researches for reducing the cost and losses that are related to safety aspects like fatal and injury accidents in the new highways.**

***Index Terms*— Highway optimization design, Safety parameters, Accident features, Road safety**

I. INTRODUCTION

The roads are considered to be as a main artery of any state that plays an important role in determining the economic, culture and policy. If these roads are not designed and not implemented with the help of perfect research can led to the cause of an irreparable damage to the individual, environment and property. The parameters that determine the best candidate for highway are constraint, costs, safety and the existing models for optimizing the highway provides lesser attention for the safety aspects. In the country like Iran nearly 900,000 accidents happens and nearly 20,000 people die and more over 300,000 are injured during the year mainly because of the road accidents. According to the researches carried out in Iran the main causes of accidents are due to human factors (70%), road and environmental factors (20%) and vehicle factor (10%) according to the findings of (Sajjadi et al., 2014). The above statistics clearly indicates that the effect of road and environmental factors in creating a car accident are considered to be significant with the correct design and use of all effective parameters in designing of road that includes compulsory point, sea, marshes, rivers, hydrology, geology, faults, landslides through which the rate of accident can be reduced.

The road accidents impose serious problems to the society and the costs of road accidents to individuals, society and property are significant. In addition to this there are considerable costs which are related to road accidents like human costs, medical costs that are related to road accident injuries, costs of damage to property and vehicles, administrative and police costs and insurance costs as per the survey of Department For Transport (2011).

The safety parameter is considered during the highway design by most of the researchers mainly because of its importance. Till now various studies are being performed that are related to the factors leading to accident. Among those the most important factors in creating accidents can be referred to as environmental, road, drivers, vehicle and traffic factors from the already existing theories.

The optimal alignment to choose highway candidate is determined especially when the parameters mentioned above are assessed simultaneously. Most elaborative researches have been carried out so far in order to determine the optimal alignment throughout the world that has led to the emergence of many different types of algorithms and models. This current study examines the literature on both the methods that are involved in determining the optimal candidate needed for highways and the factors that are related to road safety.

II. HIGHWAY ALIGNMENT OPTIMIZATION

Highway alignment optimization models that have developed and evolved during the three past decade is a true reality in the fact that it is a complex method and moreover requires significant values of data than the vertical alignment as per OECD (1973). The cost factors in making highway is complicated and till now many models for optimizing the highway are being provided among which some of the most important ones areas below:

1. Calculus of variations
2. Network optimization
3. Dynamic programming
4. Numerical Search
5. Genetic algorithm
6. Genetic algorithm and Geographic information system
7. Multi-Objective Optimization

The optimization model with using genetic algorithm and with or without using GIS has being expanded by many researchers until now. The models that are presented for the highway alignment optimization perform alignment optimization with the aim of minimizing the total cost involved. All of the performed studies for the optimization of highway are shown in Table 1.

Table 1: Highway alignment optimization studies [1]

Target for optimizing	**Optimization approach**	**References**
Horizontal alignment only	Calculus of variations	Howard et al. (1968), Shaw and Howard (1981, 1982), Thomson and Sykes (1988), and Wan (1995)
	Network optimization	Turner and Miles (1971), OECD (1973), Athanassoulis and Calogero (1973), Parker (1977),Trietsch (1987a,b)
	Dynamic programming	Hogan (1973) and Nicholson et al. (1976)
	Mixed integer programming	Easa and Mehmood (2008)
	Neighbourhood search heuristic with mixed integer programming	Lee et al. (2009)
	Genetic algorithms	Jong (1998) and Jong et al. (2000)
Vertical alignment only	Enumeration	Easa (1988)
	Dynamic programming	Puy Huarte (1973), Murchland (1973), Goh et al. (1988), Fwa (1989)
	Linear programming	Chapra and Canale (2006) and ReVelle et al. (1997)
	Numerical search	Hayman (1970) and Robinson (1973)
	Genetic algorithms	Jong (1998), Fwa et al. (2002), and Jong and Schonfeld (2003)
Three dimensional alignment	Numerical search	Chew et al. (1989)
	Distance transform	Mandow and Perez-de-la-Cruz (2004) and de Smith (2006)
	Neighbourhood search heuristic with mixed integer programming	Cheng and Lee (2006)
	Genetic algorithms	Jong (1998), Jha (2000), Kim (2001), Jong and Schonfeld (2003), Tat and Tao (2003), Jha and Schonfeld (2004), Kim et al. (2004a,b, 2005, 2007), Kang et al. (2007, 2009, 2010), and Kang (2008)

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A. Calculus of variations

The calculus of variation is purely a mathematical modeling which explains that two spatial points (start and end) are connected to each other with the integration of cost function that is minimized with a curve [2]. So that the cost function will be continuous between the two spatial points which in reality is unlikely in real-world problems? The same concept of Optimum Curvature Principle (OCP) was also used for the horizontal highway alignment design by Howard, Bramnick [3]. The maritime path through a dynamic ice field [4] and horizontal alignment of the expressway in flat south Florida [5] are the real world applications of this model.

B. Network optimization

The network optimization model is used for optimizing the problems that are related to the network. This method in particular has divided the search space into small cells and has presented the highway alignment as a network of cost and location. The costs are represented by links and the locations are represented by nodes of the cells. This method is widely used by many researchers for developing a horizontal alignment according to the finding of [6-8]. This method is also used for the vertical alignment along with the horizontal alignment that is developed with a two-stage method as per Parker [9]. According to Jong [10]it can defined as a corridor and not as a highway candidate. Moreover the estimate of cost information for each link is needed by this method and is computationally intensive in nature with the need of notable amount of total storage space and in this method the cost information of more than one objective cannot be used.

C. Dynamic programming

The complexity of highway alignment optimization can be handled well with the dynamic programming and has divided the main problem into a number of sub-problems in such a way that the portion of the objective function value from each sub-problem is independent and increasable according to the findings of Jong [10].

This method also has subdivided the search space into a number of orthogonal spaces and has optimized the objective cost function for each of the orthogonal space one after the and in each orthogonal space the alignment for the optimized cost function is joined to form the final alignment. The optimization of the horizontal as well as 3-dimensional alignments could be achieved by this method [11-13]. The increase of the number of orthogonal spaces can improve the precision of this method. However the limitation of this method is that the computational burden becomes increased and creates problems in smoothing the alignment by fitting the curves as a result only a smaller search area with simple cost functions can be used in this method.

D. Numerical Search

The numerical search is a model based on calculus of variations that was developed by Chew, Goh [14] and can optimize a 3-dimension highway alignment. In this model at the end a smooth alignment is generated but a global optimum solution cannot be guaranteed by this model according to the researcher Jong [10]. The predefined initial set of solutions is dependent by the convergence of this model and can be made as a semi-automatic process and by the use of this model in real world problems is made cumbersome with the difficulties in the inclusion of location-dependent discontinuous cost information.

E. Genetic algorithm

The developments of efficient optimization algorithms and advancement in the software and computers have sophisticated highway alignment optimization methodologies. The genetic algorithm (GA) to optimize highway alignments was first used by Jong [10] and these customized GAs are most widely used in the process of highway alignment optimization and considered to be different with the classic GAs in many ways as per Goldberg and Holland [15]. In their method the search space was into orthogonal sections perpendicular to the line as to join the start and end points. This methodology resulted in the generation of point intersections (PI) randomly on the orthogonal sections and further joined with a circular, transition and tangent sections for making a smooth alignment. Such generation of alignments has estimated the different cost components of the objective function that includes socio-economic cost, structure cost, earthwork cost, travel time cost, right-of-way cost by using the empirical equations and also this model has added these cost components to form minimizing the total cost of the highway alignment. Further, in order to generate a new set of PIs, the GA operators are needed for estimating the total cost information. So, basically this is an optimization approach for a single objective and the process is repeated until no progress is registered in the total cost over the successive generations[16]. This study is limited for the total cost optimization of highway alignment and moreover at the end of this model there is no guarantee for the simultaneous optimization of all the cost components according to the findings of Maji [16].

The model provided by Jong [10] was further modified by Jong, Jha [17]; Jong and Schonfeld [18]. The modified GAs has evaluated several numbers of members (i.e., candidate Alignments) in each generation and also the selection/replacement scheme specified has replaced less fitted members with the newer one. Moreover, the developed GAs has shown retention and used for the better fitted members to create as offspring by means of genetic recombination. After the evaluation of all members of the population it will terminate a generation and the process will be continue through successive generations until the progress in the objective function becomes almost negligible. The evaluation of each member in a generation is called as iteration and thus 3,600 alignments will be evaluated through a search through 100 generations with 36 iterations in each of the generation.

F. Genetic algorithm and Geographic information system

The Jong's research in 1998 by integrating genetic algorithm (GA) with GIS was expanded by Jha [19] and was considered that the comprehensive costs are sensitive to geographic. The costs being investigated in Jha's model are costs related to right of way, earthwork, structure, pavement, maintenance, environment, travel time, vehicle operating and accident.

Also, Jha [19] provided a comprehensive earthwork cost formulation that considers the detailed cut and fill cross sections. The unit costs of cut and fill in his formulation was assumed as soil type function. Jha and Schonfeld [20]further improved and modified the previous works involved in highway optimization with GIS and GA.

The alignment of optimization model by Jha and Schonfeld [21]involved in the development of the model provided by Jong [10] and Jong and Schonfeld [18] is shown in Fig 1for a more practical highway optimization model that can also work with the maps and GIS databases.

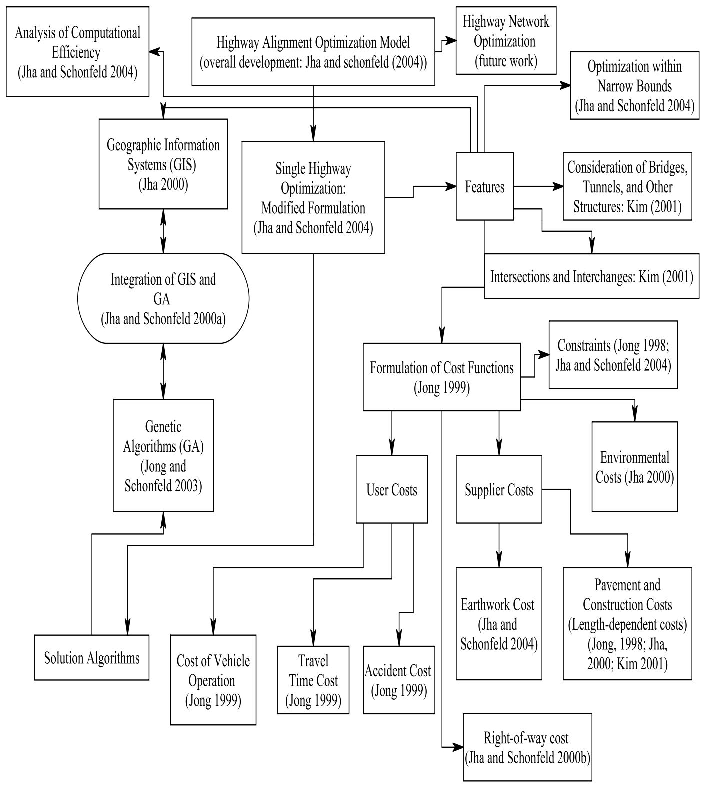

Fig 1: Alignment of optimization model [21]

Whereas the integration of GIS and GA will allow the direct use of databases and real maps to increase the computation time and this increase may be due to the following facts:

1. Required spatial analysis in environment for GIS computing
2. Several geographic entities involved in the search space like the existing highway networks, environmentally sensitive regions, land parcels.
3. Several alignment alternatives to be investigated by the genetic algorithms.

It was expressed by Jha [19] that the computation time increases along with the increasing number of geographic entities in the search space that includes streams, land parcels and roads.

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G. Multi-Objective Optimization

The multi-objective optimization is normally defined as the optimization and search of multiple conflicting objectives and a set of optimal solutions known as Pareto-optimal solutions was led by the search of Deb, Mohan [22]. In this method a non-dominated solution is known when the value of at least one objective is better than the rest of the solutions and the non-dominated set of solutions has made the Pareto-optimal front. According to Deb [23] there are many applications and algorithms of multi-objective optimization but none is applied for a complex decision making problem like optimization of highway alignment. Most of the complex real-world problems are avoided by the existing available algorithms and any given multi-objective optimization problem transforms into a single-objective optimization problem mostly by devoting the weights onto objectives. The transformed single objective function can apply these algorithms and theories for the classical single-objective optimization and appears to have a basic difference in between the transformed single-objective optimization and multi objectives according to Deb [23].

III. SAFETY DURING HIGHWAY CONSTRUCTION

Many serious problems are imposed by road accidents to the society and the costs of road traffic accidents on the society, individuals and property are considered to be significant. In Europe more than a million are injured and nearly 40,000 people die in a year due to the road accidents [24].There are also considerable costs which are related to road accidents that includes direct economic costs of lost output; costs of human (e.g. willingness to pay to avoid grief, pain and suffering); costs of damage to vehicles and property; medical costs related to road accident injuries; insurance costs and police costs according to the survey of [25]. It was estimated to be around £15 billion for the total costs involved in reporting the road accidents that happened in Great Britain, 2010 [25] and it is also estimated that the economic costs of road accidents for high income countries are around 2% of their Gross National Product [26]. Therefore, road safety improvement is one of the main concerns in transport policy making.

There are several research efforts in the recent years for developing the factors concerned in affecting the road safety like (what contributed or caused to accident) and developing road safety theories (why accident occurred) according to the research carried out by Wang, Quddus [27].

A. Road safety theory

It can be seen that there is a lack of solid theoretical grounding and research efforts that are related to road safety mainly because traffic accident are difficult to predict and more over road accident happens randomly [28]. More over there is effect of regression-to the- mean as a result road accidents may be non-experimental and truly random according to the findings of Fridstrøm and Ingebrigtsen [29]. In other hand, it is also expressed that accidents are decisive events rather than a random event [30] and therefore the functions that are determining the accidents are considered to be random mainly because the factors affecting accidents cannot be accurately determined by the analysts Wang, Quddus [27].

The injury severity and accident occurrence are expressed by several researchers, for instance Elvik [28] has explained two important theories that are concerned to road safety and are associated with the human behavioral effects and engineering aspects. According to him road lighting enhances vision capability (engineering effect) but users of road tend to be less alert (behavioral effect). Most of the parameters can be associated either with human behavioral or engineering effects and moreover in addition engineering effects can also explain the factors that are associated to vehicle. As an example in comparison to cars larger trucks have most unique parameters that is considered to be most important due to its longer length, high gross weight and poor stopping distance that can be related to the different levels of risk as mentioned by Chang and Mannering [31]. In the same time other vehicle facets like electronic stability control can affect the road safety. Also, other safety theories can be expressed based on the behavioral and engineering theories for example the risk compensation theory that is associated with the behavioral theory expresses that drivers can adapt their behavior to the positioning of a perceived lower risk either by reducing attention or increasing speed particularly when lower risk is created due to the counteraction of accident [32, 33]. The physiological theory may also be associated with and the behavioral engineering theory. For instance drivers are likely to fall asleep or bored on monotonous, straight or two-lane roads with a little traffic [34]. According to this theory if drivers change their behavior according to the types of road either monotonous and straight roads and on the other hand road engineers mainly focus on the road environment as to decrease the driver boredom so that road accidents can be decreased according to Wang, Quddus [27] .

B. Accident creating parameters

According to Wang, Quddus [27]traffic accidents can occur due to the parameters like

- Traffic-related parameter that includes the following sections:
  - Speed
  - Traffic density
  - Traffic flow
  - Traffic congestion
- Environmental parameters
- Vehicle characteristics
- Driver parameters
- Road characteristic features

IV. ROAD CHARACTERISTIC FEATURES

The engineering theory of road accidents can be expressed as that roads which play an main role in road safety and with the improved infrastructure and geometry design it would certainly help to enhance road safety as per Wang, Quddus [27]. According to Lamm, Psarianos [35] highway safety design is an important gold, for instance design speed is considered to be as a developmental context for roadway.

Shankar, Mannering [36] investigated the geometric effects of various roadway (vertical and horizontal alignments) on road accident frequency which can support the above mentioned hypothesis. Also, Shankar, Mannering [37] showed that along with the increasing number of horizontal curves per kilometer on rural freeways it will certainly decrease the possibility of accident occurrence in a 'property damage' related to a 'possible injury'. In the study of Milton and Mannering [38] they observed the frequency of annual accident on the sections of main arterials in the state of Washington and with NB model they found out that short sections have lesser chance to experience the occurrence of accidents than the longer sections; narrow lanes (less than 3.5 m) and the sharp horizontal curves tend to reduce the accident frequency in eastern Washington. A positive correlation was also found between the tangent length and accident frequency before the horizontal curve. These findings expressed that designs of road infrastructure will show effect on the road safety. However, the spatial relationship was not investigated by the authors for the aspect of an accident on one road segment can be associated to the one on the adjacent segment when they are sharing environmental conditions, similar traffic or infrastructure.

A nearly similar type of study was carried out by Noland and Oh [39] ;Haynes, Jones [40] and Haynes, Lake [41] for the factors associated to aggregate area level. Noland and Oh [39] also investigated the data of county-level highway from the State of Illinois in US and showed that there was increase in the number of lane widths and the lanes were related to the increase in fatalities and the increase in the outside shoulder width was expressed to be related to the reduced number of accidents.Kononov, Bailey [42]in their study showed that the increase in the number of lanes will always led to the increase in number of accidents and most probably it is because of the increased potential lane-change-related to conflict opportunities.

Haynes, Jones [40]The road curvature and its relationship to traffic accidents at the regional level in England and Wales was investigated by Haynes, Jones [40].Their research showed a number of measures for road curvature and that was obtained from the regional level, road curvature is a preserver parameter meaning that more curved roads in an area leads to lesser number of road accidents, which resembles the results of Milton and Mannering [38]. The similar type of study associated to the New Zealand data [41] showed that road curvature has an inverse relationship with accidents leading be fatal in urban area. The curvature was detected as a preserver parameter and the results were nearly equivalent with their previous research based on the Wales and England data [40], although the findings were not consistent. It is mainly because the two countries have different demographic and land parameters also the used units of spatial are also appears to be different (regional vs. territorial local authority). A similar research carried out byWang, Quddus [43]showed that road curvature are negatively related to road accidents using section-level data in England, which is associated to the findings of Haynes, Jones [40].

According to the above mentioned study it is observed that road curvature is preserver (i.e. reduce accidents).This is also counter-intuitive and possess conflict with some of the existing researches being carried out. For example Abdel-Aty and Radwan [44] detected that the degree of curve enhances the number of accidents on the road segment. This may be because of the using of different curvature parameters such as mean horizontal deflection angle, degree of horizontal curve per 100 m arc, minimum radius, number of horizontal curves per mile, bend density as per the results of Abdel-Aty and Radwan [44], Haynes, Jones [40], Noland and Oh [39] and Shankar, Mannering [36].These above mentioned researches were also carried out at different scales by Openshaw [45]. The curvature can be considered relatively dangerous when considering its engineering effects and thus from the behavioral facts, drivers may drive more cautiously and slowly on the curved roads. As mentioned above on straight roads, drivers are more likely to get bored or fall asleep (physiological theory). So, the total safety effect of road curvature (compared to straight roads) is probably being mixed and extra research is needed for further analyzing the road curvature effect on the road safety measures.

The improvement of road infrastructures (e.g., road pavement and upgrading) and roundabout design are also considered to be beneficial for safety. Navin, Zein [46] have shown that not only better vehicle design, but improvements in safety parameters of road can also decrease the injuries severity during the occurrence of accidents and this can be done by complex intersection geometric upgrades or through the enhanced signal visibility. Perez [47]also expressed that improvement of highway quality has positive effect on the significance of road safety.

The effects of various parameters that are associated with the characteristics of road safety were reviewed in this section which includes road geometry (number of lanes, road curvature) and infrastructure (road upgrading and etc.). It is also found that due to the decrease in the number of lanes in roads would certainly decrease the cause of accidents and the improved infrastructure of road also would decrease accidents. Among the various parameters, road horizontal curvature significance is found to have a mixed effect on the safety of road [27], whereas some research found it to be negatively related to road safety.

V. SUMMARY AND CONCLUSIONS

The determination of optimal road candidate is one of the important objectives for designing and planning the highways. In order to find out the optimal road candidate effectively it is very important to understand what and how factors that affects the trend of optimization. The factors affecting the alignment optimization are numerous. This paper has offered a review of current literature on road optimization models and the effect of various parameters, with a focus on the factors related to safety (road, traffic, environment, vehicle, and driver). It was also found that many of these factors have been investigated from a range of perspectives using various methods; and some of the factors effects are mixed for the determination of optimal road candidate.

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