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Road Upgrading in Terms of Geometric and Functional Characteristics

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Abstract

The road network plays a vital role in the economy of any country and maintaining the infrastructure at a level that serves the current traffic needs is a critical element. Road maintenance directly affects road users. If it is not adequate or if it is not done in time, the damage that will occur, in a national and provincial network, may be unmanageable and will affect the increased operating costs of vehicles, delays in travel, increase in the accident index and generally reduce the reliability of transport services. When corrective interventions can no longer be postponed or cancelled, extensive restoration and reconstruction work takes place, which costs much more than the simple / preventive maintenance that can be planned and carried out in a timely manner. The protection of the existing road network is necessary and its maintenance in good condition is a dominant issue for a Management Body and often precedes as a priority even a new investment in the field of road infrastructure. This paper focuses on road network management from the point of view of upgrading and maintenance. An optimization methodology is proposed depending on the condition of the road, so that the choice of operation is optimal for the current situation. In this way, unnecessary expenses, which are brought about by the usual maintenance works, are avoided, while the street cannot serve modern traffic needs efficiently.

Keywords: Management systems; upgrade model; load-bearing capacity; road maintenance.

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1. Introduction

In the age of the post-industrial revolution, common restoration processes of the road network are extremely incomplete, which is presumably based on the maintenance of road damage in most cases, excluded few exceptions. The proposed model relies heavily on the one proposed methodology by the author in [1], but presents greater simplicity and flexibility in work planning as it distinguishes three levels of upgrade and considers the performance of road sections an important selection factor. The qualitative and quantitative criteria are integrated to a greater grade in the Greek reality with the almost exclusive use of the road design study guidelines (RDSG-OMOE). The investigation of the most appropriate option begins with the operational classification of the road network and the calculation (or forecast) of the required level of service, the use of the three safety criteria if possible from the available means, while there is additionally the proposition of the C index and the ECR correlation equation (Estimated Crash Rate) as a new geometric element of competence, where the number of accidents can be estimated when no data is available. Alternatively, as far as the social impact is concerned, either the procedures of the HSM Highway Safety Manual or the author's model manual, in [4] are proposed to predict and calculate the accident rate. The type and degree of upgrade work depends to a large extent on the future level of service required, as long as the growth rate of traffic can be predicted. The basic levels of upgrade are:

- Minor upgrading
- Moderate upgrading
- Major upgrading

The first level of upgrade proposes exclusively maintenance work and possibly small construction interventions. The second level of upgrade mainly involves restoration work (redesign of level junctions) or extensive maintenance (installation of a new asphalt pavement throughout the section), but under certain conditions (third case of safety criteria) reconstruction work may be required. Finally, the third level of upgrade includes the most expensive work, which is the reconstruction or redesign of the road [1,2,3,4].

2. Literature Review

Globally, researchers and various organizations have been working for many years on the maintenance of the road network and especially road surfaces. Existing upgrade models need to be constantly improved, and the harmonization of various parameters and criteria calculation processes is in urgent need of implementation worldwide within a single framework. Currently, some models and methodologies from the international literature are being considered, as well as the strategies followed by some countries, as follows:

1. The Transport Research Board of the United States set a decision methodology for sustaining and reconstructing roads of low traffic, in order to calculate financial issues for rehabilitation and suggest an index for the estimation of road roughness [5].
2. The World Road Association's Handbook for the Development and Management of Highways includes the forecasting of road performance and maintenance, the results of road improvement, the costs and

benefits of users, environmental impact assessments, financial indicators etc [6].

3. The Transport Research Board of the United States, in 2003, published the results of a study titled "Geometric design consistency on high-speed rural two lane roadways". They made a survey of geometric design consistency, specifically for two or more lane rural roads. They produced a series of rules and equations, in order to improve design consistency, which they are available for use in expert systems, for example, IHSDM (Interactive Highway Safety Design Model). A designer can also use those rules in order to make his own evaluation [7].
4. Research programs by Fitzpatrick and his colleagues in [9] that review design consistency quantitatively and the authors in [8] on the design adequacy of the road based on quantitative criteria such as, geometric features (type, station, work-load potential rating Rf, 85 percentile speed, sight distance to geometric feature, separation distance from last geometric feature, carry-over factor, feature expectation factor, driver unfamiliarity factor, driver work-load factor, in order to calculate the level of consistency of feature WLn [8,9].
5. Research project of Alexander and his colleague in [10] on the design adequacy of the road based on quality criteria. They described the ways of prospect and prospect violations that affect the driving performance. They used historical data in order to describe a variety of situations in highways where expectancy influences driver's behavior. Finally, they introduced an approach to analyze equivocal locations and develop a system of improvements [10].
6. The Project Development and Design Manual (PDDM) of the Federal Highway Administration (FHWA) proposes a built-in a five dimensional model based on cost, schedule, technical, context (external influences) and financing (project funds) [11].
7. The Minnesota Department of Transportation (Mn / DoT) uses three indicators to present and quantify the state and condition of pavements. Those three axis include maintenance needs, preservation needs and improvement needs [12].
8. The Transportation Association of Canada (TAC) publishes the Canadian Guide 3R / 4R where in 3R (Resurfacing - Restoration - Rehabilitation) it incorporates the concept of Reconstruction. The main scope of the 3R/4R guidelines tend to prolong the life of existing paved highways and amplify road safety on network basis. Also,it promotes the motivation of using low-cost opportunities for rehabilitation [13].
9. The Vermont Transport and Communications Directorate uses a system that includes various "Level of Improvements" (LOIs) that are mainly based on the functional categorization of the road, Those LOIs include interstate/freeway, other principal arterial, urban minor arterial <5000<, rural minor arterial <2500<, major collector <2500< and urban collector [14].
10. The state of Saskatchewan uses a similar system to that of Vermont for low-traffic roads, meaning that this approach is based on specific "levels of improvement" (LOI) which depend on the geometric characteristics of the road, the grading of the road surface and the surrounding state of the network. Minor upgrading has appliance on physical, functional and safety problems, major upgrading includes changes to subgrade, improvement to horizontal/vertical alignments and reconstruction includes the design, rebuilding and major improvements [15].
11. Road maintenance strategies in France and South Africa. France uses two preservation treatments, the

first is mill and inlay including the application of a high modulus asphalt mix and the second adopts the application of cold asphalt mix. While in South Africa mainly utilize chip seals and in some cases in combination with hot asphalt mix overlays [16].

12. Road upgrades in India, specifically the case of Pakistan where a continuous speed profile was used and all data were collected with a VBOX device (GPS device) that it was mounted on a car. All collected data were combined with the driver's behavior in order to reach a holistic result [17].
13. Road upgrade program in New Zealand and Australia. The first country has a three division management which includes transport planning with a thirty year horizon, capital projects with long term investment programs and network operation which includes maintenance and operation functions. The second country uses a policy which is based on maintenance, preservation and environment road operation which includes roads, bus-ways and light rail [18,19].
14. Maintenance practices in the UK, which uses a three step management, in particular prevention is better than cure, do the job in the right way from the first time and clarity for the public [20].

3. Suggested Model

First of all, the model is based on the OMOE-LKOD (Roadmap Studies Study Guides-Road Network Operating Guidelines), OMOE-D (Roadmap Design-Cross-sectional Studies) and OMOE-X (Roadmaps), where the evaluation of engraving features is taking place. The road section under consideration is classified into functional group, level and cross section. The methodology of the Highway Capacity Manual (HCM 2000) is used to calculate the service level. Finally, the segmentation of the road network, meaning the subdivision of the road under consideration into similar sub-sections, is an important step, because it largely determines the correct assessment of the road condition and the proposed model mainly uses the instructions of the HSM (Highway Safety Manual). If there is a service level E or F, after the calculations, the project is automatically classified in the third level of upgrade (major upgrading) regardless of the condition in the functional and geometric characteristics of the road, which are taken into account during the evaluation. The best choice between reconstruction or redesign arises after assessing the environmental impact of the study area and assessing inherent constraints related to possible adjacent sites (archaeological or historical) or whether there are grounds for accessibility or even road safety such as the incidence of a large number of traffic accidents. If there is a service level D, after the calculations, then the second upgrade category (moderate upgrading) is selected which may include either extensive maintenance work with successive coatings of asphalt mixture along the entire length of the road (case 1, safety criteria), or road restoration works with geometric improvements at the junctions and in the curved sections (case 2, safety criteria) or as a rule reconstruction (case 3, safety criteria) even to a lesser extent compared to the maximum upgrade or, finally, simple corrective construction interventions (special: case 3, criterion 3). If the service level is C or B or A, then minimum upgrading is selected and safety criteria should be considered in order to perform specific maintenance work or small construction interventions. These works (renewal of road surface with carpet, crack sealing, maintenance and repair of protective parapets, etc.) take place after the assessment of the condition of the road surface and the research of the safety equipment and the study of the traffic. In the road section under consideration, the technical works that may also interfere are also checked, such as upper or lower crossings. In the case of a requirement of great widening of the road (case of major upgrading), the need to blow up and build a new bridge with new and modern specifications will be imperative. The cost of the work in this case may be very high due to the large interventions (blasts, molds, concrete, and reinforcement), the required excavation works and the forced expropriations [2,21].

3.1 Evaluation of the condition of the road

It is an on-site quality investigation of the occurrence and to what extent (through visual inspection or through electronic recording) of possible cracks, potholes, folds, ruts. The number and width of traffic lanes are also investigated, if there are emergency lanes (LEAs), multi-use lanes or guidance lanes, hard or soft shoulders, etc [2].

3.2 Evaluation of safety and traffic control equipment

A visual inspection examines the existence and condition of the safety parapets, the electric lighting poles (if any) and the condition of the slopes and the side vegetation that prevent visibility. Finally, the horizontal and vertical marking and the marking of the level nodes in terms of their suitability and adequacy are checked [2].

3.3 Evaluation of road placement features

The methodology for determining the category of road in the study area consists of five steps (issue 1, OMOE-LKOD, p. 19). Then follows the evaluation of the cross section of the road with the help of the OMOE-D instructions, issue 2. Based on the appropriate cross section (a to z) the sufficient width of the traffic lane is selected based on the OMOE Table and is compared with the actual one in terms of adequacy. The illustration of the typical cross-sections with separate traffic surfaces and with a single traffic surface with the complete descriptions are described in detail in the OMOE-D guide. The allowable values of the road characteristics are then defined so that they can be compared to the values of the real conditions and the road surface can be evaluated in terms of these characteristics. The elements that mainly interest us are the minimum radius of curvature, the maximum length of the slope, the maximum inclination of curves and the minimum lengths of visibility for stopping, overtaking and deciding [2].

3.4 Road service level assessment

For the evaluation of the required level of service (LOS, Level of Service) the methodology of the Highway Capacity Manual for the two-lane roads is followed (Fig 1). According to the methodology, the input data are the geometric and functional elements of the road (traffic lane width, shoulder width, length of study section, road category, hourly traffic load, traffic composition, access points, percentage traffic direction distribution, peak hour rate) the required demand volume and the SFM field speed or the BFFS (Base free-flow speed).

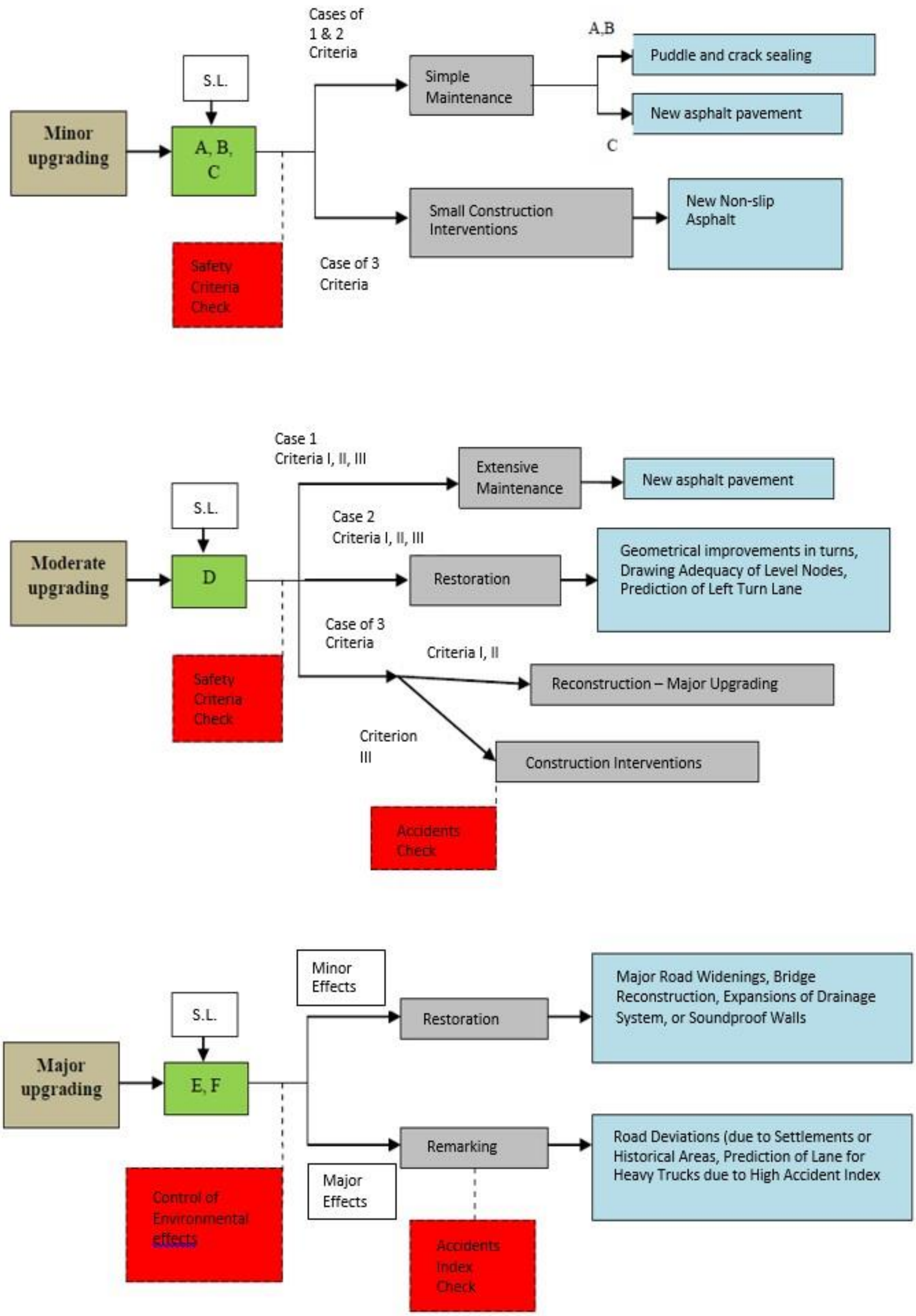

Figure 1: Logic diagram of a proposed road network upgrade model

Then the average travel speed ATS and the percentage time (%) spent following PTSF are calculated and finally the level of service of the road axis of the study area is estimated [21]. Two alternative strategies can be used to calculate the traffic load: (Giannopoulos, 1986)

- Hourly loads during peak hours along sections of roads
- Average daily traffic loads during the days of a week, a month, or a year

Measurements to determine loads during peak hours cover only the hours of heaviest traffic. The measurements should cover all these hours and it is desirable to cover a period of one week (Monday - Friday). For each day the peak load results as the highest hourly traffic load measured during the period of the highest loads and from the respective measurements of all days the average is derived [22]. The calculations of the traffic load and the LOS of the case study are presented in Annex A. The model proposed for Greece was based on a different approach focusing directly on the effectiveness of alternatives. A key priority was the categorization of the road into four classes and the upgrade alternative for each road category is determined specifically according to the shortcomings of the road. The best alternative strategy is selected through the specific selection criteria, considering all the important issues, including safety, adequacy of the layout, level of service, comfort and environmental adaptation. The existing model does not only focus on the road but also examines alternatives based on clear criteria including social impact. The following is the proposed road network upgrade model with three distinct levels [1].

4. Implementation of a proposed model

According to the methodology of determination OMOE-LKOD, this is a category of AII road of cross section c2 with a unified traffic surface. Initially the road network should be divided into analysis units consisting of homogeneous sections. According to the proposed segmentation methodology, the initial section of approximately 318m has a different functional classification because it includes three traffic lanes (one in one traffic stream and two in the opposite traffic stream) and is defined as the first distinct section. The second section with a length of about 3km has as a special feature access to the adjacent properties and the third section with a length of 2,946m has as a special feature non-access to the adjacent properties (fig 2).

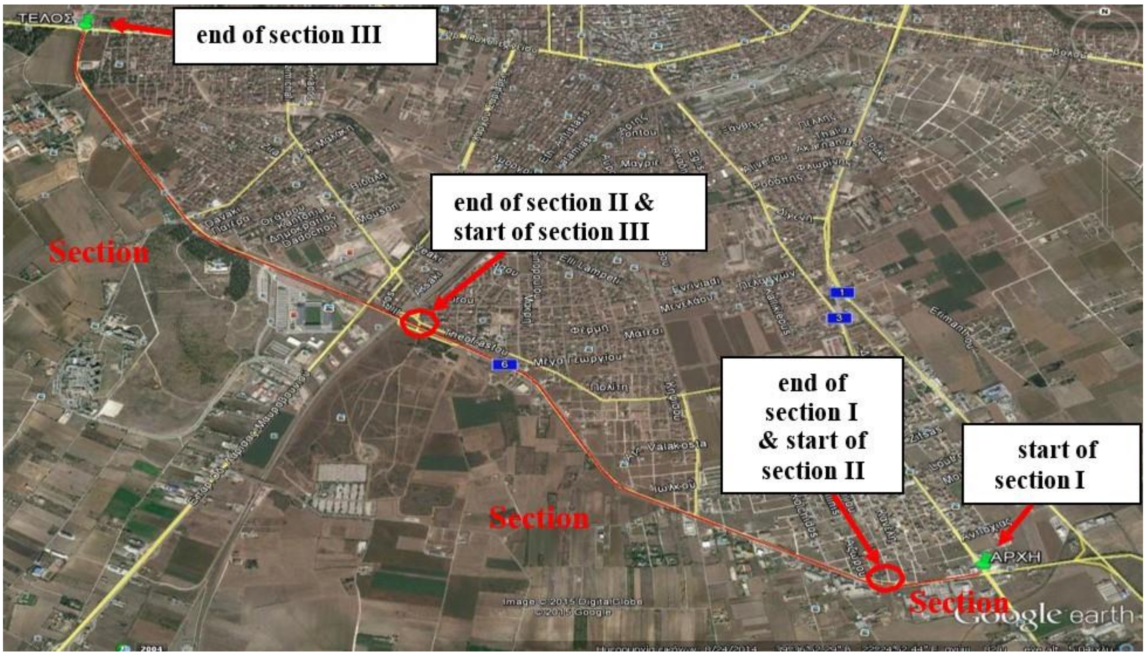

Figure 2: Case study segmentation (source: Google Earth)

The assumptions taken into account are the following:

1. The service level is calculated only in sections II and III and is considered constant throughout their length;
2. No separate calculation of L.O.S. is carried out on traffic light regulated nodes and are not considered to have a significant effect on the functional characteristics of the components to which they belong,
3. The ground is considered flat as there are no particular elevation differences apart from the bridge access where there is a slight longitudinal slope; and
4. The dense access (entrance / exit) to the large shopping malls of the road section I decisively affect the speeds of the vehicles and therefore the operating speed, therefore this section will be checked only visually regarding the geometric and functional characteristics.

Table 1: V_{85} measurement criteria (source: NTUA Transport Engineering Laboratory, 2006)

I	Off-peak measurements, holidays and weekends
II	Good weather conditions
III	Free flow of vehicles (vehicle transit time interval greater than 5sec)
IV	At least 125 speed measurements per direction
V	Duration of measurements not more than two hours (Stop the measurements after two hours, even if the required minimum number of 125 measurements per direction has not been collected)

Hourly loads during peak hours were used to calculate the traffic load (Annex A). The calculation of L.O.S. in sections II and III is done for a design period equal to 20 years, taking into account a rate of annual increase in traffic load equal to 1.5%. The low rate is justified in times of economic crisis. Operating speed V_{85} is calculated for both curved sections and straight ones. For its calculation in each section, the method of journey speed was used, subtracting each time 15% of the highest speed measurements, while the criteria proposed by the Transportation Technical Laboratory of NTUA were observed (Table 1).

According to the OMOE-X instructions, the velocity of study Ve for existing roads, in case this cannot be determined, is taken to be equal to the speed limit imposed by a traffic sign. After an on-site survey on the road section under study, it was found that there is a regulatory sign with a speed limit of 90km/h, so for the needs of the existing study we will have Ve = 90 km/h. Therefore control of the road study data and the safety criteria will be done based on the calculated speeds V_{85} and the study speed Ve = 90 km/h. Figure 3 shows the exact position of the AB line and the CD curve, where the velocities V_{85i} and V_{85+i} were calculated for the road section III. The length of the line is equal to 500m and the length of the curve is approximately equal to 192m.

Figure 3: Sequential data of the "straight-curve" study for the calculation of the V_{85i} and the V_{85+i} on road section III (source: Google Earth)

4.1 Evaluation of the condition of the road

This is a classic two-way street with a soft variable width shoulder. The average width of the traffic lane is equal to 3.60 m and the average width of the support varies up to 0.6 meters. The road surface presents longitudinal cracks with a high degree of wear in some places, transverse cracks of lesser intensity but also alligator cracks. Intense deformations (swelling and pushing) occur at the level junctions due to intense braking effects but also sweating effects.

4.2 Evaluation of safety and traffic control equipment

The safety equipment needs to be replaced in some places and there is a lack of railings in dangerous sites. Signage is considered satisfactory.

4.3 Evaluation of road placement features

Based on the V_{85} operating speed, the maximum inclination in the curves and the minimum visibility lengths for stopping and decision exceed the limit values provided by the specifications. In the examined curve the minimum length for overtaking (min_{Su} = 525m) is not available for this and there is a double line overtaking prohibition. In the straight, although the length is available for overtaking, there is a relative prohibition due to road widening works and design of a level junction with provision for a deceleration lane. Finally, according to the category of the road, the relevant specifications for the relevant widths of traffic lanes and supports are met.

4.4 Evaluation of the requested level of service

The required level of service according to the calculations for a 20-year plan, i.e. for the year 2035 is equal to D (according to HSM) [3].

4.5 Evaluation of safety criteria

According to the first safety criterion, in the straight segments the difference between the design speed and the operating speed V_{85} is between 10 km/h and 20 km/h, so the design is considered mediocre and improvement work is required on a case by case basis. On the contrary, over the curve the difference is marginal at 10 km/h so the design quality is considered good and no improvement work is required in the layout. According to the second safety criterion, the difference between the operating speeds over the straight segments - curves is less than 10 km/h so there is harmony and continuity in the layout. For the third safety criterion, good design quality results when the available lateral friction coefficient fR is equal to or greater than the required fRA coefficient. For operating speed on the curve V_{85} = 80 km/h, the maxfR allowable = 0,124 is derived, so from the instructions the available coefficient fR will be equal to fR = 0,0868. In conclusion, the minimum required radius of curvature for good design quality is equal to R_{min} = 343m. According to L_{amm}, the calculations are more conservative and using the equation for a flat topographic relief results in a minimum radius of 284m [23,24].

4.6 Selecting an upgrade level

Based on the requested S.E. for a 20-year plan, road upgrade works of major level upgrading (major upgrading) are proposed, and in particular reconstruction works and not redesign works. The presence of the Byzantine Museum, the sports facilities and the shopping center that is planned for construction, make the first choice mandatory. Extensive widening works are proposed at selected points and formation of level nodes with provision for lanes for deceleration and acceleration. Also for safety reasons, parking on the side of the road at the height of a private school should be prohibited. At the level junction with signaling at the height of the ATEI of Thessaly, road widening works and redesign with a small increase in the width of the traffic and deceleration lanes (left turn) are proposed. Finally, asphalt paving works should be carried out due to extensive damage to the pavement and the use of safety railings at selected points to prevent dangerous maneuvers and the passage of vehicles from the side road to the main road [25].

5. Conclusions

The operation and maintenance of any fixed value constitute the third phase in a complete life cycle consisting of a total of four phases. Optimal management of the road network, as a fixed value, will arise if it is planned and implemented at the appropriate time and implemented in the appropriate location. The objective of optimizing the upgrading and maintenance of roadways will only be considered successful when the economic, social and environmental benefit of road users is taken into account at the same time. The methodology followed is largely based on the Greek Road Works Study Guidelines (LKOD) which are framed by the Motorway Traffic Capacity Manual of the Transport Research Board (TRB). The actual data required come from the visual inspection of the study area, the possible knowledge of elements of the road section implementation study, rural measurements, photographic impressions, etc. Measurements of operational speed and traffic load are critical elements for determining the existing road safety situation and for assessing the level of service requested respectively. Through the evaluation of the current situation, which prevails internationally but also the Greek reality, which concerns the methods of upgrading and maintenance of roads, relatively useful conclusions can be summarized as follows:

1. The optimization methods traditionally used rely heavily on objective evaluation and the use of prioritization rules. The latter are based on either economic criteria or technical criteria. Examples of financial criteria are the cost-benefit ratio and the cost-effectiveness method. Technical criteria include parameters such as the category of the road, the traffic load and the quality indicators of the road [26].
2. Upgrading the existing road network to the current reality of the severe economic crisis without any unnecessary and pointless expenses is a prominent issue for the responsible authorities. The previous tactic of improving the road without planning and with rough studies has resulted in recklessly spending money which could be used towards other more useful purposes. Based on this finding, a road network upgrade and maintenance optimization model is proposed that provides three key alternatives. These proposals are both comprehensive and clear and are based on the results of the evaluation of the functional and geometric characteristics of the road, the surface condition of the road, the environmental adaptation and possible accessibility and proximity restrictions [27].
3. The usual practice of visual inspection of the surface condition of the road for its evaluation, is supplemented by the assessment of the functional and geometric characteristics of the road. In this way an overall picture is presented without degrading some features, so the proposed solution, if not optimal, is at least very close to it.

6. Suggestions

1. The use of an alternative criterion was proposed, which correlates geometric design adequacy with road safety and accident rate. It is also proposed to investigate a model of accident analysis based on geometric elements of the road. Although not applied in the case study, as specialized measurements are required, future use in practical problems will be quite interesting for a more accurate investigation.
2. In a road network, which consists of individual sections, the decision to maintain one of them depends not only on its condition but also on its geometric characteristics and its traffic load.
3. The segmentation process for any case study is a critical element in the optimization process. Correct segmentation of the road is always one of the most important parameters. In the international literature, various methods are proposed so that the results of each evaluation reflect the true picture of the road

network.

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