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DETERMINATION OF ENVIRONMENTAL IMPACTS DUE TO ROAD FUNCTION IN FORESTED AREAS

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ABSTRACT
The tendency to apply mathematics generic models to completely different projects, without any adjustment, must be viewed with a critical attitude. This is especially true in cases concerning the complex problem of environmental impacts with many different weighting factors for the various components. The need for a flexible resource that brings together the virtues of speed in the analysis and simplicity in the presentation of the results led to the creation of a set of PC subprograms in the Transport Engineering Laboratory of the Democritus University of Thrace. A procedure has been developed through which for a given road alignment the loss in surface area is calculated. The main expected impacts under consideration are the total loss of woodland, the temporary damages to the forest, long-term and delayed damages due to emissions, and damages due to lowering of the water table. The software output permit the location of spots where damages to the environment are expected making it possible to provide measures which could minimize the adverse effects of a road project on the environment. The program needs improvements in the handling of data in order to cooperate with other modern tools and compare different applications in real project situations.

KEYWORDS: software, effect, forest road, design.

INTRODUCTION
The continuous effort to protect and promote the wealth of each region in a country imposes harmonious integration of motorways in the environment; therefore, the road works should meet all requirements of the current legislation [1, 2]. The protection of the environment from all project activities, the monitoring of potential effects due to the construction and operation of the road, and the implementation of appropriate protective measures are defined as primary objectives. In this context, computer programs may play an important role. Software can quickly, accurately and efficiently attribute the existing situation and, through combinatorial analysis of the weight of each effect, can lead to a decision in the direction of conservation and protection of natural wealth in the region crossed by a roadway [3].
The obligations of contractors regarding the conservation of the integrity of the natural beauty, the sound protection, removing litter and waste, the protection of soil and water from pollution are determined in environmental terms for the project (Approved Environmental Terms and Conditions). In these terms, monitoring programs should be included, as well as actions to mitigate gaseous air pollutants and noise [4]. Continuous improvement of the system is feasible provided that the provisions of the international standard ISO 14001 for the protection and management of the environment, which is designed to apply to any part of the world, are fulfilled [5].
The construction of a new road is a significant intervention in nature and in landscape. Any attempt to standardize it using mathematical models, which are mandatory generalized, will require deep knowledge of the effect of a road alignment on the ecosystem and the landscape [6, 7]. The tendency to apply universal mathematical models for completely different projects without any adjustment must be viewed critically. This does not mean that applicable rules and relationships do not exist in order to be used in the construction and amendment of models; it must rather make a great effort to this direction.
An effort oriented to the resolution of the discrepancy between universal models and the proposed road alignment is the subject of Environmental Impact Assessment achieved by various systems. A system of sub-programs of this type has been developed in the Transport Engineering Laboratory of the Democritus University

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of Thrace in order to analyze the full geometric characteristics of a road project and assess the impact caused by both the construction and operation of roads to ecological potential of space.

MATERIALS AND METHODS

The part of the computer program relating to the impacts on the environment due to the operation of roads whose alignment passes through forested areas has been analyzed. The goal is to highlight the dominant idea on which the software is based and the way the relationship between the user and the computer is interactively developed when data is imported as well as when the management of results is necessary.

The model of road impacts on woodlands investigates the way roads affect the ecosystem of the forest during their construction as well as during the period of their operation. The expected impacts are divided into:

(a) Total loss of woodland (due to tree cutting for the alignment).

The corridor opened into the forest along the roads, must be wider than the width of the alignment (occupancy width) including all embankments and road cuts. Moreover, there is a need to construct forest roads. To protect the traffic in the roads by falling trees, a safe distance along both sides of the road is required. This distance is calculated in the alignment software as clearing width and is dependent on the height of the trees [8]. In Greece, the safe clearing distance can be considered to be equal to 10 m, while the width of the corridor in the forest can be as large as 30 m [9].

(b) Temporary damage to the forest (trees brought down due to wind, bark burning).

All trees may be brought down at some level of force from wind, acting either singly or in combination with snow or ice. This can be explained by the windthrow phenomenon which can uproot a tree, depending on its height and diameter. With the tree-trunk acting as a lever, the force applied to the roots and trunk increases with height; thus trees having larger heights are more susceptible to windthrow. The intense of the phenomenon increases for trees which have lost the physical protection offered by surrounding trees removed by clearing cuts for road construction. The neighboring trees keep the others from bending very far and break. Trees being most at risk are those found in environments changed during the last five to ten years.

If trees on the sunset side are removed in order to construct a new forest road, then it is possible for a trunk burning from the sun to appear. The severity of the damage determines the degree of the risk for the tree and the time interval which can last. The damage due to sunburn could be similar to the one caused by a lightning. Young trees and trees with thin bark are most prone.

(c) Long-term and delayed damages caused by emissions during the period the road is in service (exhaust gas, deicing salts, etc.).

The exhaust emissions from vehicles (SO_2, NO_x and photochemical oxidants dangerous for the forests) as well as their distribution in the soil and in the air have long-term impacts on the remaining woodland surfaces [10]. The impact of the emissions distribution is calculated by the program as surfaces of a specific depth from each boundary line of the carriageway, wherein increased pollutant concentrations can be observed in relation to the daily motor vehicle traffic, the prevailing wind (angle relative to the axis of the road in each position) and the topography.

Many different types of vegetation damage caused by road salting there exist in the forest. It has been shown that the deposition of sodium chloride declines exponentially with the increase of the distance from the road. The greatest spray damage to various species is found within a zone of around 10 or more m from the road. The magnitude of salt damage to vegetation is determined by the variation in climate and local soil characteristics.

(d) Damage to the development of the forest due to lowering of the underground water table.

In forest areas, the lowering of the water table due to road-cuts has a direct adverse effect on the aged tree population, because the forest ecosystem (young trees) is adapted to the new underground water regime, while the older trees could not be adapted. Therefore, the root system of old trees is partially dried and does not supply the tree, while on the other hand the dried part of the roots does not participate to the support of the tree which becomes prone to “fall due to wind” impact. This impact extends to a width dependent on the lowering of the water table, on the tree species (all but pine trees are sensitive to bring down effects), on the age and position (whether it is a part of forest in the interior or on the edge where the impact is mild).

To run the software, the woodland areas are needed as input in the form of thematic maps. On these maps all stocks should be described, i.e. all varieties of trees, in terms of species, age or other diversification, due to which there may be a different effect. Furthermore, the results of the software program employed to perform the calculations of the geometric resolution of the alignment of the road (horizontal alignment, vertical alignment, sections) and which cooperates directly with the analysis and impact assessment sub-routines are required. For the need for thematic maps to be satisfied, not all maps referred in the development of the software are required, but at least the integration of the calculations the following is behooved: any recording or mapping of ecological data, a mapping of sites, landscapes and culture elements, and land use map covering many needs of the program. With the term long-term damage to the forest, the hampering of vegetation growth caused by the lowering of groundwater is meant. Following the temporary damages caused to the forest by the lowering the water table, the forest ecosystem is adjusted in the long-term to the new groundwater regime [11]. That is, the ecosystem reacts sensitively to any change of the balance of groundwater caused by the construction of either road-cuts or embankments.

For the problem of forest damage in Europe, observations in the field and evidence from experiments have indicated that acid rain and its gaseous precursors –mainly oxides of nitrogen (NO_x) and sulfur dioxide (SO_2)$^-$ in high concentrations can be serious contributors. However, there is limited evidence of forest damage at moderate concentrations which are typical of much of Europe. So, it is not straightforward to construct a damage function which can relate forest damage to atmospheric concentrations or deposition of acidifying pollutants on a European wide basis, since usually the data are not supported by field observations. To overcome such problems, models are required which will allow to explore the loss of growth in a forest for varying pollution levels whenever SO_2 and NO_x deposition limits are exceeded.

If the alignment of a road crosses a forest, trees are cut to form a corridor with a width of several meters along the axis left and right beyond the edges of the carriageway (usually about the height of a tree). In the case of forest, the area affected by intense sunshine depends on the orientation of the axis, and the influence of the wind is mainly characterized by the direction of the axis relative to the main wind direction [12]. The width of the forest region depends on the wind component perpendicular to the road axis. The surfaces are calculated as additional "corridor width" in the forest.

Trees in dense flat sites develop thin trunks without branches and thus they are left unprotected after the clear cutting, exposed to direct sunlight without protection capacity for the vegetation. Therefore, the bark is broken and finally the tree diebacks. Such damage has been observed to varying depths from the edge generated after clearance and ranges with sunshine from 0 m to 15 m or even 20 m, in fir and beech forests regardless of the tree age.

In forests, trees are normally protected from the action of the wind. The pathways opened in the forest create corridors where high wind speeds are developed which attack mainly trees with a shallow root system and located perpendicularly to the wind direction. The effect varies in depth between 0 and 30 meters from the edges and is calculated according to the prevailing wind direction [13]. The wind effect is also directly dependent on the lowering of the underground water table, which is caused by the road-cuts [14, 15].

RESULTS AND DISCUSSION

The results furnished by the software include the formulas and calculations of earthworks (volumes of cuts, fills, or embankments), the description of the roadway lane, the clearance width in the road axis route, existing polluted areas in the space crossed by the road, etc. Information related to the effect of cuts on groundwater, to the fluctuating climatic conditions and to weather effects such as sun, rain, wind, snow, polluted air should not be omitted.

As it is shown in the flowchart in Figure 1, the total surface required to be occupied by the route alignment (and thus must be considered as a direct loss of forest surface) is the union of the surfaces: $V=A\cup B\cup C\cup D$, where:

A The surface corresponding to the width of clearing the forest from trees and bushes in order to be protected from fire as well as to protect the road traffic from tree falls (depending on the height of trees). This surface is available for the construction of forest roads. As a rule, a fixed width on both sides of the carriageway is considered.

B the surface required for the construction of embankments,

C the surface of the lane of the pavement, and

D the surface required for the construction of cut sections.

The derived result is finally entered to the program (indication A in the flowchart). Instead, a prepared thematic map with the land occupied may be inserted. Thus, two quantities are obtained: (a) the direct loss of forest surface due to the road (intersection between A and B, $A\cap B$), which is provided by the program in the form of a thematic map and of a table of surfaces with remaining resources and (b) the remaining forest surfaces ($R=A\setminus B$) as the difference of existing forest surface minus the forest surface loss once again in the form of a thematic map and of a table of surfaces with remaining resources, in order to investigate other impacts.

The long-term damage to the forest due to its adaptation to the new circumstances is specifically calculated by the program as an intersection of the "road-cuts effect on groundwater" surface (indication A in the flow chart) with the "remaining" forest surfaces (indication B in the flow chart) providing the possible (long-term) forest losses by the lowering of groundwater", namely: $D= A\cap B$.

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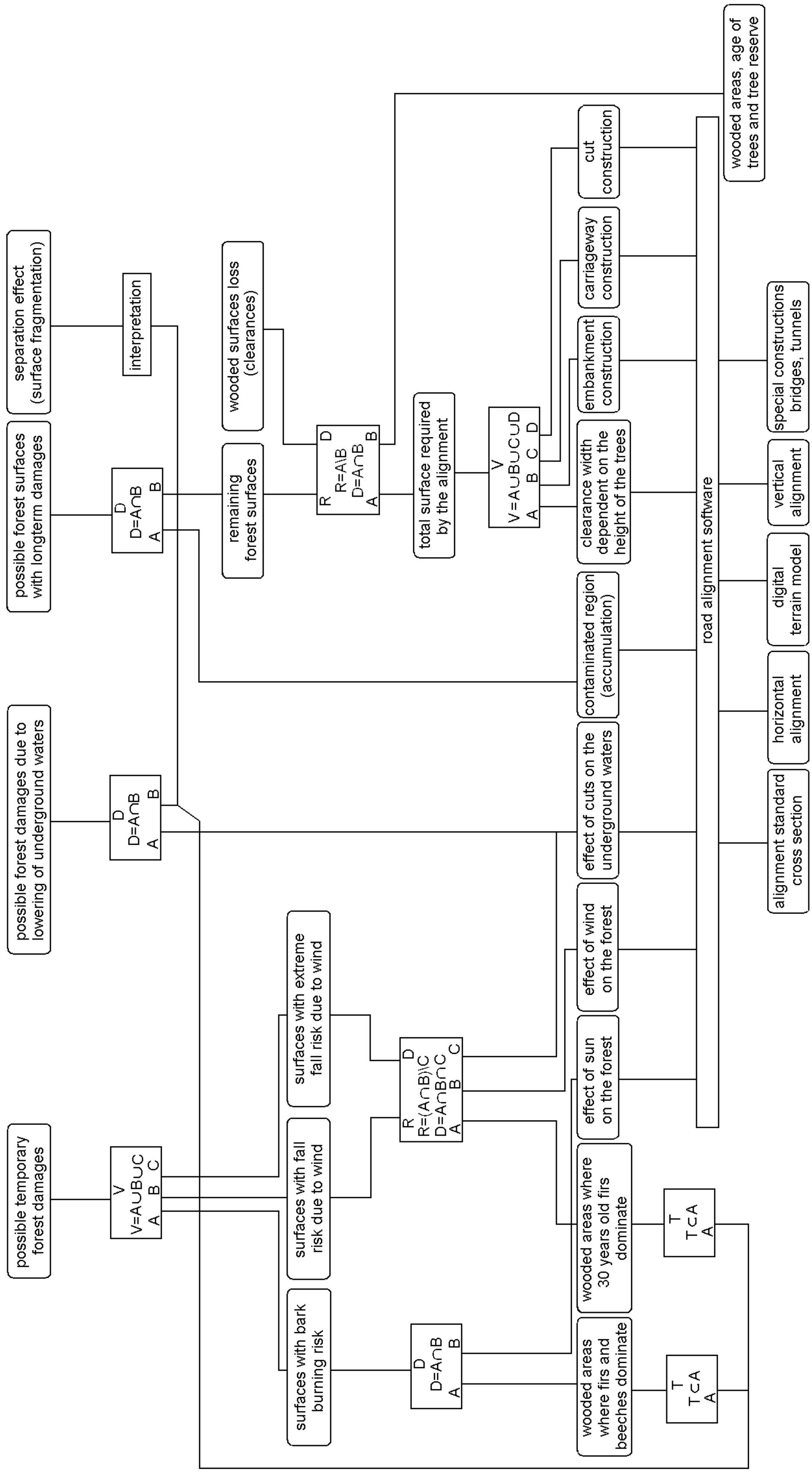

Figure 1: Impacts model of road alignment in woodland regions.

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To determine "surfaces with a risk of falling trees from the action of the wind" A (remaining 30 year old firs) and B (wind effect on forest) in the flowchart will intersect and from the result the surfaces "effect of road-cuts on groundwater" (C in the diagram) will be subtracted. The "surfaces with great risk of tree-falling due to the wind" are defined as intersection of "woodland surfaces with 30 years old firs", indication A, "wind effect", indication B and "road-cut effect on groundwater", indication C. Finally, all surfaces with a risk of falling due to wind action and surfaces with bark-burning are joined to the "potential damage" in the forest, which may not occur in every case.
The program calculates the "surfaces with exhaust gases pollution" on both sides of the road. Instead of the term "surfaces contaminated by exhaust gases", the term "contaminated surfaces" may equivalently be used. The intersection of those two surfaces (in the flowchart is shown as input A) and the "remaining forest surfaces" (data B input to the program) gives the forest surfaces with possible long-term damage, i.e., $D = A \cap B$.
In the program, the effect of high-speed winds is assimilated to a width of up to double of the cut-depth. The result is given as "effect of road-cuts on the underground water-horizon".

CONCLUSION

The management of environmental impact problems due to road function presents great complexity. Regardless of the location-specific characteristics, the integrated assessment of a road's impacts on the environment imposes the construction and use of software capable to compose data from many different sources and varying influence factors categories as well as data of different form (digital files, maps, tables, etc.). The most important outcome will be the alternative scenarios dealing technically with the consequences of major road projects such as those of the new road axis construction.
In the described method a procedure has been developed through which for a given road alignment or alternative options the loss in surface area due to space occupation by the carriageway is calculated. The results permit the location of spots where damages to the environment are expected. Thus, it is possible to take measures in order to minimize the adverse effects of a road construction project on the environment,
The software outlined in this work needs many trial applications, so as to improve the way the input data are it handled, in order to be capable of presenting the results in forms manageable by modern tools, such as geographic information systems, and to compare different hypotheses raised by the user on the basis of the real status of both the project and the environment.

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