

DEVELOPMENT OF THE DESIGN TECHNIQUE FOREST ROAD NETWORK FOR EFFECTIVE TRANSPORT DEVELOPMENT OF WOODLAND IN BELARUS

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Abstract

Given the need to improve the Belarusian forest road networks and the severe constraint on the resources needed to plan these improvements, it is important to target these efforts based upon the available information. Previous research based on existing forest compartment and road network data produced the concept of a methodological study of forest accessibility. This article is devoted to development of the design technique forest road network for effective transport development of woodland in Belarus. The results of this analysis, obtained by use of Geographic Information System (GIS), help the forest manager to allocate efficiently the resources to specific forest areas. The results of the analysis are based on data that are easily obtained with GIS. GIS measures of skidding distance, skidding costs and desirable accessibility are included in the model. Relative accessibility and forest road network efficiency are two important calculated results. The article presents a detailed description of each step of this work.

Key words: forest roads, location, forest network, road density, transport development of woodland.

1. INTRODUCTION AND SCOPE RESEARCH

Forest cover in Belarus now accounts for 37,7% of land area or circa 9,3 million ha. According to the state account of woods for the period with 1994 for 2005 there were positive changes in structure of wood fund of Belarus [1]:

- The area of wood plantings has increased on 392,8 thousand hectares;
- The percentage of forest land of territory of republic has increased with 35,5 up to 37,7 percent;
- The general stock of wood on a root has increased for 320,5 million m³.
- The settlement cutting area on cabins of the main using a wood on republic (scientifically proved norm of annual preparation of wood which is defined by presence of ripe woods) has increased about 5,9 million m³ in 2000 up to 7,2 million m³ in 2006.

Significant investment in forest roads will be required to access this roundwood. To date, due to the pattern of forest ownership, the State has been the major builder of forest roads. However, as private plantations mature and enter the thinning stage, forest roads will increasingly be required by private logging enterprises [2].

Forest roads are necessary to provide access to the forest for general management, maintenance, timber extraction and recreation. Apart from initial establishment, roads represent the single greatest capital investment by the owner. There is a need not only to provide a cost efficient road design and layout suitable for extraction but also to ensure that the forest road is compatible with environmental values.

Forest owners might neglect the timing of forest road construction as roading only assumes relevance when the crop is ready to produce timber. However, if planned at the time of crop establishment, many advantages ensue including:

- ease of layout and survey;
- alignment of road with the existing drainage system;
- unplanted road lines can act as firebreaks;
- reduces risk of windthrow as there is no opening up of the crop;
- improved opportunity to enhance biodiversity; and
- access.

The exception is on peat soils, where road reserves are only cut prior to road construction as the tree roots can provide a base for road formation.

The main stages in road construction are:

- **planning** - roading requirement, road density;
- **survey** - layout, alignment;
- **technical design** - specification, drainage, construction method, costing;
- **contractor selection** - based on detailed specification;
- **formation** - construction of the road base;
- **completion** - surfacing of the carriageway following a period to allow formation to dry;
- **final inspection** - ensuring the road was constructed correctly;
- **commissioning** - putting the road into use.

Once built, roads will require on-going maintenance by the forest owner, especially after harvesting operations and periods of heavy rainfall.

Forest roads in upland areas will be either contour, valley or connecting roads. Contour roads run at approximately the same elevation along their length and therefore will be, more or less, at a level grade. They are cut out of the hillside and are economical to construct. Valley roads are nearly always at a gradient, varying from almost level to the maximum permitted and are located to optimise timber extraction. Connecting roads are those which join up the system into an overall road network.

2. THE DESIGN TECHNIQUE FOREST ROAD NETWORK

2.1. Environmental considerations

The construction of forest roads represents one of the more visible forestry operations and can have a number of environmental impacts including landscape, water, soil, habitat and social/community. This design technique includes practices and guidelines to ensure that all phases in the construction of forest roads are carried out in a manner that is compatible with environmental values and sustainable forest management [3].

Table 1 - Environmental values for various road network construction phases.

Phase	Aim
Planning	Potential environmental risks and construction difficulties are identified at road planning stage to ensure adequate design standards consistent with minimising environmental impacts.
Design	New and upgraded roads designed to a standard capable of carrying anticipated timber haulage traffic for a crop rotation to meet environmental requirements and with safety.
Location	Roads located so as to minimise risks to environmental values and road construction to take account of environmental values during all stages of formation and completion.
Construction	Forest roads and access points to county roads constructed in planned engineering stages, to minimise disturbance to the site, and well in advance of timber harvesting and road haulage.
Drainage	Roads properly formed, consolidated, completed and drained to ensure that the impact of run-off on water quality is minimised.
Maintenance	Road surfaces and drainage works maintained to protect the road foundation, disperse water and minimise environmental impact.

Road density is the number of linear metres of road per hectare. For any given site there is an optimum road density that minimises the combined cost of construction, maintenance and timber extraction. In calculating the optimum density, it is essential to have reliable estimates for:

- volume and quality of timber to be harvested over the rotation;
- cost of road construction;
- cost of road maintenance; and
- extraction method and 'off road' movement cost.

The optimum density is only used as a guide to the appropriate roading for an area. There are many factors which may cause deviation from the optimum and these will be examined later in this chapter. Also, optimum road density does not take account of all the costs and benefits, e.g. recreation, hunting, access for fires etc., so it may be necessary in some circumstances to undertake a more complete cost benefit analysis before proceeding with road construction.

Road density is closely related to the planned harvesting and extraction methods. In Ireland, the most common extraction method is forwarder, although there are some sites which due to slope and/or ground bearing capacity can only be extracted by skyline (cable extraction). There are other methods of extraction that can be used but the two mentioned are the most economical in relation to road density. Typically for forwarders, roads are spaced at 800 m centres providing an average haul of 200 m. For cable extraction, road spacing, and therefore density, is determined by the maximum haul distance (length of cable). Typically in Ireland maximum haul distance for cable equates to 350 m.

2.1.2. Recommendation

1. Calculate the volume of timber to be served throughout the rotation by the planned road.

This volume varies from block to block depending on factors such as site conditions, species, yield class and silvicultural practices but will be independent of road density. Volumes can be calculated using yield models, e.g. and should be reduced to allow for stocking and unplanted/unproductive areas.

2. Calculate the average road construction cost per linear m

The cost of road construction will vary with site conditions and the requirement for any special construction works, e.g. culverts, bridges etc. This cost per m³ of timber increases as road density increases.

3. Calculate the average off road movement cost per m³ of timber (to take the timber from inside the forest to the road).

The movement cost depends on the type of extraction planned, being smallest for forwarder and largest for cable extraction. This cost decreases as road density increases.

2.1.3. Elements of road cost

There are a number of factors that contribute to the overall cost of a forest road and include [4]:

- right of way (r.o.w.) development/purchase;
- road drainage;
- methods of road formation and construction;
- culverting;
- road completion (surface dressing) works;
- large waterway crossings or other structures;
- annual maintenance; and
- operational overheads (planning development charges, design costs, holidays etc.).

Not all of these would be included in optimum road density calculations as they would likely be incurred regardless of the constructed density and therefore do not influence movement cost. They would however have to be considered as part of a cost benefit analysis.

The excluded costs from the density calculations are the r.o.w. costs, and the overheads. Bridges and large culverts have traditionally been included in the calculation but will have a very negative effect on short lengths of road as they add a considerable cost per linear m. It can be argued that like a r.o.w. development cost, they are an extra to the road and do not contribute to a reduction in movement costs. It is left to each forest road developer to make their own decision on this.

2.1.4. Elements of extraction cost

The cost of timber extraction comprises the following [4]:

- setting up on site (machine delivery/skyline set up/removal, etc.);
- machine upkeep (fuelling, operator maintenance, etc.);
- travelling from road to timber (empty movement);
- loading;
- travelling loaded to forest road (full movement);

- unloading and stacking; and
- overheads (machine management, downtime, etc.).

When calculating optimum road density, the only part of the extraction cost that is considered is the off road movement cost as the travel distance is related to the road density. The other elements of extraction cost are independent of road density and are not considered at this time. If undertaking a full cost benefit analysis, the full cost of extraction and harvesting will need to be considered.

2.2. Geometric design standards for forest road network

The purpose of forest road network design is to provide the optimum road geometry to accommodate the planned vehicle sizes and traffic. Optimum forest road network design should minimise the cost of construction, transportation, maintenance and impacts on other resources, and provide for user safety and a stable road with appropriate alignments and travel speeds.

2.2.1. Recommendation

1. Standard forest roads are designed to carry vehicles conforming to maximum legal weights and dimensions applicable to public roads. However economic and external factors will sometimes result in the design of a road to less than full standard.

- e.g. intractable limitations in either public road or right-of-way access routes, terrain (heavy rock outcrop, deep peat) may limit what can reasonably be provided; and
- departures from full road standard must not be lightly undertaken, each case being carefully evaluated on its merits. Such departures must be clearly documented by competent designers.

New and upgraded roads should be designed to:

- comply with the standards set out later in this chapter;
- accommodate the anticipated frequency, type and speed of traffic;
- take cognisance of soil and sub-grade conditions;
- provide for road drainage and water quality requirements; and
- incorporate landscape and environmental values.

It is a characteristic of all forest roads that they are subjected to low-intensity, slow-moving traffic so that some risk of partial structural failure can be taken, where this would not be acceptable on a public highway. However, these risks must be limited to situations where road user safety is not endangered. Safety considerations preclude risk-taking with bridges and embankments.

The designer must bear in mind at all times that the primary purpose of forest roads is for timber extraction.

While some forest roads are constructed to facilitate development and general control of large blocks (development roads), the bulk of road construction will be for extraction purposes. Indeed, where development roads are provided it is almost invariably intended that they should, perhaps after future strengthening, become part of the extraction network. The provision of a forest road is therefore the first element of the harvesting process and represents a significant capital investment.

2.2.2. Element and standards of a forest road [5]

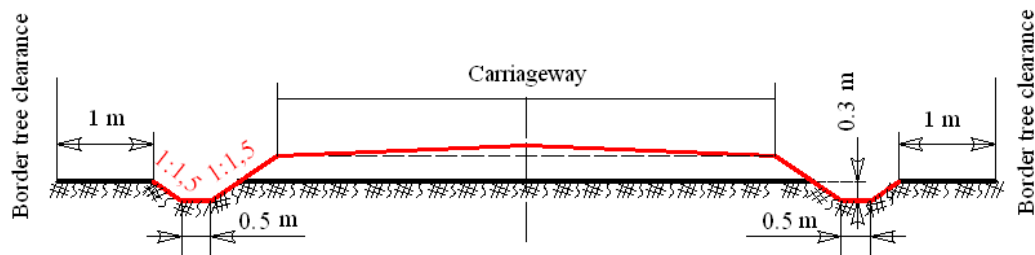


Figure 1. Typical forest roads cross sections for embankments.

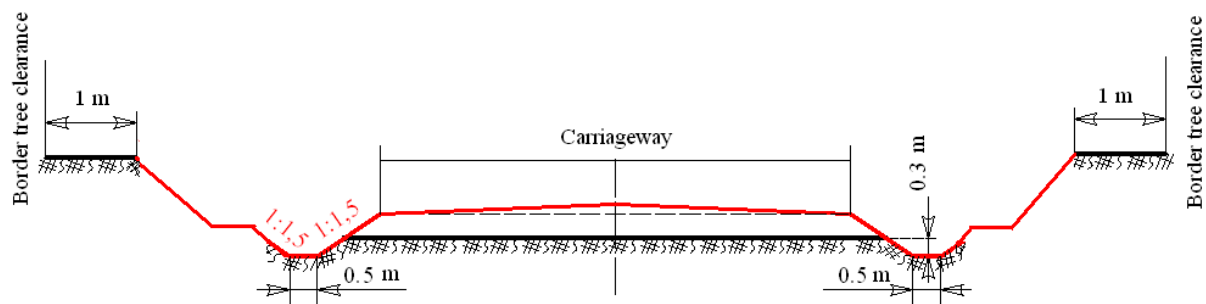


Figure 2. Typical forest roads cross sections for hollow.

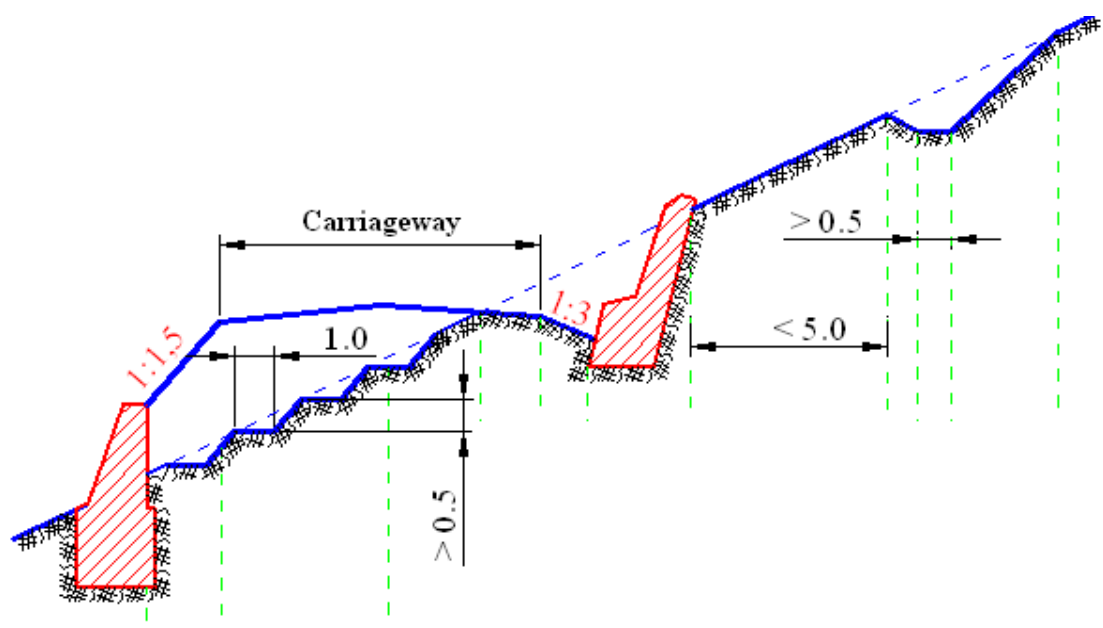


Figure 3. Typical forest roads cross sections for sloping sites.

Road reserve

The strip of land immediately affected by roadworks. In an existing plantation it corresponds to the tree clearance width.

Standard tree clearance width shall be a minimum of 15 m.

Tree clearance width for Reversal Roads shall be a minimum of 20 m.

The roadway

The area between the extreme limits of earthworks.

- In side-hill construction, its width is from the edge of the excavated section to the toe of the fill section.
- In a cutting, it is the width between the top edges of the cutting plus width occupied by any spoil on the verges.
- In a full embankment (excluding reversal), it is the width between the bottom edges of the embankment.
- In a reversal road, the width depends on the method of construction. Outer edge could be either the toe of the embankment, the borrow pit/drain or the spoil.

Formation (road foundation)

The area between the usable limits of earthworks.

- In side-hill construction it is the width between the toe of the excavated section and the top edge of the fill section.
- In full cutting it is the width between the bottom edges of each side.
- In full embankment it is the width between the top edges of the embankment.

Forest road - I type

Min. formation width = 10 m

Forest road - II type

Min. formation width = 6.5 m

Forest road - III type

Min. formation width = 4.5 m

Carriageway

The section of the formation strengthened for the passage of vehicles. This strengthening may take the form of:

- Compaction of the natural formation (or sub-grade), where its composition is such as will give adequate strength.
- Placing and compacting a layer of imported base material on the compacted formation, followed by a compacted layer of imported surfacing material.
- Placing and compacting a layer of surfacing material only.

Straight sections of road

Min. carriageway width = 3.5 m

Along curves and at junctions

Surface to within 500 mm of formation edges to provide for vehicle track-in.

Min. carriageway width = 4 m

On embankments

Carriageway width on substandard embankment formations must be at least 4.0 m

Drainage

The provision of channels, to remove excess water and prevent ingress of water in the future.

The provision of adequate drainage is the most important activity in road making. On it depends the strength and stability of the entire roadway. The ease with which effective drainage can be provided is a major consideration in the precise location of the roadway.

Three types of drain are commonly used [5]:

I. **Subsoil drains**, to lower a high water-table, are provided at some distance (min. 2 m) from each side of the roadway prior to excavation or building of an embankment. Where it is intended to build an embankment road, particularly on peat sites, these drains should be provided as long as possible (many years, ideally) before construction of the embankment is undertaken.

II. **Interceptor (or cut-off) drains** provided approximately parallel to roadway prior to excavation to catch run-off from higher ground. In undisturbed ground the cheapest way to do this is by excavating two or three drains parallel to the roadway so the closest drain is a minimum of 3 m from the estimated position of the top edge of the excavation.

III. **Roadside drains** at the edge of the formation. In general the angle between the toe of the cutting and the edge of the cambered formation will be adequate to control the runoff from the formation area itself. Occasionally a deeper drain may have to be provided where a high water-table persists in the formation, especially in cuttings.

The distance between the edge of subsoil or interceptor drains and the formation edge must always exceed 1.5 times the drain depth.

Sub Soil Drains	Min. 2 m from edge of roadway	450 mm to 750 mm deep on mineral sites. 750 mm deep on peat sites.
Interceptor Drains	At least 3 m from top edge of excavation.	Deeper than existing plough furrows.
Roadside Drains	At formation edge.	300 mm to 400 mm deep.
Culvert Spacing	This depends on road gradient and susceptibility to soil erosion. Usual interval range is 40 to 100 m. Culverts must in all cases be provided at the lowest point of long of longitudinal section and at each end super elevated sections.	

3. EXPERIMENTAL STUDY

The recommended time for road planning is prior to the commencement of planting. This will reduce the cost of planning by making site inspection and initial alignment much easier and enable the site and road drainage system to be planned together. It also prevents the opening up of the crop prior to thinning, reducing the risk of windthrow. The exception is on peat soils, where tree roots can provide a base for road formation but it is advisable to leave a 5 m wide unplanted strip beside the road site.

Having decided upon the road density for the forest block, the next step is to plan a system of roads as soon as possible, even though construction work may not be carried out for a number of years. Good planning will ensure access to the maximum volume of timber with the minimum length of road. Not only should the road density be correct, but the roads should be in the right place to facilitate harvesting and minimise environmental impact [6].

The three basic steps in road planning are:

- thorough site inspection of the area;
- initial road alignment on map; and
- confirm alignment by walking road lines and amend as necessary.

Forest road planning is the first phase of a forest road construction project. At this stage the need for a road has been identified and the forest owner/agent must now identify the criteria which must be met to achieve the desired objectives.

The objectives to be achieved by a forest road must be clear. The primary purpose of a forest road is that it must be capable of safely carrying timber haulage vehicles. It must also provide satisfactory access to the forest property and work areas and have minimal impact on its surrounding environment.

Potential environmental risks and construction difficulties are identified at this stage, to ensure adequate design standards consistent with minimising environmental impacts and construction difficulties.

To achieve appropriate standards, forest road designers will normally be engineers with considerable forestry experience.

3.1 *Recommendations*

1. Roading plans to be prepared well in advance of harvesting and transport operations to enable the roads to be located on alignments and grades that provide the required standard of access without compromising environmental values.
2. Roads to be kept to the minimum total length consistent with management objectives, located in the best landscape position possible, constructed under suitable weather conditions and well consolidated before use.
3. Roading plans to be based on detailed surveys and environmental care principles that ensure that all environmentally sensitive locations are identified and appropriate design and construction techniques adopted.
4. Establish if the area to be roaded lies within or contains [7]:
 - an area identified as being environmentally sensitive in a Forestry Development Plan,
 - a part or whole of a Special Area of Conservation (SAC), Special Protection Area (SPA) or proposed Natural Heritage Area (pNHA),
 - an aquatic zone,
 - archaeological sites and monuments or
 - important habitats retained for biodiversity.

If any of these areas are affected by the road plan then the planner must lease with the Ministry of Forestry, Local Authority.

5. Identify if the road plan could create any local social/community impacts.
6. Identify the site conditions:
 - soil types;
 - ground conditions; ground slopes;
 - watercourse locations;
 - areas to be harvested;
 - likely method of timber extraction; and
 - landscape;

as these will have a bearing on construction methods and environmental impacts.

It is recognised that not all issues will be fully definable at the outset and like any good planning process they must be monitored, reviewed and updated as necessary throughout the planning, design and construction phases of the forest road.

3.2 *Existing roads or tracks and development roads*

One further matter to bear in mind at this stage is the presently intended purpose of the road. Is it intended to be a development road or a harvest road? The answer to this will have some bearing on how issues are dealt with but it must also be remembered that most development roads will ultimately become part of the harvest road infrastructure [7].

Consideration should be given at the planning stage to the future use of any existing substandard roads and tracks. Decisions will usually take the form of:

- a) retention, and possibly extension, as a forwarder network instead of a new road; or
- b) retention in present form as a forwarder track to supplement a new road system; or
- c) network up-grading to full road standard and integration into a new road system.

The decision taken should be recorded to avoid the possibility of the plan's intention becoming obscured with the passage of time.

3.3 *Public road entrances design*

In designing a forest road system, the designer must take care to ensure that it causes least impact to the public road network. Forest road entrances should be kept to a minimum and they should be located wherever possible on the better quality public roads.

3.4 *Soil types*

Identifying the type of soil in the area to be roaded is very important as it will greatly influence the method of road construction and will also have a major bearing on the timber extraction for the property.

The erodibility of the soil, its susceptibility to damage and its silt content will influence the likelihood of watercourse pollution and hence the measures required to combat this.

3.5 *Ground conditions*

Ground conditions are concerned with localised features on the site. Areas of rock, marsh, callows, deep peat, etc. need to be identified as road construction in many such areas can be very difficult. In addition to the difficult construction conditions, it is often more difficult to incorporate mitigation measures to minimise a road's impact on its environment in these areas.

Landscape features such as ravines, ridges and saddles also need to be located at this stage to aid good road planning.

Ground condition will also effect extraction and so it is important to take account of this at road planning stage. Other ground condition obstructions such as banks, cliff faces, and boulders can have a major adverse affect on timber extraction.

3.6 *Ground slopes*

Contour maps of the site should be consulted early as they provide clear indications of areas that will be difficult to road. There are limits to road gradients and steeper cross slopes involve considerably more work. The tree clearance required for steep cross slopes needs to be greater and the resulting visual scarring on the hillside, although temporary in nature, will also be far greater.

Once again, ground slopes influence timber extraction methods and costs and this need to be taken account of when planning a road.

3.7. Areas to be harvested

For a forest road to be successful, it must adequately serve the forest area to be harvested. The catchment area for harvesting needs to be clearly identified. However, it is also very important that road building is not carried out in a piecemeal fashion. Thus, it is normal and recommended practice to design and construct forest roads to serve a full forest property/forest block [8].

The road engineer/designer has to understand all harvesting systems to ensure the road is sited so as to optimise the harvesting costs. Ground haulage systems are best served by roads located to reduce the average haul distance whereas cable systems are best served by roads located to maximise the length of cable used (fig. 4).

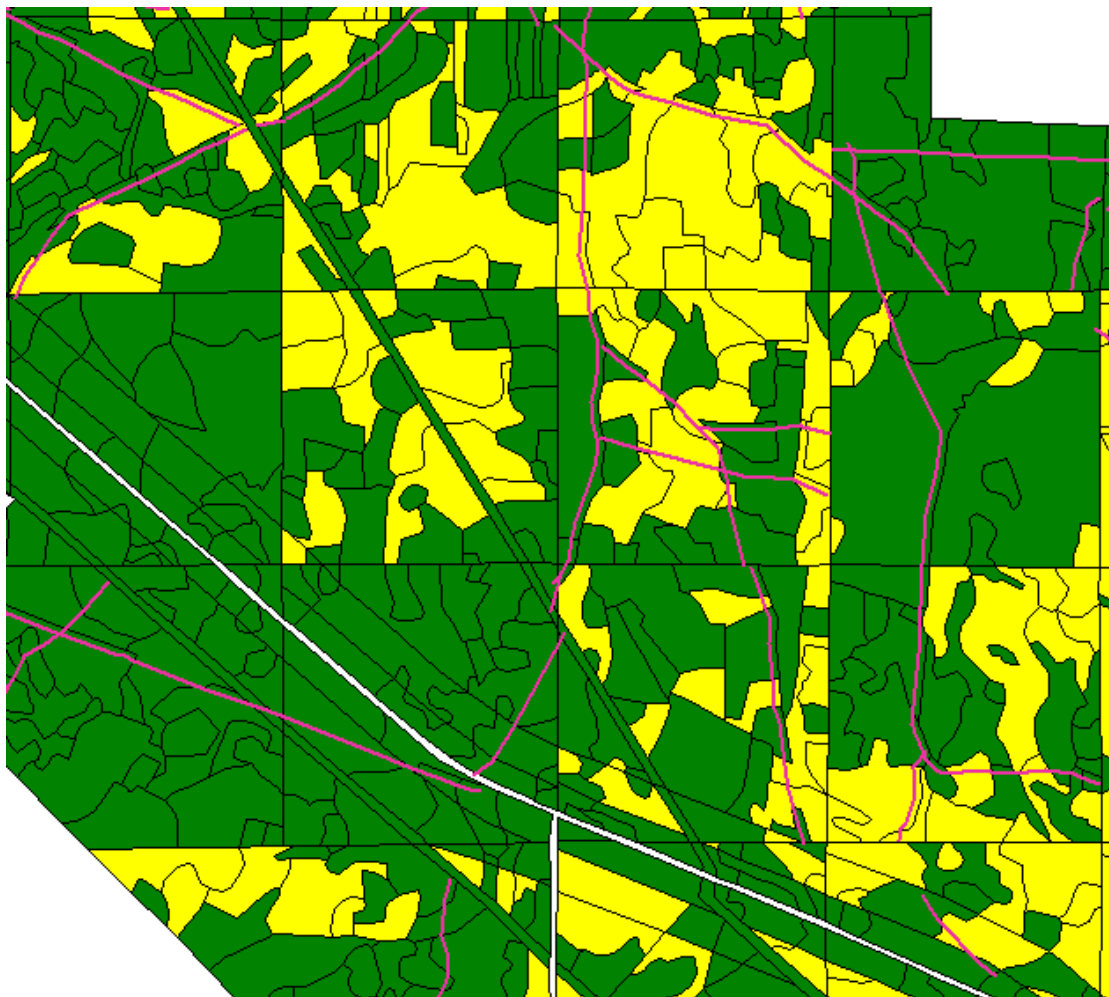


Figure 4. Forest exploitation areas with a homogeneous environment.

3.8. Likely method of extraction

Forest roads are mostly constructed for harvesting purposes. The cost of extraction is influenced by a number of factors but the two greatest are probably the road density and the type of extraction machinery that will likely be used. Optimum road density is also dependant on the type of extraction (cable, forwarder, horse or skidder) and so it is very important to ascertain this at planning stage. Also, as noted in earlier paragraphs, many factors influencing extraction method also influence road construction and so a reasonable balance needs to be found (fig. 5).

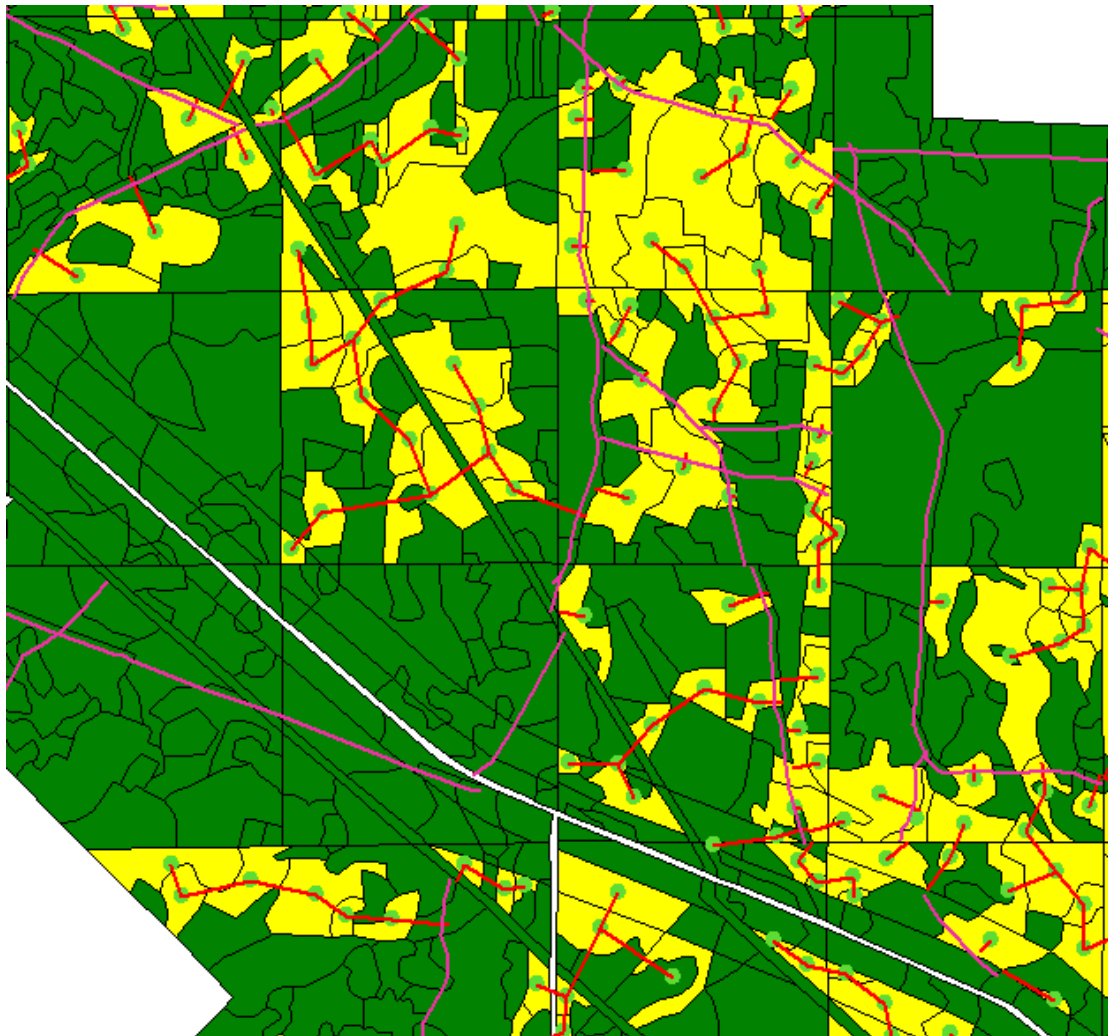


Figure 5. Designing forest road network

3.9. *Other factors*

At planning stage, a road designer may well consider other issues, most of which will develop as the planning stage passes into the design stage. These issues could include resources, such as what road construction equipment and road surfacing material is available in the area[9].

The designer should begin to address Safety and Health issues at the planning stage. A designer must identify hazards associated with the site and the construction work. A small sample of hazards could include overhead power lines, steep drops, boggy ground, loose boulders, fast flowing or deep water and substandard road junctions to name but a few [10].

The property owner/agent may also want the road designer to provide necessary information for a road grant application, where applicable. Although it will not be possible to submit this until the design has been carried out, much of the information required should have been obtained at this planning stage.

4. RESULTS AND DISCUSSION

At all stages of forest road planning and design, it must be remembered that the primary purpose of a forest road is to provide access for harvesting and timber extraction. This must be achieved at an

economic cost (including optimum density) while taking account of environmental values during all stages of formation and completion.

Roads should be located so that they [11]:

1. avoid strictly protected areas, scientific research areas and designated archaeological and cultural sites;
2. minimise the number of stream crossings and interference with natural drainage;
3. keep earthworks to a minimum by matching wherever possible, road alignment with topography of the site;
4. avoid environmentally sensitive areas;
5. avoid steep (>60%) and unstable slopes and areas prone to landslips;
6. avoid disturbance to streams, buffer strips and riparian vegetation;

Forest road networks must eventually join the public (county) road network. These intersections most frequently occur along minor, and often substandard, public roads.

The public roads are the responsibility of the Local Authorities and the National Roads Authority. It is important for forest managers to ensure that adequate consultation takes place between themselves and the Local Authorities Engineers.

Great care must be exercised to ensure that the forest business makes the least impact possible on the public road network. Junctions must be of the highest standard possible and all forest activities, other than timber and materials transport, kept off the public road.

1. Forest road facilities should be located so that minimal lengths of substandard public roads are used in so far as practically possible.
2. The number of forest entrances should be kept to a minimum.
3. Forest road entrances must be provided with adequate drains and culverts.
4. Forest road drainage must be kept within the confines of the site.
5. Pull-in lay bays (longitudinal loading bays) on public roads should not be provided, except where unavoidable.
6. Forest owners/managers/agents must liaise with Local Authority staff about principal activities and main developments.
7. Harvest operations and timber loading must never take place on a public road.

It is necessary to adopt the best standards of practice in respect to the use of public roads. The key points of this practice are:

- public roads must not be used by extraction equipment;
- public roads must not be used for the handling, stacking or loading of timber; and
- public roads are to be used solely for the transport of timber. A good motto to adopt is 'Keep Forestry in the Forest'.

ACKNOWLEDGEMENTS

The Authors wish to thank Mr. Nikolay Pavl. Vyrko for his valuable help in the analytical work. Thanks are also due to Mr. Michail Naskovets for his assistance in interpreting the model, and for helping to create the forest roads network.

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