# Comments

Overall, I think you have a good starting point for a manuscript. I haven’t dived deep into the type of edits required by a reviewer since this isn’t at that stage. I wrote down some areas that need more clarity but some of these include me trying to map the story in my head. I’d recommend you look at Anderson and Nelson (2004) to get ideas about structuring various sections since this paper is very similar.

Axel E Anderson and John Nelson. Projecting vector-based road networks with a shortest path algorithm. Canadian Journal of Forest Research. 34(7): 1444-1457. <https://doi.org/10.1139/x04-030>

I**ntroduction**

This is the flow I took from the introduction:

Roads are important for a variety of reasons related to biodiversity and wildlife

Forestry roads are major components of linear disturbance in BC

Stochastic simulation models don’t incorporate roads

The “roads” package can project roads

We are going to compare the observed roads with the roads projected from roads package to “assess the performance of the package and to showcase its usefulness within forest simulations”

I agree with the general flow presented but I would like to see greater detail on:

* Direct biological outcomes of forestry roads on wildlife. You state roads impact wildlife but how? What empirical evidence do we have of this – not necessarily the concepts of fragmentation or other ecological processes that “could” or “may be” explain the impact on wildlife but rather what is the biological effect or amplitude of road disturbances? What evidence do we have of this? RSF literature is rich with these like: “caribou tended to avoid areas within 500 m of a road” or “roads reduced the quality of caribou habitat by 50%” or “roads increased the predation risk of caribou by 42%”.
* Why aren’t roads or road indicators being tracked in stochastic forest models? I’m not convinced of this – I believe somewhere, someone must of thought of projecting roads. Ok maybe not under the classification of stochastic forest simulation models but I know of several papers that project roads for purposes of forest planning (see Axel Anderson’s work). So,
  + How are roads being projected in other types of models?
  + What are their assumptions?
    - Are these assumptions good or bad?
  + Do we have a means to test these assumptions? Why or Why not?
* As a reader of Forest Ecology and Management – why do I care about the “roads” package? What does it mean to someone who doesn’t use R? I’d suggest broadening your objective to something that more than a R user can enjoy. In other words, what’s your scientific objective –in my opinion showcasing an R package doesn’t highlight all your great work and misses the opportunity to document all the complexity and sensitivity of assumptions that go into road projection modelling. Also, since you’re not running stochastic forest simulations but rather road projections I wouldn’t include “usefulness within forest simulations”. Also try to avoid words like usefulness – if you don’t state what usefulness means – this can have many interpretations and leaves your objective being rather vague.
* In short, I think the introduction needs to clarify the scientific problem that the paper is attempting to address and then how this paper will overcome the stated problem. Once you have these two key pieces, the methods, results and discussion will be easier to write and read because they are consistent with the literature presented in the introduction. Some of these are already posed as questions in the discussion: “How does pixel size of the cost surface influence the results of the projections?” and thus they need to be put upfront in the introduction.
  + I think an opportunity for this paper is to evaluate road projection in terms of wildlife indicators which clearly does not need a sophisticated level of operational detail?

**Methods**

Study Area

* Be careful about TSA in the title. That acronym isn’t defined yet?
* Need a description about road development. In BC, forestry roads are developed by forest licensees under a timber harvesting permit. Various considerations go into road development including soils, grade, and economics. What type/classification of roads are you looking at (primitive roads, paved roads, etc). What’s the maximum grade? ---can find a lot of this verbiage in the Interior Appraisal Manual. How are they maintained – do they last forever -see Auditor General Report.
* Number of pixels or nodes?
* How much of the Revelstoke TSA overlaps with caribou range? Elevation? Climate? Flora/Fauna?
* Fig 1. Needs a scale bar, north area, etc
* Maybe add a table of descriptive statistics presenting information about roads in the Revelstoke TSA and the other TSAs you mention? By Caribou Range? – road density, road length, cutblock area, cutblock density, etc

Data

* Consider putting ‘Road projection methods’ before Data – that way the verbiage like ‘cost surface’ is already presented?

Consider grouping? “*2.4 Running the projections” and “2.5 Metrics”* into “Analysis”

**Results**

This title is confusing: *Metric means*

In short, I get lost here and I think this section could be improved with better flow and consistency with stated objectives/hypothesis in the introduction. In other words, the headings of this section could be each of the objectives or hypothesis stated in the introduction. This way the manuscript is organized making it easier to find which of your objectives were achieved followed by the magnitude of the effect.

Some of this should be in the Methods. “Difference maps highlight areas of discrepancy between the projections and the observed forestry road networks”.

# Paragraphs requested

**Road Projection methods**

Various optimization and simulation techniques have been used for projecting forestry roads into the future and across landscapes, however, we focused on the simulation methods that link multiple harvest units (a.k.a cutblocks) to an existing road network for strategic purposes. Dean (1997) described this road projection problem as the multiple target access problem (MTAP), where the objective is to find the minimum-cost locations for new roadways that link forested stands or landings (i.e., log deck) to the existing road network. We used three methods for solving the MTAP in the roads package. These methods represent a gradient of computational complexity and operational detail, starting with the least complicated or the snapping approach, followed by the least cost paths approach (LCP) and finally, the minimum spanning tree approach (MST). In the remainder of this paper, we will focus on the LCP and MST approaches given their assumptions are well aligned with how forestry professionals would strategically design road networks.

The LCP approach solves the MTAP by decomposing the problem into several smaller problems called single target access problems (STAP). For each STAP, a least cost path from a single source to sink was solved using Dijkstra’s shortest path algorithm (1959). Dijkstra’s algorithm minimizes the distance between a landing and the current road network, subject to costs or penalties incurred from road construction and travel (the details of this process are described later in the section “weighted graph”). Each STAP was then solved sequentially, with the newly projected roadway updating the existing road network and subsequently the costs of road construction. This method was first developed by Anderson and Nelson (2004) and provides a feasible solution to the MTAP, however the projected network is sensitive to the ordering of the STAP. They recommended a heuristic for connecting the landings and finding optimal branch locations to deal with this sensitivity.

The MST approach extends the LCP approach by providing a heuristic for linking landings or evaluating road branching opportunities. Dean (1997) showed that heuristics with branch evaluation were able to reproduce 80% of the observed road locations in their study area. Our MST approach has three steps towards evaluating branch locations while projecting roads: 1) estimat the least cost paths that link each of the landings and the least cost paths that link each landing to the existing road network, 2) creating a weighted graph where each node is either a landing or point on the existing road network and each edge or arc is weighted by the costs estimated in the previous step and 3) solving the minimum spanning tree for this graph. The minimum spanning tree was solved using Kruskal’s algorithm (1956) where every node in the graph was linked to form a tree such that the sum of edge weights is minimized, and the links do not form a loop. This method was most similar to Clark et al. (2000) approach which used a minimum spanning tree to project simple road networks during harvest scheduling. An important difference was that they based the edge weights on spatial Euclidean distance, whereas the MST approach used the costs estimated from least cost paths.

**Weighted graph**

A mathematical weighted graph consisting of nodes and edges was used to parameterize either Kruskal’s or Dijkstra’s algorithms. When solving least cost paths using Dijkstra’s algorithm, each node in the graph corresponded to a pixel in a raster of our study area (100 m x 100m resolution). Whereas, in the graph used for solving the minimum spanning tree via Kruskal’s algorithm, each node represented either a landing or a point on the existing road network. Therefore, a node can be represented by any one of three attributes in the forest road network: (i) a landing, (ii) a point on an existing road, or (iii) an intermediate point. The landing nodes represent log decks or sources of timber and the point on the existing road is the sink where the timber will end up. The intermediate points are plausible locations to construct a road and are thus free of barriers like major waterbodies. The edges connecting the nodes follow a “queens” case or allows a maximum of eight possible edges for a given node. Thus, our methods utilize a grid pattern which does not support curvature or switchbacks in road design as required in operational road design, thus we ascertain that our road projection methods are for strategic modelling purposes only. Edges are assigned weights which penalize the algorithm to account for various impedance and road construction costs. When solving least cost paths, a cost surface raster was used. The pixels of the cost surface raster corresponded to nodes in the weighted graph and thus the edge weight was the average cost between the two nodes or pixels. When solving the minimum spanning tree, the edge weight corresponded to the total cost of the least cost path between the two nodes.

**Cost Surface**

To spatially define the cost of constructing and traveling on a forestry road we developed a cost surface raster. We used several spatial raster layers describing the roading cost structure, barriers to road development and road impedance. For intermediate nodes, the roading cost structure followed the Interior Appraisal Manual of BC (source) where the cost per kilometer of road was a linear function of slope. Separate costs for river and pipeline crossings were then added to the roading cost. Barriers for road development masked the cost surface raster and these included the major waterbodies of BC. Lastly, to coerce the algorithm to follow existing roads, all nodes representing the existing road network were assigned the smallest cost (Table X).

|  |  |  |  |
| --- | --- | --- | --- |
| Cost Type | Road Attribute | Value ($ per km) | Source |
| Barriers of road development | Major lakes | infinity | Major waterbodies of BC |
| Impedance | Existing roads | 0.01 | Assumed |
| Road Construction Cost Structure | Pipe crossing | 1911 | Interior Appraisal Manual |
| River crossing | 2130 | Interior Appraisal Manual |
| Base cost | 16178 + 504\*slope | Interior Appraisal Manual |