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Challenges in Forest Road Maintenance in North America

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Abstract

Maintenance is a key component of managing a forest road network. Forest road networks in North America are managed to provide economic access to forest resources while minimizing the environmental impacts of those roads. While managers understand the importantance of road maintenance, there is a considerable backlog in the maintenance required on most forest road networks. This article reviews challenges across North America in forest road maintenance. Challenges reviewed include those associated with climate change, changing land use and intermingled ownerships, legacy roads, decision support, and financial barriers.

Keywords: road drainage, climate change, recreation use of roads, legacy roads

1. Introduction

Forested areas cover approximately 775 million ha of North America (Oswalt and Smith 2014, Torres-Rojo et al. 2016, NRCA 2018), accessed by nearly 3 million km of unpaved roads (Rhoda and Burton 2010, FHWA Highway Statistics 2012, NRCA 2018). These forests underwent extensive development throughout the 20th century and are now in a phase where most new road construction is limited to short access roads within existing road networks (USFS Road Fact Sheet). This necessarily places a focus on maintenance of existing infrastructure.

Forest roads are maintained for two overarching objectives: trafficability, specifically in order to provide economic access to forest resources, and minimization of negative environmental impacts. In fire-prone regions, a third objective of access for fire management activities may also be included. The relative importance of these two objectives varies by land owner and landscape, specifically the owner's value of resources at risk within that landscape. Often these two objectives are met with many of the same road maintenance techniques. Regardless of the overarching objective, road maintenance primarily focuses on managing the flow of water; thus, the focus is here on road drainage systems.

The negative environmental impacts of forest roads have long been a topic of study (ex. Gucinski et al. 2001, Benitez-Lopeza et al. 2010, Robinson et al. 2010). In the US, the 1972 Federal Water Pollution Control Act (a.k.a. Clean Water Act) required states to develop forestry best management practices (BMPs). These BMPs cover all forest management activities, including road maintenance, and range from voluntary guidance on best practices to regulatory forest practice acts. Cristan et al. (2016) and Anderson and Lockaby (2010) reviewed the literature to examine the effectiveness of these BMPs and found that, when applied, BMPs have been proven to protect water quality. However, the majority of these effectiveness studies necessarily confine their sample populations to recently harvested sites. Given that the majority of BMPs only apply at the time of harvest, this is appropriate. It does, however, largely miss the question of ongoing road maintenance activities. For example, the state of Montana has been evaluating the application and effectiveness of forestry BMPs since 1990 (Sugden et al. 2012). The evaluation in 1998 found that across all ownerships, 94% of surveyed practices met or exceeded BMP requirements and that 96% of these practices provided adequate protection of soil and water resources. For comparison, a similar study in South Carolina found 92% and 96% compliance in 1993 and 1994, respectively, for all road practices and 42% and 79% compliance with BMPs at road-stream crossings (Adams 1994). However, during this same time period, Plum Creek Timber Company, the largest industrial forest land owner in Montana at the time, completed their own audit and found only 44% of their road network compliant with BMPs

(Sugden 2018). Likewise, most BMP effectiveness studies find that federal land management agencies have similarly high compliance with BMPs (Cristan et al. 2016, Ziezak 2018), yet the US Forest Service reports that of the 595,000 km of roads and 13,000 bridges within their management, they carried a $3.45 billion USD deferred maintenance backlog during fiscal year 2015 (USDA 2017). These examples illustrate that implementation of existing road maintenance BMPs, which are known to minimize environmental impacts (ex. Anderson and Lockaby 2010, Sugden 2018), is not widespread enough in practice nor is it well captured in the current literature. The volume of sediment produced by roads as compared with background sedimentation rates and other land use practices varies widely across North American based on geology and land management practices (Fulton and West 2002). The legal case Northwest Environmental Defense Center vs. Brown alleged that forest road drainage structures, such as culverts, should be treated as point sources of pollution under the Clean Water Act, and therefore require a pollution discharge permit. While the US Supreme Court ruled in favor of not classifying forest road culverts as point sources of pollution in 2012, this case highlighted a concern over sediment produced on existing forest roads.

The discussion that follows is based on a review of existing literature informed by an informal survey of experts from across North America. The challenges facing managers to proper implementation of road maintenance are broken down by key drivers and include climate change, changing land use and intermingled ownerships, legacy roads, decision support, and financial barriers.

2. Climate Change

It has been well documented that climate change is resulting in more extreme weather events, higher-frequency peak flows, warmer winters, and shifts in precipitation timing and form (IPCC 2014) and that these changes will have a significant impact on the forestry sector (Johnston et al. 2010). These shifts in patterns away from historic conditions poses several challenges to road maintenance (NRC 2008, Gopalakrishna et al. 2013), specifically in terms of adequate sizing of road drainage features, road damage due to seasonal operations, and the restriction of some low-cost management options.

2.1 Road Drainage

Improper road drainage can lead to rutting, gullying, pot holes, impassible roads, and unacceptable sediment production (Orr 2003). Sedimentation and resulting water quality impacts are the primary environmental impact of concern that can be mitigated with proper road maintenance (Reid and Dunn 1984, Sugden and Woods 2007, Araujo 2013). North America has many fish (ex. Reid 1998, NRC 2004) and other aquatic species at risk (Hendrickson et al. 2008), therefore minimizing water quality impacts resulting from road sediments by adequately designing and maintaining road drainage is frequently a high priority for BMP protocol and road maintenance activities. To manage for threatened and endangered species (both aquatic and terrestrial) and minimize uncertainty in enforcement requirements, many forestland owners, public and private, have entered into habitat conservation plans under the Endangered Species Act in the US or a permit under the Species at Risk Act in Canada. These plans or permits specify management actions to minimize impacts to threatened or endangered wildlife habitat and often include road management requirements to minimize sediment production from forest roads (ex. WDNR 2018).

Maurer et al. (2017) modeled stream flows across the western United States under high emissions but accepted climate models and estimate that peak flows will increase by 14–19% during the early 21st century, 31–43% by the end of the 21st century, as compared to flow conditions between 1971 and 2000. Additionally, the authors estimate that, by the end of the 21st century, a 100-year event from the end of the twentieth century will correspond to the peak flow of a 40-year event at the end of the 21st century, meaning a 2.5-fold increase in the probability of a given peak-flow event over the course of the century. Similar results have been found for Alberta (Kuo et al. 2015) with an overall increase in peak flows of 29% by the end of the century.

Current procedures for sizing culverts and other stream crossings involve estimating design flows based on an intensity-duration-frequency (IDF) curve developed from site- or region-specific data that correlates drainage area and precipitation to expected flows for given storm return intervals. This requires sufficient historic data to create robust IDF curves. For example, IDF curves currently in use in Montana are based on gauging stations with ten or more years of record (McCarthy et al. 2016). Some regions have made efforts to update IDF curves for management purposes (Burns et al. 2015). However, given the wide range of climate impacts expected over both large and small geographic scales (Zhu et al. 2012, Chen et al. 2013, Surfleet and Tullos 2013, Kuo et al 2015, Simonovic et al. 2017), these modifications to IDF curves will necessarily need to be region- and watershed-specific.

Most BMP programs provide guidance to managers regarding ideal spacing on drainage control structures such as drain dips, grade rolls, or waterbars. With expected increases in extreme precipitation events, this guidance needs to be updated to account for higher overland flow volumes. Currently, managers base the spacing of drainage control structures on a combination of BMP guidance, professional experience, and in the case of maintenance and upgrades, evidence of excessive water volume causing unacceptable sediment transport off the road prism and disruption of the road travel surface. Professional experience and physical evidence will eventually catch up to current conditions, but both leave road managers in reactive positions for the time being.

With changes in precipitation timing, form, and quantity, it is not uncommon for road managers to find themselves in the situation where existing road drainage systems are inadequate to handle an increased volume of runoff or the appearance of new sources of water. For example, dry draws that become streams or the appearance of springs or seasonally wet areas where none were before all pose road maintenance challenges whereby drainage systems need to be added to existing roads.

2.2 Road Damage Due to Seasonal Operations

The window of time when roads are most susceptible to damage within the portion of North American subject to winter freezing is spring break-up (Daniel et al. 2018). During spring break-up, road soils primarily melt from the road surface down, suspending saturated soils over an impervious layer of frozen soils. Depending on surfacing strength, managers may either impose load weight restrictions or close roads to all hauling until soils dry and road strength returns. The choice of seasonal hauling restrictions and timing of those restrictions have major implications on road maintenance needs.

Historically, seasonal load restrictions have been set by either consistent calendar dates or inspection of individual roads. While instrumentation is available to assist in making spring load restriction decisions (Miller et al. 2013), the expense is generally only justified on mainline or arterial roads. Given Daniel et al.'s (2018) estimation that currently (2000–2029) the frozen period each winter is 10–20% shorter than it was during 1970–1999, and by century's end, this frozen period is expected to be 30–40% shorter, set calendar dates for seasonal load restrictions become increasingly problematic. Additionally, the period of time where temperatures hover around freezing may lengthen (Gopalakrishna et al. 2013), leading to a longer spring break-up. This leaves road managers few options given current technology: expend more on road surfacing to increase road strength during wet periods; expend more on truck configurations and weight limits (which decrease transportation efficiency) that allow for hauling with minimal road damage during wet periods; increase hauling curtailment periods recognizing that this will have supply-chain wide implications; or increase maintenance expenditures.

2.3 Restriction of Some Low-Cost Management Options

Many regions depend on frozen soil conditions to access forest resources. This is particularly the case in areas with high water tables or an over-abundance of surface water, such as the Lake States in the US and boreal regions of Canada and Alaska. In these regions, ice roads and ice bridges allow for low-cost construction of access using naturally-occurring snow and ice (Blinn et al. 1998, Kuloglu et al 2019). In addition to low-cost construction materials, these structures generally require little to no maintenance after they melt. Without these options, more significant and/or permanent structures are required, which not only increase expense but also greatly increase the likelihood that post-hauling maintenance will be needed to either abandon or maintain these structures.

3. Changing Land Use and Intermingled Ownerships

Like most regions of the world, North America has an increasing population that continues to expand its footprint into forested areas (Alig et al. 2003, Alig et al. 2010, Coulston et al. 2014, Oswalt and Smith 2014). Additionally, changes in the forest industry have equated to large-scale changes in forestland ownership (Irland et al. 2010). As forestland ownership continues to diversify, fewer of these owners are participating in traditional forest management activities (Butler et al. 2016). These factors have combined to create maintenance challenges related to shared jurisdiction of roads, an increase in the diversity of forest road users and vehicles, and safety concerns.

3.1 Shared Jurisdiction

As discussed throughout this paper, there are many challenges associated with road maintenance. These issues are only compounded when multiple entities have jurisdiction over a given road. In landscapes where ownerships are intermingled, it is common for road use agreements to be entered into by two or more road users that specify how expenses and responsibilities are divided. If values, acceptable road standards, and willingness to pay are similar between the entities involved in shared road management, then these agreements can be beneficial to all parties involved. However, once one or more of these factors becomes dissimilar, road maintenance becomes more complicated.

In an evaluation of BMP effectiveness in reducing forest road sediment, Sugden (2018) found the greatest decrease in sediment production (–84%) pre- versus post-BMP implementation in a watershed where the timber company conducting the road upgrade activities owned 83% of the watershed area and managed 85% of the total road length. Conversely, the watershed with the lowest percentage of road length managed by the same timber company (62%) had the lowest reductions of sediment delivery after upgrades (–9%).

3.2 Increased Diversity of Forest Road Users

Any expansion in vehicle classes will add to maintenance needs on a road. For example, the US Forest Service requires safety signage on roads open to passenger vehicles (USFS 2012), adding additional road features that must be maintained. All-terrain vehicles (ATVs) and other recreational off-road vehicles may cause increased surface wear due to aggressive tire tread and driving characteristics. Additionally, in unregulated settings, off-road vehicle users tend to not stay on the road, posing significant environmental damage to streams and other resources adjacent to the road.

With increasing human population near forested areas, there is also increased pressure for recreational access. White et al. (2014) estimate that recreation on forested lands in the US will increase 31% between the period 2008 and 2030 to nearly 70 billion days. Grace and Clinton (2006) report that, as of 2006, only 0.5% of road use on US Forest Service system roads has been directly related to timber harvest. It has long been known that traffic is a driver of fine sediment creation on roads (Ried and Dunn 1984, Bilby et al. 1989, Araujo et al. 2013, Sosa-Perez and MacDonald 2017). Additionally, road use during wet times of the year has the potential to cause excessive damage to the road surface and drainage systems. The social acceptability of seasonal road closures varies by community (Grace and Clinton 2006). Where road closures are accepted, this can be a low-cost way of minimizing road maintenance needs. Where road closures are not accepted, managers are left with the decision of road closures, high maintenance costs, or investment in road surfacing sufficient to carry traffic during otherwise low-strength conditions. All of these options represent tradeoffs with significant costs associated with them (Gucinski et al. 2001).

Long-term road closures, also referred to as road storage, limit management options by limiting readily-available access (USFS 2012). Stored roads can be reopened when needed, such as a planned timber sale or unplanned emergency access for wildfire. Assuming care was taken when the road was closed to establish a self-draining road and motorized traffic was successfully excluded from the road (Eubanks 2006), this can be a method for drastically minimizing ongoing maintenance costs. If either of these factors fail, however, environmental impact (Clinton and Vose 2003), maintenance complexity, and expenditures increase drastically.

Road maintenance needs resulting from uncontrolled wet-weather traffic may vary from a blading to smooth the running surface and maintain surface drainage to a complete rebuild of the road prism and drainage system (Swift and Burns 1999). The latter, resulting from extensive damage to the surface, subgrade, and drainage control structures such as drain dips and ditches, can be nearly as expensive as initial construction activities with significant environmental impacts between the time of damage and repairs. If left unmaintained, even small ruts or depressions in the road travelway will channel water and increase sediment production and loss of road surface material.

The sediment generated during wet weather traffic originates from the road surfacing itself, therefore roads where wet weather traffic will be allowed needs strong pavement systems, whether crushed aggregate or bituminous pavement, that will resist rutting and minimize the development of fine sediments (Toman and Skaugset 2011). This can be difficult in many regions of North America where crushed aggregate suitable for road pavements is scarce or absent (Skorseth and Selim 2000). Jahran et al. (2005) recommend a procedure for evaluating the financial decision of when to upgrade surfacing levels of low volume roads considering the costs of pavement, upgrades of road design features, and savings in annual maintenance. However, it is important to note that for many ownerships across North America, financial criteria are often not the most important criteria in road management decisions (ex. Luce et al. 2001, Coulter et al. 2006a).

3.3 Safety

Any time additional vehicle types are added to a road network, the potential exists for safety issues. Most forest roads were designed and/or built with a log truck or other heavy-haul truck as the design vehicle, operated by professionals with radio communication between drivers, at relatively low speeds (CDOT 2018). With the addition of recreation traffic, driver and vehicle characteristics change to smaller vehicles with drivers unfamiliar with the roads traveling a variety of speeds without the benefit of radio communication with other road users (CDOT 2018). In addition to user safety concerns, this shift in road use will also mean a greater demand for more frequent surface maintenance and roadside brush control, installation of turnouts to accommodate two-way traffic without radio communication, and less severe drainage features to accommodate lower-clearance vehicles.

The expansion of population into the forest also leads to a need for dust control on forest roads near residential and recreation areas (Lunsford 2001). In some specific locations, exposure to amphiboles and asbestos in road dust may be significant (EPA 2014). Commonly used dust suppressants across North America are chloride compounds and lignin (Addo et al. 2004). Chloride compounds attract atmospheric moisture and use this to bind smaller particles to larger ones. Lignin acts as a cement to bind all particles together. While professional experience of many road managers is that chemical dust suppressants maintain a smoother road for longer in between surface grading, only limited tests have been conducted to determine the impact of dust suppressants on maintenance costs and environmental impacts to air and water resources. Addo et al. (2004) found that dust suppressants minimize air quality impacts for a time, may minimize road maintenance needs while active, and have uncertain impacts on water quality. These results varied by road surfacing material and indicated that some dust control additives may need to be applied at intervals of less than a year to remain effective. Other tests of water quality impacts of common products have found inconsistent and conflicting results (Irwin et al. 2008).

4. Legacy Roads

Many of the roads making up the extensive forest road networks throughout North America were constructed prior to modern BMPs and are a legacy of past timber, mining, grazing, and settlement practices. These roads were often located along the path of least resistance and used the most expedient methods available to provide road surface drainage, specifically intentional drainage to the nearest stream or waterway (Wemple et al. 1996). These legacy roads pose significant maintenance challenges for road managers. Roads built adjacent to streams may have little opportunity to filter road sediments prior to reaching live water, a common requirement of BMPs. Additionally, legacy roads with poor drainage have often lost large volumes of road material over time and are now at a lower elevation than the surrounding ground, leaving few options for adequate road drainage beyond the import of large volumes of suitable road material. This leaves managers with the choices of relocating the road upslope, retrofitting the road to meet current BMP standards, or accepting high maintenance costs and impacts (Swift and Burns 1999).

Relocation of legacy stream-bottom roads in mountainous terrain can be difficult and expensive to implement. Upslope locations may be much steeper meaning that prohibitively expensive construction methods, such as full-bench, are required. Short-term tradeoffs include removing a fully-vegetated road and disturbing a new area upslope (Grace 2002). Road alignment is often better for the valley-bottom road location as compared to a location upslope, increasing transportation time and costs.

Legacy roads may be at grades exceeding current design standards. These steep road segments are known to produce more sediment than roads at lower grades under the same surfacing and traffic conditions (Bilby et al. 1989, Sugden and Woods 2007). Maintenance options include frequent blading, increased surfacing, greater in- or out-sloping, more frequent waterbars or drain dips, and the addition of structures such as open-top culverts and rubber water diverters. Waterbars and drain dips become problematic for vehicle passage at grades above about 10% because of the need for a full grade reversal to force water off the road. Open-top culverts and rubber water diverters are suitable options with minimal impact on vehicle passage, however require frequent cleaning and replacement, the rate of which goes up with sediment movement and traffic, and may not be appropriate for roads which will receive winter snow plowing or frequent grading.

An issue common to coastal areas of North America and unstable mountainous terrain throughout is landsliding associated with forest roads (Swanson and Dryness 1975, Amaranthus et al. 1985, Goetz et al. 2015). To prevent road-related landslides from occurring, VanBuskirk et al. (2005) recommend focusing maintenance activities on road drainage to minimize concentration of flow in unstable areas. Repair of roads after a landslide is frequently prohibitively expensive and technically difficult (Helwany 1994).

One way road managers have attempted to minimize construction and maintenance costs of lesser-used forest roads in mountainous terrain through outsloped road prisms. The idea behind outsloped roads is that they are narrower, have no inboard ditch, and disperse runoff. These outsloped roads, however, cause safety issues during winter hauling. It is not uncommon for snow to be plowed such that the resulting driving surface is flat to insloped, providing greater security to heavy vehicles. The maintenance issue with this practice comes either during the spring melt or if snow plowing operations removed some of the road surface on the inside edge of the road. Both of these factors can cause water to concentrate along the inside edge of the road, effectively creating a ditch where none was intended. This creates a loss of road material, narrowing of the travelable surface, and leaving road drainage to the path of least resistance.

As North American transportation infrastructure ages, an increasing number of bridges have become weight restricted (Bradley 2015). As many states increase load weight limits, allowing for larger payloads and thus more efficient log hauling, federal interstates in the US have not increased their allowable weight limits. Both of these factors have combined to route more traffic onto woods and rural roads, increasing the cost of transportation (Smidt 2013), safety concerns related to routing heavy haul traffic through rural and residential areas, and increasing maintenance needs on roads that may not have been designed for heavy vehicles.

A common feature requiring upgrade or replacement on legacy road systems is stream crossings (Swift and Burns 1999). This is frequently the focus of upgrade plans intended to protect and enhance aquatic habitat, such as habitat conservation plans. Extensive guidance is available for road managers for evaluation, design, and construction of new stream crossing structures (ex. Hendrickson et al. 2008, BCMF et al. 2012, Heredia et al. 2016).

5. Decision Support

A number of decision support systems have been developed for road management. For example, Luce et al. (2001) developed criteria for the prioritization of road decommissioning. Coulter et al. (2006a and 2006b) used a multi-criterion decision analysis method to prioritize road investments based on environmental criteria. Switalski et al. (2004) evaluated techniques for road removal. However, all decision support systems that have been developed require a level of site-specific road inventory data that is time consuming to gather, update, and maintain over time (Blagojevic et al. 2019). For example, Sugden (2018) found that the majority of sediment introduced into streams was generated at a minority of sites. Determining which road-stream crossings are problematic requires a site visit and detailed maintenance or upgrade plans must be developed based on the specific geometry of each site. These factors result in no commonly-used decision support systems that have been deployed in practice.

6. Financial Barriers

The largest challenge road managers face is the ability to pay for the maintenance, repairs, and upgrades that are needed. Historically, organizations paid for much of their annual road maintenance through timber sale receipts. On public lands in the US, in particular, the precipitous decline in timber harvest has also meant a decline in the ability to complete road maintenance and upgrade work. As design criteria have evolved to focus on minimizing environmental impacts, the number and cost of structures and drainage systems has risen. As land management organizations have entered into regulatory agreements that require significant investments in road system upgrades (for aquatic organism passage, for example), the available budgets to complete other maintenance tasks has decreased. Staffing in many public agencies has declined in recent decades meaning that there are fewer experts available to evaluate and direct maintenance activities.

The challenge of relying solely on funds generated through traditional resource extraction activities has lead many land managers, both public and private, to develop additional revenue streams to support road upkeep. For example, many public land management agencies have proposed recreation fees. Private landowners may charge access fees associated with hunting or recreational vehicle access. These efforts have been met with mixed public reaction.

7. Conclusions

Overall, forest road managers know what needs to be done to adequately maintain forest roads for logistical and environmental goals. While technical issues remain, particularly in adapting to climate change, understanding tradeoffs between maintenance options, and decision support to implement those options, the largest challenges faced by road managers are social and budgetary. These are all topics that are site- and organization-specific.

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