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Transportation Engineering Basics for Drilling Engineers

Jeffrey Tyson, P.E., Scott Energy Technologies, LLC

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Abstract

The American Society of Civil Engineers defines "transportation engineering" as the application of technology, scientific principles, and integrated strategies focused on smart and sustainable development to planning, functional design, operation and management of facilities for any mode of transportation for movement of people and goods[1]. Every oil and gas company owns and operates such facilities, but few companies are aware of the economic impact that any such facilities can have on their operations.

The oil and gas industry drills thousands of new wells each year in the United States. Before drilling can efficiently start at a vast majority of the sites chosen for drilling these wells, some form of site preparation will be required and will often include pad and road design and construction. Therefore this part of site preparation is within the definition of transportation engineering.

The engineers responsible for managing a well's construction and associated costs are often not trained in transportation engineering, leaving them ill-equipped to make economically sound decisions about pad and road design and construction. This paper will serve as a primer on transportation engineering and has been specifically developed to provide drilling engineers with the essential tools necessary to engage construction contractors and consultants in meaningful conversations, increase the quality of work, reduce maintenance and rework, understand lifecycle cost analysis, reduce overall costs and drive sustainability.

Introduction

The exact quantity of road mileage owned and operated by the oil and gas industry in the U.S. could not be determined based on publicly available information; however, conservative estimates indicate that there are well over 300,000 lane miles of lease roads owned and operated by oil and gas Exploration and Production ("E&P") operators (in contrast, the entire U.S. interstate system is made up of only 221,229 lane miles2). Transportation planning, development, design, construction and maintenance of these facilities ideally should be based on principles and standards set forth by the transportation industry and should minimize overall life-cycle cost. Unless otherwise stated, any mention of E&P roads refers most directly only to those roads that are not open to the general public and whose primary purpose is to provide access to exploration and production facilities. However, many of the same principles discussed for E&P roads are also applicable to other E&P facilities, such as drill and well pads, tank battery pads, compressor station pads, etc., especially in relation to pavement structures and materials, construction and quality control, and maintenance.

The author's experience in both the transportation and E&P industries has provided him with an unusual understanding of the needs and challenges associated with E&P roads and infrastructure. E&P roads offer a different set of challenges than most public roadways. Each of these challenges; however, can be addressed by utilizing the well-established methods developed by the transportation industry for planning, design, construction, and quality control, maintenance and life-cycle costing. The sections below will provide the reader with a basic understanding of transportation engineering principles, including transportation planning, geometric design, pavement structures and materials, construction and quality control, maintenance, and life-cycle cost analysis. Each topic in this paper will discuss standards typical of the transportation industry in the U.S. and then discuss the key take-away points that can and should be considered by the E&P industry.

This paper is not intended to be an all-inclusive, in-depth overview of every aspect of the transportation industry. Various references are made within this document to sources that can provide more detailed information regarding transportation engineering. Readers are encouraged to visit these sources if they wish to obtain additional or more in-depth information. The Texas A&M Transportation Institute (TTI) has an entire focus area dedicated to the study of transportation economics, which helps ensure that resources are applied as efficiently as possible.[3] The Transportation Research Board (TRB) also has programs and activities focused on economics related research specific to transportation engineering.[4] Two additional sources of information are the Highway Capacity Manual (HCM) published by the Transportation Research Board, National Research Council, and A Policy on Geometric Design of Highways and Streets, also called the "Green Book," published by the American Association of State Highway and Transportation Officials (AASHTO).

Transportation Basics

Transportation Planning

Transportation planning is the focal point for information and coordination of the transportation industry. It is where all transportation data and information come together from each sector and are analyzed, and is where key decisions are made. The planning process not only looks at current needs, but also forecasts future needs and makes various assumptions that are used by the individual sectors. In general, transportation decisions need to be made in an environmentally sensitive way, using a comprehensive planning process that includes the public and considers land use, development, safety, and security.[5] Transportation planning takes a comprehensive approach, generally developing a 5-year plan, 10-year plan, 20-year plan and long range plan. These plans include financial and fiscal constraints and also look at expected economic and regional development in order to provide safe and efficient transportation that is also economically feasible.

Each of the sectors that are discussed in the sections below will utilize information and assumptions that are developed as part of the planning process. Geometric design, for example, is largely dependent upon current and future land use. Materials used to construct the road are based upon the amount and degree of traffic loading, and also the frequency, degree and cost of expected maintenance activities. Construction and Quality Control schedules should fall within the scope of the plan, and also account for a significant portion of the overall life-cycle cost. Finally, each decision has an associated cost, and therefore effects life-cycle cost analysis.

The planning team for E&P roads should include personnel from the Land Department, Drilling Department, Completions Department, Production Department and Environmental Department. The planning process doesn't have to be a long and drawn out process, but it should ensure that the needs of each stakeholder are met, and input from each will be needed in order to develop a sufficient plan. Although there is much more involved in the planning process, there are a couple of key questions that should be addressed for E&P roads.

"*How long will the road be in service?"* Many times, E&P roads are built with one thing in mind – getting the rig and supplies to and from the well site. In fact, E&P roads are commonly used for multiple decades after they are built, not only by drilling, but also completions and production and often times even landowners. When determining what materials to use and looking at the life-cycle costing, it is important to have an idea of how long the road will be in service. The answer will likely be tied to the expected life of the well or wells to be served, and possibly even the expected life of the field.

"What traffic loading will be expected?" This question is two-fold and involves both the weight of each load and the number of loads that are expected. For E&P roads, the loading from passenger vehicles is typically small enough to be negligible, and design criteria will be based on trucking. It can generally be assumed that loading from trucks on E&P roads is similar to that allowed on public roads; however, the forces applied to E&P roads and drill pads during rig moves can far exceed what is allowed on public roads. Answering this questions adequately is important when determining which materials to use and how often maintenance activities will be required. The answer will be based on several factors, including the number of wells served, the number of loads needed to drill and complete each well, the number of loads during production and even the number of loads required to plug and abandon. During the early stages of development, E&P roads are likely to observe much more extensive loading than later in development, once additional infrastructure is in place. For example, if frac water is trucked to location vs. pumped, there will be considerably more traffic loading. The same goes for product and/or produced water. Based on the expected production and the other information that is known, a fairly accurate estimate of the number of truck loads should be simple to determine for each road.

Geometric Design

Geometric design of roadways involves not only the shape and size of the roadway itself (width, slope, crown, elevations, etc.) but also the horizontal and vertical alignment (curves and hills). Geometric design is dependent upon the functional classification of the roadway itself. There are multiple classifications of roads and highways based on their operational purpose, functional class and geometric types, including, urban and rural principal arterials (for main movement), minor arterials (distributors), collectors, and local roads and streets. The main goal of geometric design is to ensure that the road is safe to travel on considering its functional classification and purpose. Roads with higher traffic volume will require different physical attributes than roads with lower volumes, and roads with higher speed limits will require different features and layout than roads with lower speed limits. E&P roads can generally be considered rural local roads, or sometimes rural collector roads, for design purposes. Rural local roads primarily provide access to land adjacent to the collector network and serve travel over relatively short distances. E&P roads serving multiple wells over longer distances (sometimes referred to as a trunk road) can be considered a rural collector.

For the purposes of this paper, the key geometric variables that will be discussed are limited to alignment and shape. Design speed is the maximum safe speed that can be maintained on a road under ideal conditions, and varies from the legal speed, which is influenced by other factors. Design speed is an important factor for E&P roads for financial reasons, which will be discussed in the Life-Cycle Cost Analysis section. Drainage is another key factor that should be considered due to the effects of water on the materials used in construction. It is not uncommon to hear that E&P roads are fine… until it rains. At that point they can become difficult to use safely at their design speed, or worse, impassible, which is due in part to poor geometric design.

One key factor that affects horizontal and vertical alignment is sight distance. Sight distance is the distance that a driver can see along the roadway at any given point. For a long, straight roadway, the sight distance can be up to several miles, but when hills or curves are involved, it can be less than 100 feet. Sight distance is one parameter that is used to determine the safe travel speed based on driver perception/reaction time and braking distance. It is important to determine the minimum sight distance required based on the desired design speed.

According to Exhibit 3-1 of in the AASHTO *Green Book*[6], a safe stopping sight distance for a 45 mph design speed is 360 feet. As will be discussed in the Life-Cycle Cost Analysis section, a 45 mph design speed is ideal for E&P roads, as design speed has a considerable effect on user costs. Note that in transportation design, design speed is an overall design control that is used to determine parameters such as sight distance and slope, not the other way around.

Another variable that affects design speed is cross-slope, especially the cross-slope in a curve, which is called superelevation. (Think of superelevation as the bank in the curve of a racetrack.) E&P roads rarely have superelevation, and generally only have a normal crown. Based on tables provided in the AASHOT *Green Book*, a normal crown section is sufficient if the radius of curve is 6000 foot or greater at 45 mph design speeds. If a curve is sharper than having a 6000 foot radius, the speed should be limited for that area. Cross-slope is what creates a crown, or high point, in the center of a road. For most E&P roads, a cross slope of 1.5 to 2.0 percent is sufficient to shed water at an ideal rate. Roads without a cross slope will not shed water, which will lead to issues such as rutting.

Pavement Structures and Materials

A pavement structure is the combination of a subbase layer, a base layer, a structural course, and a surface layer placed on top of a subgrade that is used to support and distribute traffic loading. Subgrade is essentially the uppermost portion of natural soil on which the remaining pavement structure sits. It is typically the soil that is exposed after clearing and grubbing operations have occurred and topsoil has been removed. On top of the subgrade is the subbase and then a base layer. Depending on the design, the subbase and base may be combined into a single layer. The purpose of these layers is to support the structural course and distribute the load to the layers below. The structural course is typically what we think of as pavement. It includes any material that takes the direct brunt of the traffic loading, and may be constructed using asphalt or concrete, but can also be constructed from compacted rock or chemically stabilized materials. Sometimes a surface layer is placed on top of the structural course and acts as a wearing surface to provide friction and drainage and resist weathering and abrasion.

There are various models that are used in pavement design, but the ultimate goal of each model is to design a pavement structure that is reliable and resists failure based on expected traffic loading and volume. In other words, the pavement structure needs to be put together so that it doesn't rut, crack, shove, heave or pump. For E&P roads, 2" of gravel on top of a soft subgrade is not going to be sufficient to withstand loading from heavy trucks, but it is also expected that an airport runway design is not needed either. In order to determine an adequate, cost effective design, due diligence must be performed during the planning phase in order to determine what loading is expected. In general, a pavement structure designed to withstand 10,000 applications of an 18,000 lb single-axle load with less than 1 inch of rutting will be sufficient for E&P applications. Designs of pavement structures will specify the strength and thickness of each pavement layer so that the cumulative strength is sufficient to withstand the design life.

Typically, materials used in pavement structures can be divided up into two main categories: bound and unbound. Bound materials include asphalt and concrete as well as chemically stabilized material, such as soil cement. Unbound materials include compacted rock and soils. The common materials used in the construction of E&P roads include unbound materials and chemically stabilized material. Each pavement design relies on the use of suitable materials, that is, material that will provide a stable foundation. Some materials may require manipulation (drying out, watering, chemical modification) in order to be considered suitable. Have you ever heard the phrase "it's just a bad location"? That's because the materials used to construct the location or road were not suitable materials, or because there were no construction specifications. In order to determine if a material is suitable for use, it should be tested in a geotechnical or materials laboratory to determine its physical properties. There are multiple properties that can be tested and different variables that are used depending on the pavement design method. Common parameters used in pavement design are California Bearing Ratio (CBR), unconfined compressive strength and resilient modulus. Unbound material such as soil and rock will generally have a large degree of variability in these parameters with changes in moisture content. In other words, a soil high in clay content may provide good bearing capacity at a low moisture content but have very little bearing capacity at higher moisture contents. Conversely, a poorly graded sand is likely to have the opposite variation. The mechanical properties of bound materials such as soil cement typically do not vary as drastically as unbound materials with changes in moisture content, which is the main reason that soil stabilization (soil cement) is becoming increasingly popular for construction of well pads.

Part of the pavement design process will involve developing construction specifications that will be discussed in the following section. Pavement design is a relatively inexpensive process that can drastically reduce the overall life-cycle cost. It will also remove any guesswork during the construction process and provide an avenue of a performance based system. For additional information regarding transportation materials, review the *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects*[7] or the *Federal Lands Highway Field Materials Manual*[8] published by the United States Department of Transportation, Federal Highway Administration (USDOT, FHWA).

Construction and Quality Control

In transportation engineering, when a project is ready for construction, there are a clear set of plans and specifications that must be followed. A good set of construction plans should provide the contractor with detailed geometric design and layout as well as establish specifications for the pavement structure itself. Establishing construction goals allows contractors to achieve those goals however they most see fit, but also provides an avenue of verification through quality control to ensure that the specifications were achieved. Because developing a set of specifications for each project can become redundant and repetitive, standard specifications are often used. In fact, each state's department of transportation has some form of standard construction specifications that are commonly referenced in construction contracts. For example, the Texas Department of Transportation publishes the *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*[9]. Nearly every other state with oil and gas activity publishes a similar document, and most are updated on a regular basis.

Quality control plans should ensure that the construction specifications have been achieved. There are various quality control parameters that can be used depending on the type of material utilized. Compaction, or density, is one of the most commonly used quality control parameters in construction operations. If material is not properly compacted when it is placed, it will not perform to the design standards. Conventional construction equipment such as graders and dozers may not be sufficient to achieve the necessary compaction, and therefore compaction equipment may be needed. Another common quality control parameter that can be tested in the field is the bearing capacity. Bearing capacity can be easily verified through direct CBR tests in the field or through a penetration test such as the dynamic cone penetrometer (DCP) test. In addition to density, CBR and DCP testing, moisture and compressive strength tests can be performed on chemically stabilized materials such as soil cement, which will help ensure that the performance criteria have been achieved.

Maintenance

As with most other things, routine maintenance of roadways is an important part of ensuring proper operation. Roads degrade over time due in part to repeated traffic loading and in part to natural weathering. Having a maintenance plan for your roads will ensure they remain in operable condition. Whether a road has one truck per month or one hundred trucks per hour, having dependable access to the well site is important. Roadway maintenance can be broken into two categories: routine maintenance, which may be as simple as grading and compacting, and rehabilitation, which will require more effort to bring the pavement back into serviceable condition. Maintenance should be preventative, not reactionary. A common term that was coined by the transportation industry is "worst-first," meaning that the roads in the worst condition received attention, and funding, first. For many years, this "worst-first" idea was a common practice; however, the transportation industry has reviewed decades' worth of data and has shown that when maintenance is neglected, both user costs and life-cycle costs increase dramatically.[10] The reason behind this is that the older a pavement structure is, the faster it will degrade.

Because all pavements degrade over time, even with proper design, construction and maintenance, it is sometimes necessary to rehabilitate a pavement in order to bring it back to serviceable conditions. Rehabilitation can range from simply replacing the surface layer to completely re-constructing everything down to the base layer. For E&P roads this may involve heavy grading and compaction or possibly replacing materials that have been lost over time. In addition to the cost of maintenance and rehabilitation itself, these activities increase user costs as well, which have an effect on the overall life-cycle cost analysis. Both maintenance and rehabilitation activities should be planned based on the life-cycle cost analysis.

Life-Cycle Cost Analysis

Life-cycle Cost Analysis, or LCCA, is an engineering economic analysis tool useful in comparing the relative merit of competing project implementation alternatives.[11] LCCA considers the overall cost to operate an asset, not only the direct, up-front cost of construction. The USDOT has developed a method for performing lifecycle cost analyses for transportation officials to follow, which can and should be followed when making decisions regarding E&P roads. LCCA considers costs of design, testing, construction, maintenance, rehabilitation, user costs and any removal or abandonment costs.

It is often assumed that the largest cost involved for an E&P road is the construction cost, or the initial capital expenditure. In fact, the real cost involved for E&P roads is the user cost, which is made up primarily in trucking. User costs are not only affected by the geometric design and pavement design, but also maintenance and rehabilitation activities, which are a function of both design and construction. Considering that trucking makes up a significant portion of E&P costs, being able to reduce trucking costs in any way can have a drastic effect on overall well cost. Take speed limit for example. Many E&P companies implement a speed limit of 15 mph without warrant and without understanding the consequences of that policy. Speed is a safety concern and should be monitored; however, the speed chosen should be warranted and supported by transportation industry standards. For many existing E&P roads, a speed limit of 15 mph may in fact be warranted due to insufficient design, construction and maintenance, but this comes at potentially extreme cost. When roads are properly designed, constructed and maintained, there should be no safety issues operating at speeds of up to 45 mph and possibly greater, depending on design parameters.

Tripling the speed from 15 mph to 45 mph can drastically reduce overall user cost. Compare two alternative designs for a five-mile lease road. The first option is a poor quality road, and therefore has a 15 mph speed limit. The second option is properly designed and has a 45 mph speed limit, but also has a higher up-front cost. Each of these alternatives will have the same number of truck trips for drilling and completions, which can be approximately 2000 one-way trips per single, horizontal well (Dutton and Blankenship, 2010). Using a trucking rate of $120/hour, the second alternative will result in a savings of $106,667 in trucking costs. These savings may be offset by the increased construction cost; however, depending on the amount of trucking necessary during production, overall savings over the life of a single well in this scenario can extend into the millions, far offsetting the additional cost of construction. Maintenance costs will also be largely reduced as well.

Conclusions

The E&P industry owns, constructs and operates a considerable amount of transportation infrastructure and engineers in E&P are capable of managing such projects if they have the tools necessary to make appropriate decisions. Cost and safety are two of the most important aspects of any transportation related facility, and the standards established by the transportation industry are focused on ensuring safe and efficient modes of transportation than can be adopted by the E&P industry. The transportation planning process for E&P should involve stakeholders from land, drilling, completions and production and ensure that the needs of each are being met. Design and construction specifications should be based on life-cycle cost analysis to ensure that money isn't wasted. If a location is inherently "bad" because of high initial access or access maintenance costs, it should be possible to predict such problems before beginning drilling, so that a more promising location can be chosen before money is wasted by starting to drill.

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