Design of Bulk Railway Terminals for the Shale Oil and Gas Industry

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ABSTRACT: Railway transportation is playing a key role in the development of many new shale oil and gas reserves in North America. In the rush to develop new shale oil and gas plays, sites for railway transload terminals are often selected on the basis of land availability and environmental constraints before full consideration is given to rail design and operating requirements. The result can be terminals that poorly utilize the available space or operate inefficiently and face long-term capacity constraints. Additionally, preliminary concepts may omit or underestimate the need for staging tracks, switching leads and other rail infrastructure required to support train operations, potentially altering the economics of a terminal. To facilitate more informed decisions regarding railway terminal sites and better track layout concepts, this paper presents design requirements for bulk railway terminals to support shale oil and gas development. Guidelines for sizing facilities and layout of different track arrangements, including stub-end, inline and loop facilities, are presented. Considerations for mainline access and multi-train operation to ensure terminal capacity to support current and future demand are also discussed. Developers following these guidelines will likely obtain greater returns from their real estate and facility investments through faster railway approval of design concepts and more efficient rail operations.

INTRODUCTION

Large quantities of crude oil and natural gas are trapped beneath the ground surface in non-permeable shale rock in the United States. Technological advances such as directional drilling and hydraulic fracturing have combined with the recent trend of higher crude oil prices to make extraction of shale oil and gas economically feasible. The resulting increase in U.S. crude oil reserves and production is concentrated in North Dakota and Montana (and bordering Canadian provinces), and Pennsylvania and Ohio, away from traditional domestic oil production centers in Texas, Oklahoma and California. This means that these new sources of oil, or shale oil and gas "plays", are located far from the refining and pipeline infrastructure that developed along the Gulf Coast to serve traditional production centers and in the Northeast to serve oil imported via tanker ship. Since new refining infrastructure near developing production centers will take years to permit and construct, for the oil from places such as North Dakota to reach market, it must move overland to existing pipeline and refining infrastructure. The sudden demand for transportation of large quantities of oil is being met by the rapid development of new infrastructure.

Most crude oil transportation in the United States has traditionally been via pipeline, with a dense network serving historical production centers in Oklahoma and Texas and long distance pipelines from storage hubs to refining centers in the Midwest and Northeast. Similar pipeline networks exist to move imported oil inland from Northeast and Gulf Coast ports. With a shift in production to regions where there are relatively few pipelines with limited capacity and geographic coverage, the new production centers are poorly served by this transportation mode. Like refineries, new pipelines take many years to permit and construct. Thus, it will be many years before the pipeline mode can adapt to handle all of this transportation demand. In the meantime, rail is being used as an alternative.

Due to their history of agricultural production and transportation of crops via rail, North Dakota and Montana are served by a dense network of rail lines. Thus transportation of crude oil via rail is a natural alternative to pipeline. Oil by rail can take advantage of existing transportation infrastructure to provide producers with safe, efficient and cost-effective transportation of their product until pipelines can be developed. This is evidenced by the rapid growth in oil traffic experienced by the Class 1 railroads during the past five years. In 2008, U.S. Class I railroads originated just 9,500 carloads of crude oil. In 2012, they originated nearly 234,000 carloads and, according to the Association of American Railroads (2013) are projected to originate around 400,000 carloads in 2013. Even after new pipelines are developed, rail still offers advantages such as routing flexibility to serve multiple refining centers and the ability to divert shipments to capitalize on rapid price swings and market demands. Thus, although some market share will be lost to pipeline development, oil by rail is seen as a long-term transportation option for the oil and gas industry.

The efficient and effective transportation of crude oil by rail requires the development of new transload terminals that support efficient access to railway operations. A properly planned transload terminal that can expedite the loading of railcars near a production center and unloading of railcars near a refinery or pipeline access point is key to effectively providing a continuous, uninterrupted supply of crude oil. Despite the importance of these facilities, in the rush to develop new shale oil and gas plays, sites for railway transload terminals are often selected and purchased on the basis of land availability and environmental constraints before full consideration is given to all railway design and operating requirements. The result can be track layouts that poorly utilize the available space or terminals that operate inefficiently and may face long-term capacity constraints. Additionally, preliminary concepts may omit or underestimate the need for staging tracks, switching leads and other rail infrastructure required to support train operations, potentially altering the economics of a terminal and decreasing return on investment.

To allow shale oil and gas terminal developers to make more informed decisions regarding railway terminal sites and better plan track layout concepts, this paper presents guidelines and design requirements for bulk railway terminals to support shale oil and gas development. Guidelines for sizing facilities and layout of different track arrangements, including stub-end, inline and loop facilities, are presented. Engineering requirements for curvature, gradient and special trackwork are included in this discussion. The paper also covers considerations for mainline access and multi-train operation to ensure terminals have capacity to support efficient operations under current and future demand.

RAILCARS AND UNIT TRAINS

Two important parameters in the design of a transload terminal are the lengths of the railcars and trains to be served by the facility. To provide the most efficient transportation possible, railcars are optimally sized to carry a specific commodity. For crude oil, the optimally-sized tank car with a gross rail load of 129,727 kg is approximately 113,562 to 121,133 liters. Based on current designs, this translates into tank cars between 18 and 19 m in length over the couplers. It is this overall coupled length, and not the length of the tank itself, that is critical for terminal design.

To further increase efficiency, crude oil moves in unit trains that transport large volumes of a single product between two points. Unloaded on arrival and returned promptly for another load, unit trains cut costs by eliminating intermediate yard and switching operations. This decreases cycle time and increases equipment utilization. Crude oil tank cars are most commonly moved in unit trains ranging in length from 80 to 120 cars. The selected train length depends on several factors, including oil production rates, expected traffic volumes and any constraints on train length, such as the length of passing sidings where meets between trains traveling in opposite directions on single track occur. The overall train length (L_t) includes three components as described by Eq. 1:

$$L_t = L_l + L_b + L_r N \tag{1}$$

where L_l = length of locomotives; L_b = length of buffer cars; L_r = length of loading or unloading rack; and N = integer number of railcar “cuts” in the train, where a “cut” is a group of railcars that stay coupled together as they are moved about the facility during the transload process.

Typical loading and unloading racks are 365 to 439 m in length such that they can simultaneously handle a group of 20 to 24 railcars. Thus, a facility with a 24-car rack is likely to be served by a 96-car train that is composed of four groups of 24 tank cars. Such a train is loaded or unloaded in four stages, either by advancing the intact train in 24-car increments through an unloading rack on a continuous loop or by splitting the train in to four groups of 24 tank cars and successively moving them in and out of several storage tracks and a rack located on a stub-end track.

As noted in Eq. 1, the design train length includes the length of locomotives and buffer cars. A buffer car, minimum 13.7 m in length, must be placed between the locomotives and the tank cars to satisfy federal regulations. The typical high-horsepower mainline locomotive is 22.9 m in length and a typical unit train may require two to five locomotives depending on the speed and grade profile of the route. All locomotives may be coupled to the front of the train or they may be split between the front and rear of the train in a radio-controlled distributed power configuration.

Based on these characteristics, an example 96-car unit train with one buffer car and three locomotives will be 1,838 m in length. Such a train can transport approximately 11,500,000 liters (72,600 barrels) of oil.

DESIGN STANDARDS AND GUIDELINES

In developing a site as a transload terminal, track curvature can be a limiting factor in the ability to efficiently use available space. In an effort to maximize the capability of a particular site, there is a tendency to squeeze in more track by using sharper curves of smaller radius and turnouts with larger diverging angles. To support unit train operations, curves should be no sharper than 7.5 degrees (233-meter radius by chord definition) and number 11 turnouts are preferred over smaller number 9 turnouts within the facility. These curves and turnouts reduce in-train forces when moving railcars about the facility, increasing efficiency, and also reduce wear and track maintenance cost. Spirals and superelevation are not used within a facility with the exception of mainline connections where trains may be entering or exiting the facility at higher speeds and larger number 15 turnouts may be required. Reverse curves may be separated by as little as one car-length of tangent but operation of unit trains is made more efficient if there is 61 m between reverse curves.

Gradient should be kept as close to level (0%) as possible where railcars are being positioned at the loading and unloading racks to reduce the in-train forces needed to precisely handle the heavy groups of tank cars. Where possible, the transload and storage tracks where railcars will be left standing should be designed with a slight 0.1% descending grade towards the middle of the track to create a depressed "bowl" shape that helps prevent railcars from rolling out of the track.

To help prevent railcars from accidentally rolling out of the facility and on to the mainline where they pose a collision hazard, the transload facility should be designed at a lower elevation than the main track. Since this is not always practical and some cars may gain enough momentum to roll up ascending grades, the lead track into the facility must be equipped with a derail. Due to the size and weight of the cuts of 20 or more railcars that are typically moved about a transload facility, it is recommended that a double-switch point derail be used.

While the preceding general guidelines are typical of the Class 1 railroads, the specific industrial track design standards of the connecting Class 1 railroad should always be referenced.

SITE AND LAYOUT CONSIDERATIONS

The guidelines in the previous section relate to the technical requirements of specific elements of rail transload facility design. They do not speak to the overall facility layout and its related operating concept. Thus it is possible to design a facility that meets all track specifications but has an overall layout that does not provide the required capacity in an efficient manner. Inefficient terminal operation will increase railroad shipping rates, reducing the return on terminal developer investment. The terminal developer should engage the connecting Class 1 railroad early in the process to ensure the selected site and preliminary track layout provide the most effective combination of location, shipping rates and serviceability.

In evaluating potential sites along a rail line and their corresponding track layouts, a terminal developer should carefully consider the following series of questions:

- **What is the traffic density and capacity of the connecting rail line?** Class 1 railroads are taking steps to limit access to their densest and most capacity-constrained corridors. Facilities on these lines will require additional track to ensure that terminal operations have minimal impact on the fluid movement of through trains.
- **At what speed are trains expected to enter and exit the facility?** Trains that must reduce speed on the mainline to enter a transload facility consume mainline capacity. On busier mainlines where capacity is a concern, additional track will be required between the facility and mainline connection to allow acceleration to and from track speed to occur off of the mainline.
- **What signal system is in place on the connecting rail line?** Connecting to a line with wayside signals will be more expensive than in unsignaled ("dark") territory. Additional project schedule time will be required to design the signal interface prior to installation of the mainline connection. This amount of time can be reduced if the mainline turnout can be installed near an existing signal control point, passing siding or crossover.
- **What is the direction of local train service?** Stub-end facilities are most efficiently served if a train travelling in the direction of local train service can pull past the facility and then back up through the mainline turnout into the stub-end tracks of the transload terminal.
- **Can the mainline or existing siding tracks be used for terminal operations or must all operations be contained within the facility?** At facilities on low-density lines, traffic may be infrequent enough to occasionally allow transload terminal operations use of mainline and passing siding tracks for switching movements. However, where traffic density is higher, dedicated switch leads and run-arounds must be constructed, increasing the required length of track at the facility.
- **Are there any existing bridges, grade crossings or rail customers on the mainline within one train-length of the proposed site?** Existing constraints can prevent or increase the cost of establishing switching and departure tracks of length required to support efficient operations.
- **What is the anticipated frequency of train arrival/departures?** A facility that is expected to service more than one train per day will require sufficient track to stage more than one train in the facility at once, increasing space and infrastructure requirements.
- **Will mainline locomotives remain with the train or will a locomotive based at the terminal be used to reposition railcars?** At loop facilities, mainline locomotives often stay with the train but at stub-end facilities, these locomotives may be taken away and returned when a loaded crude

oil train is assembled for departure. In such cases, the track layout must include the crossovers and specific track arrangement required to remove the locomotives from the train. This can be further complicated by the presence of distributed power. Where dedicated switching locomotives will be stationed at the terminal, space must be allotted for a locomotive storage track that is convenient for refueling and servicing from trucks.

- **Will any inspection and railcar repair occur at the facility?** If routine inspection of tank cars that may result in light maintenance and running repair activities will take place at the facility, the track layout should incorporate a short set-out track with easy truck access where railcars can be repaired. A second track may be used to stage spare tank cars used to replace railcars removed from the train for repairs. Adding these cars to fill out unit trains to their desired operating length increases efficiency.

The answers to the above questions will make some potential sites more attractive than others. Sites along high-density mainlines requiring additional track to address mainline access concerns will need to be longer, favoring long rectangular parcels parallel to the mainline. Where this is impractical, it may actually be better to investigate sites that are remote from the mainline but can be accessed via a long lead track from the mainline constructed along a narrow right-of-way. Examples of these arrangements are illustrated in Figure 1. Where mainline access is less of an issue, square or rectangular parcels become more attractive as they allow for stub-end and loop layouts. Where all adjacent parcels are unavailable or there are parallel constraints, the only practical option may be to develop an inline facility on a narrow easement parallel to the railroad right-of-way. Specific layout considerations for stub-end, inline and loop facilities are presented in the following sections.

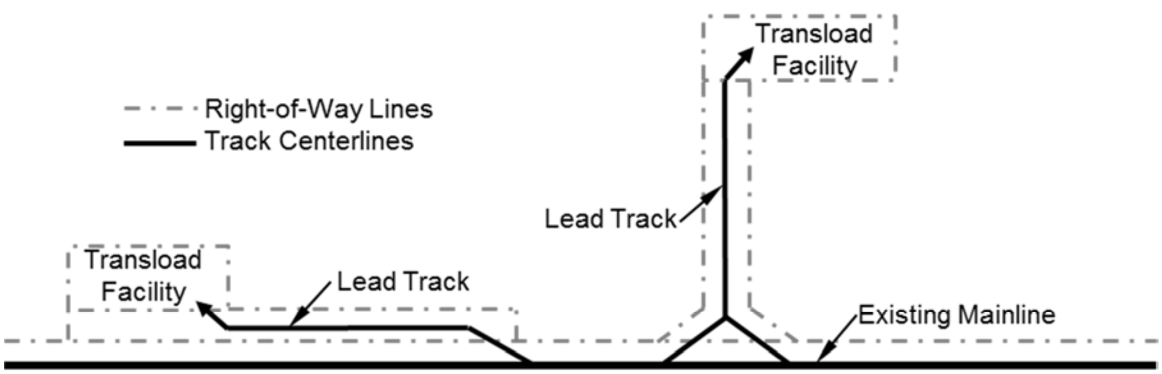

FIG. 1. Property requirements to support extended lead tracks from the crude oil transload facility to the mainline.

STUB-END FACILITIES

The most compact transload facilities consist of a series of parallel stub-end tracks. One or more of the tracks will be adjacent to the loading or unloading rack while the remaining tracks are used to temporarily store railcars before or after their turn at the rack. The general layout of a stub-end facility is illustrated in Figure 2.

Empty trains arrive at the stub-end facility on the lead track. A terminal switching locomotive splits the unit train into groups of cars matching the length of the loading rack and moves them into the storage and loading tracks. As the groups of cars are loaded, they are moved from the loading track to a vacant storage track. Then an empty group of tank cars is moved from a storage track to the loading track. When all of the tank cars are loaded, they are reassembled into a unit train on the lead track.

Based on this operating pattern, suggested track lengths are illustrated in Figure 2. A key consideration is to have a lead track that is long enough for groups of tank cars to be moved between the loading and storage tracks without using the mainline. There must also be a single track long enough to reassemble the unit train without using the mainline track. Each storage track must be longer than the loading tracks, allowing each to hold an entire group of railcars. To reduce the number of heavy switching movements with multiple groups of railcars, it is recommended that there be one storage track for each group of railcars expected to be in the facility at a time. For a facility that will only handle one train per day, four storage tracks are required when the loading rack is one-quarter the length of a unit train. For a facility that will depart two trains per day, eight storage tracks are required.

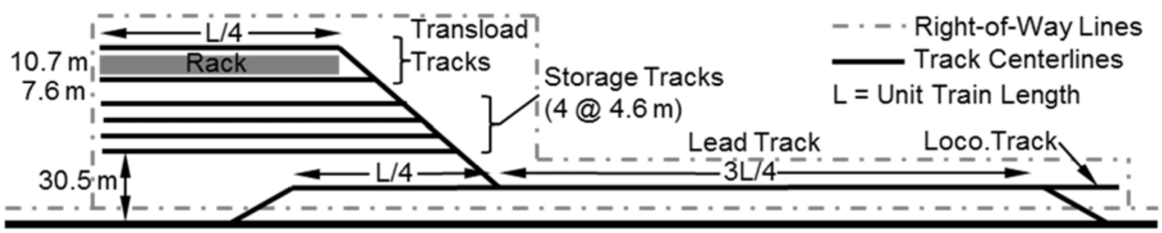

FIG. 2. General layout of parallel stub-end crude oil transload facility.

Any track used to store or transload tank cars must be located at least 30.5 m from the mainline track. Track centers can be spaced at 4.6 m but if access is required between tracks, wider track centers greater than 7.6 m are required. If a transload rack is to be located between tracks, those tracks must be spaced at 10.7 m on center.

While Figure 2 illustrates a layout with tracks parallel to the mainline, the stub tracks may also be oriented perpendicular to the mainline. This configuration can make better use of rectangular parcels with a long axis perpendicular to the mainline.

INLINE FACILITIES

Where a rectangular parcel of land is not available and a long skinny parcel parallel to the existing railroad right-of-way is the only available option, an inline design should be considered. Like a stub-end facility, the inline design requires splitting the unit train into multiple groups of tank cars that are transloaded in succession. However, instead of being sorted into a series of stub-end tracks, the groups of railcars are shuffled through the facility in a more linear manner. A general layout for an inline facility is illustrated in Figure 3.

The track lengths in Figure 3 are required to support the operating pattern illustrated in Figure 4. Empty trains arrive at the inline facility on the long track running the length of the facility. Upon arrival, the first quarter of the train is already positioned at the rack for loading as a group. After this group is loaded, it is pushed back into the short siding track and the remainder of the train is pulled forward, positioning the second group of railcars for loading. This cycle is repeated for the third group. When the final group is pulled forward to the rack, all four groups will be positioned in line, albeit in reverse order, to be recoupled into a unit train.

Although this configuration can make very efficient use of a narrow right-of-way parallel to the existing mainline, it is difficult to stage multiple trains at the facility. Loading multiple trains per day requires offsite staging tracks where empty trains can be held until the train at the facility can complete the loading process and depart.

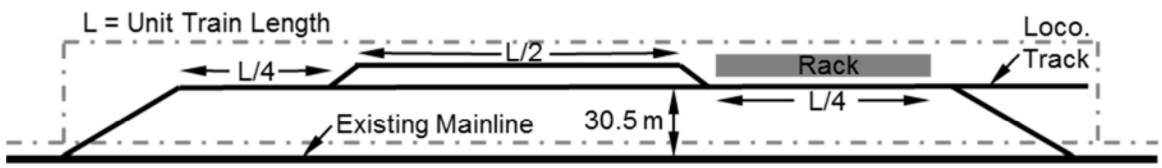

FIG. 3. General layout of an inline crude oil transload facility.

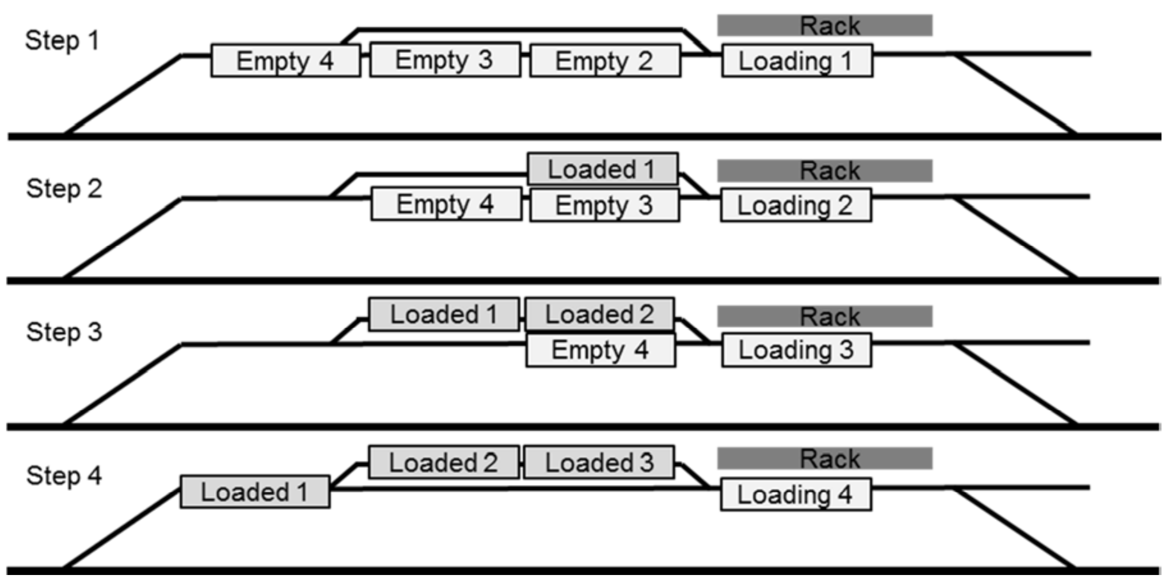

FIG. 4. Inline facility operating sequence.

LOOP FACILITIES

Unloading loops increase efficiency by allowing the crude oil unit train to transload without being split into individual cuts of railcars. As the next group of tank cars is moved forward into position at the rack, the entire train is moved around the loop together, mainline locomotives included. Loops also automatically reverse the direction of the train and eliminate movements to reposition locomotives as required at a stub-end or inline facility. Eliminating coupling, uncoupling and switching activities reduces equipment cycle times and the cost of rail transportation.

The main disadvantage of unloading loops is the space required for a loop large enough to turn a unit train. Although tight curves decrease the overall footprint of the rail loop, they create operational and maintenance issues due to the increased friction of loaded trains on such curves. From a site selection perspective, the minimum curve radius requirement described earlier sets the minimum width required to turn a unit train on a loop at 466 m, plus allowance for roadbed and right-of-way. However, as described below, there are other considerations that can increase the required size of the loop and the least measurement of the required property.

Reverse curves on loop tracks must be separated by tangents. To avoid clearance issues, it is also desirable to have the transload racks on a tangent portion of the loop. Since crude oil transload racks can be as long as one-quarter of the unit train length, the loop cannot be round and must have one side with a considerable length of tangent, as illustrated in Figure 5a. The direction of operation around the loop should be selected to minimize in-train forces given the relative position of the loaded and unloaded railcars within the partially transloaded train.

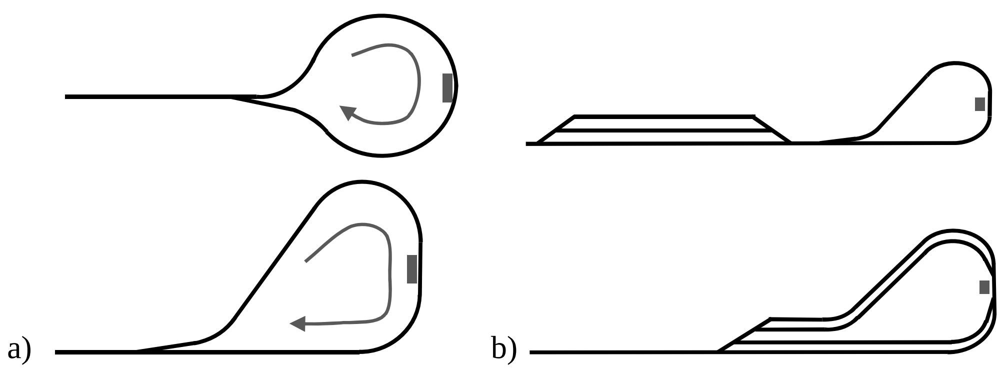

FIG. 5. a) Proper placement of tangents for loop track designs to minimize in-train forces and allow for tangent transload racks. b) Different staging track configuration to support multi-train operations at loop facilities.

On a simple loop track, the required distance around the loop is set by the length of the unit train. To obtain economies of scale and the lowest shipping rate from the railroad, this train length should be made as long as feasible. Although crude oil trains are often shorter, railroads are designing new infrastructure to accommodate 150-car trains. If space allows, designing a loop with 2,743 m of clear track length will aid the industrial shipper in future rate negotiations with the railroad.

There must be additional track between the turnout that closes the loop and the mainline connection to avoid having one end of the train on the mainline while the other end is still positioned at the transload rack. For a rack of length L/4, a minimum distance of 3L/4 is required between either end of the rack and the mainline connection. Operational considerations may dictate even longer lead track lengths.

When a terminal operator plans to have multiple trains cycling through a facility each day, it is likely that trains will be delayed, leading to bunching and multiple trains arriving within a short time period. If the loop is configured such that only one train can be at the facility, the railroad must temporarily store the train nearby, impacting their normal operations. To avoid this possibility, railroads require a loop facility to provide staging for three trains: an empty train, a loaded train and one train being moved to/from the transload rack.

There are two different strategies for providing the required storage tracks illustrated in Figure 5b. The first is to create a parallel staging yard on the spur track leading to the transload loop facility. This has the advantage of storing trains outside the main facility where they will not interfere with site operations. However, this configuration leads to downtime at the transload rack while the first train clears the loop and returns to the staging yard and the next train moves from the yard to the rack. The second strategy maximizes rack utilization by integrating the staging tracks into the loop track. By making the loop twice as long and double track (except for the segment through the rack) three trains can be stored in serial fashion. With this configuration, the second train can start transloading immediately after the first train clears the rack. However, by providing train storage on the loop, access to the interior of the loop will almost always be blocked, reducing its utility as usable space.

OPERATIONAL CONSIDERATIONS

As described earlier, transload facilities often strive to locate on property immediately adjacent to a railroad mainline. Although this minimizes the amount of track the terminal developer must construct, the proximity of the transload tracks to the mainline can be less than ideal from the railroad perspective. On certain congested corridors, in an effort to reduce track capacity consumed by trains moving slowly on and off the mainline into terminals, the railroads require that trains enter and exit the mainline at speed via a large turnout. There must be sufficient track between the mainline turnout and facility for a train to leave the mainline at speed and then decelerate to a stop prior to commencing the transload sequence. Although braking distances vary, a good guideline is to leave a minimum of two train lengths between the mainline turnout and the entrance to the main transload facility trackage.

If typical operations require a train to pass through the diverging route of a turnout while entering or exiting the plant, turnouts located within one train length of the mainline should also be large enough so as not to restrict train speed. More expensive larger turnouts are required to support this requirement. This also suggests that from an operational perspective, on a congested corridor, it may be best to site a transload facility off the mainline at the end of a dedicated spur of approximately 4 km in length. As shown previously in Figure 1, absent engineering constraints, lengthy approach tracks could be constructed parallel to the existing mainline track to effectively create more distance between the mainline and the transload site.

CONCLUSION

Railway transportation is playing a key role in the development of many new shale oil and gas reserves in North America. To allow shale oil and gas terminal developers to make more informed decisions regarding transload sites and better plan track layout concepts, this paper presented guidelines and design requirements for bulk railway terminals to support shale oil and gas development. Stub-end, inline and loop facilities all have their unique site space requirements. Selection of an appropriate configuration is driven by parcel shape and orientation, traffic levels, operational considerations and engineering constraints. Developers should carefully consider the exact size and shape of a potential parcel and its influence on the capacity and efficiency of possible transload facility layouts. A key consideration is sufficient lead track to avoid operational issues. Track layouts that follow the presented guidelines are more likely to fully utilize the available space, operate efficiently and provide long-term capacity for future operations. Developers of these terminals will likely obtain greater return on investment through more efficient rail operations, reduced equipment needs and potentially lower shipping rates.

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