H Grade Options for I-70: 4% vs. 7%

H.1 Context[1]

For the "FRA Developed Option," the Steering Committee raised a number of questions regarding the consulting team's inclusion of a 4% grade option via Pando rather than 7% grades on Vail Pass. This Appendix documents the rationale for that choice. The consulting team has recommended that 4% grade options developed in this study be retained for detailed analysis in the Environmental evaluation. 7% grades could technically work, but including them would significantly add implementation risk and raise equipment capital and operating costs. In contrast, 4% grades are manageable using off-the-shelf rail or maglev technology, and would lower operating costs.

This study has not screened or eliminated any of the original 7% alignments from further evaluation in the environmental process. As background, the current study has only examined *representative routes* and *generic technology options*, to determine whether *any* of them could satisfy the economic criteria that have been established by the U.S. Federal Railroad Administration (FRA). As a result, at least *eight* different combinations of routes and technologies that have been identified (see Exhibit H-1) could meet these criteria, and have thus been determined as economically "Feasible" alternatives.[2]

Exhibit H-1: RMRA Routes and Technology Combinations Found Feasible

Feasible Option	Type	Routing	Source
Option 2: 110-mph diesel rail in the I-25 corridor	Truncated network	I-25 Only/ No I-70	Exhibit 9-5
Option 4: 150-mph electric rail in both I-25 and I-70	Truncated network	Pando	Exhibit 9-5
Option 5: 220-mph electric rail in both I-25 and I-70	Truncated network	Vail Pass	Exhibit 9-5
Option 7: 110-mph diesel rail in I-25 and 220-mph Electric Rail on I-70	Hybrid network	Vail Pass	Exhibit 9-8
Option 8: 150-mph electric rail in I-25 with 220-mph Electric Rail on I-70	Hybrid network	Vail Pass	Exhibit 9-8
Option 9: 110-mph diesel rail in I-25 with 300-mph Maglev on I-70	Hybrid network	Vail Pass	Exhibit 9-8
Option 5W: 220-mph electric rail in both I-25 and I-70	Western Extensions	Vail Pass	Exhibit 9-11
Option 9W: 110-mph diesel rail in I-25 with 300-mph Maglev on I-70	Western Extensions	Vail Pass	Exhibit 9-11

[1] Developed in response to Comments Matrix Questions 1 and 6
[2] Capital cost rollups for each of these eight alternatives are detailed in Appendix E.

In Exhibit H-1 reflecting results of the preliminary screening, six of the feasible options used 7% grades on Vail Pass, and one option used 4% grades via Pando. It can be seen that either Vail Pass or Pando routings are "feasible," meaning they could meet FRA's economic criteria. Since *both* the 7% and 4% electric rail options were also found feasible, presumably many mix-and-match combinations of these route and two technology options could also be found feasible. This was the basis for defining the "FRA Developed Option," in addition to the original eight shown in Exhibit H-1.

Rather than screening alternatives the goal of the current study has been to identify and carry forward into the NEPA analysis as many feasible alternatives as possible. Given a wide range of possible technology and route choices, the ability to make minor or local adjustments to routes and stations provides the capability to reasonably accommodate local environmental concerns, without fear that the economics of the whole project would be undermined.

H.2 The "FRA Developed" Alternative[3]

In the initial screening Option 5, a 220-mph technology option produced the best Cost Benefit Ratio of 1.28, satisfying FRA requirements. However, since there is a +/- 30% error range associated with feasibility level projections, this Cost Benefit ratio is not quite high enough to exclude the possibility of a negative result. A result of 1.50 or better is needed to ensure the result remains positive even with a +/- 30% error range. (e.g. 1.50 * 0.7 = 1.05; 1.50 * 1.3 = 1.95, so that with a nominal value of 1.50, the true Cost Benefit ratio is likely to lie in the range of 1.05 to 1.95.)

There are multiple feasible options, and this study makes no determination as to preferred combination. However, TEMS was directed by the Steering Committee to develop an "FRA Developed" Option to form the basis of a more detailed business plan. In development of this alternative, Option 5 was used as the starting point, with the aim of improving the Cost Benefit ratio. A "Mix and Match" analysis was performed to develop a combination of I-70 Highway and off-Highway segments that would be likely to improve performance. This reflected the input received from the RMRA Steering Committee, Public Input meetings and from members of the I-70 Coalition, as well as the recommendations of the consulting team. Other factors considered in route selection were potential environmental concerns (e.g. avoiding Clear Creek canyon) and retaining system flexibility (e.g. diesel operations from Aspen, Steamboat and Glenwood Springs potentially as far east as Frisco, Dillon and Silverthorne.)

While some segments of both the original 7% and 4% alignments were included in the "FRA Developed" network, a major goal was to reduce the amount of costly tunneling that was recommended in the original 4% alignment, while still preserving direct rail service to the resort areas and communities. Some of the tunnels eliminated were on the suggested southern corridor past Lake Dillon. By using the I-70 corridor from Keystone to Silverthorne to Frisco to Copper

[3] Developed in response to Comments Matrix Question QS1

Mountain, not only were the tunnels avoided but access to the local communities was also improved. These changes improved the Cost Benefit ratio.

Another goal was to minimize the environmental intrusiveness of the rail system, resulting in selection of the El Rancho 7% alternative rather than Clear Creek canyon for inclusion in the FRA Developed Alternative. However, the operational analysis clearly found that the 4% Clear Creek alignment would be both faster and less costly to operate than the 7% grade over El Rancho. Furthermore, it is expected that more exhaustive engineering and environmental studies could develop alternative 4% grade options across El Rancho or even along Clear Creek that would be acceptable. For this reason it is suggested that the Clear Creek alignment be retained in the NEPA process, until an alternative practical 4% option can be identified to take its place.

An important third goal articulated by the Steering committee was to minimize construction impacts on the existing I-70 highway. To reduce maintenance-of-traffic impacts, the consulting team was directed at the August 22, 2008 Steering Committee meeting to develop an I-70 "Unconstrained" alternative that would remain independent of the I-70 Highway Right of Way. This was further documented on page 12 of the September 26, 2008 Steering Committee meeting as Corridor Scoping Team input to the Study, confirming an "Explicit desire to not limit alignment options to highway routes" for the same reason.

Going via Pando has lower capital costs, lower grades, preserves the diesel option for a local transit system (all the way from Summit County to Steamboat, Aspen and Grand Junction) and minimizes construction impacts on the I-70 highway. Minimizing grades reduces risks associated with equipment procurement and rail operations. The proposed FRA Developed option including Pando was presented to the Steering Committee on May 22, 2009, and approved.

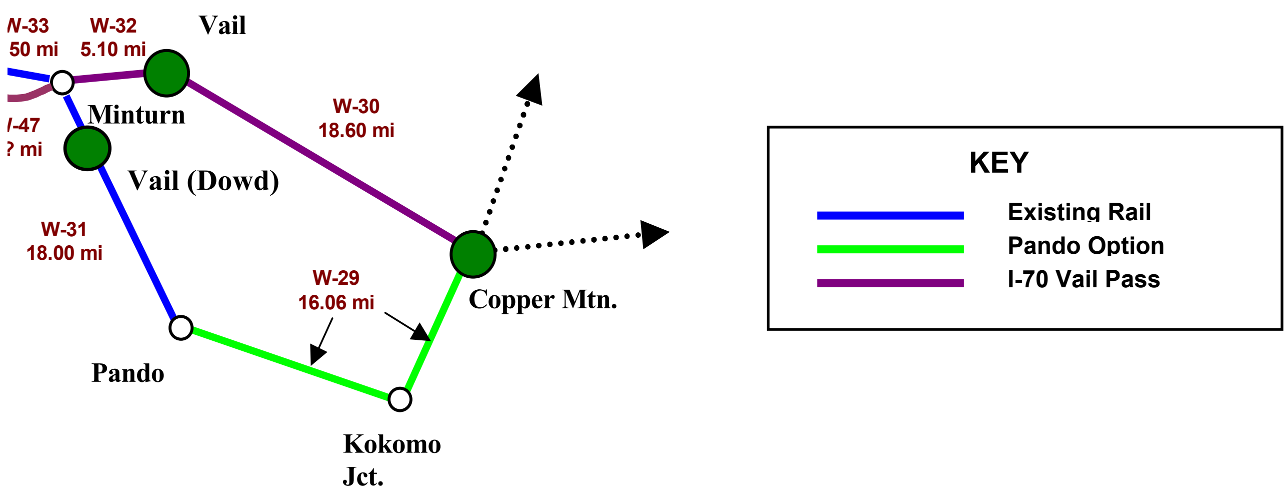
A phased implementation plan was developed identifying specific timing of Capital cash flows, and detailed year-by-year operating projections. The choices made resulted in an improved Cost Benefit ratio of 1.49 for the FRA Developed Alternative.

There is nothing necessarily optimal (in engineering or environmental terms) about this particular selection, however it is likely that it produces the best or close to the best possible Cost Benefit results of any option likely to be considered. The main concern of this study has been to evaluate the economic feasibility of High-Speed Rail and Maglev options, and specifically if a comfortably positive Cost Benefit ratio could be achieved for any representative route. This objective was achieved.

H.3 Capital Costs[4]

Exhibit H-2 shows a portion of the Costing Segments schematic showing the two possible alignments from Copper Mountain to Dowd Junction. The Vail Pass option consists of two segments: W-32 and W-30; while Pando consists of W-29 and W-31.The Pando option utilized in the FRA Developed Alternative does not include a spur into Vail, as agreed with the Steering Committee: the Vail station would be at Dowd Junction for this alternative, and downtown Vail for the Vail Pass (I-70) option.

Exhibit H-2: Copper Mountain to Vail via Pando or Vail Pass
Showing Alternative Vail



The Vail Pass route comprises:

W-30	$ 1,808.9 M
W-32	$ 275.0 M
TOTAL COST	$ 2,083.9 M

The Pando route comprises:

W-29	$ 818.8 M
W-31	$ 911.4 M
TOTAL COST	$ 1,730.2 M

The Pando route is $354 million less expensive than the Vail Pass alignment. While there is potential to “Optimize” the Vail Pass route, it should be recognized that because of maintenance of traffic concerns on I-70, difficult topography and adjacent commercial/residential development, the implementation of this alignment will be very challenging. Starting at Copper Mountain, the topography is very difficult for 16 miles. The Vail Pass alignment would be elevated in this area.

[4] Developed in response to Comments Matrix Q116 and Q130

SATO's rail alternative (page 2-27 of the Tier 1 Final PEIS) is also elevated. For the last few miles into Vail, the SATO alignment went to ground. However, we rechecked the topography and we believe that it is better to stay elevated through Vail. The roadway is constrained by topography and commercial/ residential development. Ultimate resolution of this issue will need a detailed Environmental Study.

The Pando alternative and Tennessee Pass rail alignment does have some serious constraints. These were included in the costing of those segments. For W-31 (Pando to Minturn) an 18 miles segment, this included 25,000 ft of double-track elevated structure and an additional 8 miles of retained fill structure due to the very constrained conditions. About 70 % of this segment is constrained. There is also a need for 1000 ft of high level structure and two major river crossings included in the costing for this segment.

Overall, Pando would be $353.7 Million cheaper and has much more manageable grades. The grades can be less because the route is slightly longer in mileage. Grades via Pando are mostly only 2-3% with only short stretches of 4%.

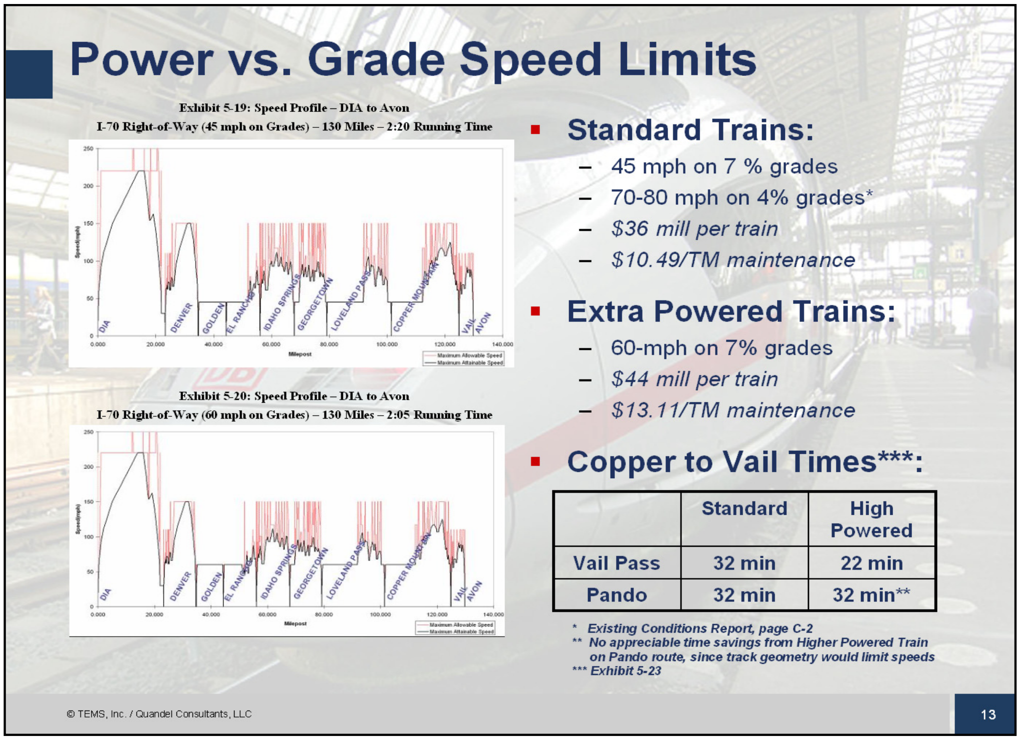
H.4 Operating Costs[5]

Exhibit H-3 shows that if 7% grades via Vail Pass were included in addition to those over El Rancho, there would be a need to buy substantially more costly trains because of the need for the added power. Standard trains could operate on 7% grades, but the best they could do would be 45-mph. Added power could boost speeds to 60-mph, which is the maximum the curves would allow. However, as shown in Exhibit H-3, adding power is expensive: raising capital cost from $36 to $44 million per train costing $400 million; and train maintenance costs from $10.49 to $13.11 per train-mile, costing $510 million over a 30-year life of the system.

While the Vail route is shorter than Pando, schedule times of 32 minutes via either route would be the same for standard trains. A 10-minute savings is possible using Vail Pass if high-powered trains, which will cost more money than those assumed for the Pando alignment, are used. This results in a trade off: Pando is less expensive using standard trains for the same timetable. Vail Pass has higher operating costs, infrastructure and vehicle capital. However, it would be slightly faster than Pando if high-powered trains were used and could directly serve downtown Vail. These options should be explored in a future study.

[5] Developed in response to Comments Matrix Q100, Q102, Supp A Gonzales pg 9-22, Supp G Hall alt calc

Exhibit H-3: Equipment Trade Offs for 4% vs. 7% Grade Options



H.5 Station and Route Selection[6]

Final route and station selection should be a product of the next step, i.e. the Environmental analysis process. As such, we assume that the route through Vail Pass and a potential station in downtown Vail will all be considered. However, given the agreed assumption of a Vail station at Dowd Junction, the Tennessee Pass line via Pando option costs less, and works best to support the improved 1.49 Cost Benefit ratio calculation.

We have no doubt that, if environmentally acceptable, the Vail Pass option might be quicker (if high-powered trains are used that can go 60-mph in the grades); but selection of a 7% option may also preclude the development of a single-seat commuting option from areas farther west (such as Glenwood Springs) into Summit County stations using 110-mph diesel technology. Given the shortage of labor and established commuting patterns, as well as the potential for local trips between resorts in this area, it is likely that such a service would be viable, and ought to be at least evaluated as part of the proposed Western Extensions study before the potential for it is foreclosed. This would provide a significant regional benefit to parts of western Colorado that at present are not served by the truncated system. However, both the Pando and Vail pass options remain potentially viable, and both ought to be carried into any future Environmental process.

[6] Developed in response to Comments Matrix, Supp H. Dale 5 5.2.1

In conjunction with the Pando alternative, the FRA Developed Alternative includes a stop at Vail (Dowd Junction) to avoid the need for building the expensive and difficult-to-operate branch line into Vail. Since many of the riders at Vail are destination (multi day) travelers it is likely they will need to use local transportation to reach their hotels or timeshares. A minority of riders, primarily day-trippers, would go directly to the slopes, and the local free Vail bus system could be used to provide internal circulation within the resort. The Steering Committee agreed that a Vail (Dowd Junction) station was an acceptable planning assumption in conjunction with the Pando option.

The potential use of Copper Mountain as an option for accessing Vail is actually a positive for the Pando option, since it provides another option for day-trippers to go directly to Vail without having to actually construct a rail line over the Pass. Alternatively, multi-day travelers with luggage are less sensitive to minor differences in rail travel time, and much more sensitive to comfort, ride quality and convenience factors. We believe that these riders will probably still find the Hotel shuttles and related local transportation more convenient at a Dowd Junction station. In either case however, whether a rider chooses Copper or Dowd, the system still captures the ridership and revenue. This is a relatively minor distributional issue for predicting the actual pattern of station usage, which can certainly be addressed in future studies.

H.6 Grade Speed Limits[7]

Assumed timetable comparisons depend on the speed capability of the trains, both ascending and descending the 7% grades. Our concerns regarding selection of 7% alignments apply equally to either rail or maglev technologies, since they primarily relate to in-vehicle forces experienced by standing passengers on such alignments and the need to meet FRA passenger safety regulations, particularly under emergency braking conditions. As such our concerns are independent of vehicle technology, since passengers will experience the same dynamic forces regardless of the type of vehicle they are riding in.

For the train performance runs, speeds have been capped at 60-mph reflecting the maximum capacity of the train's electrical system to both power the train uphill and also to brake the train in regenerative mode going downhill. However, achieving this speed potential on 7% grades requires application of substantially more electrical equipment than is ordinarily used on either 220-mph electric or maglev trains.

While the normal operating mode going downhill would be to use regenerative braking, additional disk, eddy current and/or magnetic track brakes can also be added to shorten the train's stopping distance. From a perspective of being able to stop a train on 7% descending gradient, there is no real question of the capability for installing a braking system that is powerful enough to do it. Light Rail (LRT) vehicles use magnetic track brakes, which gives them an outstanding emergency braking capability.

[7] Developed in response to Comments Matrix, Q80, Q82

Automobiles routinely descend 7% grades at 60-mph, but their occupants are seat-belted. The real question is not the ability to stop a train, but rather what may happen to standing passengers in case of a full emergency braking application. This concern of "passenger dynamics" and "forces exerted on the occupants of a vehicle" for non-seat belted passengers, restrains the maximum allowable acceleration, braking and banking capabilities of both Rail and Maglev vehicles. Irrespective of the selection of Rail or Maglev vehicle types, it is the comfort factor, and the limitation of on-board dynamic forces within safe ranges, that will fundamentally determine the quality of the customer's on-board experience.

Because of the LRT precedent for using a back-up magnetic track brake system for emergency use, a 60-mph speed has been assumed to be safe for descending as well as ascending gradients. Consistent assertions of Maglev vendors regarding the downhill speed capabilities of their vehicles have also been accepted without prejudice.

In can be seen that while 7% grades may be technically feasible for a rail system, it would require highly specialized purpose-built equipment. Including such grades would add to both the economic and technical risk factors associated with implementation of the system.

For this reason the Consultant team continues to recommend the retention of 4% gradient as well as 7% grade options into the NEPA process. All these 4% options are well within the proven capabilities of existing off-the-shelf rail and maglev vehicles (e.g. 4% gradients exist on the Yamanashi Maglev Test Line in Japan, and 3.5% gradients are used in the English Channel Tunnel and elsewhere on existing international HSR networks.) It should also be noted that Japan Central Railway, who is in the process of introducing both rail and maglev technologies into the U.S. market[8], has recommended limiting gradients to 4% which is the maximum they employ on the Yamanashi Maglev Test Line. They have said that although their maglev technology is technically capable of operating on higher grades, in commercial operation they would tunnel to avoid gradients over 4% and in fact have done so on the Yamanashi line.

H.7 Train Timetables and Running Times[9]

Travel times from Denver to Vail are practically the same on the I-70 7% "Constrained" or 4% "Unconstrained" alignments. However, the trains needed to achieve this performance are not the same:

- The 7% alignment needs a very high-powered train that approaches the maximum power that could possibly be packed into a train, using today's technology.
- The 4% alignment uses a standard off-the-shelf High-Speed train.

Exhibit 5-23 of the main report shows the results of an exacting, final analysis of detailed alignment data. This analysis revealed that the two alignments have offsetting differences: While the Clear

[8] See: http://www.dailyfinance.com/story/bullet-trains-in-the-u-s-japan-central-says-all-aboard/19284146/
[9] Developed in response to Comments Matrix, Q76, Q78, Q83, Supp H. Dale 5 .2.1 pg 5-25

Creek canyon is 10 minutes faster, Pando is 10 minutes slower than Vail Pass (assuming a 60-mph top speed with high-powered trains on the 7% grades) so the overall running time for either of the original alignments would be the same. These results are summarized in Exhibit H-4.

As a sensitivity, a 45-mph top speed analysis (shown in Exhibit H-3) was developed. The 7% grade option over El Rancho is slower even at 60-mph than the 4% Clear Creek canyon alternative. The Vail Pass route is faster than Pando at 60-mph, but it is slower at 45-mph. This risk factor on equipment performance could cause the Vail Pass route to lose its speed advantage. In an "apples to apples" comparison using off-the-shelf High-Speed trains with a 45-mph speed on the grades, the 7% alignment would be 10-15 minutes slower than the 4% alignment if an were used.

Since the hybrid alignment used for the FRA Developed Alternative uses El Rancho combined with Pando, the schedule for the Developed Alternative is 10 minutes longer than either of the original "pure" 4% or 7% alignments. This running time has been reflected in the ridership forecast, but still maintains a finding of feasibility for the FRA Developed Alternative.

Exhibit H-4: Running Time Summary by Technology and Segment

	220-mph EMU 4% Unconstrained	**220-mph EMU 4% Unconstrained w/o Clear Creek Canyon**	**220-mph EMU 7% Highway Alignment**	**300-mph Maglev 7% Highway Alignment**
DIA to Denver	12 min. 23 miles 115 mph	12 min. 23 miles 115 mph	12 min. 23 miles 115 mph	12 min. 23 miles 115 mph
Denver to Golden	10 min. 12 miles 69 mph	10 min. 12 miles 69 mph	10 min. 12 miles 69 mph	9 min. 12 miles 80 mph
Golden to Floyd Hill	17 min. 17 miles 60 mph	25 min. 17 miles 41 mph	25 min. 17 miles 41 mph	23 min. 17 miles 44 mph
Floyd Hill to Loveland Pass	23 min. 29 miles 77 mph	23 min. 29 miles 77 mph	25 min. 28 miles 67 mph	21 min. 28 miles 80 mph
Loveland Pass to Copper Mtn	24 min. 22 miles 55 mph	24 min. 22 miles 55 mph	25 min. 22 miles 52 mph	22 min. 22 miles 60 mph
Copper Mtn to Minturn	32 min. 34 miles 64 mph	32 min. 34 miles 64 mph	22 min. 23 miles 65 mph	19 min. 23 miles 73 mph
Minturn to Avon	7 min. 5 miles 43 mph	7 min. 5 miles 43 mph	7 min. 5 miles 44 mph	5 min. 5 miles 60 mph
TOTAL	2hrs. 5 min. 142 miles 68 mph	2hrs. 13 min. 142 miles 64 mph	2hrs. 6 min. 130 miles 62 mph	1hr. 51 min. 130 miles 70 mph

H.8 Conclusion

The goal or objective of this study has not been to select or determine either an "Optimal" route or an "Optimal" technology. Rather, its purpose has simply been to identify Feasible options that could be carried forward into a detailed NEPA analysis. The Feasibility Study has accomplished this goal, while leaving local route and station siting details to be resolved in future work.

This study has found that either alternative via Pando or Vail Pass can satisfy the FRA Feasibility Criteria, so either option can remain "in play" in the upcoming Environmental evaluation.