TOP SPEED VARIATION IMPACT STUDY

A Report Prepared by the
Locomotive Technology Task Force
of the
Next Generation Equipment Committee

August 11, 2011

Tasking

During discussions at Executive Board meeting on June 23, 2011, in Chicago, a participant brought up whether the required top speed to 125 for the PRIIA locomotive represented too much of an increase over today's diesel locomotive technology. Was the specification reasonable and feasible, or did the requirements equate to a design that was not fuel efficient, too heavy and cost too much to procure. A cost difference of 100% as compared to a typical passenger diesel locomotive was cited, specifically from $4 million to $8 million each. Further, regardless of the top speed contained in the Requirements Document, this speaker stated, based on conversations he had had with manufacturers, the manufacturers had an opinion that 100 mph, a typical current top speed, was adequate.

As a result of this discussion, the Locomotive Technology Task Force (LTTF) was assigned an action item to investigate the "110 to 125 mph" issue.

Contents

The LTTF discussed this requirement at its next bi-weekly meeting. Candidate questions were solicited from Task Force members—especially the manufacturer's representatives—that could be used to determine the impact of lowering the locomotive top speed requirement to 110 mph. LTTF Chairman Dave Warner and Kevin Kesler took the inputs, and generated the following questions for the manufacturers to answer:

1. What are the key challenges to successfully building and operating a diesel electric locomotive with a top speed of 125 mph?
2. What power requirements (e.g., power per gross ton) would be required to operate a typical intercity schedule with a top speed of 125 mph? Please attach distance/speed curves for the three train conditions listed in the locomotive specification, Sec. 9.2., as well as tractive effort curves.
3. What challenges exist to create a drive/suspension system for 125 mph while still maintaining the P2 force limits contained in the PRIIA locomotive specification?
4. How would you rate the impact to both cost and construction schedule for developing a truck and traction/power plant capable of a sustained 125 mph top speed? Please include in your answer the direct affect of the Tier IV emission requirement.
5. For the first PRIIA locomotive order, can you quantify the major cost drivers or estimate the relative impact of the need to design a vehicle, Tier IV emission requirements and order size.
6. These questions assumed the "technological/cost" break point for diesel locomotive design/construction was between 110-125 mph. Is this

correct? If not, at what speed is there a "knee" in the “technological/cost" curve. What is/are the cost driver(s)?

Manufacturers agreed to providing answers within three weeks so that the results could be given to the Executive Board quickly. Five manufacturers provided answers to the questions, and in the tables below they are identified as A, B, C, D and E. The level of detail and approach to answering the questions differed among the manufacturers. Tractive effort curves, when provided, are included after the answer table. Each manufacturer confirmed that no proprietary information was included in their answers.

Question	A	B	C	D	E
1. What are the key challenges to successfully building and operating a diesel electric locomotive with a top speed of 125 mph?	This question needs to be answered in two parts: *Successfully building* a 125 mph DE locomotive in the United States does not represent a problem as this is being done in Europe today. *Successfully operating* such a unit at top speeds of 125mph on a permanent basis represents a number of challenges for operator, maintainer and infrastructure owner. While the key challenge for the operator is likely energy consumption, for manufacturer and infrastructure owner it will likely be weight. The European standard for Rolling Stock TSI High Speed sets the weight limit for vehicles running at top speeds 125mph (200kph) to 22.5 metric tons per axle (49,600lbs). While our past experience and analysis showed that this limit can certainly be stretched a little - depending on the track conditions and actual running time at max. speed – we got clear indications that the higher the weight, the higher the maintenance effort was on both, locomotive and infrastructure, even on equipment that uses fully suspended drives and the lowest possible unsprung mass.	• Light Weight Locomotive to reduce P2 Forces. i. Full FRA/APTA structural requirements ii. CEM – push back coupler – adds weight • Meeting Tier 4 Emission Regulation i. No Engine Manufacturer currently has an engine that will meet Tier 4 without after-treatment – potentially a 10% to 15% fuel penalty. ii. Without Urea – Class 1s are dead set against urea. • Most potential suppliers will need to develop a new high speed light weight truck • Meeting 100% Buy America.	Reduction of unsprung mass and integration of disc brakes. Both features are also positive for a 110mph locomotive with respect to dynamic wheel/rail forces and reliability of suspension bearings.. Generally, weight reduction of the locomotive is a must for any passenger locomotive!	In general, the challenge in designing a locomotive that is able to operate at 125 mph is dependant on a truck/drive/suspension system that achieves industry-accepted dynamic performance characteristics. Experience with higher-speed applications in markets outside the US demonstrates the trend that when the desired operating speed goes above 90 - 100 mph, the design of the truck/drive/suspension system changes from an axle-hung traction motor configuration to a (truck) frame-hung traction motor configuration to reduce unsprung mass and dynamic wheel/rail forces at the higher operating speeds. We haves already taken the preferred 125 mph operating speed into consideration and are prepared to offer a compatible product configuration. In this regard, we do not consider it a challenge to deliver a locomotive that can operate at 125 mph.	Maintaining satisfactory P2 forces (Not speed, but PRIIA-related is the Tier IV compliance)

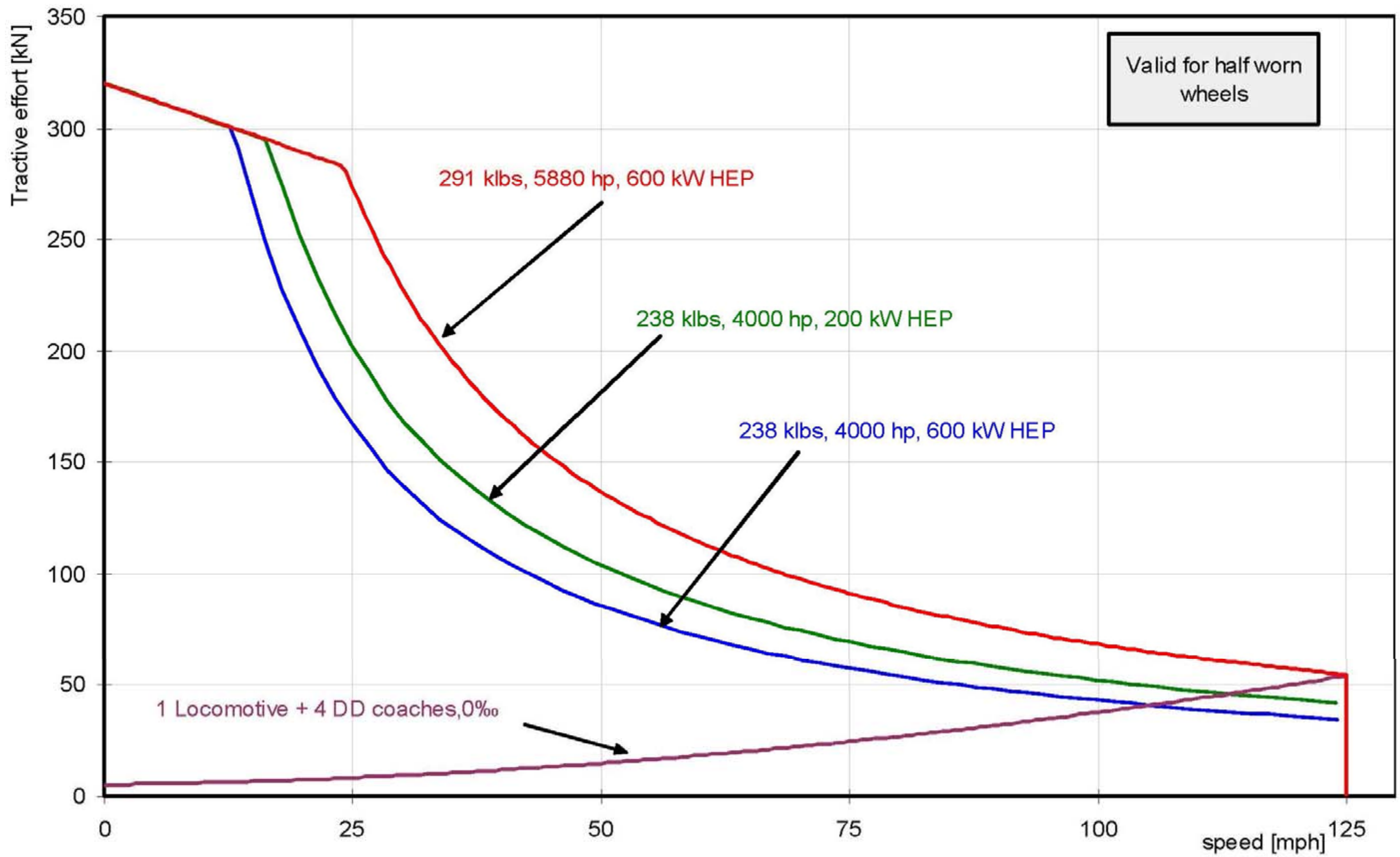
Question	A	B	C	D	E
2. What power requirements (e.g., power per gross ton) would be required to operate a typical intercity schedule with a top speed of 125 mph? Please attach distance/speed curves for the three train conditions listed in the locomotive specification, Sec. 9.2., as well as tractive effort curves.	We did run a number of simulations for the specified trainloads as per chapter 9.2. of the PRIIA DE locomotive specification, following is a brief summary/extract of the results. Figure 1 shows examples of the TE diagrams for 1 locomotive and 4 double deck (DD) coaches. The locomotives are either equipped with a today's 4000hp or a 'hypothetical' 5880hp diesel engine, which is the rating required to propel the specified train with the given parameters of chapter 9.2 to 125mph (Davis, max HEP load as well as weight and structural clearance of the DD coaches). We did some simulation runs for a '*1 – 8 DD –1*' consist with two 4200hp units (around 4200hp is what we think can reasonably be installed on a 4 axle locomotive today), and it barely reaches top speed, here simulated on the route Chicago – St. Louis. As can be derived from the graph, this is not enough power to operate and maintain an intercity schedule with a top speed of 125mph. Another calculation revealed that just because of the lower wind resistance, for example a consist with 10 single level coaches would be a much better option for such an operation, which shows it is not only a question of power per gross ton alone.	The PRIIA assumption is that 2 locomotives will pull 8 cars@125mph. I understand that at least 7,500 HP for traction would be required, not including HEP or auxiliary loads. There are very few engines that can produce this HP and many of them are too heavy to be considered. In fact the two most popular rail engines in North America from EMD and GE that could produce this level of HP are most likely too heavy to be packaged in a passenger locomotive light enough to create P2 forces low enough to allow 125 mph operation on a four axle locomotive. None of the manufactures are likely to officially make this statement, but the dichotomy of CEM and the increased weight of Tier 4 Emission Appliances may make obsolete the medium speed engine in Transit locomotives with enough HP to achieve the hp required for 125 mph operation.	The power requirement is nor only determined by the top speed. Even a locomotive for 110mph will require more than 3000kW diesel engine power to operate a 4 car train with reasonable reserve for grades and higher trailing load; please refer to Figure 2.	The ability to utilize the 125 mph higher-speed capability of the next-generation passenger locomotive is dependant on a number of factors including but not limited to ... • Horsepower of the prime mover • Head end power system architecture • Head end power demand from the passenger cars • Number, size weight and other design characteristics of the trailing passenger cars • Number of locomotives included in the makeup of the train • Route profile • Distance between station stops ... and, potentially, the configuration of locomotive equipment that can be accommodated within the allowable weight, clearance and length specifications of the vehicle. A top speed of 125 mph is generally attainable at the anticipated locomotive power rating. Further detailed studies with specific train sizes and route details will be required to quantify the benefits of specific trains operating at 125 mph.	Increasing the top speed from 110 to 125 mph raises the gross HP required from apprx. 4,500 to 8,500 (based on a train of six cars, each weighing 170,000 lbs. See Figure 3 for tractive effort curves.

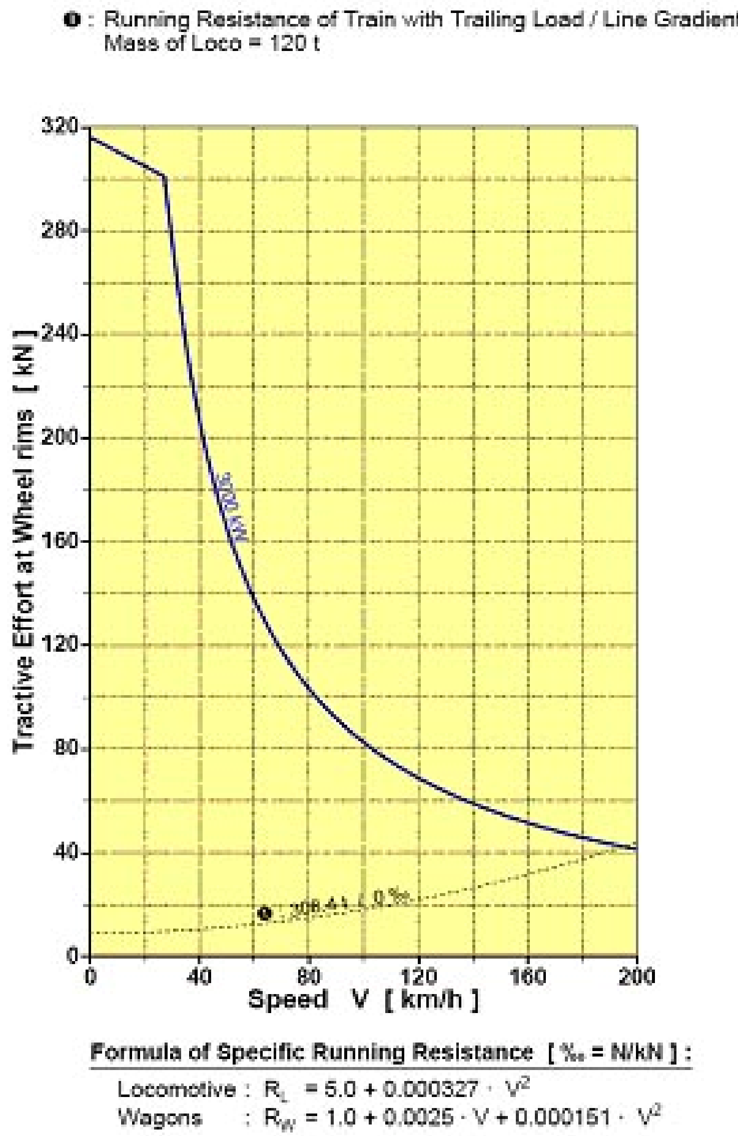
Question	A	B	C	D	E
3. What challenges exist to create a drive/suspension system for 125 mph while still maintaining the P2 force limits contained in the PRIIA locomotive specification?	There are no challenges to create a drive/suspension system for 125mph as it already exists today.	Drive Train/P2/TM curve	A fully suspended drive is mandatory for 125 mph and of great advantage for 110mph (see answer to Q1 above)	As indicated in item 1 above, we are currently able to offer a drive/suspension system compatible with operation at 125 mph.	P2 forces increase with the increase of speed. Unsprung mass is required to be reduced in order to keep P2 forces at satisfactory safety levels. (See Figures 4 through 6)
4. How would you rate the impact to both cost and construction schedule for developing a truck and traction/power plant capable of a sustained 125 mph top speed? Please include in your answer the direct affect of the Tier IV emission requirement.	There will be no challenges to provide truck, drive or traction systems for 125mph as these already exist today. Based on the train load requirements provided in the PRIIA specification and as mentioned in questions 1,2 above as well as shown in attachment Fig 1, the amount of power required to accelerate the train to and move it at 125 mph is considerable. To fit a sufficiently sized diesel engine, cooling plant, Tier IV aftertreatment equipment as well as silencer on the locomotive is the challenge.	Truck/Engine Schedule	There is no impact for suppliers which have the technology for trucks and traction chain available. Tier IV will not considerably influence the schedule when using industrial engines (Multi engine concept)	The PRIIA specification calls for a demanding combination of locomotive performance requirements and physical constraints. The requirement for Tier 4 emissions performance presents challenges for accommodating the size and weight of the associated equipment for the power plant required for 125 mph operation. We consider the packaging and integration of the Tier 4 equipment to be the more significant aspect of the product development and construction schedule as the running gear for 125 mph operation is a matter of applying existing technology.	More complex truck design increases the cost, as well as maintenance. Not specifically a vehicle concern, but raising the maximum speed from 110 mph to 125 mph will increase track maintenance costs.

Question	A	B	C	D	E
5. For the first PRIIA locomotive order, can you quantify the major cost drivers or estimate the relative impact of the need to design a vehicle, Tier IV emission requirements and order size.	The major cost drivers for the design of a new PRIIA DE locomotive are centered around the diesel engine with the new Tier IV emissions requirements and the measures to keep the locomotive within reasonable dimensions of length and weight. A quantification of the cost is not yet possible because the engine builders are in the stage of assessing their development efforts, which in turn will determine what the locomotive builders will have to add.	1st Order PRIIA Design	Tier IV: This is a mandatory requirement, independent from speed rating 110 or 125mph. High influence for single engine concept, lower influence for Multi engine concept . Truck/Drive/ brakes: more expensive for 125 mph when the disadvantages of conventional solutions are considered as tolerable for 110mph.	When considered individually, each of the technologies identified in the PRIIA specification are generally known within the industry and no one technology is anticipated to be the singular, critical driver in the design of the vehicle. The Tier 4 emissions system is somewhat exceptional in this regard as it will add new technologies, equipment and maintenance requirements and associated costs that, heretofore, have not been included on locomotives in North America. Except for the impact of Tier 4, the major cost driver comes not from a specific individual technology or feature but, rather, from the unique combination of the many state-of-the-art technologies and physical packaging constraints included in the PRIIA specification. The aggregate cost for the required equipment and for the engineering required to package that equipment into the available space on an all-new, compact, lightweight, high performance locomotive is the major cost driver for a product that will be produced in relatively low-volume quantities.	Tier 4 emission compliances drive: Aftertreatment (Urea and non-urea) • Packaging challenges • Weight Engine design • Fuel pressure and common rail …weight increase Push back couplers and anti climbers • Packaging challenges and weight increase Tier IV drives changes and weight increase (range of 10-35,000 lbs.)

Question	A	B	C	D	E
6. These questions assumed the "technological/cost " break point for diesel locomotive design/constructio n was between 110-125 mph. Is this correct? If not, at what speed is there a "knee" in the ttechnological/cost " curve. What is/are the cost driver(s)?	The technological breakpoint for higher speed locomotives used to be around 100mph. Below that speed, cannon box design drive systems were regarded as sufficient although the unsprung mass was high and frequent continuous running at that speed was tending to be maintenance intensive. Above that speed suspended drive systems needed to be applied. The unsprung mass of the drive system was reduced, but the drive system itself used to make the locomotive more expensive. With the development of advanced drive systems the cost issue was costly eliminated and with it the “knee” in the technological cost curve.	• This is difficult to predict where this will actually end up due to the high level of interest and competition. It is possible that a competitor will “buy” the first project just to be the first mover for this new product anticipating raising the price later. • What we do know today is that the current price for a Tier 3, 110 mph locomotive is north of $5M each. If a Tier 4 125 mph locomotive were priced today with normal profit associated with the product risk and cost of development it could easily be north of $6.5M - $7.5M each.	As explained above, even 110mph needs more than a conventional solution. The “Knee” is seen at 90- 100mph if locomotives will run over considerable distance with the rated top speed (Remark: Diesel locomotives in US are today mostly running well below the rated top speed – there is no experience with 100mph over long distance!)	When the intended operating speed is less than 90 mph, an axle-hung traction motor and drive arrangement is generally a satisfactory solution with regard to wheel/rail forces and other locomotive performance parameters. Above 90 mph, a semi or fully suspended drive arrangement is preferred to achieve desired wheel/rail force and other vehicle dynamic performance characteristics. Between 100 and 110 mph, the semi-suspended, frame-hung traction motor arrangement ceases to be a preference and becomes a requirement in order to meet the performance needs of the customer. A further vehicle design consideration with regard to operating speed is the configuration of the mechanical brake system. In conjunction with the transition from an axle-hung to a frame-hung traction motors, the friction brake transitions from tread braking to disc braking to reduce wheel wear and improve equipment thermal performance while at the same time improving stopping distances.	Increasing the percentage of time at 100-110 mph will reduce travel time, but speeds >100mph today in the U.S. are used <10%. Track maintenance will be a much larger concern at 125 mph top speed.

Fig 1: Tractive Effort Diagram





❶ : Running Resistance of Train with Trailing Load / Line Gradient
Mass of Loco = 120 t
Tractive Effort at Wheel rims [kN]
320
280
240
200
160
120
80
40
0
0
40
80
120
160
200
Speed V [km/h]
Formula of Specific Running Resistance [‰ = N/kN] :
Locomotive : $R_L = 5.0 + 0.000327 \cdot V^2$
Wagons : $R_W = 1.0 + 0.0025 \cdot V + 0.000151 \cdot V^2$

Figure 2

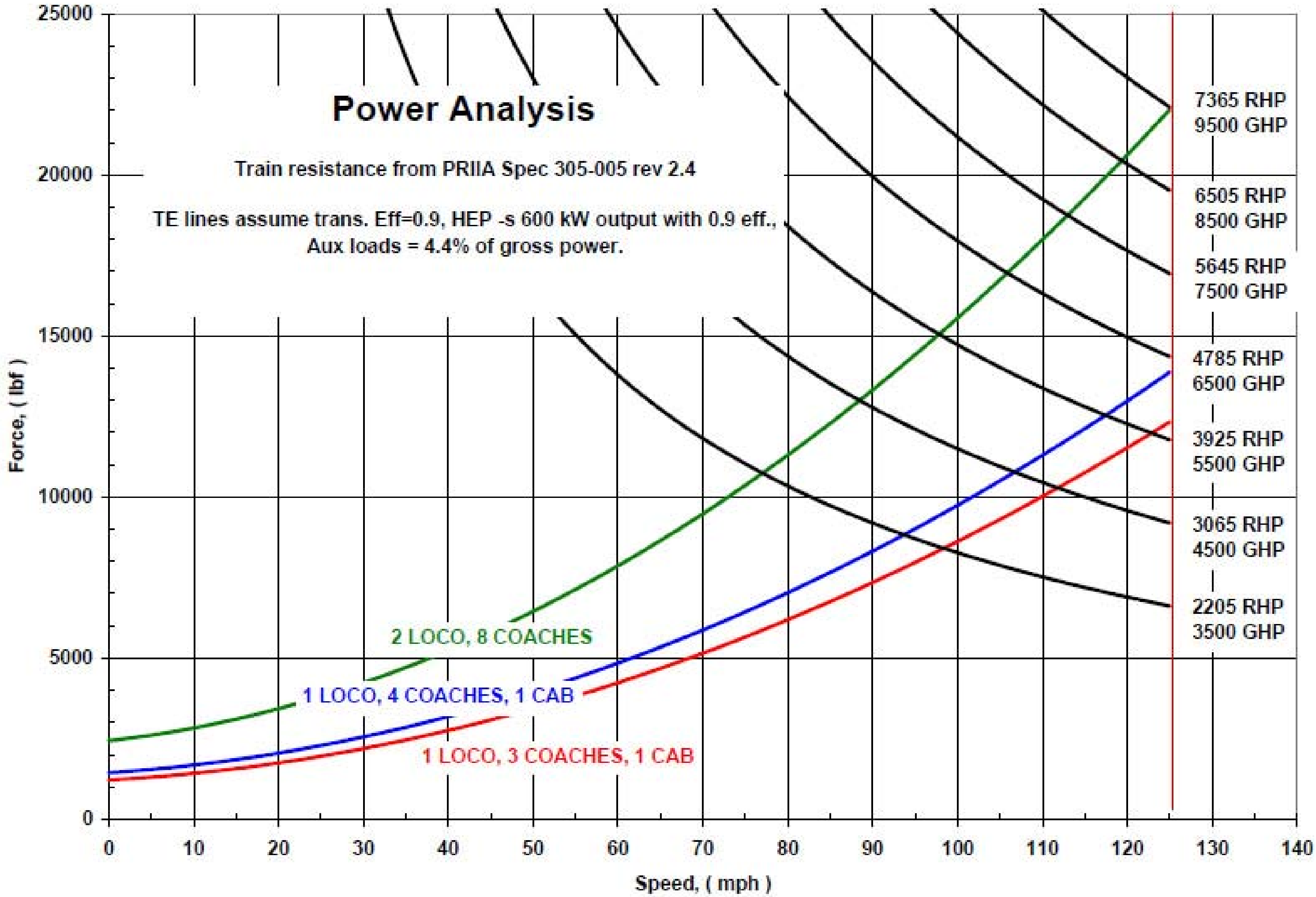

Power Analysis
Train resistance from PRIIA Spec 305-005 rev 2.4
TE lines assume trans. Eff=0.9, HEP -s 600 kW output with 0.9 eff.,
Aux loads = 4.4% of gross power.
7365 RHP
9500 GHP
6505 RHP
8500 GHP
5645 RHP
7500 GHP
4785 RHP
6500 GHP
3925 RHP
5500 GHP
3065 RHP
4500 GHP
2205 RHP
3500 GHP
2 LOCO, 8 COACHES
1 LOCO, 4 COACHES, 1 CAB
1 LOCO, 3 COACHES, 1 CAB
Force, (lbf)
25000
20000
15000
10000
5000
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Speed, (mph)

Figure 3

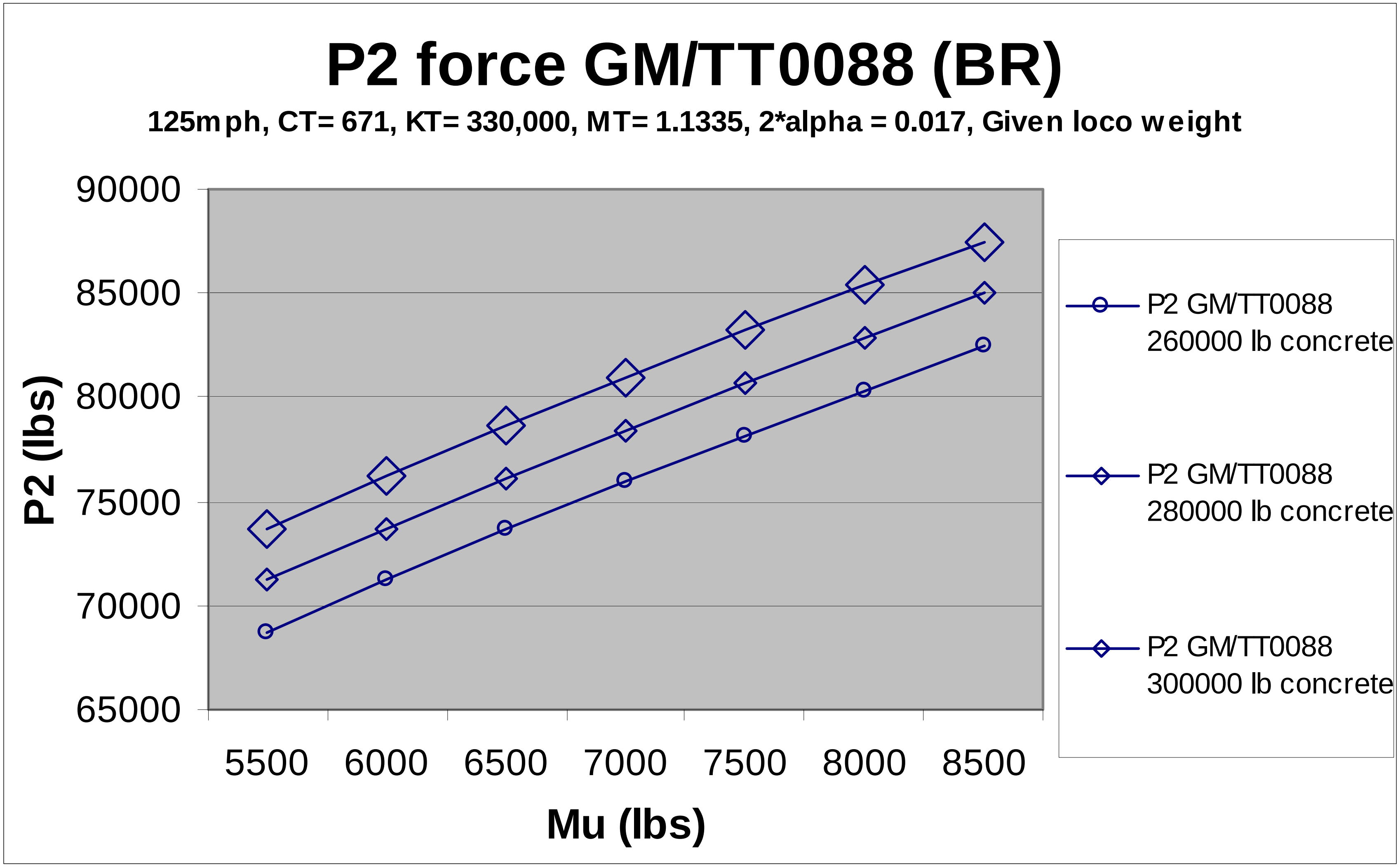
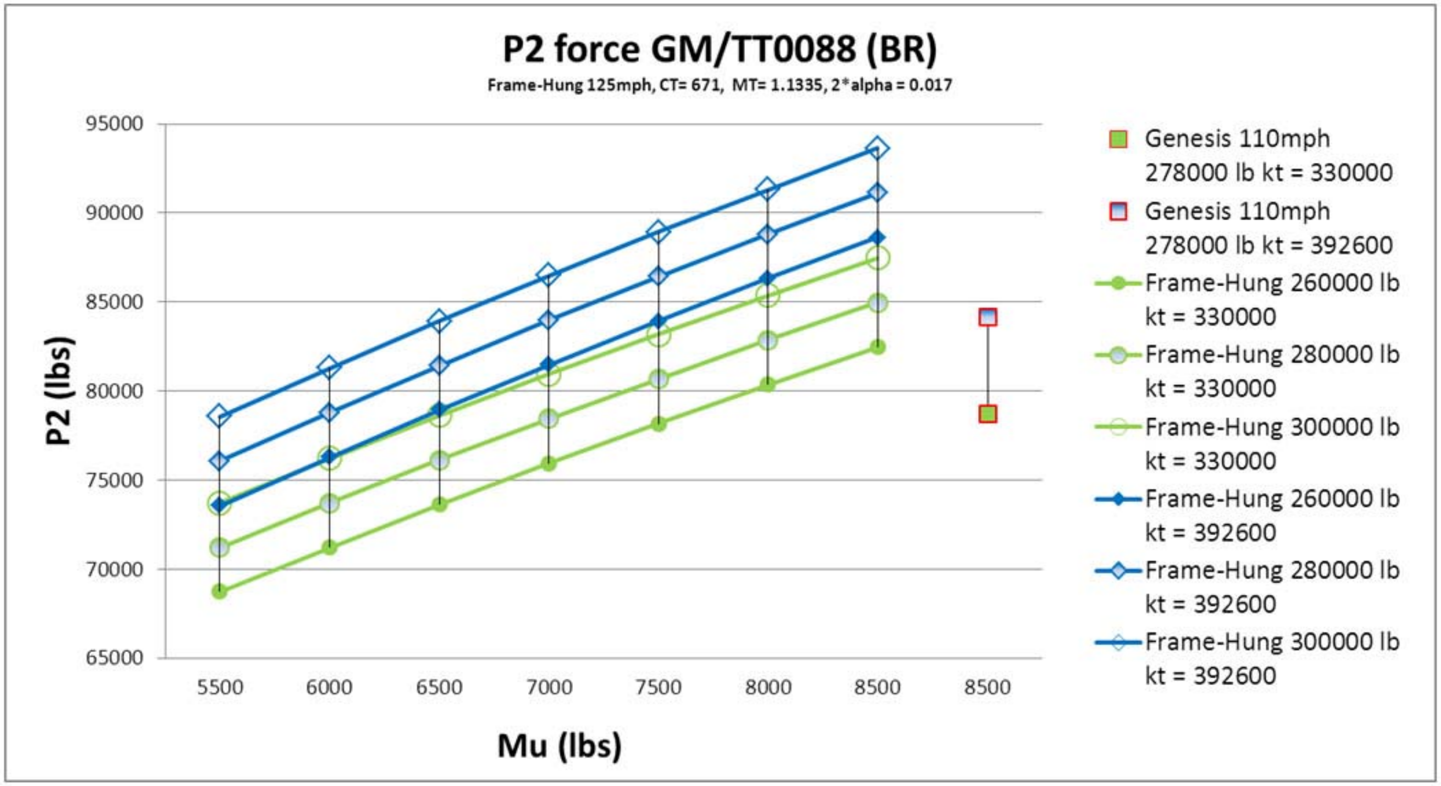

P2 force GM/TT0088 (BR)
125mph, CT= 671, KT= 330,000, MT= 1.1335, 2*alpha = 0.017, Given loco weight
90000
85000
80000
75000
70000
65000
P2 (lbs)
5500
6000
6500
7000
7500
8000
8500
Mu (lbs)
P2 GM/TT0088 260000 lb concrete
P2 GM/TT0088 280000 lb concrete
P2 GM/TT0088 300000 lb concrete

Figure 4

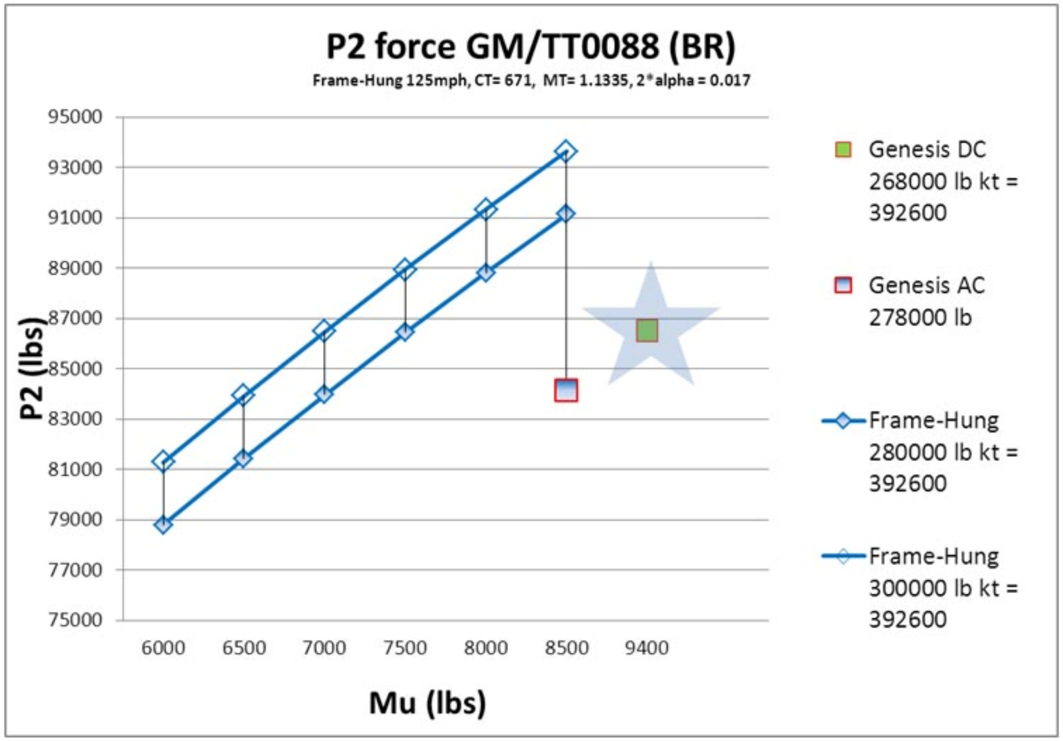
Currently proposed limit for P2 force is **82, 000 lbs.**



For 300K loco, with Kt= 330,000 we had allowable unsprung weight at slightly above 7,000 lbs. Changing the Kt to 392,600 drives the allowable Mu to **6000 lbs.**

Competition Mu is 6100 lbs
with lighter loco <290k

Figure 5



DC loco has heavier motor and **higher P2 force** even though the overall locomotive weight is lower

P42DC operating at **110mph**, produces a **P2 force** of **86522 lbs**

	110 mph	110 mph	125 mph		
	Genesis DC	Genesis AC	Frame-Hung		
	268000 lb	278000 lb	260000 lb	280000 lb	300000 lb
Mu (lbs)	kt = 392600		kt = 392600		
5500			73561	76061	78561
6000			76297	78797	81297
6500			78930	81430	83930
7000			81473	83973	86473
7500			83932	86432	88932
8000			86316	88816	91316
8500		84145	88630	91130	93630
9400	86522				

Figure 6

Conclusions

The PRIIA 305 Next Generation Equipment Committee Executive Board established requirements that PRIIA-specified equipment be capable of a maximum sustained operating speed of 125 mph. There are clear signs from the government to upgrade the US rail network and to establish high speed intercity corridors. Because most of the agencies involved in purchasing PRIIA-specified equipment do not presently have corridors suitable for operating above 110 mph, is it reasonable to purchase a capability not needed?

A diesel locomotive with a design top speed of 125 mph will cost more than one with a top speed of 110 mph. However, quantifying how much more is very difficult, and a clear answer did not emerge from this study. It does appear that the cost differential as reported in the Executive Board meeting at which this tasking originated, i.e., roughly $4 million for current locomotives to $8 million, may be high. Builders were not asked to provide specific dollar estimates, though one did provide some rough numbers.

Two recent orders of diesel locomotives, both from MPI, provide some insight into the current basic locomotive costs. Virginia Railway Express, in 2009, began a series of orders for MP36s that eventually totaled 20 units. These were an existing design with Tier II compliant engines, DC traction motors and a top speed of nominally 100 mph. The average cost was $3.8 million, though that included several remanufactured engines, trucks, traction motors and alternators. Had everything been new, the price probably was in the vicinity of $4.5 million. In 2011, the Massachusetts Bay Transportation Authority ordered 20 new-design HSP-46s from MPI, with an option for 20 more. These 110 mph top-speed locomotives, with Tier III-compliant engines, all-new components and AC propulsion,, cost approximately $5.3 million each.

Other conclusions from this study:

1. Manufacturers perceive the “knee” in cost/technology in the range of 90-125 mph, but the exact speed depends upon what vehicles they presently have in their design book. One manufacturer mentioned that because of dynamic loads and rotation speed loads on traction motor support bearings, new locomotives in Europe intended for sustained operations above 90 mph have fully-suspended traction motors.

2. Mechanical/suspension components, especially suspension elements will likely be beefier/upgraded/different for 110 vs. 125 vehicle. How that cost of design/manufacture is different from costs that would be incurred with a typical new design vehicle is inconclusive.

3. The PRIIA locomotives will represent a new vehicle, and as such, there will be a cost associated with creating and verifying the new design. A

total of 33 locomotives were identified in the recent press release announcing the granting of $336 million for Next Generation Equipment purchases. If all 33 are ordered, that will definitely lower the per-unit cost.

4. Independent of the top speed, the Tier IV emission requirement represents a very real engineering challenge, and will be a cost driver. Manufacturers are, in general, presently unable to predict the magnitude of the impact.

5. Manufactures have not taken the opportunity to say “the PRIIA locomotive is a pipe dream that can not be built.

6. A key driver will be P2 forces being maintained at an acceptable level. This has a “design cycle” impact in that it isn’t necessarily as major a concern for a 110 mph top speed as it would for a 125 mph top speed. Again, depending upon what a manufacturer already has in its design book, this may or not be a cost driver.

7. Is a 125 mph top speed necessary? The answer to that question was not considered in this study. As stated above, the requirements document presently requires a 125 mph top speed. Individual railroads/operating authority/states are the ones to provide an answer because it involves the entire route infrastructure, environment and operating conditions for not only the acquisition of equipment, but also the maintenance of equipment and infrastructure.

Members of Task Force

The following individuals were members of the PRIIA Locomotive Technology Task Force as of the date of this report.

Al Bieber (STV, Inc.)
Richard Brilz (MotivePower)
Richard Chudoba (Electro-Motive)
Michael Coltman (Volpe NTSC)
Robert Doyle (Progress Rail Services)
Steve Fretwell (CalTrans)
Greg Gagarin (Amtrak)
Jeff Gordon (Volpe NTSC)
Heinz Hofmann (Siemens AG)
Kevin Kesler (FRA-Office of Safety, R&D)
James Klaus (Cummins)
Michael Latour (Siemens AG)
John Madden (NYSDOT)
Jack Martinson (Bombardier Transp.)
Curtis McDowell (NC-DOT)
Jim Michel (Marsh USA)
John Pannone (EAO Corp.)
Allan Paul (NC-DOT)
Charles Poltenson (NYSDOT)
John Punwani (FRA-Office of Safety, R&D)
Lutz Schwendt (Bombardier Transp.)
Melissa Shurland (FRA-Office of Safety, R&D)
Phil Strong (P S Consulting)
Graciela Trillanes (GE Transportation Sys.)
Mike Trosino (Amtrak)
Dave Ward (Siemens AG)
David Warner, Chairman (Amtrak)
David Watson (GE Transportation Systems)
Bruce Wolff (MTU)

Disclaimer

The views, opinions, conclusions, recommendations expressed in this report are those of the authors themselves and do not represent the policy or position of their respective employers or the Section 305 Next Generation Corridor Equipment Pool Committee (NGEC) or any of its officers or members.

(*adopted 1/3/2012*)