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# Innovation and Competition in Locomotive Manufacturing, 1950 - 2000

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## INTRODUCTION

As with many other aspects of railroad technology, the development of diesel locomotives in recent years has been characterized by slow and prudent innovation. This has not always been the case, however. In the period immediately following World War II, when rapid dieselization created demand for a profusion of new models by six or more builders. Although many of the locomotive builders were ultimately unsuccessful and left the market, the rapid introduction of new models in the post-war years led to the "horsepower race" of the 1950s and 1960s. Despite a domination of the market by the Electro-Motive Division of General Motors (in some years, EMD captured 85% of railroad diesel sales), as late as 1957 there were still three locomotive builders besides EMD (Baldwin, ALCO, and Fairbanks-Morse). And despite EMD's dominance, there was still a healthy competition in the introduction of new models of diesel locomotives. In particular, horsepower per unit increased steadily. The 1,500 HP units of the immediate post-war period gave way to the 1,800 HP GP9 and its competitors. They in turn faced competition from the 3,000 HP Baldwin "Centipede", and from F-M's "Trainmaster", which at 2,400 HP was the most powerful locomotive unit of the decade produced in quantity.

In 1957 Baldwin produced its last railroad locomotive, and in 1959 Fairbanks-Morse withdrew from the new locomotive market, leaving only ALCO as a competitor to EMD. However, General Electric (which for many years had supplied electrical components to ALCO and others) apparently saw an opportunity in these departures from the market, and in 1962 began marketing the U25 locomotive to North American railroads. This 2,500 HP unit was a challenge to EMD in the same way as the Trainmaster, and EMD responded with the GP35. The horsepower race continued.

ALCO introduced the 2,400 HP C424 in 1963, and continued to develop even more powerful units. In 1965, ALCO introduced the C630, a 3,000 HP unit which with further development became the C636 (3,600 HP). Not to be left behind, EMD and GE produced 3,000 HP models (SD40, GP40, U30) in the late 1960s, and GE managed 3,600 HP from its 16FDL engine with the U36. EMD responded with a 20-cylinder SD45, producing as much as 4,000 HP in experimental versions, but rated at 3,600 in production models.

There were even more powerful locomotives produced in limited numbers. Beginning in 1963, Union Pacific ordered a series of custom designs from Alco, GE and EMD, with two prime movers on a single frame and six or eight axles. Southern Pacific also ordered some of these units from EMD. The most successful of these was the EMD DD40AX, an eight-axle, 6,600 HP unit. Fifty were produced starting in 1969, and ran systemwide on Union Pacific for fifteen years.

And then, abruptly, the horsepower race was over. The EMD SD45 went out of production in 1975, as did GE's U36 model. Maximum horsepower available from production units retreated to 3,000, and would not increase much beyond that level for almost two decades. Figure 1 illustrates this history graphically.

The reasons for the abrupt end of the horsepower race are complex. They include the Arab oil embargo of 1973, the maintenance cost of the EMD 20-cylinder prime mover in the SD45, and the relatively primitive state of wheel-slip control in the 1960s (which meant that the tractive effort of high-horsepower units was limited by a low factor of adhesion -- typically 20%). At least in part, however, the end of the horsepower race was the result of diminished competition in locomotive manufacturing. With the railroad industry financially weak in the 1970s, and only two manufacturers competing for sales, there was little incentive to continue innovating. And so innovation essentially stopped.

The next new locomotive models to come from the two builders were "experimental" models introduced in 1979. EMD managed to produce 3,500 HP from the 16-cylinder 645 engine, while GE simply recycled the 3,600 HP 16FDL of a decade previous, making minor improvements and adding better wheel-slip control. Ultimately, these experimental units led to the EMD 50 series in 1981, and the 4,000 HP GE Dash 8 of 1982. Unfortunately, the EMD 50 series was essentially a failure, with high-maintenance electricals and an ineffective wheel-slip control system. The Dash 8 fared better, and by the end of the decade GE had come to dominate the diesel locomotive market in North America, despite the introduction of the 60 series units by EMD in 1984.

In summary, it can be seen that while the 1950s and 1960s were periods characterized by the rapid introduction of new models, in the period from 1975 to 1993 GE and EMD introduced a total of three new production locomotive models each (and, in each case, one of the three in 1993 or 1994). Even more noteworthy, the Dash 8, 50 series, and 60 series units represented only modest improvements over older locomotive models. Until the 1993 announcement of plans for AC traction by both builders, locomotive technology remained almost unchanged for nearly two decades. If computer development had progressed at the same rate, IBM would still be selling the System 370 and PCs would still be in the design stage!

However, rapid change appears to be returning to the locomotive market. This may (at least in part) result from the entry of a new competitor into the market. Just as GE challenged EMD in 1962, Morrison Knudsen Corporation is moving from remanufacturer to producer of new diesel locomotives. Morrison Knudsen's MK Rail subsidiary announced last year its plans to produce an entirely new line of very high horsepower locomotives using the Caterpillar 3600 series diesel as a prime mover. Announced plans include units of 5,000 HP, 5,500 HP, and 6,000 HP using the Cat 3612, a V-12 design. This prime mover can produce up to 6,000 HP in a diesel fueled configuration. MK Rail has also announced plans for a 4,400 HP natural gas fueled locomotive using the Cat 3616. In a diesel version, the 3616 is capable of up to 8,000 HP.

Caterpillar has previously supplied diesels for use in the rebuilding of existing locomotives, but MK Rail's units will be entirely new. The first MK unit into production is the MK5000C, the first single-engine 5,000 HP unit ever produced (EMD, GE, and ALCO all produced two-engine locomotives of this horsepower in the 1960s.). Initially offered with DC traction, the MK5000 will be offered in an AC traction version by early 1996. Subsequent models from MK will use AC traction.

The effect of MK's announcement plans can be gauged by the fact that, in mid-1993, neither of the two existing locomotive builders had made public any plans for units of more than

4,400 HP. GE had announced the Dash 9-44 and the AC traction AC44 (its first new units since the Dash 8 of 1981), and EMD was preparing to deliver the first SD70MACs (4,000 HP and AC traction, and its first new model since 1984) to Burlington Northern. There were not only no announced plans for higher-horsepower units, but some railroads apparently believed that there was no need for locomotives of more than 4,000 HP[1].

Shortly after MK's entry into the market, both builders abruptly began to announce plans for additional new models. In December of 1993, EMD proclaimed the lease of 25 of a previously unknown "SD80" model locomotive (5,000 HP) to Conrail, and shortly thereafter announced a 6,000 HP SD90, to be powered by a new prime mover of a yet-to-be-specified design. What makes these announcements interesting is that EMD had never previously indicated any plans for a 5,000 HP prime mover (it will apparently be based on the 20-cylinder 645 used in the SD45 of 20 years ago), much less a 6,000 HP engine of any kind!

Not to be left behind, in the winter of 1994 GE announced the sale of 53 6,000 HP units to CSX. At that time, GE had no known plans for a 6,000 HP engine either! It eventually appeared that GE would buy a design from MWM Deutz (a German firm), develop it from a straight-8 to a V-16 version, and build a new production line at Grove City, PA to build it -- all in time for a 1997 delivery date (since revised to "late 1996")![2]

The entry of MK Rail into the new locomotive market certainly seems to have accelerated the introduction of new locomotive models. In the midst of this rapid introduction of new and more powerful locomotive models, and AC traction, the question must be asked: why might a railroad *want* a 6,000 HP locomotive? What economic advantage might AC traction and high horsepower convey? Is a very high horsepower locomotive the best choice for general railroad service? These questions are interrelated, and depend on economics, physics, and the reliable application of technology. A fuller discussion of the advantages and disadvantages of what will be called "very high horsepower" locomotives is contained in the following sections of this paper.

## THE ECONOMICS OF HIGH HORSEPOWER

The proliferation of "B" (cabless) units forty years ago, and the horsepower race of the 1950s and 1960s, suggest that there was at least a perception of economic benefits from higher horsepower very early in the diesel era. While the "B" units of the early diesel era were designed primarily to evade union demands for a fireman on every unit, they also reduced the costs of multi-unit consists (of which there were many). Even after the labor issues had been put to rest, horsepower per unit continued to increase as well. The aim was "unit reduction" -- doing more work with fewer locomotives.

The trend to higher horsepower that became clear in the 1950s raises an obvious question: where might the economies of high horsepower be found? With B units, the savings comes from elimination of the cab, saving the purchase price and maintenance cost of all the necessary cab equipment. While no B units have been built by manufacturers since the early 1980s, some railroads have designated certain units "non lead equipped" or have rebuilt them into cabless units, permitting a saving of the maintenance cost for cab equipment. This is, however, a relatively minor savings and greatly reduces flexibility in locomotive assignments.

High horsepower in a single unit, with a single prime mover, is a more effective means of assuring more horsepower at lower cost.. All things being equal, diesel engines of larger displacement per cylinder and larger power output can achieve lower specific fuel consumption than smaller, less powerful diesels, due to the higher thermal efficiency of large-displacement cylinders.

Since more powerful units still have only a single control cab, the same number of traction motors, one braking system, and other such components, it is likely that the cost per horsepower will decrease as unit horsepower increases, making more powerful units less costly on equivalent horsepower basis. This was a factor in the horsepower race of the 1950s and 1960s (and especially in the production of the very high horsepower two-engine units of the mid 60s). However, while cost per horsepower may have declined during the years of the horsepower race, the evidence from recent locomotive sales does not indicate any clear trend. Published information on recent locomotive sales is shown in Table 1.

**TABLE 1**

**Projected Cost per Horsepower Current and Proposed Units**

| Unit | Estimated or Actual Price | HP | Price/HP |
|---|---|---|---|
| EMD SD60/GP60 | $1.33 million | 3,800 | $350 |
| GE Dash 9-44B/C | $1.5 million | 4,400 | $341 |
| EMD SD70MAC | $1.9 million | 4,000 | $475 |
| MK5000C | $1.8 million | 5,000 | $360 |

**NOTE:** Prices in Table 1 are based on published information regarding recent sales. Actual purchase prices may be less than indicated by publicly available numbers. Price for the MK unit is estimated.

The message of Table 1 is decidedly mixed. Based on recent sales, the GE unit appears to be aggressively priced. The EMD SD70MAC, by contrast, is very expensive, while the MK unit is only a bit more costly than the EMD 60 series. However, there is yet another dimension to locomotive costs. If *maintenance* cost does not increase in proportion to horsepower for the very high horsepower units, and if unit reductions can be achieved. there may still be significant savings even at the very high price of the SD70MAC.

Unfortunately, railroad recordkeeping is not as detailed as might be desired, so it is very difficult to determine the difference in maintenance cost between a low-horsepower and a high-horsepower unit. However, studies have indicated that the largest part of locomotive maintenance cost is mileage-based or time-based, and largely independent of horsepower[3]. FRA-mandated 92-day inspections are required on every unit, regardless of horsepower. Carbodies, running gear, brakes, and couplers are similar on all locomotive models. Further, an SD70 has the same number of traction motors as an SD40-2, the same number of engine components, and a similar control and braking system. It is difficult to see why maintenance procedures should require more time. Assuming similar operating life specifications and design criteria for components in higher horsepower prime movers, maintenance costs should be similar as well, although parts might be more costly. Holding all other factors constant, it seems unlikely that maintenance cost will increase nearly in proportion to horsepower.

If maintenance cost per unit does not rise in proportion to horsepower, and if cost per horsepower is the same or less for the very high horsepower units, there are major savings to be realized from "unit reduction", the replacement of older units by a smaller number of more powerful new units. This was the motivation of Union Pacific in specifying the DD40AX, and of many other railroads in ordering 3,000 HP and 3,600 HP units in the late 1960s.

It costs about $1.00 per mile to maintain a modern diesel locomotive. If a new 6,000 HP unit can actually perform the work of two 3,000 HP units (and this will depend upon tractive effort as well as horsepower -- see discussion below), it will produce net savings as long as it costs no more than twice the price of the units it replaces and no more than twice the maintenance cost per mile. Any fuel savings will be in addition to maintenance and ownership savings, and there will certainly be fuel savings because the 6,000 HP unit will probably weigh little more than one of the two units it replaces. Reduction of the train weight by 200 tons will save fuel, even if the prime mover is no more efficient.

This analysis assumes, *ceteris paribus*, that there are no improvements in design as horsepower increases. However, technological improvements have made locomotive components more reliable. It may be that newer, higher-horsepower units are actually *less* costly to maintain, per unit mile, than the locomotives they replace. It seems reasonable, therefore, to assume that economics favor higher horsepower. So why did the horsepower race abruptly cease in 1975, and why did it take so long to resume? To begin to answer this question, it is necessary to digress for a moment, to consider the factors influencing the purchase and assignment of locomotives by railroads.

## HIGH HORSEPOWER AND RAILROAD OPERATIONS

So far, this paper has focused on horsepower as the measure of locomotive capacity. But there are, in fact, three variables that determine how much of the potential of a locomotive may be usefully applied. In addition to horsepower, they are tractive effort and the factor of adhesion.

Diesel-electric locomotives have been the universal choice of North American railroads (and of railways on many other continents) because of the characteristics of their transmissions. Where a mechanical linkage forces a direct relationship between engine speed and track speed, an electric transmission allows for maximum power output at *any* speed, even a dead stop. If voltage remains constant, the torque of an electric motor increases as its speed is reduced. So does amperage. In practice this means that a diesel-electric produces maximum tractive effort at zero speed -- exactly what a railroad needs to start a heavy train. It has been said that, while steam locomotives can move any train they can start, diesels can start any train they can move. The latter is more useful in railroad operations.

It would seem, then, that tractive effort and horsepower would go hand in hand. The more of one, the more a locomotive would have of the other. This is where the factor of adhesion comes in, along with locomotive weight.

The maximum axle load for which locomotives are designed in North America is 33 tons (US). This limits the weight of a four-axle unit to 132 tons, and a six-axle unit to 198 tons. In practice, many railroads add ballast to increase tractive effort, raising axle loads slightly above the 33 ton level and producing typical weights of 140 tons for a four-axle unit and 210 tons for six axles. Recent purchases of freight cars with 36-ton axle loads suggest that at least some railroads might be willing to look at increased locomotive axle loads as well.

The actual maximum tractive effort of any locomotive is its weight multiplied by its factor of adhesion (a measure of "slipperiness"). There are two kinds of adhesion measures: starting adhesion and continuous or "dispatchable" adhesion. Starting adhesion, especially on dry rail, can be much higher than maximum continuous or dispatchable adhesion. For many years, a continuous adhesion factor of 20% was typically used to assign power to trains, meaning that a 200 ton locomotive could produce about 80,000 lbs. of tractive effort at minimum continuous speed. Improvements in wheel slip control raised that value to about 28% in the latest models with direct current (DC) traction motors. AC motors, used on the SD70MAC and the GE AC-44, have better adhesion. Combined with a radial truck design, they produce a measured 35% adhesion factor for the SD70MAC, which permits a continuous tractive effort of about 143,000 lbs., versus the 80,000 lbs. of a 1972-vintage SD40 Starting adhesion for the SD70MAC has approached 45%, versus less than 30% for DC locomotives of two decades ago. This is, needless to say, a very substantial improvement, especially with an increase of only 33% in horsepower.

Higher horsepower produces a less obvious benefit. Even at a 35% factor of adhesion, 5,000 HP and 6,000 HP units will be *adhesion-limited* rather than horsepower-limited if existing locomotive configurations (a maximum of six axles) and axle loads (no more than 35 tons) are retained, and even if AC traction is used. Their maximum tractive effort will be limited to the same 143,000 lbs. as the SD70MAC by their weight and the factor of adhesion. By contrast, a 3,000 HP SD40 can use all the tractive effort it can produce and is therefore *horsepower-limited*. The ultimate example of a horsepower-limited unit is the SD38-2, with a 2,000 HP prime mover and six axles. At speeds below 10 mph it is the equal of the SD40 in tractive effort, but it simply cannot attain speeds much higher than that with a train it can start. Most SD38s are in hump yard service.

It is worth taking a moment to consider the physical limitations on assignment of power to trains. Regardless of the capabilities of the locomotives, the maximum tractive effort that can be assigned to the *head end* of any train is a product of the total trailing weight, the strength of the drawbars on the cars, and the ruling grade on the railroad. For example, five SD40-2 locomotives must exert about 375,000 lbs. in total tractive effort to take a 15,000 ton coal train up a 1% ruling grade. If the grade is steeper than 1%, the train will stall. Adding more head-end power will simply break the drawbars (typical rating of Grade E steel drawbars on coal cars is 375,000 lbs.).

Every locomotive model has a fixed relationship between tractive effort and horsepower. Thus, the five SD40-2s required to move the unit coal train can produce 15,000 HP and 375,000 lbs. of tractive effort. Three SD70MACs will produce the same tractive effort, but only 12,000 HP. The result of this relationship is that the train with the SD70MACs will require more time to operate over the railroad.

In slow-speed, bulk commodity service, locomotive assignments are generally based on pulling power rather than speed, so the longer running time may be acceptable. Tractive effort is certainly more important than horsepower in this application. However, railroads in North America move a variety of commodities. While coal and grain may not require high-speed operation, intermodal traffic (typically time sensitive and of high value) must be operated on fast schedules to meet truck competition. Using an SD70 on an intermodal train makes as little sense as using an SD-38, since horsepower rather than tractive effort is required. The horsepower race of the 1960s was primarily aimed at enabling railroads to maintain fast schedules. Why else produce a 4-axle U36B? With a 140-ton weight and a 20% adhesion factor, this was the ultimate in adhesion-limited locomotives.

A 5,000 HP or 6,000 HP unit that can achieve no higher maximum tractive effort than a 4,000 HP SD70 MAC will be restricted to the same maximum tonnage. However, the additional horsepower will produce higher average speeds. In bulk service on a dedicated railroad, higher speeds are of no value. But when unit trains must share a route with higher-priority, higher-speed services, additional horsepower (as opposed to tractive effort) will reduce the speed differential between bulk trains. This can increase line capacity, and will also simplify the job of train dispatching.

It is worth pointing out that the DD40AX -- a reasonably successful 1967 design -- was limited to the same 20% adhesion factor as other units of the time. With eight axles, this 6,600 HP unit weighed about 280 tons, and could produce a maximum of 112,000 lbs. of tractive effort -- perhaps 40% more than a 3,000 HP SD40. Nevertheless, the DD40AX was widely used in high-speed mixed freight and intermodal service, where its horsepower was of value in maintaining fast schedules.

Adhesion-limited locomotives may have a place in railroading. However, tractive effort determines whether a train can climb the ruling grade, and whether it will remain intact while doing so. The effect of grade is completely linear; thus, a 15,000 ton maximum train size becomes a 7,500 ton train on a 2% grade, and so forth. Figure 2 shows the relationship between tractive effort and maximum train size on range of grades. Note that horsepower is not shown. It is irrelevant to whether a train can climb the ruling grade. Heavier trains may be operated if tractive effort is distributed throughout the train (for example, by use of helpers or radio-controlled "slaves"). However, if only head-end power is used, the limiting tractive effort is shown by the curve marked "tractive effort" in Figure 2. This limitation produces the maximum train weights shown.

New and more powerful locomotives -- whether AC or DC --- will not change the physical realities of Figure 2. They will *not* eliminate helper districts. They will, however, reduce the number of units required to move any particular train.

The point of Figure 2 is that maximum train size will be determined by tractive effort. Horsepower, however, will determine performance over the road. AC traction changes the relationship between tractive effort and horsepower in a fundamental way. A heavy train may be moved with less horsepower, at a price in overall travel time. The simulations described later in this paper will quantify the travel time penalty for two types of trains on two routes.

The profusion of new locomotive models from MK Rail and the two established builders has revived the question of horsepower vs. tractive effort. Recent locomotive sales have been almost entirely of six-axle units, indicating that railroads value tractive effort as much as (or more than) horsepower. Only a few GP60s and Dash 8-40Bs have been sold. However, the appearance of AC traction has changed the equation once again. Burlington Northern, the only purchaser to date of the SD70MAC, touts it as "the greatest revolution since the replacement of the steam engine by the diesel".[4] This claim is based on assumed savings through unit replacement (three SD70s for 5 SD40s). But it is not clear that every railroad will choose to operate in this way.

The EMD SD80 and SD90 and the GE AC60 (tentative designation) will all use AC traction, but will be adhesion-limited if they are conventional six-axle units. Thus, they will throw away much of the advantage claimed by BN for the SD70. This might, nevertheless, be a rational decision on the part of the purchasers. If high speed operations are required, horsepower may in fact be the most important variable.

## THE TECHNOLOGY OF VERY HIGH HORSEPOWER

Improved wheel-slip control was one factor behind the slow increases in unit horsepower during the 1980s. From the 20% value of 1970, EMD claimed to have reached 29% with the SD60 (although few railroads would dispatch locomotives on that basis). In theory, this produced nearly a 50% increase in tractive effort with an increase of only 800 HP. EMD advertised the SD60 as able to replace the SD40-2 on a two-for-three basis. Unfortunately, the claimed adhesion value could not be reliably achieved in the real world, and a three-for-four replacement was closer to the truth. Nevertheless, the improved wheel ship control technology held promise. GE soon produced the Dash 8, a 4,000 HP unit which (based on comments by railroads) came closer than the SD60 to realizing a 29% adhesion factor. Still, at 29% there seemed little point in going beyond 4,000 HP, since the units would become adhesion limited and the perception of the two builders was that tractive effort was the most important variable.

The advent of AC traction reinforced this conclusion. AC traction provides for greatly increased tractive effort without an increase in horsepower. In designing the SD70MAC, EMD quite deliberately made only a marginal increase in horsepower over the older SD60, counting on the increased tractive effort to sell locomotives. Railroads appeared to concur at the time; some stated that they saw no need for further increases in horsepower.[5]

Until 1993, EMD had attempted to sell AC traction mainly on the strength of a presumed reduction in maintenance requirements. But the sale of 350 units to Burlington Northern was closed on the strength of increased tractive effort. The higher tractive effort is of value (especially in heavy haul applications) if a railroad dispatches on the basis of tractive effort. In this circumstance, there seems little point to a 6,000 HP unit unless it has either eight axles or 39-ton axle loads. On the other hand, perhaps there is an advantage to high horsepower in some applications, even if less than 100% of it can be converted to tractive effort at low speed. This will depend upon an individual railroad's operating strategy. The new builder in the locomotive market, MK Rail, obviously thought horsepower had value when it announced plans for 5,000 HP and 6,000 HP AC units.

Again, the question arises: why would a railroad *want* very high horsepower units? The following comparative simulations of a 5,000 HP DC unit and a 4,000 HP AC unit may help answer the question.

## HORSEPOWER VS. TRACTIVE EFFORT -- A SIMULATION

Every railroad has different operating characteristics: different train lengths, train weights, operating speeds, topography, speed limits. It is therefore difficult to draw general conclusions about the suitability of one or another type of motive power for any specific service without a detailed investigation. Short of actually testing locomotives in service, computer simulation is the best way to evaluate current or proposed operations. Various types and combinations of motive power can be simulated with trains of varying weights, without the risk of either stalling on a grade or breaking a train in two. If the simulator has been well validated, conclusions can be used with confidence to formulate operating policies.

To determine the relative benefits of tractive effort and horsepower in general railroad service, two simulations have been undertaken on two very different routes. They include:

1. A 100-car mixed freight train in relatively flat territory
2. A 115-car coal train in more demanding territory

In the first case, total simulated one-way distance is about 950 miles. In the second, the one-way run is 1,200 miles. The first simulation uses the same motive power throughout. In the second, there is a helper district 50 miles long, plus two en-route adjustments of the motive power consist. The first simulated route handles moderate coal tonnages, plus mixed freight and intermodal traffic; the second is a major coal trunk route for a US railroad, and carries virtually nothing else.

Table 2 gives some characteristics of the two routes, and the base case operations over them:

## TABLE 2

### Operating Characteristics of Simulated Trains

| Operating Parameters | Train 1 | Train 2 |
|---|---|---|
| Route length (mi.) | 950 | 1200 |
| Train length (cars) | 100 | 115 |
| Train weight (tons) | 13,200 | 15,300 |
| Ruling grade (note 1) | 0.65% | 1.00% |
| Motive power (note 2) | 3 SD40-2 | 5 SD40-2 |
| Helper units | none | One location |

NOTE 1: Most severe non-helper grade.
NOTE 2: Simulation 2 current motive power varies between three and five units (plus two helpers on a section with 1.25% grades).

The Train Energy Model (TEM), developed by the Association of American Railroads, was used to perform the simulations. TEM is widely accepted in the railroad industry as an accurate simulator. It has been extensively validated against a number of different types of rail service. TEM provides calculations of running time, fuel consumption, speed, and drawbar force. Trains are handled by an automatic train handling algorithm, which eliminates differences in train handling as a cause for differences in the simulation results.

Two alternative locomotive consists were simulated on each route:

- A 4,000 HP locomotive with AC traction
- A 5,000 HP locomotive with DC traction

The AC unit is modeled on the EMD SD70MAC, which entered service late last year with Burlington Northern. However, the exact tractive effort of this unit is an educated guess based on typical transmission efficiency, and is not based on EMD data. The 5,000 HP DC unit approximates the MK5000C, a new design which entered production at Morrison-Knudsen in early 1994. Despite the difference in horsepower, the two units produce almost the same tractive effort at minimum continuous speed, due to the higher adhesion of the AC unit. This high adhesion also makes it possible to use two of the new units where three SD40-2s are required in the base case, and three where five are required. Of course, with the AC units the reduction in horsepower results in a slower operating speed.

The 5,000 HP DC unit can be substituted for the base case power in the same way: two for three and three for five. Thus, both the AC and DC units achieve a reduction in unit requirements relative to the base case, but neither can achieve a unit reduction over the other.

A pair of SD40-2 helper locomotives is required on Train 2 to assist both locomotive types over a segment of line with a maximum grade of 1.25% (the ruling grade, or maximum non-helper grade, on this route is 1%). No helpers are required on Train 1. Train 1 operates at 50 mph speeds throughout; Train 2 is limited to 45 mph while loaded, and 50 mph empty, per the policy of the railroad.

Results of the simulations provided an insight into the differences between the two locomotives simulated. The AC units performed very well, considering that there was a reduction in total horsepower amounting to as much as one SD40-2 (at points where Train 2 required only three, rather than five, units). Four SD40-2s would not have been able to ascend a 1% grade with a 15,300 ton train, yet three AC locos with equivalent horsepower were sufficient. However, this performance came at a price in terms of running time.

The very high horsepower DC units also performed well. On the ruling grades, they managed a somewhat higher speed than the AC units, but their real speed advantage showed in more moderate terrain, where their 1,000 HP per unit advantage allowed them to reach track speed more quickly, and maintain it for a longer time, than the AC units. Of course, this performance had a price as well: somewhat higher fuel consumption than the AC units. Table 3 compares the results for the base case, the AC locomotive, and the DC locomotive:

**TABLE 3**

**Simulation Results**

| 1. Moderate Territory | Running Time (round trip) | Fuel Consumption |
|---|---|---|
| Base Case | 50.9 hours | 13,713 |
| AC Locomotive | 51.7 | 12,152 |
| DC Locomotive | 48.7 | 13,176 |
| 2. Severe Territory | Running Time | Fuel Consumption |
| Base Case | 59.8 hours | 19,129 gal. |
| AC Locomotive | 64.1 | 16,880 |
| DC Locomotive | 60.6 | 17,959 |

As can be seen, the high tractive effort of the 4,000 HP AC loco comes at the price of significantly longer running time -- about 7% longer than that of the 5,000 HP DC locomotive in both simulations. While a 7% difference in running time is undoubtedly negligible on a short haul, on these long movements it translates into three to four hours of additional running time, with all that the additional time may entail: longer cycle time, possibly additional crew costs, and a reduction in line capacity.

The DC locomotive, replacing the horsepower of the base SD40-2s on a one-for-one basis, achieves equal or better running times in both simulations. This running time advantage over the AC units does come at the cost of some extra fuel consumption, because more net work is being performed.

What does this simulation say about the relative merits of these two units for railroad service? As always, the answer depends upon the operating patterns of each carrier. Costs are approximately equal. On a dedicated heavy-haul railroad, the SD70MAC will move the same train as the MK5000C with less horsepower and less fuel consumption, but also at a lower speed. On a busy mainline carrying a mix of traffic, the performance of the AC units may cause dispatching problems. Here, a higher horsepower unit capable of higher speeds might be desirable or even essential.

## CONCLUSIONS

Competition is a wonderful goad to innovation. Without it, products may remain unchanged for decades, and the adoption of new technology may be painfully slow. Eastern Europe and the Soviet Union are prime examples of this.

Innovation in railroad diesel locomotives has been almost inexcusably slow over the last two decades. One result has been the trend in recent years to rebuilding of older locomotives; with progress in design innovations so glacial, why not simply rebuild old units to take advantage of the modest improvements in engine efficiency and control systems? To some extent, EMD and GE bear responsibility for the torpid market in new locomotives over the last decade and a half.

Now, however, some real competition has appeared. For the first time since 1962, an entirely new original-equipment manufacturer has entered the railroad locomotive market. Further, the new manufacturer (MK Rail) is offering a line of locomotives that neither GE nor EMD can match at present -- prime movers with twelve cylinders and up to 6,000 HP. These locomotives are aimed at a market that appears to be horsepower-hungry, and that has been kept semi-starved by the slow progress at GE and EMD.

MK Rail's units use a proven diesel prime mover that is now in production for other applications (marine and stationary). GE and EMD, by contrast, face the difficult task of developing prime movers that can exceed 4,400 HP. Their competitive response has therefore been instructive. For its 5,000 HP locomotive, EMD will revive a 20-cylinder design that was abandoned twenty years ago due to high fuel consumption and high maintenance costs. EMD's planned 6,000 HP prime mover will, according to early reports, be a four-stroke rather than a two-stroke design -- a major change for EMD.

GE has purchased a test-stand eight-cylinder design from a German manufacturer. The company intends to develop a 6,000 HP, 16-cylinder version, build a production line, and begin manufacturing -- all in less than three years. That is an amazingly short time to produce a new engine design. If GE had started a few years ago, there would not be such a need for speed.

On the other hand, a few years ago MK Rail was only a rebuilder, not a manufacturer, of locomotives, and EMD posed no threat of developing a very high horsepower locomotive.

While the current flurry of innovation is certainly welcome, it appears to have occurred almost without regard for the real requirements of railroads. For example, there will always be some demand for locomotives of moderate horsepower, yet none are being produced by any builder (except for the MK Rail 1200G gas-fueled switcher, which is designed for special service). Are railroads expected to switch industrial tracks with 4,000 HP units, or must they depend entirely upon rebuilds for this service? There are still serious questions about whether any of the manufacturers can produce price-competitive new locomotives of moderate horsepower.

The rush to 6,000 HP seems to be a classic example of producer behavior in an oligopolistic market. None of the three competitors wants to be left out of the horsepower race, yet there has been an almost total absence of real analysis. These locomotives will be double the horsepower of most locomotives now in railroad fleets. Whether they can in fact replace existing units on a one-for-two basis will depend upon reliability and tractive effort as well as horsepower. Economic benefits will depend upon purchase price and maintenance costs -- both unknown at this point.

AC traction is another unknown. Its cost advantage (if any) over conventional DC transmissions is yet to be documented. Its ability to change the relationship between tractive effort and horsepower is well known. The uncertainty is over what types of locomotives the railroads might choose to buy. If they opt for very high horsepower, the tractive effort available from AC motors may be of limited value, but the maintenance cost of AC technology will become a major concern.

One general conclusion may be drawn. Until now, all locomotives have used DC motors, and motive power has been assigned in terms of horsepower per ton. As long as all units have about the same adhesion and transmission efficiencies, this process will produce predictable performance. But when the relationship between tractive effort and horsepower is changed -- as it apparently has been by AC traction -- the possible consequences to operations must be carefully evaluated. The old methods of power assignment may no longer be valid.

So what does this renewed competition buy the railroad industry? If history is a guide, the result will be a variety of locomotive products, all more powerful and more reliable than in the past. They may even be less costly. If MK Rail can remain in the business (and GE and EMD may be expected to make use of their long relationships with railroads to try to shut MK out), the result will be a broader range of better products for an industry badly in need of them.

## ENDNOTES

* Vice President, Costing and Economic Analysis, ZETA-TECH Associates, Inc.

1. "Engines of Change", *Railway Age*, July 1993.

2. "The Great AC. Locomotive Race", *Railway Age*, June 1994.

3. See "Economic Implications of Heavy Axle Loads on Equipment Design, Operations, and Maintenance", by Ronald R. Newman, Allan M. Zarembski, and Randolph R. Resor. American Society of Mechanical Engineers, Rail Transportation Division, *RTD Vol. 4, Rail Transportation*, (New York: 1991). Also, discussions with motive power officers

on several Class I railroads have indicated that FRA-mandated 92-day inspections, traction motor maintenance, and repairs to control equipment are a major portion of locomotive maintenance cost. This suggests that maintenance cost for a higher-horsepower unit would not increase proportionately.

4. "Remarks by Ed Bauer, Chief Mechanical Officer, Burlington Northern Railroad, at Association of American Railroads Cost Analysis Organization Spring Seminar, Jacksonville, FL. April 29, 1994.

5. "Engines of Change", *Railway Age*, July 1993.