CONFIDENCE FINDINGS ON THE POTENTIAL OF 6X2 AXLES

ABSTRACT

This report documents the confidence that North American Class 8 trucking should have in specifying and buying tractors with a 6x2 axle configuration. The study team engaged the entire industry in the data that is presented here. Thanks to all of those who contributed to this important work.

Trucking Efficiency

Trucking Efficiency is a joint effort between NACFE and the Carbon War Room to double the freight efficiency of North American goods movement by 2016 through the elimination of market barriers to information, demand and supply.

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The fuel costs faced by the tractor-trailer industry have been swiftly and steadily rising over the past decade. By 2012 diesel fuel costs reached $0.64 per mile, surpassing even the combined cost of wages and benefits for the drivers. This recent surge in fuel prices has reshaped the economics of trucking, and the industry is in need of solutions if it is to stay profitable.

Fortunately, a myriad of technologies which show strong potential for achieving cost-effective gains in fuel efficiency for Class 8 trucks are readily available on the market today. Unfortunately, the industry's uptake of such technologies has been stymied by a multitude of barriers, central among those being a lack of data about the true performance gains offered by these technologies, and, what's more, a lack of confidence in the data that does publically exist today. In order to overcome those barriers and facilitate the industry's trust in and adoption of the most promising fuel-efficiency technologies, the North American Council for Freight Efficiency (NACFE) has partnered with the Carbon War Room (CWR) to form the Trucking Efficiency Operation. The Operation's work has begun with a series of Confidence Reports, of which this report on 6x2 axles is the second.

This report focuses on these axle technologies because they stand to increase fuel efficiency by 2.5%. Specifically, this report documents the confidence that the North American Class 8 trucking industry should have in whether or not it is economically rational for them to specify and buy tractors with a 6x2 axle configuration. Based on the claims of 6x2 manufacturers, along with some anecdotal data, NACFE's initial research into a variety of fuel-efficiency technologies suggested that 6x2 systems will offer cost-effective fuel savings to the vast majority of fleets. But although such single-axle drive tractors are widely used in European trucking and have been for some time, their penetration into the North American market thus far has been very slow, and today they make up only 2.3% of new line haul tractor sales.

In looking into possible reasons for such low adoption rates, the aforementioned market barrier of a lack of data and confidence was found to be particularly applicable to the situation of 6x2 systems.

BY 2012 DIESEL FUEL COSTS REACHED $0.64 PER MILE, SURPASSING EVEN THE COMBINED COST OF WAGES AND BENEFITS FOR THE DRIVERS.

The test findings, which are explored in depth in the report, are summarized in this table:

	NACFE @ PIT			OEMS		Fleets				
	#1	#2	#3	Volvo	Freightliner	Con-way	XXX	UPS	Nussbaum	YYY
Truck Description	KW w/Dana Axles -Mod 1	KW w/Dana Axles -Mod 2	Volvo 6x2 w/Meritor Axle	Converted Volvo 6x4	Converted Cascadia 6x4	Kenworth 6x2, 6x4	FL Columbia 6x2, 6x4	Mack Pinnacle Day cabs	Volvo	ProStar+
Test Type	Type II	Type II	Type III	Mod Type II	Mod Type IV	Freight Miles	Freight Miles	Same route each day	Freight Miles	Freight Miles
Number of Units (6x2, 6x4)	1,1	1,1	1,1	1,1	1,1	1224, 59	7,11	1,1	10,4	27, 112
Test Date	Jun-13	Jun-13	Jun-13	12-Jul	Nov-12	Jan-12 to Dec-12	Jun-10 to May-11	Jun-12 to Jun-13	Apr-13	Jan-13 to Apr-13
MPG Delta	**1.9%**	**2.8%**	**2.3%**	**1.6%**	**2.2%**	**3.2%**	**3.9%**	**4.6%**	**4.0%**	**1.9%**
Avg	**2.3%**			**1.9%**		**3.5%**				

Fuel Economy Test Results

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Numerous market research studies, including some conducted by NACFE, suggest that fleets trust the experience of other fleets more than any source of information besides their own. And yet, prior to the publication of this report, there was very limited data on the actual experience of early-adopting fleets with 6x2 systems.

BY ANALYZING THESE VARIOUS SETS OF TEST DATA, TRUCKING EFFICIENCY FINDS THAT FLEETS CAN BE CONFIDENT THAT THEY WILL ENJOY ABOUT A 2.5% REDUCTION IN FUEL USE, AND PAYBACK ON INVESTMENT IN ABOUT 20 MONTHS, BY ADOPTING CURRENTLY AVAILABLE 6X2 AXLE TECHNOLOGIES.

Thanks to an extensive series of interviews, and permission from the industry to publish their preexisting test results, this confidence report marks the first and only place where the actual data of various fleets' experiences with 6x2s is shared publically. This report also represents the first time that a variety of different sources of data and testing results are collected and shared in one place, side-by-side, making the findings of this report not only more compelling but also more likely to be relevant to a range of fleets and truck owners.

Seven sets of existing testing data, five from fleets and two from OEMs, are presented in this report. That data is supported by three additional sets of track tests on 6x2 performance that NACFE commissioned in the course of conducting its research. Along with the test results themselves, this report supplies details on the testing protocols used in each case, so that readers can better judge which tests are most applicable to their own needs or duty cycles.

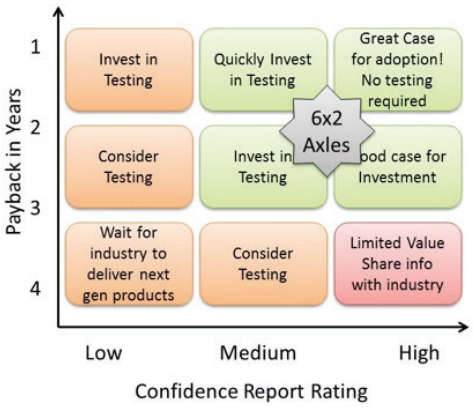
Additional interviews were conducted with 6x2 technology manufacturers and other stakeholders in the sector to round out the conclusions drawn from this test data.

By analyzing these various sets of test data, Trucking Efficiency finds that fleets can be confident that they will enjoy about a 2.5% reduction in fuel use, and payback on investment in about 20 months, by adopting currently available 6x2 axle technologies.

In sum, this report places the 6x2 technology near the top-right quadrant of the Trucking Efficiency Confidence Matrix, giving it a medium-to-high Confidence Rating – meaning that Trucking Efficiency is confident in that the existing data, given its the breadth and accuracy, does demonstrate that 6x2s will have an acceptably short payback period as to justify their widespread adoption by the industry:

This Confidence Rating indicates that Trucking Efficiency is highly confident that 6x2 axle configurations offer significant fuel-efficiency gains. Besides fuel-savings, other benefits of 6x2s include weight reduction, lower maintenance costs and improved truck stability.

Along with discussing the benefits of 6x2s, this report catalogues the concerns most commonly cited as reasons not to adopt 6x2s, including challenges of traction, overall tire wear, resale value, and driver acceptance. These are indeed justified concerns. However, this report considers each concern individually, and concludes that the benefits of 6x2s today outweigh these concerns for a variety of reasons. For example, new technologies



Payback and Confidence

For more information, contact
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for automatic load shifting, limit the traction difference between a 6x2 and a 6x4, and therefore Trucking Efficiency recommends such technologies be automatically specified for any 6x2 tractor.

To complement these new figures for the average predicted efficiency gains offered by 6x2 axle systems, this Confidence Report includes a Payback Calculator, with which individual fleets or truck owners can more accurately predict the gains that they themselves would experience with a 6x2 configuration. Users input various figures and details specific to their operations, and duty cycles, and receive a tailored picture of whether or not 6x2 axles are going to be right for their operations.

Unlike many other such calculators, the Payback Calculator presented in this Confidence Report considers both the benefits or savings and the challenges or costs posed by 6x2s in determining its results. The goal of the Payback Calculator is not to provide complete and thoroughly accurate data of how 6x2s will perform for a given fleet, but rather to suggest whether users should seriously explore the technology for themselves, perhaps by specifying on a few of their trucks, or otherwise investing in their own rounds of testing.

Along with the results of the Payback Calculator, fleets can use this Confidence Report as an initial decision-making tool by considering whether the best practices for 6x2 performance detailed here are relevant to or replicable in their own operations.

Future research should attempt to verify some initial findings, also discussed in the report, around the much greater potential efficiency gains offered by installing a suite of complementary technologies, which Trucking Efficiency has dubbed the "6x2 package." The report also gives some initial findings of the impact of 6x2 axles on tire wear, but additional test data is needed to strengthen those numbers.

Additionally, Trucking Efficiency is always seeking to expand the data or case studies that we can provide to the industry. We invite you to share with us your own experiences with 6x2 axle systems – whether you have adopted them already, are considering doing so, or have chosen not to pursue them at this time.

It is the hope of the Trucking Efficiency Operation that this report will catalyze significant new interest in the 6x2 axle technology as a way to increase fuel efficiency and obtain other benefits.

TO COMPLEMENT THESE NEW FIGURES FOR THE AVERAGE PREDICTED EFFICIENCY GAINS OFFERED BY 6X2 AXLE SYSTEMS, THIS CONFIDENCE REPORT INCLUDES A PAYBACK CALCULATOR, WITH WHICH INDIVIDUAL FLEETS OR TRUCK OWNERS CAN MORE ACCURATELY PREDICT THE GAINS THAT THEY THEMSELVES WOULD EXPERIENCE WITH A 6X2 CONFIGURATION.

About Operation Trucking Efficiency

Operation Trucking Efficiency is a joint effort between NACFE and the Carbon War Room to double the freight efficiency of North American goods movement by 2016 through the elimination of market barriers to information, demand and supply.

Worldwide, the heavy-duty freight trucks emit 1.6 gigatons of CO_2 emissions annually – 5.5% of society's total greenhouse gas emissions. These emissions are the result of the trucking sector's dependence on petroleum-based fuels. From a global

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perspective, truck manufacturing is a growth market which will likely see up to 33 million new units built by 2015. But this growth, though profitable, could result in massive increases in trucking's emissions – unless the trucking sector improves its fuel efficiency as fast as it expands.

With fuel prices continuing to rise, the adoption of efficiency technologies by all classes of trucks and fleets offers significant cost-savings to the sector while reducing emissions. For example, for a typical heavy-duty truck in the United States, a 5% reduction in fuel-use gained through improved efficiency offers yearly savings of over $4,000. Technologies capable of conferring such gains are relatively cheap to implement and widely available on the market. Many have the potential to be retrofitted onto existing trucks.

But in spite of the potential cost savings, even the most promising of these technologies are not yet being widely adopted by the North American trucking industry. Operation Trucking Efficiency finds that the following market barriers are responsible for this:

Lack of Confidence in the Data on Efficiency Technologies – New technologies abound, but fleet owners lack cross-comparable, credible, and widely available data proving their potential performances. Often the only existing data are producer claims, which fleets put low trust in. Fleets worry that savings will be less than promised, and that technologies will negatively impact their operations.

Information is Not Shared – When fleets do independently test a technology, the tests are expensive and time-consuming, leading to 18-month average implementation times and low purchase quantities. Fleets tend to test in parallel, rather than sharing their test results or otherwise collaborating in obtaining performance data, resulting in an unnecessary duplication of cost and effort.

This Confidence Report series from Operation Trucking Efficiency was born out of not only the identification of these barriers, but also conversations with the industry, which made it clear that the elimination of these barriers requires a credible and independent source of information on fuel efficiency technologies and their applications. The Confidence Reports aim to serve of the first such source on the

About the Carbon War Room

The Carbon War Room is a global nonprofit, founded by Sir Richard Branson and a team of like-minded entrepreneurs, that accelerates the adoption of business solutions that reduce carbon emissions at gigaton scale and advance the low-carbon economy. The organization focuses on solutions that can be realized using proven technologies under current policy landscapes.

Working collaboratively in sectors where we have proven that profitable emission-reduction opportunities exist, the Carbon War Room aims to create well-functioning, high-growth, and low-carbon marketplaces by launching Operations in those sectors. The War Room's current Operations include Maritime Shipping Efficiency, Green Capital for Energy Efficiency in the Built Environment, Renewable Jet Fuels, Smart Island Economies, and Trucking Efficiency.

For more information, please visit www.carbonwarroom.com.

About NACFE

The North American Council for Freight Efficiency will drive the development and adoption of efficiency-enhancing, environmentally-beneficial, and cost-effective technologies, services, and methodologies in the North American freight industry by establishing and communicating credible and performance-based benefits. The Council is an effort of fleets, manufacturers, vehicle builders and other government and non-government organizations coming together to improve North American goods movement.

More can be learned about the NACFE at www.nacfe.org.

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1 Introduction

This report forms part of the continued work of Trucking Efficiency, a joint initiative from the North American Council for Freight Efficiency (NACFE) and the Carbon War Room (CWR), highlighting the potential of fuel-efficient technologies and practices in over-the-road goods movement.

The fuel costs faced by the tractor-trailer industry have been swiftly and steadily rising over the past decade (Figure 1). By 2012, as Figure 2 shows, fuel costs had reached $0.641 per mile, surpassing even the costs for the driver (wages plus benefits).

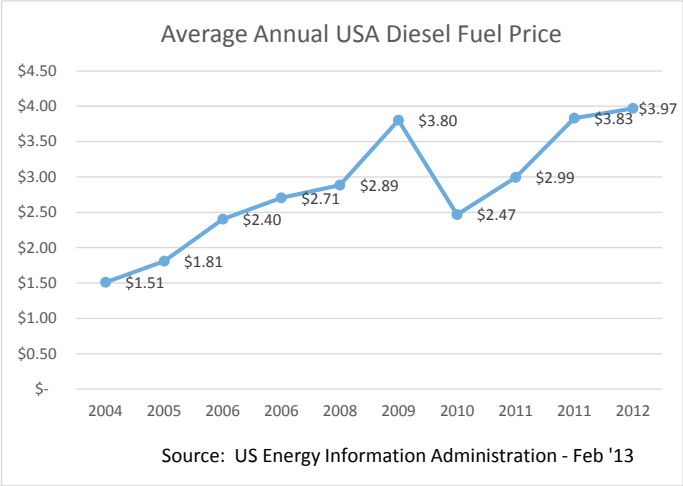


Figure 1: US Annual Diesel Fuel Prices

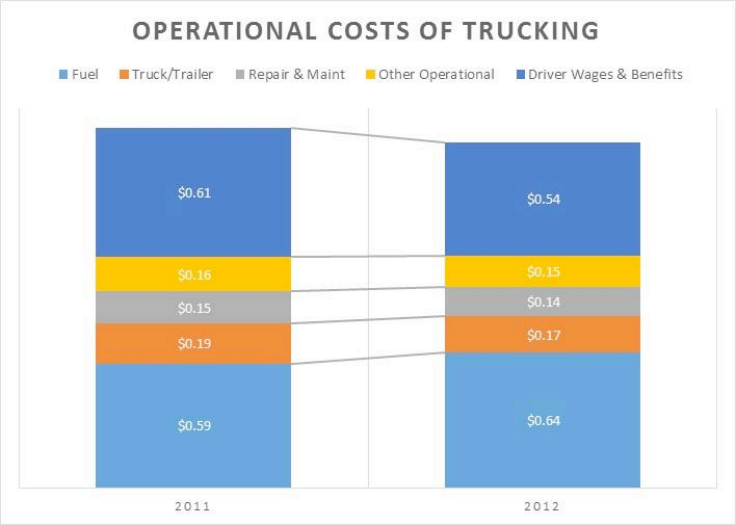


Figure 2: Trucking Operational Cost

Source: American Transportation Research Institute 2012. Operational Costs of Trucking.

Investment into technologies and practices that allow a truck or fleet to increase their fuel efficiency – meaning they can do the same amount of business while spending less on fuel – is a hugely promising option for the industry in light of this trend.

To understand, and thereby better facilitate uptake of such technologies, NACFE conducts an annual review, "the Fleet Fuel Study," of the industry-wide adoption rates of over sixty fuel-efficient technologies currently available for Class 8 tractors and trailers. This work, available on the www.nacfe.org website, has been called "The most comprehensive study of Class 8 fuel efficiency adoption ever conducted." (Truck News, 2012)

Figure 3: NACFE Fuel Study Participating Fleets

In February 2013, NACFE completed the first annual update of that study, and, for the first time ever in any study, included additional research into the use of fuel-efficient products and practices by ten of the largest, most data-driven fleets (Figure 3). Those fleets represent both regional and long-haul tractors and trailers, in both dry goods and refrigerated cargo movement, and boast a combined inventory of 41,000 tractors and 125,000 trailers. The 2013 study reviewed a decade of those ten fleets' specific experience with the sixty-plus technologies. Each fleet shared the percentage of their new purchases of tractors and trailers which included any of the technologies. They also shared ten-years-worth of annual fuel economy data for the trucks in their fleet. With these two pieces of information, which will be updated each year for future reports, NACFE is able to share insights into the following trends with the industry:

- Adoption curves for each of the sixty-plus technologies, indicating which technologies have the steepest adoption rates, which are being adopted steadily but slowly, and which are not being purchased at all. These curves also show how uniformly (or not) fleets are acting in their adoption patterns.
- Identification among the various fleets of the innovators, early-majority or late-majority adopters, and even laggards in new technology adoption as described specifically in the report.
- Comparison of technology adoption to overall fuel efficiency.

The overriding take-away from this study is that fleets are enjoying dramatic improvements in their fuel efficiency by adopting the various technologies surveyed - saving about $5,700 per tractor per year in fuel costs compared with a fleet who has not invested in any efficiency technologies.

1.1 Confidence Reports

The Fleet Fuel Studies provide useful insights into adoption trends in the industry and the practices of different major fleets, and NACFE hopes that this information could spur additional investment, particularly by fleets that may be lagging behind the overall industry when it comes to certain widely-adopted technologies. However, in the course of conducting the studies, it was clear that some technologies which show strong potential for achieving cost-effective gains in fuel efficiency are only being adopted by the most progressive or innovative of fleets. In order to facilitate the wider industry's trust in and adoption of such technologies, NACFE and the CWR formed the Trucking Efficiency operation. The operation has begun a series of reports, called "Confidence Reports," which will take an in-depth look at those technologies one-by-one.

6x2 axles are one such technology that shows limited initial adoption rates in spite of promising results, and therefore 6x2 axles were found to meet Trucking Efficiency's criteria for a technology to investigate further. Specifically, the NACFE Technical Advisory Committee (TAC) found that this technology should be a priority for additional research due to the fact that rarely does a single technology offer fuel-saving, weight-reduction, and cost-neutrality or even cost-savings – and initial data on 6x2s find that they can offer all three benefits. Other benefits of 6x2s include lower maintenance costs and improved truck stability. The challenges associated with the adoption of 6x2s that NACFE found in its initial consideration of the technology included concerns around traction, overall tire wear, resale value and driver acceptance.

This Confidence Report was produced in order to confirm or refute those benefits and challenges, and provide more information to the industry on 6x2 axles. This exploration of 6x2 axles is the second in this new series of similar studies the first of which was published in August of 2013 on Tire Pressure Systems.

Confidence Reports provide a concise introduction to a promising category of fuel-efficiency technologies, covering the key details of their applications, benefits and variables. The reports are produced via a data mining process that combs both public information and otherwise-private information that is shared with Trucking Efficiency for the purpose of the report, in order to collect an unparalleled range of testing data and case-studies on a technology. The information gathered in each Confidence Report will typically include:

- Suppliers' Bench Tests – For instance, predicting fuel economy for vehicle performance.
- Fleet-Reported Case Studies – Best practices and optimal use of technology.
- Truck Manufacturers – How the technology performs in engineering testing, as well as their product introduction and ramp plans.
- Public Reports/Test/Data, press information, etc.

Each Confidence Report is published in tandem with a simple and accurate 'Payback and Performance Calculation Tool,' that will facilitate a fleet's adoption of a technology with the confidence that it is indeed right for them.

The objectives of this study are the following:

- Understand the history of the development of the 6x2 axle concept and the current 6x2 products available to North American trucking operations.
- Work with the industry to detail the fuel efficiency performance of the technology.
- Document both the benefits and adverse consequence of adoption, and outline best practices.
- Calculate a payback and develop a tool for use by fleets and others to determine their return on investment of this technology.
- Report an industry-wide 'level of confidence' that end-users can have in both the existing data and actual gains they will enjoy by adopting 6x2 axles.

2 Methodology

Trucking Efficiency's approach to Confidence Reports, illustrated in Figure 4, is centered in the recruitment of an unbiased team of trucking experts who will conduct the work. For this 6x2 study the core team included:

- John Fehring, Program Manager and Key Technical Lead, Hoosier Performance Engineering
- Bruce Stockton, Early Adopter and Fleet Perspectives, Stockton Solutions
- Sue Slick, Sr. Researcher, NACFE
- Mike Roeth, Executive Director, NACFE

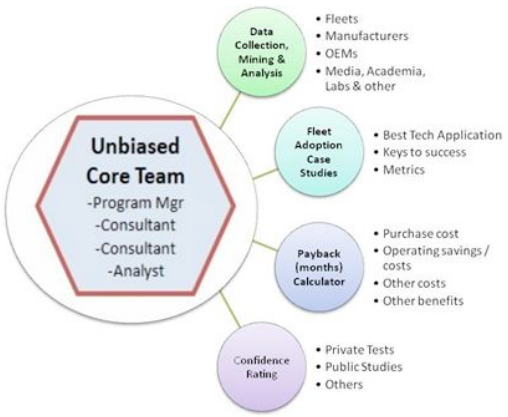


Figure 4: Approach to Confidence Reports

The NACFE TAC, via Trucking Efficiency, commissioned this report in August 2012, and the study team began actively working on the project in September of that year. The team first spent three months reviewing all publically available information on 6x2 axles and creating a list of the expected benefits and challenges of adopting this technology. Next, the team met multiple times with the two primary providers of 6x2 technology (who are also sponsors of this study), Dana Holding Corporation and Meritor Inc., visiting the engineering and validation locations of both companies to review the performance, cost, and weight of their 6x2 axles, and any recent improvements to their configurations. This effort included the completion of a thorough data-collection document on the offerings from both companies with regard to their key customer attributes. It also included a review of the performance predictions each company had developed, using the manufacturers' simulation methodologies given the bench testing of the axles assuming various duty cycles.

The team next moved to the tractor original equipment manufacturers (OEMs) and the fleets themselves, building on their research into public and manufacturer data by gathering private and confidential information, both qualitative and quantitative. When needed, non-disclosure agreements were executed in order to protect information while still allowing the team to utilize it in generating their findings and recommendations. The team conducted in-person and over-the-phone interviews with various tractor OEMs and end-user fleets, as well as an online survey of fleet's perspectives on 6x2 axles. The fleets interviewed included innovative first buyers, early adopters, and those considering adoption.

Trucking Efficiency also used major truck conferences to obtain additional data and perspectives from axle manufacturers, end users, and tractor OEMs, including the 2012 CALSTART HTUF National meeting

in Charlotte, the 2013 Technology and Maintenance Council exhibition in Nashville, and the 2013 Mid-America Trucking Show in Louisville.

Moreover, Trucking Efficiency decided to conduct its own fuel consumption track tests for 6x2s. These tests were conducted in June 2013 with the assistance of FPInnovations' Performance Innovation Transport (PIT) group, using their semi-annual Energotest procedures. PIT is a Canadian-based, fleet-member organization conducting research and testing for trucking efficiency. Equipment for those tests was provided with the help of Meritor, Volvo, and a major Canadian fleet.

Overall, in the course of this 6x2 study, a significant amount of new data was created, while previously private information was shared here for the benefit of the entire industry. In total, ten independent and robust fuel efficiency test reports are included in this study - three from Trucking Efficiency itself, two via the engineering departments of the tractor OEMs, and five from fleets' own rigorous testing and data collection processes, giving the study team confidence that the combined results of the testing data accurately isolated and reflected the impact of the 6x2 axles on fuel efficiency.

In crafting this Confidence Report the team analyzed all of the information, formulating fuel efficiency predictions, best practices for adoption, and more, and culminating in the development of a projected payback calculator and a confidence rating for fleets to use as they consider specifying 6x2 axles on their future tractor orders.

2.1 Primary Study Questions

A series of primary study questions was created to help guide the study team's effort:

- What 6x2 technologies are currently (or soon-to-be) available on the market, and what distinguishes each of them?
- Which of the various 6x2 systems have been adopted to date, and in what volumes?
- What degree of improvement in fuel efficiency (fuel economy) were seen with 6x2s?
- What were the adoption rates of 6x2s among the study fleets?
- Who is considering adoption, and what additional information do they need to decide whether or not to specify and buy 6x2s?
- What were the key attributes of the technology which attracted the very early adopters? (Mesilla Valley Transport, Con-way Truckload, etc.)
- Which fleets have been successful using 6x2s and why?
- Why did some fleets test 6x2s but then decide not to pursue purchasing them?
- Do the axles perform well?
- What is required to make 6x2s work well? (i.e. complementing features, components or systems?) Are tractor OEMs supporting adoption by making axles and accompanying features available?
- How did the early adopters handle traction issues?
- What other challenges are current adopters facing with these technologies, and how are they overcoming them?

3 Overview of Currently Available 6x2 Axle Systems for Tractor Trailers

3.1 History of 6x2s

As James Menzies pointed out in his Truck News December 2012 article "The 6x2s are coming" (Menzies, DAILY NEWS Dec 7, 2012 4:04 PM, 2012), truck OEMs and suppliers have successfully saturated the market with the simplest productivity improvements for fleet owners and owner/operators. The article asked, essentially, what more could easily be done to increase payload and/or improve fuel economy, given that all the 'low-hanging fruit' has been picked – 6x2s were posited as one likely answer.

Many ideas and technologies for improving fuel economy were brought to the trucking industry back in the 1970s, during that era of high fuel prices, and some of those are being given a second look today. The industry realizes that fuel prices are likely to be both volatile and high for years to come, and this fact, combined with increasing legislation surrounding CO_2 and other emissions, has brought a new focus to the fuel economy of heavy trucks. The 6x2 configuration is one of those older technologies to be gaining renewed interest, due to its potential weight savings and fuel economy improvements.

In spite of not being a new technology, 6x2 systems are still not widely used in North America and are considered by many to be an "odd-ball spec." Until recently, truck buyers had to request a 6x2 axle system through a Special Equipment (SE) order at the OEM, which can increase the lead time for a new truck's delivery. Most OEMs now offer the 6x2 in regular production as optional equipment.

The 6x2 configuration has been the standard configuration for over-the-road trucks in many parts of Europe for the last few decades. Many such technological advancements from Europe are finding their way to the North American market of late. For example, European-originated advances in electronics and controls are bringing the operating performance of a 6x2 up to par with that of a 6x4 and require minimal driver interaction and close-to-zero operational differences.

As trucking continues to be commoditized, carriers must do everything possible to increase their equipment's productivity and reduce their operating costs. (Menzies, Truck News Sep 4, 2012) Several fleets have aggressively adopted the 6x2 configuration, equipping the majority of their trucks with this system. These fleets, along with some "hyper-mileage" owner/operators, are adopting 6x2s as a means to bolster their bottom lines thanks to the additional fuel economy and payload that the systems allow. Together, these early adopters are increasing the penetration of 6x2s in the North American trucking market, dispelling many of the concerns, especially concerns over traction, that have limited the adoption of 6x2s thus far, and improving the resale values of 6x2 trucks in the process.

3.2 6x2 System Details

A typical Class 8 tractor today is equipped with three axles - a forward, unpowered, steer axle, and two rear-drive axles which are often referred to as a "live tandem" axle system. This arrangement is commonly called a 6x4 configuration, given that it involves six wheel-ends on the tractor (two on each axle), with the four rear wheel-ends all being powered. A 6x2 configuration still has the same three axles and same six wheel-ends, but only one of the rear tandem axles (2 wheel-ends) is actually 'driven,' or powered by the engine. The non-driving rear axle is often referred to as a "dead" axle, and the whole 6x2 system is often called a "dead axle tandem."

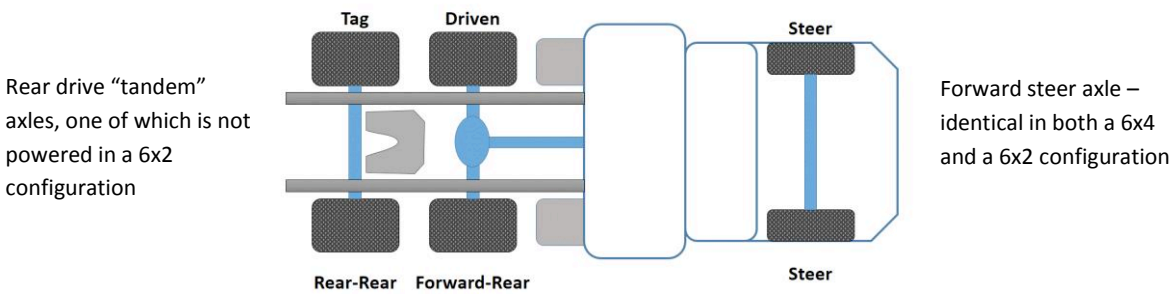


Figure 5: 6x2 Tag Axle Tractor Diagram

There are two possible configurations of the 6x2 system, differentiated by the location of the non-driving rear axle. The first and most common 6x2 system is the "tag tandem" where the forward-rear axle is driven and the rear-rear axle is the "non-driver" or "tag" axle. Alternately, a "pusher tag" 6x2 system has the non-driven axle in the forward-rear location and the drive axle in the rear-rear location.

6x2 systems are available in the same 40k and 46k tandem ratings (referring to the maximum weight in thousands of pounds that the two axles together can haul) commonly found in 6x4 arrangements, with the dead axle, whether forward-rear or rear-rear, designed to carry the same load as the driven axle. However, since all of the drive and retarding engine torque passes through a single rear axle (the driven one), 6x2 system manufactures have either specified the use of ring and pinion gear sets with a 23k max haul weight per axle (not 20k), or have developed gears and ratios specific to their 6x2 systems. Manufacturers do not recommend conversion from a 6x4 to a 6x2 arrangement by simply removing the interaxle drive shaft and gear sets for the non-driven axle, due to the increased torque that will pass through the single driven axle gear set. (That is, a 6x4 system distributes the torque across both axles and their gear sets. A 6x2 system uses slightly stronger or larger components to handle the more concentrated torque.)

The lack of internal gearing in the 6x2 configuration (as the dead axle does not need any drive gears) prevents fuel losses from the internal frictional and/or lubricant churning inherent in the use of any

gears, and thereby gives 6x2 systems higher fuel efficiency than 6x4s. 6x2 systems also weigh less than 6x4s systems, conferring additional fuel savings.

Today's dead axles utilize the same wheel-end equipment as the drive axles in the 6x2 system, meaning that their hubs and brake components are identical, which simplifies maintenance. Some 6x2 manufacturers use a drive axle for their dead axle's housing and simply plug or cover the axle ports, carrier openings and input shaft openings. Others have developed dedicated square or round dead axle housings, similar to those used in trailer applications.

Other component changes that can complement a 6x2's performance and efficiency should be considered when specifying a 6x2 vehicle configuration. For instance, engine-, transmission- and final-drive ratios may be modified to optimize the drive train for a "gear fast, run slow" setup. Additionally, trailer tires may be used on the dead axle, as their tread pattern offers reduced rolling resistance compared to lugged tractor drive tires. Wide Base Single Tires (WBS) could be specified along with the 6x2, as these can offer up to an additional 400 lbs. in weight savings and reduced rolling resistance, both of which improve fuel efficiency.

While it is accepted that 6x2s reduce weight, and generally accepted that they otherwise improve fuel efficiency, one of the major barriers to their wide-spread adoption in the US is a lingering concern over whether or not they provide adequate traction. Many inside the trucking industry equate the performance of a 6x4 tractor to that of a 4x4 pickup and the performance of a 6x2 to that of a 2WD pickup. But this perception is inaccurate. Even the earliest 6x2 systems incorporated manual dump valves that allowed the truck driver to momentarily transfer load from the dead axle to the driven axle during low traction conditions. Several manufacturers have since developed automated load-transfer systems that shift the load from the dead axle to the driven axle during low-traction moments without requiring driver interaction. In sum, thanks to these systems and as detailed later in this report, data on 6x2s suggests that these actions significantly reduce the traction issue inherent with having one less drive axle. Several truck OEMs are now integrating such load-transfer controls directly into their overall vehicle controls systems for vehicles specified with 6x2s.

3.3 System Manufacturers

Two companies, Dana Holding Corporation and Meritor, Inc., currently produce 6x2 systems for the North American market. Both of their systems have the forward-rear axle serving as the driven axle in their systems. The following contains product descriptions supplied directly from each manufacturer. More information and data can be reviewed via each manufacturers' website.

3.3.1 Dana Holding Corporation

In the spring of 2013, Dana Holding Corporation introduced its newest 6x2 system, the Spicer® EconoTrek™ tandem. Like all 6x2s, this newest system improves fuel economy through decreases in mechanical drive-train energy loss. It also reduces overall weight by up to 450 pounds compared to a traditional 40,000-pound tandem axle arrangement.

The Spicer® EconoTrek tandem axle system combines the company's newly upgraded Spicer® S170 or S190 single-reduction single-drive axles (the driven axle in the 6x2) with a new, lightweight Spicer S20-045B that serves as the non-driven or "tag" axle in the system.

First introduced in 2004, Spicer® S170 and S190 are high-performance single-drive axles designed for efficiency. Their newest iterations within the Spicer® EconoTrek system have improved durability, meaning less maintenance is required. Manufacturer Dana boasts that these newest Spicer® S170 and S190 drive axles are more resistant to differential spin-out events than ever before.

Figure 6: Dana's Spicer EconoTrek Tandem Axle with Welded Bowl Tag Axle

The new Spicer® S20-045B tag axle also features advanced designs leveraged from Dana's popular line of Spicer® commercial-vehicle drive axles. Made of high-strength, micro-alloy steel with a thin-wall, square-edge-formed axle housing box, it weighs 20 to 30 pounds less than competitive models of tag axles. The Spicer® S20-045B axle is shaped like a low-profile drive axle, which provides significant strength to the axle's vertical loadbearing capabilities, and also reduces deflection to limit tire wear while simplifying suspension and chassis installation.

The Spicer® EconoTrek tandem axle system is available with SelecTTrac™ for use with wide-based single tires, and is also optimized for use with electronic-controlled air suspension systems, such as the Bendix eTrac™ system. The eTrac™ system serves to transfer weight to the Spicer® S170 or S190 drive axles in the 6x2 system to allow for improved low-speed traction, when combined with the wheel-differential lock feature.

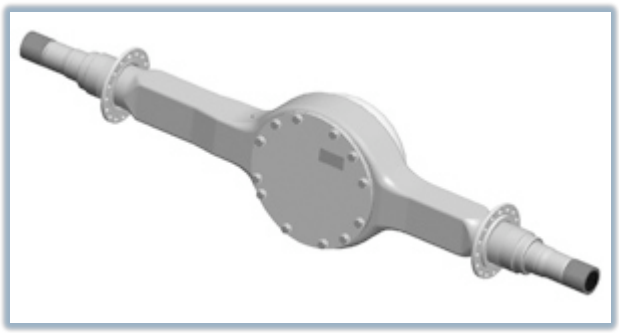


Figure 7: Dana's Bolted Bowl Tag Axle

Dana previously offered 6x2 configurations that also featured a Spicer® S170 or S190 single drive axle used in combination with a Spicer® S21-060B or S23-070B tag axle. The Spicer® S21-060B and S23-070B tag axles provided common torque rod brackets and axle seats for air-ride suspensions, as well as a common wheel-end configuration to support a wide variety of brake and hub options. These tag axles utilized standard drive-axle housings with removable bolted cover plates that could accept a drive-axle carrier assembly and axle shafts, allowing them to be converted into driven-axles in OEM pre-approved applications.

3.3.2 Meritor, Inc.

Meritor, Inc. specializes in commercial-vehicle components for the trucking industry, and their commercial literature states that they "pride themselves in developing solutions that are known for not only bulletproof reliability but also efficiency."

One such solution is their FUELite™ 6x2 system. The FUELite tandem axle set is the first member of the Meritor 6x2 configuration axle family, the SoloDrive Series. Based on their 160-Series drive axle, and named after the two key benefits it delivers, the FUELite 6x2 system offers 400lbs of weight savings compared to a similar 6x4 system, and provides an estimated two percent fuel efficiency increase.

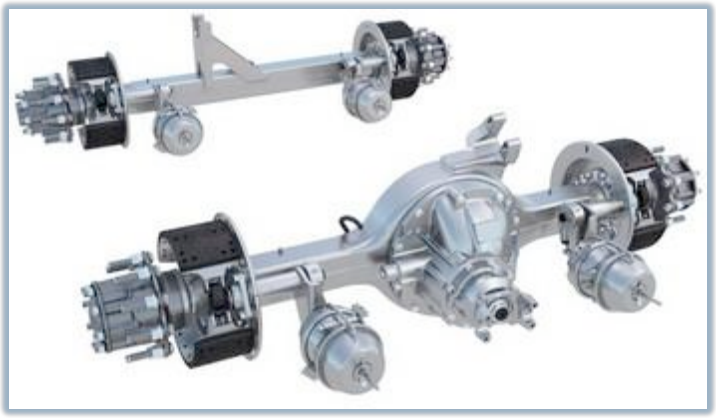


Figure 8: Meritor's FUELite Tandem Axle

Features of the drive axle within the FUELite system include: Meritor DualTrac™ housing that allows the 6x2 system to use either traditional duals or wide-based single tires, driver-controlled diff lock, and available ratios ranging from 2.50-4.10 and a 12.7 millimeter wall housing that's compatible with all current 40,000-pound tandem hook-ups.

The FUELite system also includes a new, lightweight, and unique rectangular tag axle designed for ease of OEM installation, parts commonality, and reliability. Features of the tag axle include R-series spindles, an integral upper torque rod bracket designed to accommodate all 40K line haul suspensions, and a 12.7mm thick wall housing.

The FUELite 6x2 system is compatible with various traction-management systems available today. Meritor recommends that customers always spec their 6x2 systems in a package with enhanced traction controls and a locking differential. Advanced traction-management systems, such as Meritor WABCO's electronically-controlled air suspension (ECAS) system, are designed to improve a vehicle's air suspension control system by electronically maintaining a set ride height between the axle and chassis when road and vehicle characteristics change. ECAS, for example, also offers automatic load transfer, significantly reducing drive-axle wheel spin and loss of traction control during periods of aggressive acceleration. Advanced traction-management systems, such as Meritor WABCO's ECAS system, combined with the efficiency delivered by the FUELite 6x2 axle system, allow a truck to operate more fuel-efficiently while still enjoying traction comparable to that afforded by a heavier 6x4 system in all but the most extreme situations.

4 Fuel Economy Testing and Data

As mentioned earlier, the fuel consumption savings of 6x2 axles are the main benefit of adopting them. This chapter will offer significant detail into the fuel savings achieved through specifying this technology on Class 8 over the road tractors. Data will include adoption experience and testing completed by Trucking Efficiency along with information gathered from axle manufacturers, tractor OEMs and fleets.

4.1 Previous Findings on 6x2s

NACFE has uncovered previous findings on 6x2 axle configurations via various methods over the past few years which are detailed here.

4.1.1 Adoption Rates

As will be detailed later, both primary axle manufacturers, Dana Holding Corporation and Meritor, Inc., have 6x2 products available to the industry with data book availability at 5 of the 6 tractor OEMs. Daimler, through its Detroit subsidiary, also builds 6x4 axles, but does not currently offer a 6x2 configuration.

The 6x2 (and 4x2) has been used extensively in Europe and other parts of the world for many years, yet only accounts for about 4% of new line haul tractor sales in the US market. The total US market penetration rate of 6x2s remains low at around 2.3%, but is beginning to show months of higher production as larger fleets order batches of trucks with the feature.

Adoption of 6x2 axles to date in NACFE's Fleet Fuel Study has been dominated by one of the fleets, Con-way Truckload, who has purchased around 95% of their new tractors in the past few years with 6x2s, and after ramping up over the past five years now predominately runs trucks with tandem tag 6x2 axles. A few other fleets have only purchased and tested small numbers, but reported that they are considering much larger future purchases.

4.1.2 The 6x2 "Package"

During the course of its 2012 and 2013 Fleet Fuel Studies, NACFE uncovered that, although 6x2 systems can be adopted singularly, many early-adopting fleets are choosing to purchase them as part of a specific package of complementary features, what NACFE is calling the "6x2 package." The typical 6x2 package, in addition to the 6x2 tandem axle configuration itself, can include regular wide-base single (WBS) tires on the drive, ribbed low-rolling resistance WBS trailer tires on the tag axle, a direct-drive (DD) transmission, and a "gear fast, run slow" rear-axle ratio approaching 2.50 and filled with low-viscosity synthetic lube. Moreover, engine OEMs are beginning to optimize their own calibrations around much lower engine cruise speeds. Where 1350 rpms at a cruise speed of 64 mph was once the norm, engine speeds are being lowered to run at 1200, 1150, or even lower. To complement this trend, axle manufacturers are working to provide lower gear sets for the single drive axles in the 6x2 tandems.

In 2010, noticing the trend towards the adoption of 6x2 axles within this 6x2 package, NACFE drafted a quick investigation of the benefits of such a package (NACFE website – 6x2 Executive Report), and found that fleets running the aforementioned 6x2 package were reporting a 0.4 to 0.5 mpg fuel efficiency improvement. A 0.4 mpg improvement on a 6.5 mpg base tractor represents an over 6% improvement in total fuel consumption – in fact it was found that this package is delivering approximately a 6.5% improvement over a standard 6x4 configuration with dual-tires and overdrive transmission.

From these figures on the gains offered by the 6x2 package, some in the industry have anecdotally rationalized that each individual technology offers 1/3 of the benefit – 2% for the 6x2 axle system, 2% for the wide base tires, and 2% for the direct drive transmissions. However, it is actually quite difficult to convert data on technologies in packages to data on technologies working alone, or vice versa. For example, if any single improvement to a truck's aerodynamic shape offered a 3% gain, four such improvements might only offer a 10% gain, and not a 12% gain, as a given area of aerodynamic drag can only be reduced/removed once, but multiple technologies in the package might each improve the airflow over that same area.

Therefore, in light of the inability to make firm predictions about the performance of a 6x2 system based on data about technology packages, this current 6x2 Confidence Report from Trucking Efficiency seeks to investigate and confirm the performance benefits of the 6x2 axle only.

This study hypothesizes that the primary benefit offered by a 6x2 axle system is an improvement in fuel economy. A 6x2 system allows for the removal of one drive axle's gear set, the inter-axle differential, inter-axle drive shafts and axle shafts, thereby significantly reducing the frictional and churning losses associated with those components. It is also possible to put trailer tires onto a tag axle, reducing rolling resistance and obtaining an incremental improvement in fuel economy, not to mention lowering the cost of a retread in that position.

4.2 New Findings on 6x2s

The Confidence Report study team worked with the industry to gather existing 6x2 comparison fuel economy test results. The goal was to have a significant set of data in order to confidently predict the fuel efficiency benefits of a 6x2 system.

The study team was ultimately able to accumulate robust test sets from two OEMs and five major fleets, in addition to the data from three new tests conducted for the purposes of this report by NACFE in conjunction with PIT in Canada. Finally, data was collected from the two 6x2 axle manufacturers, Dana Holding Corporation and Meritor, Inc..

The OEM and NACFE tests are the typical SAE/TMC Type II or Type III fuel economy tests, while all of the fleet data represents the results of monitoring real-world freight operations, with data collected over periods ranging from one month to twelve months. The manufacturers used simulation tools to predict the fuel economy of various duty cycles, using axle bench test efficiency data as their primary input.

Predictions from the axle manufacturers of the 6x2's fuel efficiency improvement over a 6x4 tractor are 2.0%. The results of the other ten sets of test data collected are summarized below, after a general description of the common test procedures used to generate such data.

4.2.1 Various Test Procedures

This section briefly describes the various full-vehicle test protocols available for determining the fuel efficiency improvement offered by a particular technology. These are not exhaustive descriptions, and readers should reference the associated Society of Automotive Engineers (SAE) and or Technology and Maintenance Council (TMC) practices for a full understanding of the value and appropriate use of each.

- SAE J1321 / TMC Type II – These tests are used to compare the fuel consumption of a tractor with and without a particular fuel-efficiency technology provided that the technology in question can be retrofitted onto an existing tractor. In these tests the same tractor and trailer is tested with and without the device, generally on a track, though the test can also be done on a public road for approximately 50 miles. The tests' protocols also call for a control truck to be run without the technology, to allow for the calculation of a ratio between the two trucks when run without the technology and ensure consistency of the test. Specifically-designed small fuel tanks are used to power the trucks in these tests, and the weight of the fuel consumed, as determined by removing the tanks and weighing the fuel off the truck, gives the measure of fuel efficiency. Multiple valid tests are required for statistical valid results.
- SAE J1526 / TMC Type III – These tests are very similar to the SAE J1321 / TMC Type II, but are used to conduct an 'A-to-B' vehicle test, in order to evaluate a technology that is difficult or impossible to retrofit onto an existing vehicle. In this test there are two test vehicles, one with and one without the technology installed, compared to a test and a control vehicle. Most all of the other testing protocol details are the same as the SAE J1321 / TMC Type II tests. Although much care is taken to ensure the two trucks are identical in specifications for the SAE J1526 / TMC Type III tests, component manufacturing variations can affect the results, by introducing additional variation between the test trucks, such as different powertrains or aerodynamics.
- SAE J1263 Coast Down – This test is used to evaluate aerodynamic or tire rolling resistance features. The drag or rolling resistance can be compared between a vehicle with and without a given device by allowing that vehicle to coast to a stop from a consistent speed. The longer the distance travelled, over a very flat surface with minimal wind, the more efficient the truck, and therefore the more successful the technology was at reducing drag or rolling resistance.
- TMC Type IV RP1109 – This test was developed by the TMC primarily for use by fleets. The test calls for data collection over segments of approximately 400 miles, and can be run while hauling real freight, that is, over the course of relatively normal operations. A baseline (control) truck and a test truck (one with a technology installed) are compared over the route by measuring and recording the miles driven and the fuel consumed via "topping off" the normal fuel tanks on the truck. This test's protocol includes criteria regarding the allowable difference in weight between the two vehicles, as well as other requirements.

- In-Use Tests or Freight Mile Tests – No single specific common protocol is used by fleets when they compare the fuel consumption of their vehicles with and without fuel efficiency technologies. It is common for fleets to procure and compare tractors and/or trailers with and without the technology by recording fuel usage via telematics or using other methods such as fuel card purchases versus miles driven. Generally, these calculations compare sets of trucks driving dedicated routes over certain periods of time, or via higher statistical numbers of vehicles over for-hire random routes. Each fleet tends to create its own particular methodology for capturing and interpreting this data, and to stick with it over time. Though the tests are different, certain factors are key to ensuring that a fleet's protocol is repeatable and the data viable, including limiting the difference in the equipment to only the feature under test, recording data from many miles run over many months, and using consistent measurement methods.

These tests are used by fleets, technology providers, tractor and trailer equipment builders, and others to predict the fuel economy of various technologies. Of course, each test has its limitations, and its findings may be limited to the particular testing conditions or situations. For instance, a Type II test run at 65 mph will predict the performance difference of a technology at 65 mph with limited start and stop traffic. A fleet may have a duty cycle that is similar but not identical to this situation – maybe their average speed is only 55 mph – and this will affect their experience with the technology. Also, the entities conducting the tests will sometimes "modify" them and use slightly different protocols, making it difficult for others to interpret the top-level results of any such test.

4.2.2 Industry Tests Provided to Trucking Efficiency for this Confidence Report

This section details the different tests that various industry actors, namely OEMs and fleets, have recently conducted on 6x2s, and the individual findings of each of those tests, which have been shared with the Trucking Efficiency team for the purposes of this Confidence Report. The findings of all of these tests are summarized and discussed in the following chapter.

4.2.2.1 OEM #1 –Volvo Global Truck Technology

The first OEM surveyed by this Confidence Report, Volvo, shared with the study team the results of a modified Type II (~50 miles) on-highway test that they had privately conducted. Volvo's test used a VNL670 control and test vehicle, both equipped with the D13 engines running at US EPA07 emissions level. On the test vehicle, the rear tandem was first run as a Meritor 6x4 and then later reconfigured as a Meritor 6x2 tandem, maintaining the same gear ratio and tire combinations. The control vehicle maintained the 6x4 configuration throughout. The test vehicle was also equipped with Michelin's WBS

Figure 9: Volvo's Test Vehicles

XDA Energy tires, a rear axle ratio of 2.64:1 and the Volvo I-shift transmission. The tests were run at a GCW of ~70,000 lbs. with the cruise control set at 64 mph which yielded an engine speed of 1138 RPMs in top gear. The test route had a total elevation change of less than 200 feet with a maximum grade of less than 4%, and with 89% of the route under a 1% grade. Testing was conducted with a very accurate positive-displacement-flow meter, plumbed in such a way that the return fuel flow from the engine was taken into account. Volvo found that the 6x2 configuration achieved a 1.6% improvement in fuel economy over the 6x4.

4.2.2.2 OEM #2 – Daimler Trucks North America

The second OEM to share data with the study team of this Confidence Report was Daimler Trucks North America (DTNA). DTNA ran a modified Type IV test (~400 miles) with two Freightliner Cascadia vehicles. The vehicles were equipped with the Detroit Diesel 15L engine, DT12 transmission, and Michelin XDA Energy dual tires on the drive axles. The 6x4 vehicle was also equipped with Detroit's DA-RT-40 tandem rear axles housing a 2.53:1 axle ratio and the combination was loaded to a GCW of 73,600 pounds. For the vehicle with the 6x2 configuration, the rear-rear axle was moved to forward-rear position, and a Meritor 6x2 tag axle was used in the rear-rear position. It should be noted that this reconfiguration was done solely for the purpose of fuel economy testing, and that splitting a tandem drive axle set is not recommended for on-road use without first consulting the OEM or axle manufacturer.

Figure 10: Daimler's Freightliner 6x4/6x2 Test Vehicle

The DTNA test route was over 400 miles with a maximum grade of +/-5%. The 58 mph cruise speed was pre-programed into the engine controller to remove driver error and yielded 1280 rpm engine speed.

DTNA's test found that the 6x2 configuration achieved a 2.2 +/- 0.3% reduction in fuel consumption when compared to the 6x4 axle package. DTNA also did an analysis of the daily average torque between the test 6x2 and the baseline 6x4, and found a 2.0% reduction in engine torque, which is similar to the measured data. Finally, DTNA also ran a simulation of the tested configuration and achieved a 2.2% reduction, which correlates nicely with the actual data from the road test.

4.2.2.3 Fleet #1 – Con-way Truckload

Con-way Truckload is a carrier that has been an early adopter of the 6x2 technology, to the point that the majority of their fleet is now running with 6x2s. Con-way runs several different brands of tractors and they do keep a few 6x4s in their fleet for comparison. They shared with the Confidence Report study team their 12-month rolling data from November of 2012, which contained fuel economy data for approximately 2,394 of the tractors in the fleet. Their fuel economy is calculated from the actual fuel consumed and miles traveled of those trucks (a "freight miles" test). This study has considered a subset of their fleet, comprised of 1,283 of their Kenworth tractors, in order to compare directly between the 1,224 of them that have a 6x2 configuration and the 59 of them that are configured as 6x4s. One caveat is that Con-way's "6x2 Package" also includes a direct drive transmission and wide-based single (WBS) tires, neither of which are included on their 6x4 trucks. The remainder of the specifications of their 6x2 and 6x4 Kenworth tractors are very similar.

The Con-way 6x2 package yielded a total 6.7% improvement over their 6x4 baseline vehicles across their 12 months' of data. The Confidence Report study team then consulted with several industry experts on the improvement contribution from the direct drive transmission and WBS tires. The consensus was that approximately 1.5% of the improvement was from the DD transmission and another 2% was due to the WBS tires. Therefore, the 6x2 axle configuration by itself netted a 3.2% improvement.

4.2.2.4 Fleet #2 – Fleet XXX

Trucking Efficiency also received 12 months' of data from a major fleet who understands the value to the industry of sharing data, but wishes to remain anonymous in this Confidence Report. The number of trucks in the dataset of their freight miles testing varied as units were removed from service and new units were added over the course of the year. In the end, some period of data was available for a total of 45 6x4s and 9 6x2s (with the lowest periods of data available for 11 6x4s and 7 6x2s). The trucks' average monthly mileage was 10,675 (6x4s) and 7,300 (6x2s). This test group was comprised entirely of 2010 Freightliner Columbia tractors with mid-roof cabs, running in random areas around the country. The 12 month study ultimately found that 6x2s conferred a 3.9% fuel economy improvement over the 6x4 configuration.

4.2.2.5 Fleet #3 – UPS

UPS is another fleet that provided the results of a 12 month study. Their freight miles test was a little unique in that two identically equipped Mack Pinnacle trucks with the Mack 13L engine followed each other from Charlotte, NC to Atlanta, GA twice a day for a year, accumulating approximately 87,000 miles on each vehicle. The only difference between the trucks was that one was equipped with the 6x2

configuration and the other was a 6x4. The 6x2 enjoyed a 4.6% improvement in fuel efficiency over the 6x4 during the 12 months of operation.

4.2.2.6 Fleet #4 – Nussbaum

The fleet Nussbaum provided a one-month snapshot of their fleet mileage from the month of April 2013. Data was made available from their fleet of Freightliners and Volvos, and the Confidence Report study team was able to compare between 6x2 and 6x4 Volvos, as the entire group of 113 Freightliners were all equipped with 6x2s, with no similarly specified 6x4 trucks. All of the comparison Volvo tractors were equipped with modern SCR engines and averaged slightly more than 10,000 miles per month. There were four 6x4 Volvos that had overdrive transmissions with WBS tires and ten 6x2 Volvos that had direct drive (DD) transmissions and WBS tires. Test data from transmission OEMs suggests that a direct drive transmission improves fuel economy by approximately 1.5% versus an overdrive (OD) transmission. In the Nussbaum data, the 6x2 DD Volvos enjoyed a 5.48% improvement over the 6x4 OD Volvos. Subtracting 1.5% for the DD transmissions nets a 3.98% improvement that can be attributed to the 6x2 configuration.

4.2.2.7 Fleet #5 – Fleet YYY

Another major fleet willing to share data while remaining anonymous provided the Confidence Report study team with four months of freight miles testing data (January through April of 2013) that included 55 tractors with 6x2 configurations and 312 6x4s, and running both Truckload and Less-than-Truckload routes. The tractors were both day cab and sleeper International ProStar+ models with MaxxForce 13L engines, direct drive transmissions, and a 2.47 gear ratio, and overall they averaged about 8,000 miles per month. The trucks' fuel-usage data was all pulled off of their Engine Control Modules (ECMs) and reported through the telematics tool, PeopleNET, and it included all divisions/routes of this fleet. The fleet's results showed an average (day cabs and sleepers) of a 1.94% fuel-efficiency improvement for the 6x2 configuration. The sleepers were found to perform a bit better than the day cabs, enjoying a 2.54% improvement versus the day cabs' 1.53% improvement.

4.2.3 NACFE-Conducted Tests

NACFE was fortunate enough to partner with PIT, Performance Innovation Transport, a group within FPInnovations in Quebec, and conduct tests for this Trucking Efficiency Confidence Report as part of PIT's semi-annual fuel economy testing sessions. Three separate tests that compared the 6x2 to 6x4 configurations were completed. Results are show in Appendix A: PIT Test Report.

The first two tests run were SAE J1321 / TMC Type II involved two 2012 Kenworth T660s from a cooperative Canadian-based fleet. These trucks were Canadian spec'ed and ran the larger Dana Spicer D40-170P tandem axles with a 3.21 gear ratio, which is essentially a de-rated 46k tandem axle set. The tests both involved running the two Kenworth trucks in their stock 6x4 configuration to achieve a baseline fuel economy metric. The two trucks were then converted into the 6x2 configuration in two different manners, providing the two different sets of test data. The first truck (Test 1) had the rear-rear axle housing emptied of its differential gear set and axle shafts, and the interaxle drive shafts removed. The forward-rear axle had the interaxle differential removed and the gear set changed, but retained the

3.21 ratio. The second truck (Test 2) swapped the axle positions. The rear-rear axle moved to the forward location and became the single drive axle for the truck without modification. The forward-rear axle was moved rearward and was emptied of all its driveline components - gears, differentials and axle shafts. This modification also requires relocating the frame side brackets for the transverse torque rods for both axles.

Test 1 resulted in a gross 2.6% improvement in fuel economy while Test 2 yielded a 3.5% improvement.

Figure 11: NACFE's 6x2 Test Vehicle

The larger axles used in these tests are not typically specified in North American line-haul trucks. After several discussions with the axle manufacturers on how these larger axles would perform when compared to a standard 40k tandem, it was determined that a 0.7% downward correction factor should be applied, as the larger, 46k, lower-volume tandem axles are not as efficient or refined as the higher-volume 40k tandems. As such, removal of one drive axle from the less-efficient 46k tandem will see a larger increase in fuel economy improvement. This correction to a 40k tandem nets a 1.9% improvement for the 6x2 configuration of Test 1 and a 2.8% improvement for the 6x2 configuration of Test 2.

NACFE's third test involved two similarly specified Volvo VNL 670s acquired from a dealer lot in Quebec; one a 6x4 (white cab) with a Meritor MT40-14X4C tandem, and the other a 6x2 (red cab) with Meritor's RS23-160 single drive axle and a Volvo non-driving tag axle. This test was conducted according to SAE J1526 / TMC Type III, which is appropriate for an A/B comparison of two trucks. The 6x2 Volvo achieved a gross improvement of 3.3% over the 6x4 Volvo.

Figure 12: NACFE 6x4 Test Vehicle

In addition to the drive axle configuration differences, the other notable variance between the two trucks was the lack of a few aero devices on the 6x4 model and a slightly larger trailer gap. Moreover, the 6x4 had a slightly different aero bumper and was not equipped with chassis shirts, but the under-cab, frame-mounted components were tightly packaged with minimal gaps between them. These differences were discussed with three industry aerodynamics experts and the team referenced PIT's 2007 Energotest on chassis skirts and determined a 1% correction factor for these aerodynamics affects. Thus, the net improvement for the 6x2 was 2.3% when corrected against the differences between that truck and the 6x4.

4.3 Test Results: Fuel Economy Improvements

The three types of data sets: OEM, fleet, and NACFE, all correlated well with one another. The two OEM test sets returned the most conservative results, with an average of a 1.9% improvement in fuel economy. The three NACFE/PIT data sets were all 50-mile runs on a highly controlled closed course, and yielded an average improvement of 2.3%. The data sets from the five different fleets included runs of anywhere from 8,000 miles to over 100,000 miles, all conducted in the course of actual freight hauling, and with a wide difference in the type and number of trucks tested. The data from the tests of UPS and Fleet XXX considered the smallest number of trucks, and therefore potentially a greater effect from things like driver influence, weather, etc. The fleet data overall showed an average 3.5% improvement from installing a 6x2 over a 6x4. It is clear from all of these tests that this technology does deliver a substantial improvement in fuel economy, and will significantly reduce a truck's operating cost for the year.

Table 1 below summarizes the results from the 10 sources of data considered in this 6x2 Confidence Report, while Figure 13 provides a graphical representation of the fuel economy results.

	NACFE @ PIT			OEMS		Fleets				
	#1	**#2**	**#3**	**Volvo**	**Freightliner**	**Con-way**	**XXX**	**UPS**	**Nussbaum**	**YYY**
Truck Description	KW w/Dana Axles -Mod 1	KW w/Dana Axles -Mod 2	Volvo 6x2 w/Meritor Axle	Converted Volvo 6x4	Converted Cascadia 6x4	Kenworth 6x2, 6x4	FL Columbia 6x2, 6x4	Mack Pinnacle Day cabs	Volvo	ProStar+
Test Type	Type II	Type II	Type III	Mod Type II	Mod Type IV	Freight Miles	Freight Miles	Same route each day	Freight Miles	Freight Miles
Number of Units (6x2, 6x4)	1,1	1,1	1,1	1,1	1,1	1224, 59	7,11	1,1	10,4	27, 112
Test Date	Jun-13	Jun-13	Jun-13	12-Jul	Nov-12	Jan-12 to Dec-12	Jun-10 to May-11	Jun-12 to Jun-13	Apr-13	Jan-13 to Apr-13
MPG Delta	**1.9%**	**2.8%**	**2.3%**	**1.6%**	**2.2%**	**3.2%**	**3.9%**	**4.6%**	**4.0%**	**1.9%**
Avg	**2.3%**			**1.9%**		**3.5%**				

Table 1: Fuel Economy Test Results

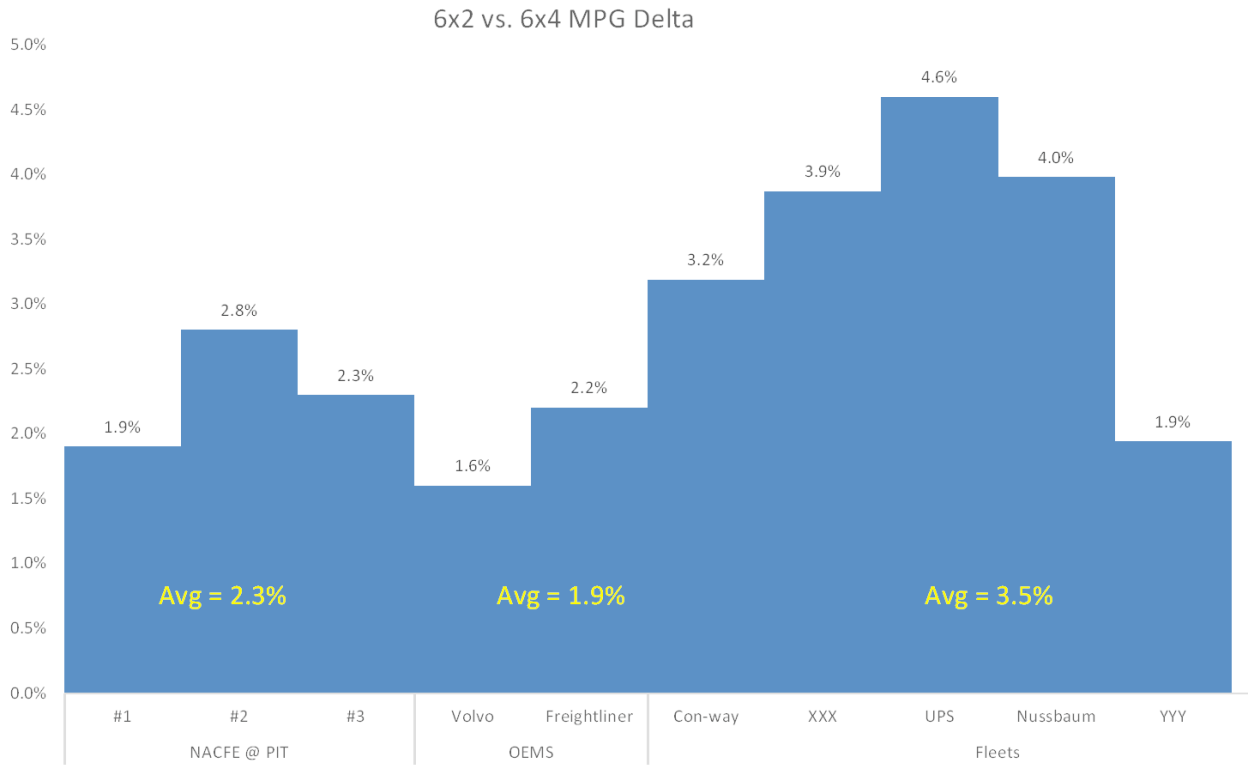


Figure 13: Graph of Fuel Economy Test Results

5 Other Benefits of 6x2s

Along with saving money by improving the fuel economy of a vehicle, 6x2 configurations, whether in a package or installed singularly, reduce a vehicle's weight, cost, and the amount of required maintenance, as well as improve its stability.

5.1 Weight

6x2 configurations offer a significant weight reduction for the chassis, as a tag axle itself weighs less than a driven axle, plus the full configuration involves the removal of the inter-axle differential and associated inter-axle driveline components, as well as one differential gear set. A small amount of weight is added for additional features such as load shifting and anti-spin measures – allowing an overall reduction of 400 to 450 pounds. End users should consult with their truck OEM to determine the proper tandem axle suspension system to complement the 6x2 axle configuration and that it is rated to handle the driving torque passing through a single axle. Depending on the OEM, the properly rated and configured 6x2 suspension may negate a small portion of the 6x2 axle weight savings. Many fleets are utilizing this weight savings to help offset the increased truck chassis weights that have resulted from the addition of new safety and driver amenity options, the last decade of emission controls programs, and the adoption of other fuel-efficient but weight-adding features such as aerodynamic fairings.

Reducing weight purely for a fuel economy improvement yields only a small benefit, as a 1,000 lb. weight reduction will yield only an approximately 0.8% improvement in fuel economy. A weight-reduction feature like the 6x2 configuration is often pursued as an enabler for other fuel-saving but weight-adding features like an Auxiliary Power Unit for anti-idling, or full tractor and/or trailer skirting. Other weight sensitive applications like bulk haul and tankers take advantage of this feature to increase their cargo capacity and value weight saving technologies more. WBS tires can be added to the 6x2 package for approximately an additional 400 lbs. of savings.

5.2 Cost

There is currently approximately a $1,000 to $2,000 upcharge for a new tractor specified with a 6x2 axle. However, in discussions with the industry, the study team found that the OEMs and 6x2 suppliers/manufacturers are in wide-agreement that, within a few years, 6x2 configurations will be approximately cost-neutral when compared to a similarly specified 6x4.

The explanation for the current cost differential is that a 6x2 system requires a larger drive gear set, as all of the engine torque and engine braking are handled by only one gear set, rather than two as in a 6x4. Moreover, as will be described in the section below on traction, additional load-shifting electronics are recommended for tractors being ordered with 6x2 axles, in order to ensure adequate traction performance. Along with these electronics, the 6x2 configuration requires higher-cost 6-channel (6S6M) ABS/Traction Control systems. Finally, several of the tag axles available for 6x2 systems are custom units

which have not yet achieved the high production volumes necessary for lower cost. However, once production volume grows, these higher-cost aspects of the systems will be offset by the 6x2's lack of inter-axle prop shafts, inter-axle differential, rear-rear gear set and rear-rear axle shafts – allowing cost parity with 6x4s to be achieved.

5.3 Maintenance

The fact that the 6x2 configuration allows for a reduction in the total number of driveline components should lead to an overall reduction in maintenance costs and labor. For example, the fact that a 6x2 lacks an interaxle drive shaft should eliminate most driveline vibration complaints, and it also means that fewer U-joint lubrication procedures are needed. The single drive axle gear set of a 6x2 reduces the overall differential fluid fill at change intervals. Additionally, when the tag axle of the 6x2 is in the rear most position, the process of stacking tractors for delivery (see Figure 14) is simplified, as there is no need to remove any axle shafts for transport. The need to remove and then reinstall the rear-rear axles on a 6x4 for delivery often leads to warranty issues from axle leakage.

Figure 14: Piggy-back Delivery of Tractors

Although there may be a slight increase in maintenance due to the additional 6x2 electronics, the reduction in mechanical components and associated maintenance should result in an estimated overall savings of $100 per year, available by virture of operating a 6x2 versus a 6x4.

5.4 Stability Improvement

An often overlooked benefit of adopting a 6x2 configuration is that it might give a truck improved stability and control when operating in slippery or poor road conditions. When a 6x4 loses traction, all four of its drive tires may potentially spin up. All of the available traction of a spinning tire is consumed by the spin, so the tire will not be able to provide the lateral forces necessary to keep the vehicle on the desired path. Moreover, without any lateral forces at the tandem tire sites, a jack-knife situation can easily occur. But, with the 6x2 configuration, the tag axle cannot spin up by virtue of not being powered by the engine. Thus it will always have some level of lateral forces available to keep the vehicle stable on its desired path, greatly reducing the potential for a jack-knife event initiated by wheel spin. One fleet manager described the tag axle in a 6x2 as a "rudder" that keeps the tractor pointed straight ahead.

Some fleets have reported a reduction in tow bills or accidents thanks to 6x2s, however their data collection systems make it difficult to isolate the 6x2-prevented jack-knife events from all other incidents. But given that the cost of a rollover event can exceed $300k in cleanup and damages, preventing just one incident has tremendous payback.

NACFE did not conduct any testing or obtain significant industry data on this particular item. Additional investigation aimed at validating the stability improvement of a 6x2 setup versus a 6x4 should be conducted.

6 Adverse Consequences / Challenges

The following section of this report will detail the various adverse consequences or challenges of using a 6x2 configuration on over-the-road tractors.

6.1 Traction

By far the largest concern voiced in the industry about the 6x2 configuration regards a loss of traction or tractive effort. Many drivers equate the 6x4's performance to that of a 4-wheel drive pickup truck, and a 6x2 to a 2-wheel drive pickup. But this analogy does not completely hold, given the loads carried by a commercial truck compared to a personal vehicle. The normal or vertical force on a commercial tire can be as high as 20,000 lbs. on the tire's contact patch, for either dual or WBS drive tires. Depending on the road conditions, a significant percentage of that normal force becomes the available tractive effort to move the vehicle forward – 2-wheel drive pickup trucks will never achieve that sort of weight-based traction.

Moreover, many of the conditions where a loss of traction might be noticed with a 6x2 system are likely situations a 6x4 truck should avoid or would otherwise have limited traction in as well. Deep snow, deep loose gravel, heavy ice, and even parking lots full of pot holes can inhibit traction enough to stop most 6x4 vehicles. When compared with the 6x4, some of the traction shortcomings of the 6x2 can be mitigated with the use of load shifting technologies to increase the weight on the drive axle at low speeds.

Unfortunately, the earliest of these 'load shifting' systems that were offered along with 6x2 axle configurations involved a manual dump valve on the tag axle. The driver could engage the dump valve at a low speed, releasing the air from the tag axle air bags and thereby increasing the load on the forward-rear drive axle. The tag axle air springs were then re-pressurized once the driver released the dump valve, or when the vehicle exceeded speeds of approximately 25 mph. However these systems were clunky and required a high-degree of interaction from drivers, making a 6x2 system unappealing to some potential adopters.

More recently, these manual dump valves have been much improved. Both tractor OEMs and various 6x2 component and subsystem manufacturers have developed automated electronic load shift systems that are integrated into the truck's electronic systems and work in conjunction with the electronic traction control systems already on the trucks. In these new systems, the trucks' ABS/Traction Control systems sense any drive axle wheel slip and request load transfer from the tag to the drive axle, engaging the differential lock automatically. As these systems release air from the tag axle springs they increase the pressure in the drive axle springs, in order to increase the load on the drive axle while maintaining the truck's ride height. Once the low-traction event is over, the systems automatically return the air springs to their proper, balanced settings, all without any interaction or input from the driver. Some 6x2 load shifting systems carry a slight offset at all times, with a bit more load on the drive

axle than on the tag axle, to minimize the number of low-traction events. This offset never exceeds the drive axle rated loading and will not allow the tag axle to become completely unloaded. Several of the OEMs are now offering proprietary automatic load shifting systems integrated into the vehicle's electronics, while others are providing other manufacturer's systems like the eTrac from Bendix, or the Meritor WABCO ECAS system.

Many fleets that use 6x2s already report that their drivers easily learn their 6x2 systems' limitations and simply try not to drive in really foul weather. By not 'venturing out into the storm,' these drivers ensure they are never at risk for being stuck or involved in an accident. Although mentioned by most fleets as a concern, none of the fleets in our study reported significant issues with 6x2 traction, and many felt that their tow bills had even dropped slightly since their introduction of 6x2s. Finally, it must be noted that the majority of trucks in Europe are configured as 6x2s or 4x2s, and that these trucks are not only used in line haul applications but also in severe service applications such as garbage trucks, dump trucks, and snow plows. That is, the European market has been enjoying the efficiency gains of the 6x2 configuration for years already, and has effectively addressed the traction concerns.

Figure 16: Hitches for Tractor Sled Pull

To bolster the finding of this Confidence Report that concerns over traction hindering adoption of 6x2 systems, NACFE conducted a traction test with the 6x4 and 6x2 test vehicles used in the fuel economy testing conducted with PIT. A competition tractor-pulling sled was acquired and special hitches fabricated to allow the tractors to pull the sled. The test was staged on a gravel perimeter road at the proving grounds and the tractors individually pulled the sled. Similar to agricultural tractor pulls at the local county fair, the sled weight translates up the sled towards the tractor, placing more and more weight on a skid being dragged on the gravel road. The test run stops once the tractor loses traction, with its wheels spinning and unable to move forward any further. Each truck made one practice run to allow the driver to become familiar with the vehicle, and then the distance traveled was recorded for three consecutive test runs. The average distance traveled for each set of three runs was calculated, and comparisons were made between the 6x2 and 6x4 vehicles. A video of this testing is available at www.NACFE.org.

Figure 15: Sled Pull Traction Test

Table 2: Traction Testing Results contains the results from the traction testing. The test found that the Kenworth 6x2 vehicle, with its tandem air suspension in normal operation, traveled about 11% less than the standard 6x4 unit. But the 6x2 truck was also equipped with a manual dump valve for the tag axle.

When this system was utilized and the weight was shifted, the 6x2 traveled an additional 15 feet, ending up only 5.4% off the distance the 6x4 was able to travel. The Volvo trucks had similar results, with about a 13% reduction in distance traveled for the 6x2 when compared to the 6x4. However, the 6x2 Volvo truck was not equipped with a load shifting system, and the impact of such a system could not be measured.

Figure 17: Sled Pull Machine

Figure 18: Custom Hitch Arm

Table 2: Traction Testing Results

Tractor Pull Traction Testings	Average Distance (ft)	% Change from 6x4		Average Distance (ft)	% Change from 6x4
Kenworth 6x4	256		Volvo 6x4	233	
Kenworth 6x2 - Suspension Aired	227	-11.3%	Volvo 6x2	201	-13.5%
Kenworth 6x2 - Tag Axle Dumped	242	-5.4%			

Although this simple tractor pull test does not give comprehensive or conclusive data on the tractive effort of a 6x2, it is an indication of the capabilities of the system, and it does confirm both 6x2 manufacture claims and the experience reported from fleets using 6x2s already in Europe and North America. The tag axle dump test on the Kenworth bolstered the conclusion that a manual dump valve or automated load shifting system allows a 6x2 to achieve improved tractive performance. The manufacturers of axle automated control systems have additional information and videos on 6x2 traction. Appendix A: PIT Test Report contains the test report on 6x2 traction.

6.2 Tire Wear

The second-most mentioned concern heard by the study team surrounded the tire wear on the single drive axle of a 6x2 system, given that, in a 6x2 configuration, all of the driving torque and engine braking torque passes through the single set of tires on the single drive axle, those tires will experience increased wear. Some in the industry assume that the driven tires of a 6x2 will wear twice as fast as the tires on a 6x4, since only half as many tires are providing thrust. But data from tire manufacturers and several fleets indicates that the useable tire life on a 6x2 drive axle is actually about one third that of the 6x4 drive tires.

Fortunately, there are several options made available by a 6x2 system that can offset the increased cost of this faster drive tire wear. A less expensive trailer tire can be used on the tag axle, and given that these tires also have a lower rolling resistance than heavy lug drive tires their use will save on fuel costs as well. Retread tires can also be used in the tag location, further reducing overall tire cost. In any case, no matter which tires are used, the fuel efficiency gains offered by the 6x2 configuration more than offsets the increased tire cost, as demonstrated in the payback calculator that supplements this Confidence Report. Depending on the tire type and cost, and the truck specifications, the fuel savings are typically 3 to 7 times greater than the increased tire costs of a 6x2.

Any significant analysis on the tire wear issue was not conducted as part of this study. Some mentioned increased tire cost ranging from $400 to as much as $1,000. Those considering 6x2 purchase, should discuss this issue with their tire manufacturers and other fleets. A rough calculation based on one fleet's observations with the WBS tires and the 6x2 configuration was created and is presented here. Table 3 shows the cost projection data of that fleet on the increased drive tire wear experienced during a typical over-the-road tractor duty cycle. The top portion of the table provides details on the different individual tire's projected performance and cost for a line haul fleet. The life of the tire, or pull point is based on 4/32nds of remaining tread depth. For the XDN2 tire starting with 27/32nds of tread and pulled at 4/32nds, it has 23/32nds of usable tread. Tire cost per mile is calculated by taking the retail tire cost divided by the Mileage Pull Point for either the 6x4 or 6x2 configuration.

Table 3: Tire Cost Analysis for Typical 6x4 vs. 6x2

Individual Tire Information				Per Tire, not per Vehicle					
6X4 Mileage Pull Point	**6X2 Mileage Pull Point**	**Tire Type**	**Axle Position 6x4 / 6x2**	**6X4 Tire Cost Per Mile**	**6X2 Tire Cost Per Mile**	**Usable 32nds of tread**	**Tire Cost Retail**	**Tire Cost Per usable 32nd**	**Tire Cost Delta Per Mile**
263,000	100,000	XDN2 -Heavy Lug Drive	All / Drive: Fwd-Rear	$0.0040	$0.0104	23	$1,042	$45.30	$0.0065
243,000	80,000	XDA Energy -Low RR Drive	All / Drive: Fwd-Rear	$0.0052	$0.0159	20	$1,269	$63.45	$0.0106
263,000	200,000	XDN2 vs. XTA Ribbed Retread	None/Tag: Rear-Rear	$0.0040	$0.0024	9	$471	$52.33	($0.0016)
		XTA is trailer tire mold cure retread							

Option 1: X One XDN2 Heavy Lug Drives on 6x4	Tire Cost Per Mile	Option 2: X One XDNA Energy Drives on 6x4	Tire Cost Per Mile
6X4: (4) XDN2s	$0.0158	6X4: (4) XDNA Energy	$0.0209
6X2: (2) XDN2 drive & (2) XTA tag	$0.0256	6X2: (2) XDN2 drive & (2) XTA tag	$0.0256
Increase in tire cost for Tractor Tandems	($0.0097)	Increase in tire cost for Tractor Tandems	($0.0047)
Annual tire cost increase assuming 100,000 miles /year	($970.21)	Annual tire cost increase assuming 100,000 miles /year	($466.11)

The lower half of Table 3 contains the tandem tire cost per tractor and excludes the steer axle and trailer tire cost as those remain unchanged in this study. In Option #1, life cycle cost for the 6x4 drive axles with four XDN2 tires are compared to the 6x2 with two XDN2 tires on drive axle and two XTA tires on the tag axle. In this rough example, running the 6x2 has an increased cost of just under one cent per mile and is under a half cent if you are comparing the XDNA Energy tires. If you assume the average line haul tractor in the fleet is running 100,000 miles per year, then the annual increase in tire cost per 6x2 tractor is just under $500 or $1000 depending on your comparison tire.

Specifying a 6x2 tractor with a traction control system and/or automatic load transfer system will further mitigate excessive drive tire wear, as these systems can respond immediately to wheel slip and thereby minimize unnecessary spin up of the drive tires. Also, fleets can adopt higher-wear though slightly higher rolling resistance tires and tire manufacturers, recognizing the potential of 6x2s and expanded use of 4x2s are developing improved tires for these applications. Finally, driver education programs on the use and limitations of the 6x2 configuration can also help to minimize the drive tire wear.

6.3 Resale Value

This study finds that the effects a 6x2 configuration can have on the resale or residual value of a used truck at time of sale vary widely. First of all, some users, particularly private fleets, will operate their trucks to or close to the end of their useful life, so resale value will not even be a factor in their purchase decision. Other fleets who have embraced 6x2 technology and are achieving higher-than-average miles per gallon told the study team that they have buyers available to purchase their used rigs. But still other users reported their belief that 6x2s will sell for upwards of $4,000 less than a comparable 6x4 tractor. In Tom Berg's May 2013 Heavy Duty Trucking article "Is a Fuel- and Weight-Saving 6x2 for You?" he states that "the Truck Blue Book numbers for a late-model 6x2 tractors being worth $11,000 less than a 6x4, 2007-09 models at $5,500 less, yet the 2004-06 6x2 models were listed at $700 more. Go figure."

However, the study team's interviews with fleets, OEMs, and manufacturers, found that many shared the belief that the resale value of 6x2s is rising as the technology is better understood and the industry becomes better educated on its limitations. In particular, the automated traction control and load transfer systems address many of those concerns, so interviewees reported that, as those systems become more prevalent in 6x2 tractor specifications, the resale value of 6x2s should match that of 6x4s. In fact, as awareness of the lower operating costs and improved fuel efficiencies of 6x2s grows, a 6x2 truck may eventually garner a premium over a 6x4. Many owner-operators are seeing the advantage of 6x2s in trucking media and therefore are actively seeking 6x2s for their next used truck purchases. Finally, the industry reported to the study their belief that even if there is a resale penalty on the 6x2 configuration today, when a fleet might be considering whether or not to purchase their new trucks with 6x2s, that resale penalty may be gone by the time those fleets are ready to take that vehicle out of service to be sold. But a handful of other fleets cited this lower resale value as the reason for their choosing not to specify their next tractor purchases with 6x2s.

6.4 Driver Acceptance

Many people are adverse to change and professional truck drivers are, perhaps, especially so, when it comes to their workplace. The 6x2 is different – it's a change from what most drivers are used to operating. Driver training on the proper operation of a 6x2-equipped vehicle is required when adopting them, just like with any major new technology. However, the newer traction control and automated load transfer systems remove a substantial amount of onus for proper operation of a 6x2 truck from the driver, and can make the transition from 6x4 to 6x2 almost seamless. For this and other reasons, this

Confidence Report highly recommends those systems to enhance the drivers' experiences with 6x2s, as well as to reduce wear and tear on the drivetrain and drive tires and to ensure good traction.

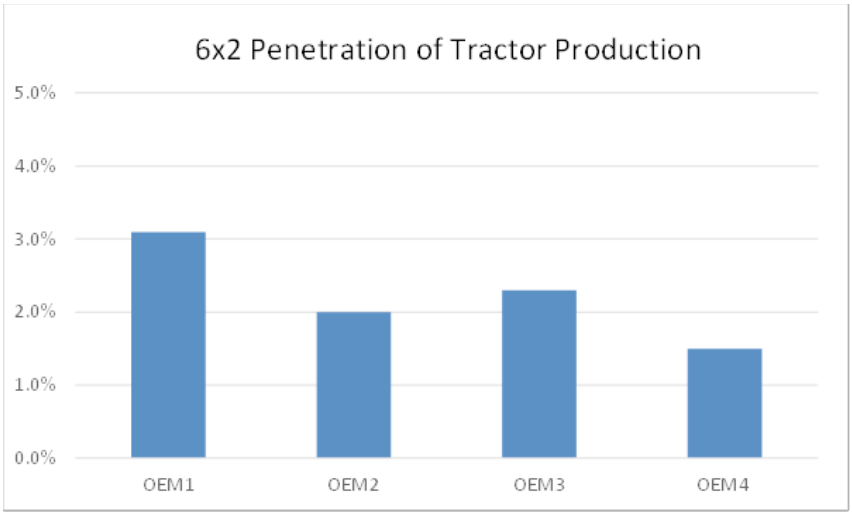
Many fleets have made a commitment to 6x2 technology and moved quickly to transition their entire fleet to the 6x2 configuration. Those fleets report that with an appropriate driver education system, they have had few driver issues or complaints, and noted little-to-no impact on their overall operations.

7 Original Equipment Manufacturers' Perspectives on System Integration

The Confidence Report study team conducted interviews on 6x2s with four of the six tractor OEMs in the sector. The following are the key points from these discussions:

- 6x2 axles have been touted as an option for improving tractor fuel efficiency for decades, but the adverse consequences of lost traction and increased tire wear, whether perceived or real, have been sufficient to prevent their widespread adoption.
    - European tractors are predominately 4x2 configurations, but some 6x2s are in use where loading requires the additional tractor axle.
- By 2010, some early adopter fleets in North America were experimenting and asking for 6x2 configurations on their new trucks. Given increasing fuel prices, and the fact that a few medium and large fleets requested these axles, tractor OEMs began designing and supplying the feature on a "by order" basis.
- By 2013, according to both axle manufacturers and multiple OEMs, the availability of 6x2s has grown such that 6x2s from both axle manufacturers are now a data-book offering at 5 of the 6 OEMs. Also, OEMs report that they are integrating the complementary technologies such as automatic load shifting systems into their product offerings this year.
- Production rates of 6x2 axles as a percent of Class 8 production at four of the six tractor makers is shown in Table 4. These are production rates as of the second half of 2013 and average about 2.3% of the over-the-road tractor builds.

Table 4: 6x2 Production Rates by OEM



- Some OEMs are developing their own 6x2 products, including their own non-driving axles and/or proprietary electronics to manage traction events.
- All four SuperTruck programs – Peterbilt/Cummins, Daimler, Navistar, and Volvo – utilize 6x2 axles in their solution set. The SuperTruck program is an industry cost-shared development and demonstration project initiated by the US Department of Energy to validate the possibility of improving freight efficiency of tractor trailers by 50%.
- Tractor OEMs believe that 6x2 adoption will grow over the next few years.
    - As one General Manger shared, "We don't know why more fleets, big and small, are not buying 6x2s. Our investigation shows that the benefits are clear".
- Discussions with major fleets on purchases of 6x2 axles is increasing. Most fleets are considering increasing their purchase of 6x2s or at least buying some for testing.
- A small niche of owner operators who are very active in pursuit of high fuel efficiency, are retrofitting their trucks into 6x2s.

8 Summary of Fleet Perspectives and Experiences with 6x2 Configuration

The study team also interviewed over a dozen end-user fleets to get their perspectives on 6x2 axles. Those fleets were qualified into two groups: 'early-adopting fleets' who have already purchased 6x2 axles, and 'evaluating fleets' who are interested in 6x2s but have not yet made a decision to pursue them. Finally, the study team conducted an additional internet survey of fleets through a Fleet Forum provided by Michelin NA.

8.1 Early-Adopting Fleets:

- In the mid-2000s, a few innovative fleets began to investigate 6x2 axles, and were able to convince "somewhat resistant" OEMs to help them test and incorporate those axles onto their trucks.
- These fleets were motivated by what they saw as an opportunity to use 6x2s to simultaneously lower fuel costs, reduce tractor weights, and limit or even reduce other costs.
- These same fleets now compliment the OEMs and axle manufacturers for their integration efforts and current product offerings.
- Due to the high level of physical change to a tractor between a 6x4 and a 6x2, most fleets believe 6x2s to be best applied onto new tractors, rather than retrofit onto 6x4 trucks.
- The only significant negative of 6x2s in the opinion of the early-adopting fleets was traction. Therefore the earliest adopters tended to operate trucks in the extreme southern states of the USA.
- After much investigation, these fleets decided to pursue 6x2s anyway, and to make the best use of manual dump valve technology available at the time by proactively working with their drivers and maintenance technicians.
- A few of these fleets noted that their tow bills and accident rates for vehicles operating in extreme weather conditions are actually lower with 6x2s, contrary to what concerns over traction might suggest.
    - "Drivers are not taking the risks to drive in bad weather conditions or off pavement where they may get stuck," stated one fleet manager.
- Early-adopting fleets chose to go "all-in" and purchase the 6x2 package of 6x2 axles, direct drive transmissions, WBS tires, and trailer tires on the non-driven axle.
    - "Change was best made in bunches" said one.

- Most of the fuel efficiency data available from these fleets was for that package, and these fleets could not "break out" the performance of each of the features independently.
- In 2012 and 2013 a few of these fleets purchased trucks with each of the features installed individually, allowing for some granularity of performance data. All of the fleets that did so confirmed that they will continue to specify and buy 6x2 axles on as many of their new trucks as possible.
- Tire life is now being studied in detail, and a few of these fleets are switching to a longer-lasting drive tire in spite of those tires' higher rolling resistance, for example moving to a Michelin XDN2 from an XTA wide base single tire. This is a tradeoff between lower tire expenses and slightly higher fuel costs, but it appears that even with this tradeoff 6x2 axles will improve fuel efficiency substantially enough to justify their continued adoption.

8.2 Evaluating Fleets

- These fleets report that they have been watching the experiences of the early-adopting fleets with 6x2 axles, and that, for at least the past two years, they have been considering 6x2 axles for their specific specs/package, procuring a few and testing them in various duty cycles. All of these fleets are calculating the paybacks and weighing all the benefits and adverse consequences of 6x2 adoption.
- These fleets report that their need for weight reduction is growing, particularly with the added weight inherent in complying with the 2007 and 2010 US EPA emissions regulations, as well as the adoption of other fuel efficiency technologies such as aerodynamics devices.
- When asked about traction concerns, they stated they are worried about operating 6x2s in snowy mountain regions and that their network must have all trucks available to haul freight anywhere in the US. These fleets, though, referenced the minimal issues reported by the early-adopting fleets, as well as their confidence in the automatic load shifting technologies now available, which they plan to specify on all 6x2 tractors, if they decide to pursue 6x2s at all.
- Tire wear is a concern for these fleets, but given the potential for improved tire life on the tag axle, and the sense that the life of the drive axle tires is not so reduced as to be unmanageable, tire wear is not preventing their adoption of 6x2s.
    - Evaluating fleets reported consulting with other fleets, tire companies, and tractor OEMs to make highly-informed decisions on tires.
- These fleets see the concerns around both driver acceptance and resale value as "self-correcting" with higher adoption rates, which will come as more and more end-users see the benefits of 6x2s.

  - But they admitted that driver attraction and retention is one of a fleet's largest challenges, and therefore any specification on a truck that limits the availability of drivers for a fleet can be a major issue.

- These fleets felt that 6x2 costs seem to be coming down with design refinement and scale.
- "We are trying to hit the adoption 'sweet-spot,'" said one major fleet manager. He continued, "As more drivers hear about the small if not unnoticeable difference [between 6x2s and 6x4s], and demand for used 6x2 trucks increases, these issues will mitigate." He shared that his fleet believes the 'tipping point' for 6x2s is 2014.
- One fleet from this group has already ordered 220 new tractors with 6x2s after a 12 month trial, and another very large for-hire fleet expects to change their standard tractor specifications to 6x2s on their 2014 purchases.

8.3 Fleet Forum Internet Survey

Michelin North America offered the use of their Fleet Forum to the study team in order for Trucking Efficiency to better understand the attitudes toward 6x2 axles held by both users and non-users of the technology. The Michelin Fleet Advisory Council is an online community of 300 plus members ranging from owner-operators to fleet managers who oversee power units, class 6-8. The Council is available on a 24x7 basis to answer questions, and the forum is also able to capture unsolicited insights that emerge from member-initiated conversations.

For purposes of this Confidence Report, the members of the Michelin Fleet Forum were asked to answer some questions with respect to the 6x2 technology. This survey was conducted from July 17th to July 31st, 2013. 51 fleets responded.

- A quarter of respondents currently use a 6x2 axle configuration on their fleet. The majority of those were large fleets.
- Those who do use 6x2s reported that they have experienced fuel savings of 0.5 mpg, and weight savings ranging from 300 lbs. to 1,500 lbs.
- The biggest concerns experienced by users are traction, resale value, and driver acceptance. Tire wear was hardly mentioned.
- Those who have yet to purchase a 6x2 axle configuration do believe that 6x2s offer significant fuel and weight savings, but they are not convinced that they will be able to sufficiently overcome the challenges of traction and driver acceptance.
- Of those who do not currently use any 6x2 axle configurations, half say that they are likely to purchase a vehicle with a 6x2 system in the near future, due to the fact that they now perceive the benefits to outweigh the risks, especially given the existence of systems such as automatic

traction control (ATC) and electronically-controlled air suspension (ECAS) that mitigate the risk of low traction.

- Fleets who have already bought 6x2s reported that it is too early for them to tell if traction is indeed a major challenge that they will face throughout the life of the vehicle, saying:
    - "Haven't taken them through winter in the north yet, but with ECAS we expect good results."
    - "Too early to tell if loss of traction is an issue."
    - "We get stuck in off road situations more frequently, however, the drivers are learning their limitations."
- Fleets who do not currently use any 6x2 axle configuration reported that they believe 6x2s will create lower rolling resistance, allowing the vehicle to save more fuel:
    - "Increased fuel mileage by reducing mechanical drag/friction."
    - "Lower weight, reduced rolling resistance and mechanical resistance resulting in increased fuel economy."

- Fleet managers who have yet to equip any vehicles with 6x2s reported that they do expect that this configuration would negatively impact the vehicle's traction, voicing their concerns around 6x2s:
    - "More challenging for drivers to maximize traction in slippery conditions."
    - "Winter operation in snow country."
    - "Traction in mountainous areas. That is about the only concern at this point."
- After considering both the benefits and challenges presented with 6x2 axle configurations, about half of respondents who had not yet purchased any 6x2s said that would be likely to purchase a vehicle with such a configuration, saying:
    - "This isn't really new, there are a few fleets that are running these now, so I am not afraid to try it."
    - "Today's emission-controlled engines are heavier and I will need the weight savings of a 6x2 to offset some of that increased weight."
    - "With the new braking systems and ATC we are likely going to try some. We definitely feel there is a benefit to them."
    - "Fuel is our single largest expense. The more we can do to reduce fuel costs the more profits we keep."

9 Payback Calculator

Along with this Confidence Report, Trucking Efficiency has created a payback calculator that estimates the payback, in months, for end users who adopt a 6x2 system on their tractors. End users are asked to input a small amount of data into the form, and the calculator uses that data along with information gathered by the study team to quantify the benefits and consequences likely to be experience by that end user, both in terms of upfront costs and year-over-year costs. This calculation is highly dependent on the upcharge or down charge for 6x2s as part of the overall tractor cost, as well as the resale value if the fleet is selling the truck before its useful life is completed. Table 5 shows an example of the payback calculator in action, assuming that both the upfront cost and the resale value of a 6x2 truck as on par with that of a 6x4 truck, as is widely predicted to occur in the next year or so.

Table 5: Payback Calculator

NACFE Study Payback Calculator: 6x2 Axles				
Yellow boxes are for user inputs				
	Now	**Soon**	**Future**	**Notes:**
Miles per tractor per year	100,000	100,000	100,000	Fleet Input
Total Installed Cost	**$ 2,000**	**$ 1,000**	**$ -**	Source 1
Benefits				
Weight Savings				
Fleet's weight sensitivity	None	None	None	Fleet Input
Weight benefit per lb	$ -	$ -	$ -	Source NACFE Interviews 2
Weight reduction in lbs	400	400	400	Source Axle Mfrs
Upcharge allowance per truck at purchase	**$ -**	**$ -**	**$ -**	Calculated
Fuel Savings				
Fuel Expense per mile	$ 0.64	$ 0.64	$ 0.64	Source 3
Fuel Expense per year per truck	$ 64,000	$ 64,000	$ 64,000	Calculated
Fuel savings per year per truck	**$ 1,600**	**$ 1,600**	**$ 1,600**	Calculated
Maintenance				
Maintenance savings per truck per year	**$ 100.00**	**$ 100.00**	**$ 100.00**	Calculated
Consequences				
Tire Wear				
Tire wear cost per mile	$ 0.0047	$ 0.0047	$ 0.0047	Source NACFE Interviews
Tire Wear cost per year	**$ (470)**	**$ (470)**	**$ (470)**	Calculated
Resale Value				
Penalty / Benefit at end of first owner life	**$ 3,000**	**$ 1,000**	**$ -**	Source NACFE Interviews 4
				Berg - Resale Values
Total of one time costs	**$ 5,000**	**$ 2,000**	**$ -**	
Total of year over year savings	**$ 1,230**	**$ 1,230**	**$ 1,230**	
Payback in months	**48.78**	**19.51**	**0.00**	Calculated

Sources:

1. An aggregation of NACFE Study interviews - 2013 - $2,000 upcharge for 6x2 with Load Shifting, shifting to cost nuetral in the future.
2. Possible new truck purchase allowance = $3/lb for slight and $8/lb for highly sensitive weight fleets (Bulk Haulers, etc.)
3. ATRI Operational Costs of Trucking, Sept 4, 2013
4. Tom Berg, Truckinginfo.com, May 2013. Truck Blue Book values.

This calculator is meant to assist in making decisions on the purchase of 6x2 axle systems. It is not meant to guarantee any specific business economic results.

10 Fleet Implementation Best Practices

After analyzing all the OEM, end-user, and fleet forum inputs, Trucking Efficiency developed this list of best practices for 6x2 adoption:

- Thoroughly study all available information on 6x2 axles.
    - Complete a detailed payback analysis for your particular duty cycle and business model.
    - Consider testing the configuration in your fleet only if it is necessary – a lot of data already exists – testing may not be required.
- Consider "going all the way" with quick adoption of 6x2s on all new tractor purchases – plan to go to 100% in the next 1-2 years on all new truck purchases.
    - Make this your NEW truck.
        - Tell drivers, maintenance technicians; basically everyone that this will be 'our new truck.'
    - Make 6x2s the specifications of your driver training trucks immediately.
- Include automatic load shifting systems your specifications for 6x2 trucks, and consider including direct drive transmissions as well as wide base single tires and/or lower rolling resistance tires, with trailer tires on the tag axles.
- Create a resale strategy.
    - Communicate with end-user buyers to educate them on your experience with the 6x2 trucks, including the benefits you have enjoyed and the strategies you have used to limit any adverse consequences.
    - Consider lengthening your ownership lifecycle plans if necessary, perhaps even by changing a few other specifications to allow for longer truck ownership.
- Collaborate with axle and tractor suppliers to get the best specifications for your needs, and to manage the costs for the feature on your new truck purchases.
    - 6x2s could result in a cost penalty for now, but effective management will decrease this over time.
- Train drivers on traction solutions including shutting down the trucks in extreme weather conditions.
    - Plan for some higher tow instances and the associated bills, but be prepared to in fact enjoy lower accidents and breakdowns.
- Stay the Course.
    - As with many changes, diligence to the change is critical to success.

11 Perspectives on Future Axle Products

Several technologies and advancements are in the works which will enhance the performance of 6x2s and improve on their already high fuel efficiency. Many of these technologies will not be available for several years, and therefore did not fit into the scope of this report.

Fleets should be on the lookout for continued advancements in gear-set designs and lubricants which further reduce parasitic losses. There will likely be continued integration of engines and transmissions, not only the hardware but also the electronics, which combined will optimize drive cycles for maximum fuel efficiency. Engine cruise RPMs will continue to drop until the OEMs find the 'sweet spot,' and axle manufacturers will need to support these changes with the optimized gear ratios. Finally, predictive cruise controls and geo-course plotting systems are also under development in an effort to minimize losses from hill climbing and even head winds.

More generally, as the 6x2 concept experiences wider and wider adoption, the market may see some variations on the current configurations. There have been some discussions around introducing a pusher axle system into North America in place of the currently-available tag axles, and a couple of owner operators are already experimenting with this setup, though pusher axle systems are a bit more complex and not nearly as weight efficient, given the longer driveline components required to reach the rear-rear drive axle position. Other discussions surround liftable axles, further reducing the rolling resistance by lifting the entire axle off the pavement. Available in pusher or tag, but there hasn't been a lot of interest in these thus far, and the benefits of such a system are unclear.

But the most promising and significant advancements surrounding 6x2 systems will likely involve their electronics and controls, as the OEMs and suppliers are continuing to work on the automated controls. Most likely, some truck OEMs will integrate traction and load shifting controls into their truck electronic systems, in an effort to reduce complexity and limit the number of electronic modules on the vehicle, as well as to enhance system performance. System suppliers will also move to integrate brake, traction, and load-shifting controls into one integrated package, also to reduce cost and complexity while enhancing overall system performance.

12 Conclusions and Recommendations

Major conclusions from this study are:

- Early-adopting fleets have paved the way for the next wave of wider adoption.
- Axle manufactures and truck builders have integrated this feature successfully into their products, and availability is widespread for fleets to pursue 6x2s with confidence.
- Given all the data in this report, Trucking Efficiency predicts a rather aggressive adoption of 6x2 axles on new truck production over the next few years, possibly doubling every year. 2% in 2013, 4% in 2014, 8% in 2015 and 16% in 2016.
- Fuel economy improvements of about 2.5% and paybacks of around 20 months should be expected from 6x2s.
- A significant amount of data and test results around fuel efficiency, traction, tire wear and resale value is available such that this report's confidence in 6x2s as a good investment adoption is medium to high.

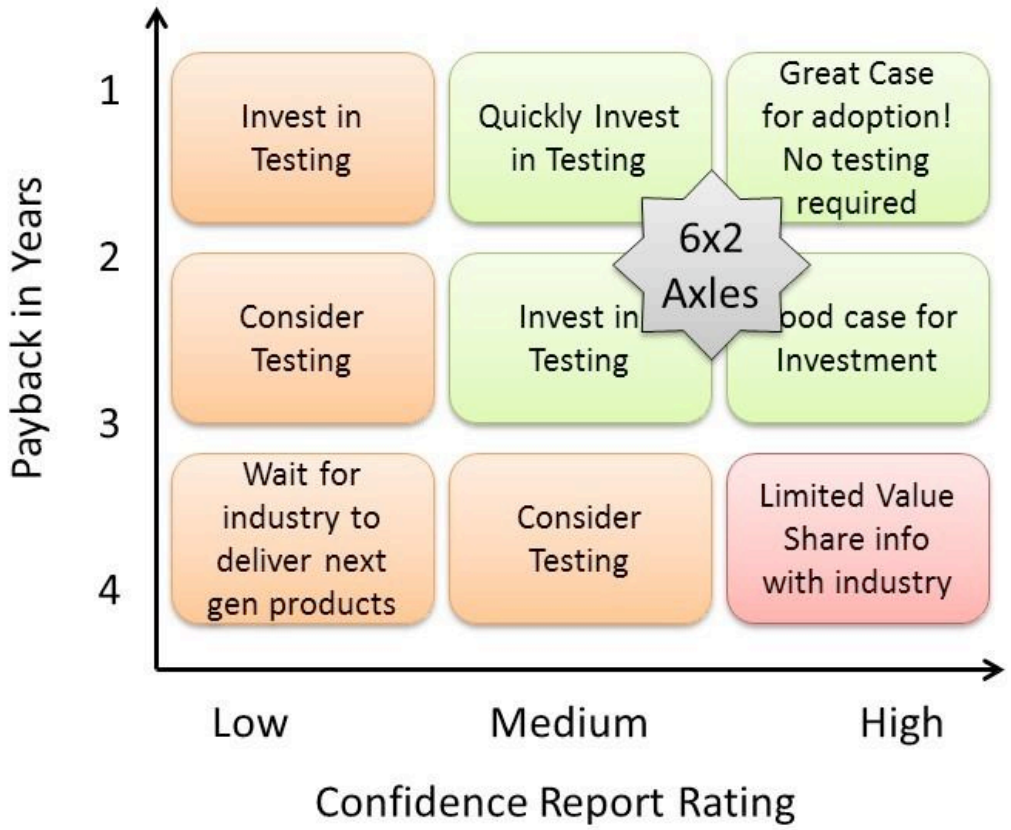


Figure 19: Trucking Efficiency Confidence Matrix

This Confidence Report recommends that fleets should:

- Consider rapidly adopting 6x2 axles, given the information contained in this report.
- Use the Best Practices stated above, and stay appraised of any new developments around 6x2s.

This Confidence Report recommends that axle manufacturers and truck builders should:

- Continuously improve the performance, reliability/durability, and cost of 6x2 systems as their adoption grows.
- Continuously develop complementary additional features for 6x2 systems.

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14 Appendix A: PIT Test Report

Performance Innovation Transport

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6 x 2 vs. 6 x 4 Tractors

Context

The objective of Energotest™ is to conduct controlled test-track studies of solutions for achieving higher fuel efficiency and lower emissions of greenhouse gases (GHG) in the trucking industry. The 11th Energotest campaign was held May 30 – June 5, 2013, at the Transport Canada Motor Vehicle Test Centre in Blainville, Quebec. Eight technologies and measures to reduce fuel consumption, from four suppliers, were tested. Performance Innovation Transport (PIT) members also conducted six private tests to evaluate some items of interest

Objective

Compare the fuel consumption and traction performances of 6 x 2 and 6 x 4 tractors.

Tested Approaches and Test vehicles

- Evaluation of OEM 6 x 2 tractors. Compared vehicles were:
  - 2013 Volvo VNL 64T: 6 x 4, rear axle MT40-14XC Arvin Meritor, 2.64 ratio;
  - 2014 Volvo VNL 62T: 6 x 2, rear axle RS23-160/161 Meritor plus Volvo non drive, 2.67 ratio;
- Evaluation of 6 x 2 tractors, modified from 6 x 4 tractors. Compared vehicles were:
  - 2012 Kenworth T660: 6 x 4: rear axle Dana Spicer D40-170P, 3.21 ratio;
  - 2012 Kenworth T660: 6 x 2: rear axle Dana Spicer D40-170P, 3.21 ratio; in-house modified rear axle: emptied rear housing, removed the drive shaft between front and rear housing, change gears in the front housing but same ratio (Mod. 1);
  - 2012 Kenworth T660: 6 x 2: rear axle Dana Spicer D40-170P, 3.21 ratio; in-house modified rear axle: switched front and rear housing, emptied rear housing; gears not changed, same ratio (Mod. 2).

Test Methodology

- Fuel consumption tests:
  - Evaluation of OEM 6 x 2 tractors, comparison between 6 x 4 and 6 x 2 Volvo: test procedure according to SAE J1526 Type III;
  - Evaluation of 6 x 2 tractors, modified from 6 x 4 Kenworth T660 tractors: test procedure according to SAE J1321 Type II.
- Pull sled test:
  - Compare the pulling distance, maximum speed, and acceleration when pulling the same set sled on similar surface.

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Fuel Consumption Test Results

Test description	Modification	Test procedure	Test results	Test conditions		Test vehicles		
			Fuel Savings (%)	Mean temperature °F	Mean wind speed, mph	Tractor trailer gap / aero gap, in.	Bogey position (to axle center), ft.	Test weight : tractor + trailer, lb.
Vovlo 6x2 vs 6x4	Factory	SAE Type III	3.29	60.4±3.05	5.02±1.62	50/29 54/38	41	17637+ 46000 18475+ 46040
Kenworth 6x2 vs 6x4	In-house Mod. 1	SAE Type II	2.57±2.04	72.25±14.94	7.56±4.17	48/29		20423+ 45980
Kenworth 6x2 vs 6x4	In-house Mod. 2	SAE Type II	3.45±1.16					20463 + 45940

Pull Sled Test

Test Vehicle	Modification	Average maximum		
		Distance, ft. (m)	Speed, mph (km/h)	Acceleration, mph/s (m/s^2)
Vovlo 6x4	Factory	232.54 (70.88)	13.09 (21.07)	2.91 (1.30)
Vovlo 6x2	Factory	201.05 (61.28)	10.97 (17.66)	1.90 (0.85)
	Difference 6x2 vs. 6x4, %	-13.54	-16.20	-34.71
Kenworth 6x4	Factory	256.07 (78.05)	17.08 (27.48)	2.95 (1.32)
Kenworth 6x2	In-house Mod. 1 suspension ON (Up)	227.20 (69.25)	14.11 (22.70)	2.10 (0.94)
	Difference 6x2 vs. 6x4, %	-11.27	-17.39	-28.81
Kenworth 6x2	In-house Mod. 1 suspension OFF (Down)	242.29 (73.85)	14.11 (22.70)	2.64 (1.18)
	Difference 6x2 vs. 6x4, %	-5.38	-17.39	-10.51

Conclusion

Fuel consumption tests showed that 6 x 2 tractors consume from 2.6 to 3.5% less than the similar 6 x 4 tractors. Although the Kenworth tractors were practically identical, the two Volvo tractors differed also by weight and some aerodynamic characteristics, such as tractor – trailer gap and fuel tank fairings.

Pull sled tests showed from 5.4 to 13.5 % shorter distance, 17% lower maximum speed, and from 10.5 to 35 % worse acceleration for the 6 x 2 tractors, when compared to similar 6 x 4 tractors.

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