

# **THE EFFECT OF UNDERCARRIAGE CONFIGURATION ON TRACTOR-TRAILER PERFORMANCE\***

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## ABSTRACT

Through legislation governing axle weights, provincial governments are encouraging the use of wider trailer axle spacings on tractor-trailer combinations. While increased axle spacing can improve axle weight distributions, it was found that the benefits must be weighed against increased fuel consumption and possible maintenance and repair costs. For example, an increased fuel consumption of 4.5% was found when the axle spacing of a quad-axle trailer was increased from 4.21 to 6.03 m. As a method to offset the negative impact of increased axle spacing, the effects of installing one and two self-steering axles were evaluated. It was found that each self-steering axle reduced the fuel consumption by approximately 4%. Thus, for the roads tested, the fuel consumption on a quad-axle undercarriage spaced at 6.03 m could actually be 4% less (if two self-steering axles were installed) than for a 4.21-m rigid axle spacing.

**KEYWORDS:** FUEL CONSUMPTION, AXLE SPACING, SELF-STEERING AXLE, AXLE CONFIGURATION, FOREST TRANSPORTATION.

## INTRODUCTION

The results presented are the outcome of a research project aimed at reducing the energy consumption of heavy vehicles. This project, conducted by FERIC in collaboration with Transport Canada and Industries James Maclaren Inc., was divided into two parts.

An earlier study determined economical driving techniques adaptable to tractor-trailer drivers in the forest industry. This phase of the project took place in 1986 and the results were presented at the 1987 annual meeting of the Canadian Pulp and Paper Association.

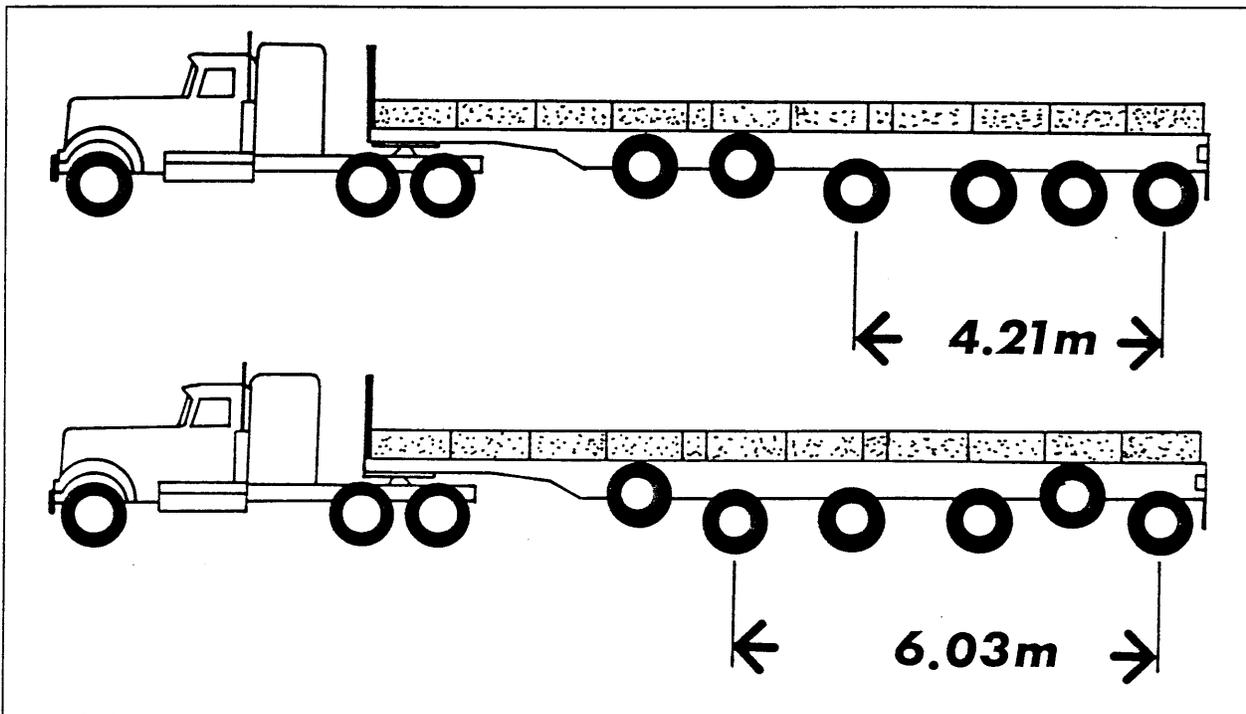


Figure 1. The axle configurations evaluated for axle spacing.

a) 4 axle configuration spaced at 4.21 m.

b) 4 axle configuration spaced at 6.03 m.

The second phase of this project, which is the subject of this paper, dealt with the effect of trailer undercarriage configuration on truck performance. This study was conducted in two stages.

The first part of the study examined the effect of increasing trailer axle spacings on fuel consumption. Through legislation governing load limits and vehicle dimensions, provincial governments are encouraging heavy vehicle operators using public road systems to widen the axle spacing of their trucks and trailers. Such regulations limit both the total load and the load per axle. Figure 1 shows the two axle configurations, spaced at 4.21 and 6.03 m, which were evaluated.

The second part of this study evaluated the use of self-steering axles on trailers and their effect on fuel consumption. Three axle configurations as shown in Figure 2 are discussed.

### EQUIPMENT AND METHODS

FERIC operates a tractor-trailer equipped for experimental purposes which it uses in conducting road trials (Figure 3). It has a 400-hp engine and is characteristic of trucks operating in the forest industry in eastern Canada.

The truck's sleeper houses a data acquisition system, a monitor and the researcher. This equipment is set up to record the necessary data for the evaluation of various parameters linking the truck and the driver to the road and the environment. The arrangement of the measuring instruments is illustrated in Figure 4.

Road speed, engine rpm, torque and fuel consumption are used to provide a comparison for analyzing the vehicle's performance as a function of the trailer's undercarriage. Other factors are also recorded to monitor the conditions of each test trip. The steering angle of the front wheels, the angle of the fifth-wheel, as well as the distance travelled, determine the path followed and help to locate the vehicle position during analysis. Temperatures are recorded to establish the operating conditions of the vehicle.

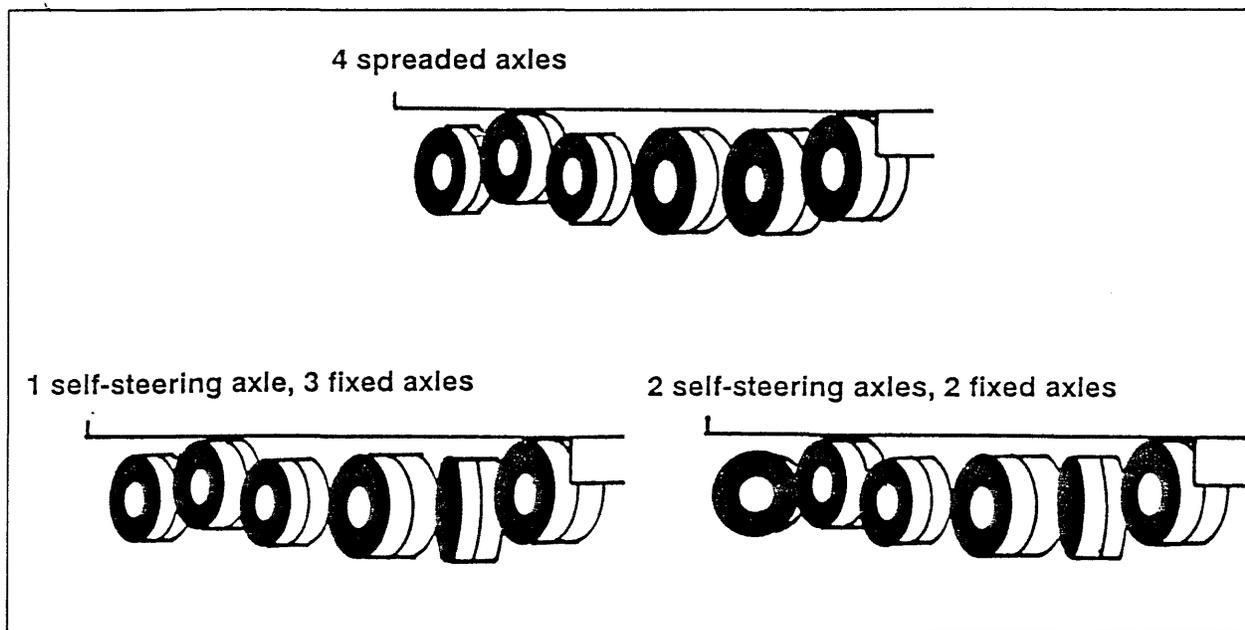


Figure 2. The axle configurations evaluated to test self-steering axles.

- a) A configuration of 4 rigid axles spaced at 6.03 m.
- b) A configuration of 1 self-steering axle followed by 3 rigid axles (6.03 m spacing).
- c) A configuration of 2 self-steering axles separated by 2 rigid axles (6.03 m spacing).

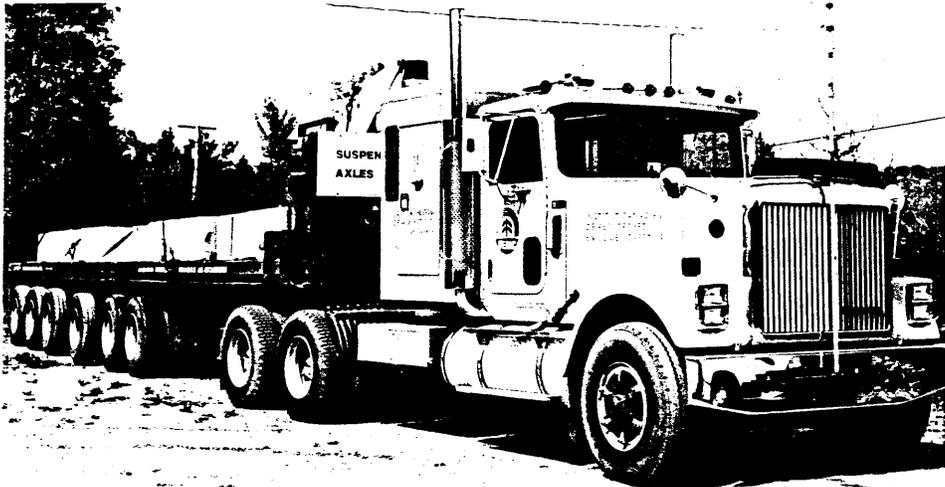


Figure 3. FERIC's mobile laboratory.

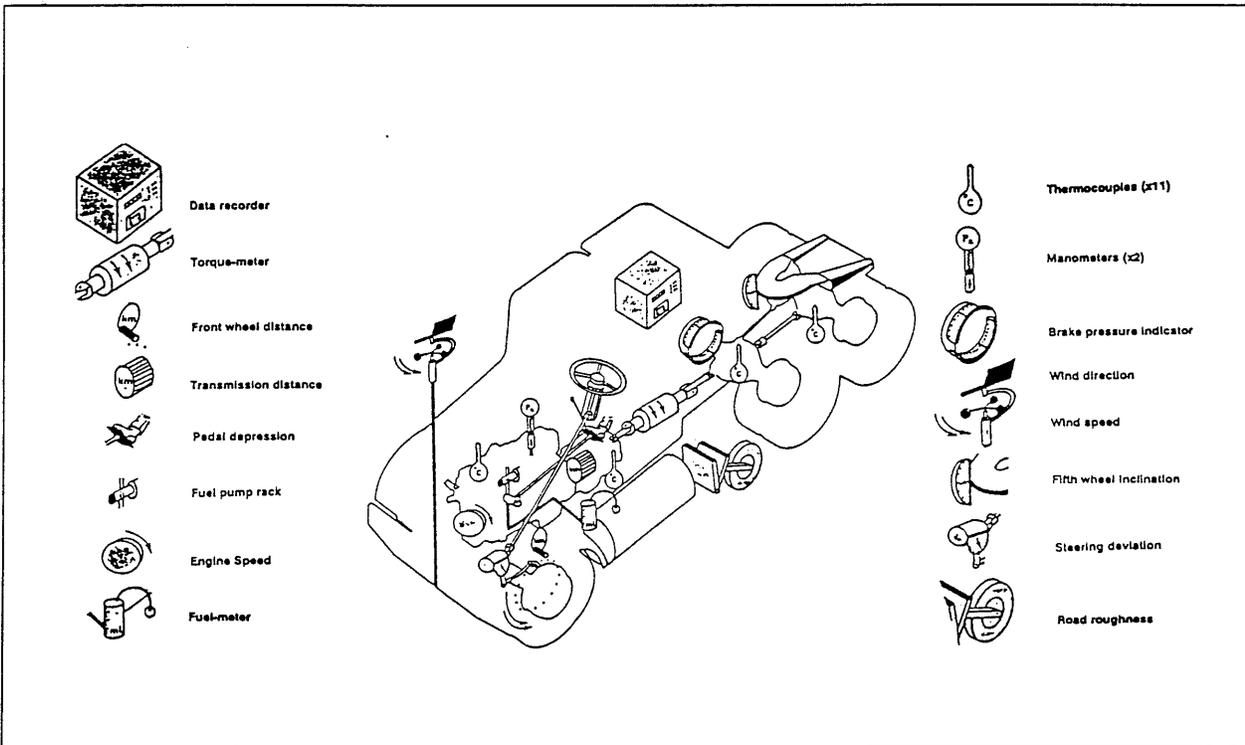


Figure 4. Instrumentation on the mobile laboratory.



Figure 5. Vehicle used for testing.

The trailer used for these trials was specifically constructed as a research vehicle for the Roads and Transportation Association of Canada (RTAC). It consists of a 13.7-m (45-ft) flat bed with 6 axles mounted on an air suspension, of which 5 are lifting axles. The trailer was loaded with concrete blocks to total weight of 48 300 kg (Figure 5).

During the course of the trial, two of the trailer's axles were replaced with self-steering axles possessing the following characteristics:

Track . . . . .	191.8 cm
Capacity . . . . .	10 230 kg
Suspension . . . . .	Air suspension
Lock . . . . .	Pneumatic
Maximum steering angle . . . . .	12.5°

The test trips took place on two different road sections: 6.6 km of paved road; and 8.6 km of gravel road (Figure 6). Both sections of road were winding and hilly, typical of the rough terrain of the region. Both road sections were relatively narrow which reduced considerably the driver's field of vision. The two sections of road were good examples of typical operating conditions found in the forest industry of eastern Canada.

Because of the rough terrain, it was impossible for the driver to travel at a constant speed. For this reason, the concept of a target speed was proposed, with the intention that it would be maintained as long as possible throughout each test trip. The target speed was set at 40 km/h for the test trips on the gravel road section. Three speeds were established for the paved road section: 30, 45 and 60 km/h. To reduce the effect of some variation in speed on the results, six test trips were made for each combination of target speed and undercarriage configuration.

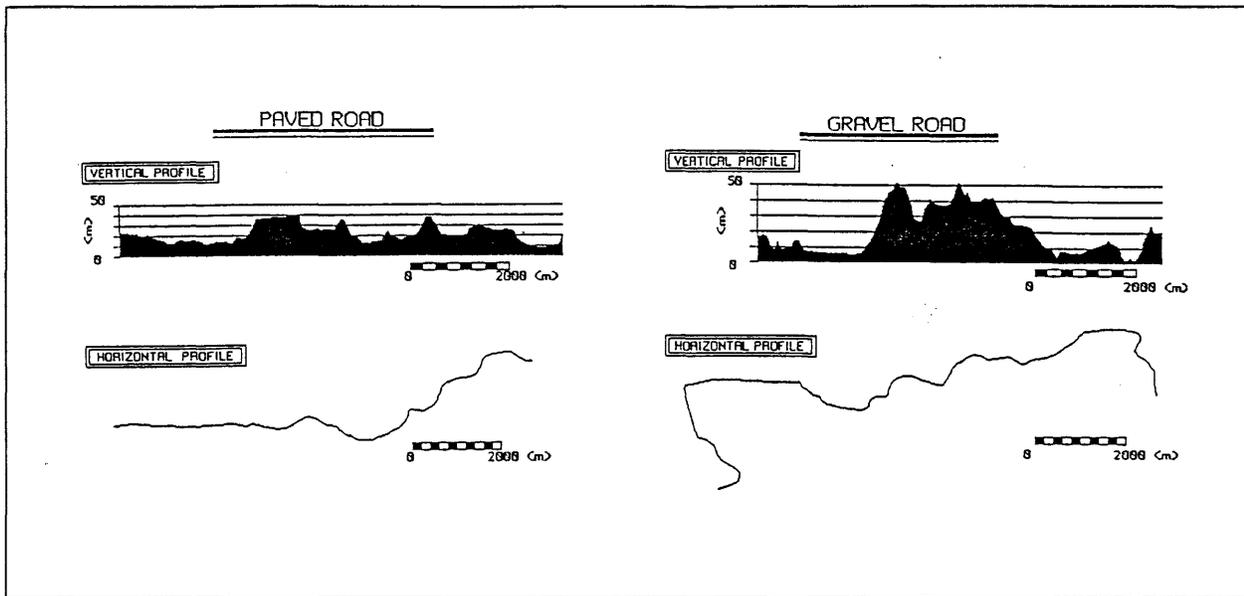


Figure 6. Profiles of the test roads.

### THE INFLUENCE OF AXLE-SPACING ON FUEL CONSUMPTION

Results of the first part of the study, the influence of axle spacing on fuel consumption, are included in Table 1. On the gravel road, an increase in fuel consumption of 2.6% was noted when the axle spacing was widened from 4.21 to 6.03 m. On paved road, the effect of higher lateral resistance caused by increasing the axle spacing was more obvious, as fuel consumption rose by 4.5% when increasing axle spacing from 4.21 to 6.03 m.

Table 1. The effect of axle spacing on fuel consumption

Spacing	Speed km/h	Fuel Consumption L/100 km	Difference %
<b>GRAVEL</b>			
Grouped 4.21 m	40	102.16	
Spaced 6.03 m	40	104.78	+2.6
<b>PAVED</b>			
Grouped 4.21 m	30	71.74	
	45	68.71	
	60	71.14	
Spaced 6.03 m	30	75.45	+5.2
	45	71.67	+4.3
	60	73.48	+3.9

Wider axle spacing would appear to have a greater effect on fuel consumption when travelling on pavement than on gravel. This may result from the fact that the lateral resistance when cornering on asphalt is likely to be higher since the tires are less prone to side slip on such surfaces. However, it must be noted that the road profiles were not identical for the two road sections studied and that this could also partially explain the difference.

It was further observed that the vehicle's traction capacity diminished with increased axle spacing. Increasing the axle spacing on the trailer actually transfers part of the driving axle's load to the trailer's axles. Since the traction capacity of the vehicle is proportional to the load supported by the driving axles, the importance of loading these axles to their maximum, while respecting the existing legislation, is significant.

Throughout the study, it became evident that the lateral force caused by tire resistance on turns has a significant effect on the vehicle durability. Wearing of the tires during the turns is one example of this (Figure 7). While tire wear may not be surprising and is something that is accepted as a fact of life, forces capable of twisting the trailer frame cannot be ignored (Figure 8). If the wider axle spacing is having such an effect on the trailer's frame when turning, could it also be influencing the crosswise stability of a load of wood?

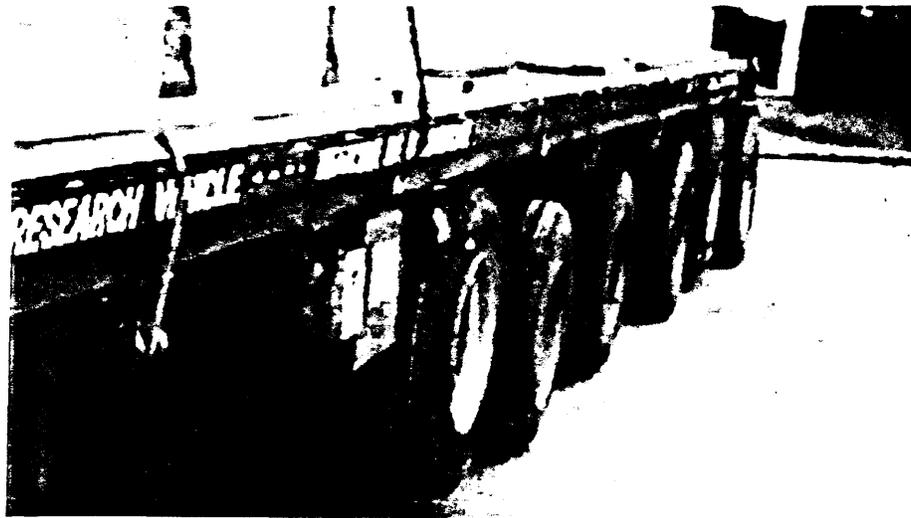


Figure 7. Deformation of the tires in a curve.



Figure 8. Deformation of the trailer's frame in a curve.

## THE INFLUENCE OF SELF-STEERING AXLES ON FUEL CONSUMPTION

Previous experience has shown that increasing axle spacing is advantageous to increase the total trailer load. While this is certainly appealing, we have ascertained that it can not be done without difficulties. However, the majority of the problems associated with the use of trailers equipped with widely-spaced axles could be result from common source, that being the lateral resistance on curves.

Therefore, the next step is to find a way to reduce the resistance on curves while maintaining widely-spaced axles. To do so, tractor-trailer operators have installed air lift mechanisms on the front axle of the trailer.

This system permits the driver to lift the axle when turning sharply. However, what effect does this have on the pavement? In fact, it results in legally overloading the other axles, thus damaging the road during the turn.

When the curve is not tight enough to require lifting the axle, the tires then offer a certain degree of lateral resistance which will, in time, cause damage to equipment and roads. To completely eliminate the detrimental forces on this axle and the problems associated with it, some operators control the pressure of the air lift mechanism so that the axle touches the ground lightly, thus fooling the authorities. This situation is very difficult to control and is why there is pressure to ban this type of axle, as was suggested by the Roads and Transportation Association of Canada (RTAC) in their report concerning loads and dimensions of heavy vehicles in Canada [2].

One proposed solution is the use of self-steering axles to replace the rigid axle. These axles, as their name indicates, are free to track in the direction offering the least resistance. They offer an interesting concept which could provide a possible solution to the problems associated with the use of widely-spaced axles.

It was the objective of this study to examine the self-steering axle to:

1. Verify whether the use of self-steering axles is an operational solution in forest hauling operations, and
2. Verify whether the use of self-steering axles is an economical solution in terms of fuel consumption.

No measurements were taken to quantify the wear or the level of stability attributable to the use of this type of axle.

Table 2 presents a summary of the fuel consumption obtained during all of the round trips conducted for the three specified undercarriage configurations. It was found that a saving in fuel consumption of 3.6% was achieved, on gravel, when the trailer's front axle was replaced with a self-steering axle. An even more significant fuel consumption saving was gained upon installing a second self-steering axle to replace the trailer's rear axle. In this case, a saving in fuel consumption of 9.5% was measured.

From the test trips conducted on the paved road section, a fuel consumption saving of 4.1% on average, was obtained when one of the four conventional axles was replaced with a self-steering axle. When the trailer was equipped with two conventional axles and two self-steering axles, the fuel consumption savings amounted to 8.1%, on average.

Table 2. Fuel consumption according to undercarriage configuration

Type of axle	Speed km/h	Fuel consumption L/100 km	Difference %
<b>GRAVEL</b>			
Rigid	40	104.78	
1 Self-steering	40	100.99	-3.6
2 Self-steering	40	94.81	-9.5
<b>PAVED</b>			
Rigid	30	75.45	
	45	71.67	
	60	73.48	
1 Self-steering	30	71.12	-4.4
	45	68.94	-3.8 } -4.1
	60	70.45	-4.1
2 Self-steering	30	67.76	-10.4
	45	67.76	-5.7 } -8.1
	60	67.24	-8.2

The fuel consumption savings achieved through the use of self-steering axles are evident. A saving in the order of 4% was obtained by replacing one trailer axle with a self-steering axle. Furthermore, adding a second self-steering axle was equally advantageous resulting in another saving in fuel consumption in the order of 4%. There are two possible explanations as to why the use of two self-steering axles may create a synergy which might have a larger impact on the fuel consumption savings.

1. When a vehicle equipped with a self-steering axle enters a turn, the lateral force acts on the axle so that the wheels adopt a certain angle of steering; whereas the rigid axles of the trailer act in the opposite direction, reducing this angle. By installing a second self-steering axle, the angle of the wheels of the first self-steering axle becomes greater because the forces opposing its movement are reduced. Thus, the lateral resistance on the tractor-trailer unit is reduced, at the same time improving the fuel consumption.
2. The second theory takes into consideration the spacing of trailer's rigid axles, as demonstrated in the following example.

To simplify this example, let us assume that the self-steering axles do not affect the tractor-trailer's centre of rotation, but that only the rigid axles interfere.

- a) Given a trailer with 4 equally spaced rigid axles, as shown in Figure 9, the centre of rotation is located at point C, the spacing of the rigid axles is represented by L.
- b) If we replace axle #1 with a self-steering axle, the centre of rotation is displaced to the rear and is now located at axle #3. The spacing of the rigid axle is now reduced to L<sub>2</sub>.
- c) Now, if we introduce a second self-steering axle replacing axle #4, the centre of rotation is found exactly between axle #2 and #3. The spacing of the rigid axles is subject to a significant reduction, shown by L<sub>3</sub>.

Given that the lateral force exerted on the trailer is proportional to the spacing of the rigid axles, we are now able to understand why the addition of a second self-steering axle has such an important influence on the lateral force.

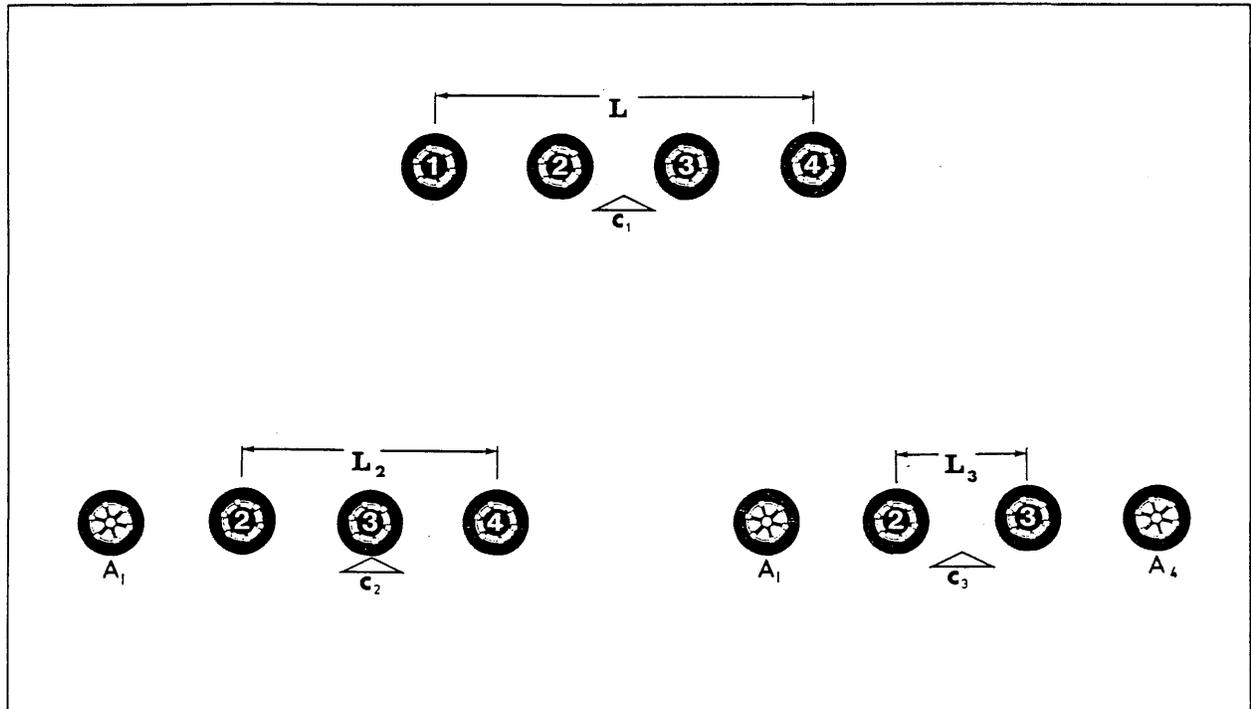


Figure 9. Spacing of the rigid axles according to the position of the self-steering axles.

It is highly probable that both theories 1 and 2 explain a part of the fuel consumption savings observed for the test trips conducted with the self-steering axles.

## CONCLUSIONS

Legislators have proposed laws limiting the total loads and the axle loads of vehicles to protect the road network. As a result, tractor-trailer operators are spacing their trailer axles farther and farther apart in an effort to maximize their potential revenues and take advantage of the existing regulations.

The results obtained from the study presented indicate that increased fuel consumption costs, up to 5.2% on the paved road tested, are the outcome when the spacing between the trailer's front and rear axle is increased from 4.21 to 6.03 m. On the gravel road tested, the fuel costs increased by 2.6%. While these results are very significant, it should, nevertheless, be noted that the results are directly related to the road profiles and are, therefore, specific to the conditions encountered in this study.

We do know that increasing the axle spacing has little effect on fuel consumption when the vehicle travels in a straight line. Given that the fuel consumption increased up to 5.2% even though 80% of the test trips followed a straight path, we can conclude that the additional effort applied on the vehicle when turning is considerable. Furthermore, we should expect this type of effort to affect the life expectancy of various vehicle parts.

Without having measured it, we did notice more than normal wear on the front and rear tires of the trailer. Bending of the trailer frame when turning was also noted. However, the effects of this intense force are probably long term making it difficult to associate a cost with it.

It is, therefore, evident that the increased haul productivity because of increased axle spacing, must be weighed against increased fuel consumption and vehicle maintenance and repair. For this reason, FERIC examined another option in maximizing the trailer loads while reducing the negative impact generally associated with a widely-spaced undercarriage configuration.

We found a reduction in fuel consumption of approximately 4% when one rigid axle on the trailer was replaced with a self-steering axle. The fuel consumption saving was 8 to 9% when a second self-steering axle was introduced.

A cost-benefit analysis was done using the results obtained for a tractor-trailer travelling 100 000 km per year, half on gravel and half on pavement. Replacing one rigid axle with one self-steering axle would result in an annual fuel consumption saving of \$1200. The substitution would cost approximately \$4000\*. The payback period for installing the self-steering axle would, therefore, be 3.3 years. There is a rule of thumb, generally accepted in the industry, which equates every dollar saved in fuel consumption to an equal saving in maintenance and repair costs. Thus, the payback period would be reduced to 1.6 years. The addition of a second self-steering axle resulted in a similar fuel savings and would, therefore, have a similar payback.

Some possible explanations are suggested to explain the differences occurring between the test trips conducted on pavement and on gravel. The road profile and the friction characteristics of the roads are considered to be the major factors responsible for these differences.

The mechanisms influenced by introducing self-steering axles are not fully understood. More research is required in this area to shed more light on the different mechanisms involved in reducing the lateral forces on an articulated vehicle.

Consideration of the trailer's stability and security is also a concern. However, no problems of this sort were encountered during the trial period of this study. Research organizations such as the Ontario Ministry of Transportation and Communications [1] are interested in these problems and are of the opinion that the use of self-steering axles present no risk and their use should be encouraged.

## REFERENCES

- [1] Billing, A.M. Test of self-steering trailer Axles on Commercial Vehicle Operations and Safety. Ministry of Transportation and Communication, Downview, Ont. 1979. 60 pages.
- [2] Road and Transport Association of Canada, Implementation Planning Sub-Committee. Recommended Regulatory Principles for Interprovincial Heavy Vehicle Weights and Dimensions. Ottawa, 1987. 46 pages.

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\* This amount could vary depending on the compatibility of the suspension in place.