CO-OPTIMIZING MULTI VEHICLE COMBINATIONS FUEL CONSUMPTION & TRACKTION IN SLIPPERY CONDITIONS

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Abstract

Northern Sweden gives challenges such as temperatures above 30°C in the summers with 24 hour of daylight to well below -30°C with darkness, ice and snow during the winters. The main winter problems are start ability and low speed grading & maneuvering.
Co-optimizing means that fuel consumption, loading capacity, start ability and low speed grading & maneuvering are taken into consideration both in loaded and unloaded conditions.

Traction and start ability when unloaded was solved by declutching and lifting the second driven axel at the same time dumping the air on the 1st dolly axle and lifting 4 trailer axles. At the same time this gave an 8% fuel reduction when unloaded. On a transport cycle 160 km loaded and 160 km unloaded this traction aid feature gave a fuel saving of 3%.

Further optimizations of aerodynamics (lower driving height on main roads) and driveline gave an improvement of 9% of the whole transport cycle. Mainly improve when driving loaded.

Keywords: High Capacity Transport, Sweden, Traction, Fuel consumption, Heavy Vehicle Truck/transport Technology

1. Introduction & Background

To input for coming new legislation, in Sweden, a HCT (High Capacity Transport) road research forum has been created. Over the last decade trials with multi-vehicle combinations have been carried out. The driving force for these trials has been transport efficiency and reduction of CO_2 emissions. The gross combination weight, GCW, of those trial combinations has been between 66 and 90 tonne. The overall combination length has been between 22 and 32 meters, and planning for up to 34 meters. The number of vehicles in each combination has varied from two to four. While increasing the GCW the maximum axle group loads have been kept the same as present legislation. This type of transport is known as High Capacity Transport (HCT).

The first HCT combination was the (One Pile More –En Trave Till) ETT-combination which started in January 2009. It was replaced after 5 years and 1 400 000 km virtually hassle-free (after the traction problems was improved) driving in northern Sweden. The replacement was a fully updated version based on knowledge gained with the first combination. The new combination has now more than 2 years of operation and more than 500 000 km driving. The transport is 160 km with 66 tonnes of timber distributed on 4 piles. This trial is on a special permission from the Swedish road authorities and a part of an investigation for a future HCT road network in Sweden

A 4 pile combination was made with full presently legal axle group load on the trailing units and 26 tonnes on the truck this gives 1 pile extra and more weight on the 2 last piles, compared to a tradition 60 tonnes round wood combination.

ETT:1 reduced fuel consumption by 22% compared to a, at that time standard Swedish, 3 pile 60 tonnes combination.

2. Area of operation

2.1 Description of the transport

The ETT trucks transport roundwood between a terminal in Överkalix and sawmill in Piteå. At both ends loading and unloading is carrier out with separate loaders, this combination drives unloaded 50% of the distance. The road is chosen so that

- roundwood can be collected up streams the loading area with traditional 60/64 tonnes Swedish timber trucks
- all bridges can hold the weight of 90 tonnes
- two drivers can do two rounds each in a working day

2.2 Geographical

The 160 km journey goes from Överkalix near the Arctic Circle to Piteå at the Baltic Sea. The location is shown in Figure 1. An enlargement with the transport route is shown in Figure 2.

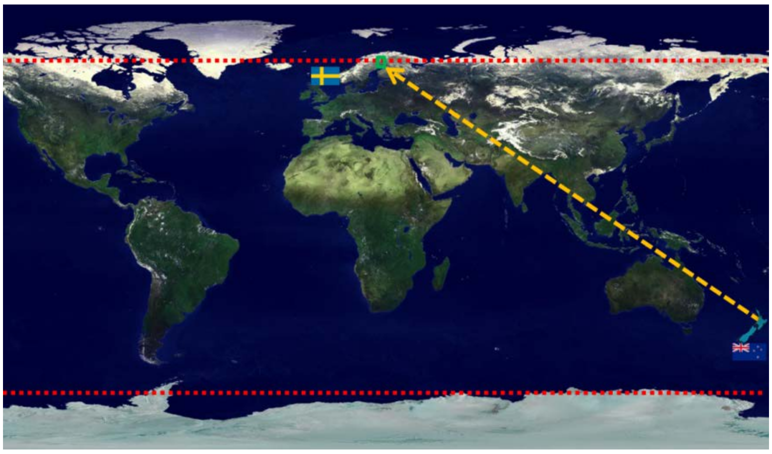

Figure 1 & 2: Earth, the green rectangle, is the location of the vehicle combination field test. Red dotted lines indicate Arctic and Antarctic Circles respectively. Field test area. From close to the Arctic Circle to the Sawmill at the Baltic Sea.

2.3 Climate

The trip starts in Överkalix, a region characterized by long dark and cold winters. The summers are always bright with 24 hours of daylight. During the winter it is common to have temperatures alternating from below freezing point in Överkalix to above freezing point in Piteå. Weather statics from Luleå between the two end points show a maximum temperature of 32.2°C and minimum of -42.0°C. Actual daily weather statistics from Överkalix and Piteå compiled are shown in Figure 3. These data has been retrieved from the SMHI (Swedish Meteorological and Hydrological Institute). Five temperature groups have been identified:

1. Stable cold weather, always below -1°C (COLD)
2. Cold with maximum between -1°C and 0°C, near thawing (ZERO-)
3. Temperatures shifting from plus to minus or vice versa (ZERO)
4. Warm with minimum between +1°C and 0°C, near freezing (ZERO+)
5. Stable warm weather, always above +1°C (WARM)

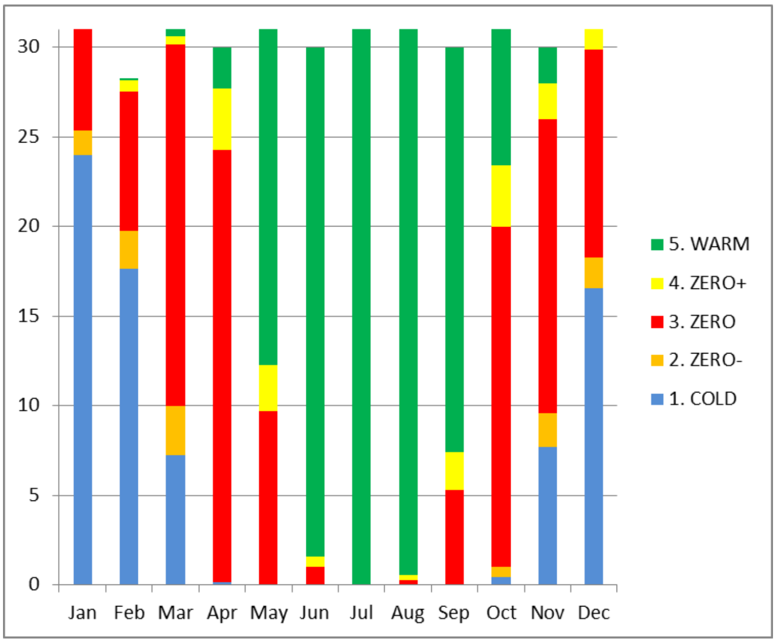

Figure 3 Actual temperature changes during the test period 2009-01-01 until 2016-03-31.

These groups show the long periods where traction problems can occur. Group 3 is the real challenge. It can be temperature shifts up and down during the transport and time of day. Group 1 and 2 means problems when warm tires and or the sun melt the ice/snow at critical areas. Group 5 is stable warm weather. This occurs exclusively, according to our statics, only in July. Freezing and thawing can occur at any day the remaining 11 months of the year. Freezing point are expected 148 days of the year on this route.

2.4 Road profile

The topography, according to Volvo, is predominantly flat. The maximum slope is 4.5% (4.5 m in 100 m). The road goes mainly along a river and coastal areas. The elevation curve is seen in
Figure **4**. The relative length of slope is presented in
Figure **5**. Only 4% of the road has an uphill slope of between 4 and 4.5%.

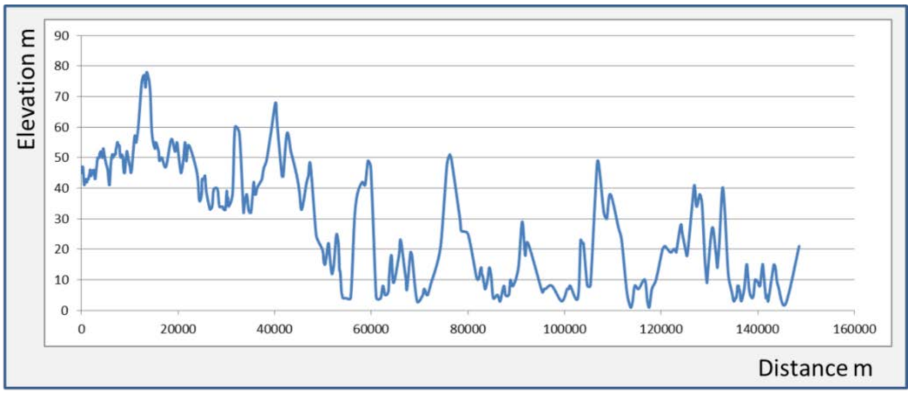

Figure 4 Elevation curve for transport seen from Överkalix to Piteå. Maximum elevation is 80 meter and minimum is almost at sea level.

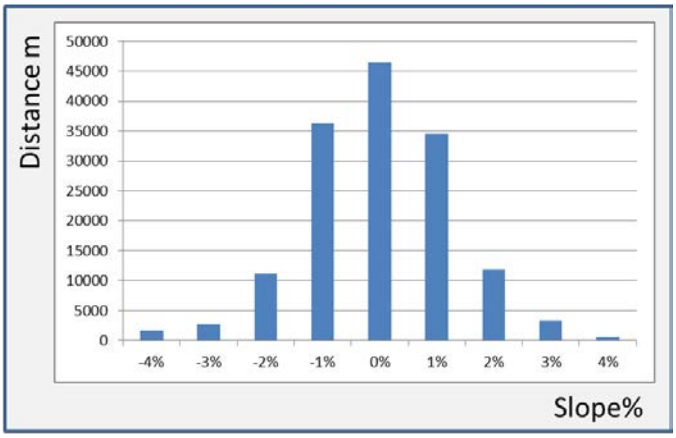

Figure 5 Histogram of slopes from Överkalix to Piteå.

2.5 Loading and unloading area

Loading and unloading area see Figure 6, 7 and 8 below.
Snow, ice and water are common in the loading area. The base structure is gravel and woodchips.

Figure 6 & 7 Winter condition at loading area ETT:2 loaded and unloaded

Figure 7 Unloading area ETT:2 loaded

3. Choice of vehicle combination

The basic vehicle was described at HVTT12: "ETT – A modular system for forest transport".

To meet accessibility, road handling and stability a Truck –dolly- link- semitrailer combination was chosen. See Figure 8 for all dimensions. The combination is optimized for 4 piles of roundwood, up to 5.5-6 m long. Maximum height is 4.5 m, total length is almost 30 m

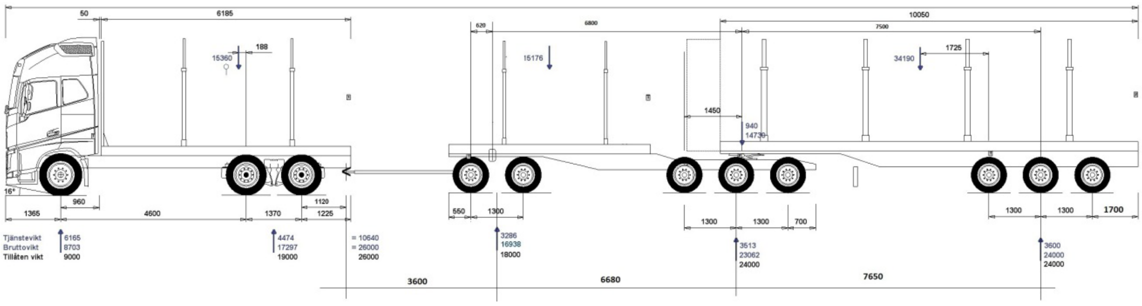

Figure 8: ETT:2 combination dimensions

3.1 Vehicle Combination Restriction

Due to the regulation for this specific test, neither the number of axles nor the position of the axles has been possible to change. This means that traction and fuel consumption has not been possible to optimize as a function of axle position and number of axles.

4. Fuel consumption (liters, liters/100 km and ml/tonne·km), Method

The fuel consumption is measured in liters. We have chosen to look at both total consumption and specific fuel consumption. Let us take the distance D_L 160 km from A to B loaded and D_U unloaded from b to a as seen in

Figure 9. Typical fuel consumption loaded is V_L 100 liters and unloaded is V_U 60 liters. Which equals 62.5 and 37.5 liter/100 km for the loaded and unloaded parts of the trip. The average round-trip is 50 liter/100 km.

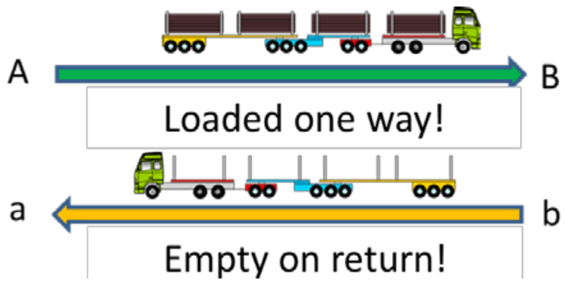

Figure 9 The ETT vehicle combination. 50% of the driving is loaded and 50% is unloaded. Capital letters describes loaded road usage and lowercase unloaded.

The transport is from A to B empty vehicle combination travels back from B to A. The specific fuel consumption, here described as the ABba method, takes the full transport cycle into account. In this example the load is M_L 66 tonnes of round wood. The return trip has no load so M_U is 0 tonne. The unit ml/tonne·km is used instead of l/tonne·km since ml/tonne·km gives numbers that are greater than one.

$$F_{ABba} = \frac{V_L + V_U}{M_L \cdot D_L + M_U \cdot D_U} = \frac{100 + 60}{66 \cdot 160 + 0 \cdot 160} \approx 0.015 \frac{l}{tonne \cdot km} = 15 \frac{ml}{tonne \cdot km}$$

5. **Results**

5.1 Combination ETT:1 versus ETT:2

The ETT:1 was in operation between January 2009 and September 2014. The improved ETT:2 started in March 2014 and is still in operation. Both combinations were operated in parallel between March 2014 and September 2014 to make a comparison of features such as fuel consumption, see Figure 10. The fuel consumption for ETT:2 combination is 9% lower than for the ETT:1.

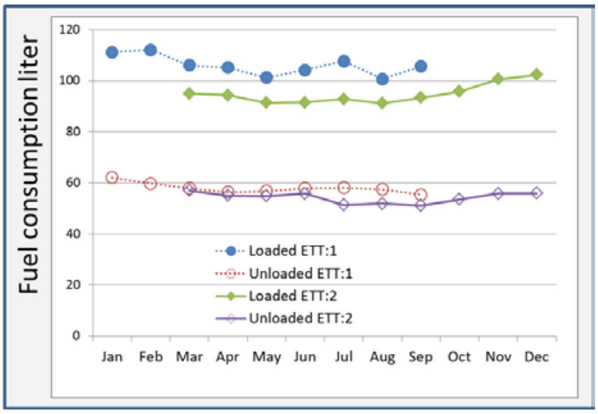

Figure 10 Fuel consumption during 2014. The ETT:2 shows an overall fuel consumption that is 9% lower than ETT:1.

The reason for this is most probably a combination of lower air resistance, including lower driving height and a better optimized driveline.

5.2 Summer and winter conditions

The Nordic climate results in large swings in fuel consumption, since the road and weather conditions are very different. The summer (June, July & August) consumption is more than 10% lower than in the winter (December, January & February) as seen in Figure 11.

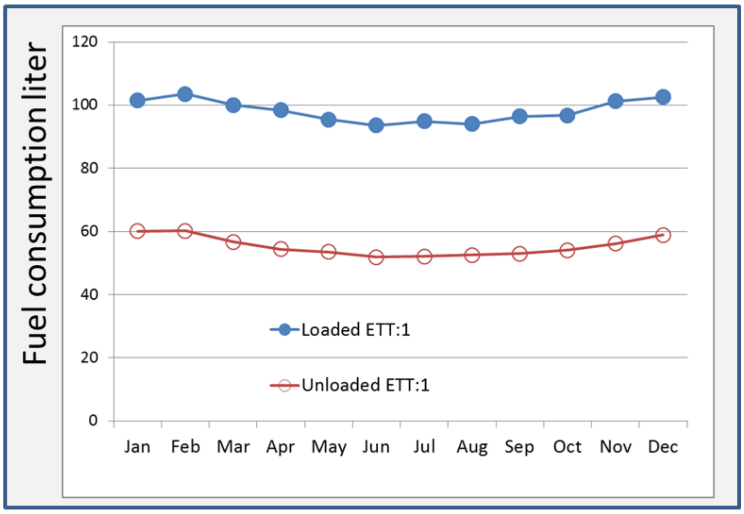

Figure 11 Average fuel consumption per month taken as average from January 2009 until September 2014 for the first combination ETT:1. The fuel consumption is more than 10% lower during the summer compared to winter.

5.3 Problem description:

Field-test with the first ETT truck started January 2009. Startability problems where identified, after unloading it was not possible to start the combination on ice in spite of the fact that the truck was equipped with sand spreader in front of drive axles. Only 16% of the GCW was available on the driven axles.

Temporarily the problem was solved with that the timber was not completely unloaded at the terminal, around 4 tonnes was kept on the truck, see Figure 12, this gives 25% of the GCW was available on the driven axles. Later a steel plate of one tonne on the truck chassis just above the drive axles resulting in 20% of the GCW was available on the driven axles.

Figure 12 Winter conditions at unloading area ETT:1 with traction “ballast"

February 3th 2010 Lena Larsson attended an NVF conference on the topic "Energy efficient Transports" in Helsinki Finland. At the conference a research project between Nokian Tyres and Helsinki University of technology was presented. The topic was "Truck Tyre Rolling Resistance and Fuel Economy & Safety". One of the parameters studied as input in this project was tire wear in different positions on truck combinations up to 25.25 meters. According to this investigation the mileage index on trailer tires on a semitrailer triple was substantially different. The center tires last 2.5 times longer as the last axle tires and the first axle 1.5 time as long as the last. See Figure 13 below. This indicates that axle 1 & 3 adds significant to the rolling resistance.

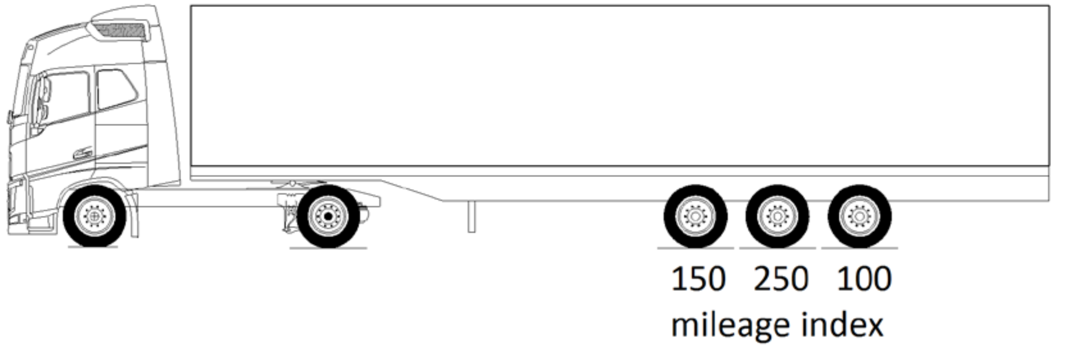

Figure 13 Tire wear on semitrailer triple

A separate fuel study was made during a weekend in August 2010. In total 5 of 11 axels were lifted when driving without load as shown in Figure 14. One of the driven axels was manually decoupled and lifted. Four trailer axels were lifted using ratchet straps. Fuel consumption was measured both with and without the lifted axels for four different drivers. The test was performed on a 51 km long section

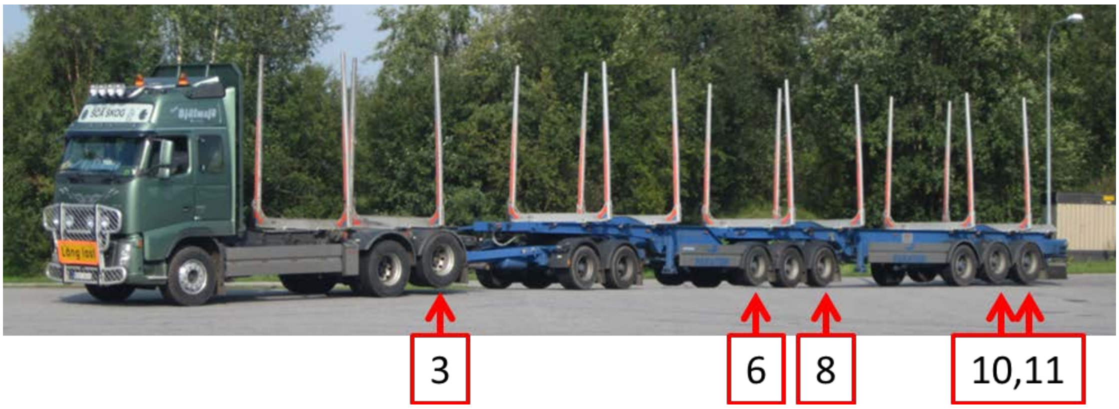

Figure 14 Test in August 2010 with 5 lifted axels

The fuel consumption decreased by 9.8% with a standard deviation of 3.5%.
These results were encouraging and led to development and rebuilding of the combination. A second study was deployed in January and February 2011 when the new automatic system had been installed on the ETT combination. The 5 axels were lifted on every second return trip and a fuel saving of 8% on the return trip was verified. Figure 15 shows clearly fuel saving on the return trip when lifting axels. The overall fuel saving is 3% for the total trip.

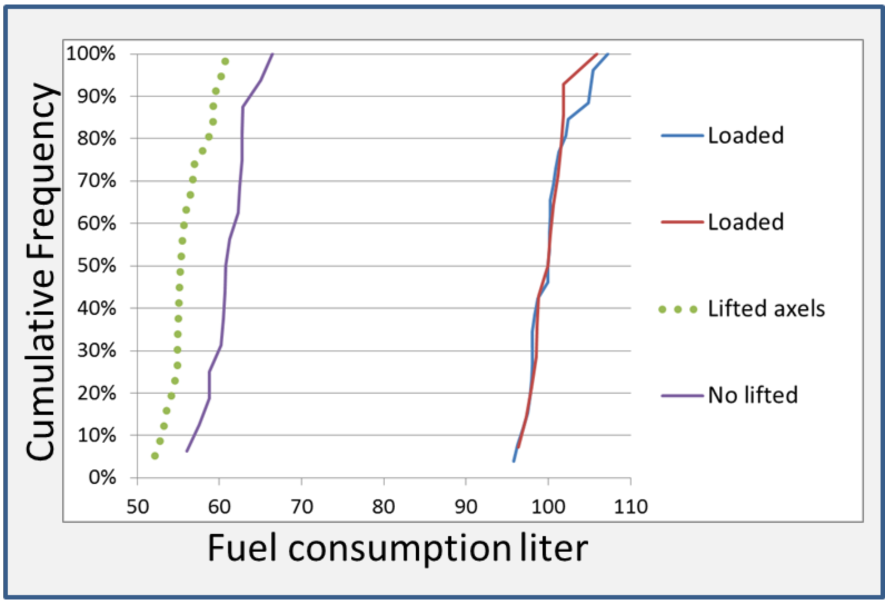

Figure 15 Cumulative frequency of fuel consumption for impact of axle lifting on return trips. The loaded curve shows comparable conditions for the test. The difference on the unloaded return trip is only dependent on the five lifted axels.

6. Concept development

6.1 Startability and driveability on low friction

Brainstorming was started, how can drive axles get sufficient load and how can aerodynamic drag and rolling resistance be minimized when driving unloaded? At that time, the following possible solutions were derived:

1. Increasing the percentage of GCW on driven axles
2. Increase friction for drive axels
3. Minimizing rolling resistance on non-driven axles
4. Minimizing aerodynamic drag

The Elphinstone concept see www.elph.com.au was studied as an inspiration; however we did not consider this concept as a way forward in our project. The result of the brainstorming and what we saw as realistic to start with within our project was to lift axles and lower timber bunks. A Master thesis work, to study further potentials, was initiated. This was carried out at Lund Technical University and named "Development Concept for Timber Truck".

6.2 Changes made on the truck combination

6.2.1 1st ETT combination

From the brainstorming we have chosen the following changes for the first ETT combination:

1. Lifted axle 3, 6, 8, 9 and 11 on return trips, truck driven as a 6x2 with lifted tag axle
2. Axel 4 was air dumped at starts with unloaded combination
3. Continues inter axle diff lock when driving as a 6x4, as a consequence.
4. On-spot was mounted (an semiautomatic snow chain)
5. Drive tires was cut in different pattern

2.2.2 ETT:2 combination

Changes made between first and second version of the ETT combination
The main changes between ETT:1 and ETT:2 is described in sections below.

Air suspension on all axles
The ETT:2 combination has air suspension on all axles. This ability means that a lower on road driving height can be set. The driver can increase the height in low speed on bad roads.

- ⇨ This makes it possible to lower air drag and load more volume (pulpwood)

Timber retainer system
The ETT:2 combination has a timber retaining system (COM90, ExTe) where the stakes is securing the timber by retracting by a hydraulic system. This means that the stakes is only as high as the timber pile and it can also retract to its half maximum length at the return trips. ETT:1 hade fixed 4.5 m bunk stakes.

- ⇨ This give lower aerodynamic drag both on full loads and empty as well as more secured tightening.

Aerodynamic layout of truck (front load protection wall and roof deflector)
On the ETT:2 truck there is an active retainer system (always trying to tightening the pile) with warning if the if the system fails, this gives an possibility to have a lover front load protection wall than the maximum timber pile height (maximum 500 mm under the max height of the pile). ETT:2 has a roof deflector with an adjustable height (adjusted with a button in the cab), to adjust it according to current pile height. The ETT:1 truck had an front load protection wall that have total height 4.5m and also the roof deflector was too low in its maximum height.

- ⇨ ETT:2 has lower air drag than ETT:1

Lift axel management

During starts in mud/ice/snow conditions it is wise to lower all axle before starting load the combination, this is to avoid that warm tires sinks in to the ground/ice.

Traction improvement systems
ETT:1 was fitted with lifetable last axle on the truck that greatly improve traction on the empty trips. Also ETT:1 hade sandboxes and On-spot automatic chains. For optimal traction loaded 19 tonnes is placed on the drive axles (maximum legal), this is why there is a gap between the front securement wall and the first pile. This gives 21% of GCW on driven axles more is needed is severe conditions. ETT:2 is also equipped with a prototype hydraulic front axle drive system this gives 26 tonnes (Coming legislation 29 tonnes) on driven axles in low speed this gives up to 28 or 32% on driven axles fully loaded, respectively.

7. Conclusion

The start problems driving empty with an ETT combination was solved with lifting/air-dumping of axles.

At the same time fuel consumption on return trips were lowered with 8 %. On the complete trip this impacted with 3 %.

With all the measures we have initiated between generation one and two of the ETT truck combination fuel consumption has been lowered 9%.

We are now down to one tablespoon, 15 ml see Figure 16, per tonne·km.

Figure 16 A tablespoon of 15 ml

However we still had traction problems when fully loaded. The new combination has the Volvo Trucks - Driven Tandem Axle Lift function and a prototype of hydraulic driven front wheel drive. This gives a very high load on driven axles. It is possible to reach more than 30% on 3 driven axels when loaded (26 to 29 tonnes out of 90 tonnes) and over 40% when unloaded (10-13 tonnes out of 24 tonnes).

Moreover the load securing has been updated with a fully automatic system which is great improvement for the drives working conditions and safety.

By utilizing the legal axle group weights, 29 tonnes, on the truck, the combination acquires several improved features:

- Better aerodynamics
- Better traction
- Better handling

ABBRIVATIONS & NOMENCLATURE

CO_2	Carbon Dioxide (global warming greenhouse gas)
D_L D_U	Distance travelled loaded (L) and unloaded (U) {km}
ETT	One Pile More (En Trave Till)
ETT:1	First generation of the vehicle combination started in 2009
ETT:2	Second generation of the vehicle combination started in 2014
GCW	Gross Combination Weight
GTT	Group Truck Technology
HCT	High Capacity Transport
HVTT	Heavy Vehicle Transport Technology
liter	1/1000 m^3
m	The meter is defined to be the distance light travels through a vacuum in exactly 1/299792458 seconds
M_L M_U	Mass of goods transported loaded (L) and unloaded (U) {metric tonne=1000 kg}
NVF	Nordic Road Association (nordiskt vägforum)
V_L V_U	Volume of fuel consumed when loaded (L) and unloaded (U) {liter}
ÅF	ÅF is an engineering and consulting company with assignments in the energy, industrial and infrastructure sectors, creating progress for their clients since 1895.

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