REPORT

ANALYSIS OF THE COST OF CARGO DAMAGES AND COST OF CARGO SECURING IN DIFFERENT LINKS IN A TRANSPORT CHAIN

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Summery and conclusions

Cost of cargo securing SEK/ton

The cost of different securing methods was analyzed with the LASHCOST-model developed by the Transport Research Institute (TFK) in Sweden. An estimation of time consumption of different lashing methods was done and the result is shown in table 4.

Securing method	Cost per lashing [SEK]
Top-over lashing	18
Loop lashing	37
Straight lashing	37

Table 4 - Cost of different lashing methods

One basic assumption is that the cargo is supposed to be loaded against a headboard with required strength to prevent the cargo from sliding and tipping in forward direction. The securing arrangements analyzed are to prevent sliding and tipping in sideways and backwards direction.

The effectiveness of each lashing method was calculated according to the regulation for the different modes of transport. The effectiveness to prevent sliding is depending on the coefficient of friction. Therefore is the distribution of friction analyzed with basic data from the SAFEDOR-project. With the distribution of the coefficient of friction above the lashing cost/ton cargo was calculated. The result is presented in table 7.

[SEK/ton]	μ	0,2	0,3	0,4	0,5	0,6	0,7	Average cost
Road/ Sea A	Top-over	36.0	15.0	5.6	0.0	0.0	0.0	2.1
	Loop	8.8	6.7	4.8	0.0	0.0	0.0	1.5
	Straight	14.2	9.7	6.4	0.0	0.0	0.0	2.1
Sea B	Top-over	60.0	30.0	18.0	9.0	3.8	0.0	10.9
	Loop	13.7	11.2	9.0	7.3	5.4	0.0	7.3
	Straight	23.1	16.8	12.3	8.8	6.4	0.0	9.4
Sea C	Top-over	90.0	45.0	22.5	13.8	7.5	3.3	15.8
	Loop	16.1	13.7	11.2	9.3	7.4	5.8	9.5
	Straight	26.4	20.6	15.4	11.6	8.8	6.4	12.2
Combi	Top-over	45.0	22.5	12.9	6.9	3.0	0.3	8.1
	Loop	10.0	8.2	6.6	5.3	4.1	2.9	5.4
	Straight	9.3	7.7	6.4	5.3	4.5	3.9	5.5

Table 7 - Cost/ton – different lashing methods

The use of different securing methods depending on type of cargo and type of CTU was estimated. With the average cost for different lashing methods the cost of cargo securing was calculated. The result is presented in table 11.

[SEK/ton]	Type of CTU	Low value	Mid value	High value
Road/ Sea A	Type 1	0.5	0.4	0.2
	Type 2	1.3	1.2	1.1
	Type 3	2.0	2.0	2.0
Sea B	Type 1	3.7	2.8	1.8
	Type 2	7.0	6.6	6.2
	Type 3	10.2	10.4	10.6
Sea C	Type 1	8.0	6.7	5.5
	Type 2	11.2	10.7	10.2
	Type 3	14.3	14.6	15.0
Combi	Type 1	2.0	1.4	0.7
	Type 2	4.8	4.5	4.2
	Type 3	7.6	7.7	7.9

Table 11 - Cost of different cargo securing methods for different mode of transport

The probability of cargo damages

One basic assumption and delimitation made in the calculations of the probability of cargo damages is that the cargo damages mainly occurs at sideways cargo shifting. This is not the whole truth especially at railway transports. More research has to be done to get better statistics on the probability of cargo shifting in all directions on different modes of transport.

The probability of cargo damages is calculated with the formula below

$$P_{mode} = \sum_{a=1}^{a=y} P_{1mode} \times P_{2mode} \times P_{3mode} \qquad \textit{(formula 1)}$$

where;

P_{mode} = Probability of cargo damages at actual mode of transport
a = Sideways acceleration
y = 5 (road, Sea A and Combi), 7 (sea B) or 8 (Sea C)
P_{1mode} = Probability of max sideways acceleration *a* in actual mode of transport
P_{2mode} = Probability of cargo shifting at sideways acceleration *a* in actual mode of transport
P_{3mode} = Probability of cargo damages at sideways acceleration *a* in actual mode of transport

Probability of max sideways acceleration (P_{1mode})
The probability of max sideways acceleration at different mode of transport was estimated from experience and some basic statistics. More research has to be done to get better statistics on the probability of sideways acceleration at different modes of transport. The result is presented in table 23.

Max Sideways Acceleration	Road	Sea A	Sea B	Sea C	Combi
1	0.8	0.82	0.77	0.71	0.72
2	0.2	0.17	0.2	0.2	0.2
3	0.003	0.01	0.02	0.05	0.05
4	0.0005	0.001	0.007	0.02	0.02
5	0.0001	0.0001	0.001	0.01	0.01
6			0.0004	0.004	
7			0.0001	0.002	
8				0.001	

Table 23 - Estimated probability of max sideways acceleration at different mode of transport

Probability of cargo shifting at sideways acceleration (P_{2mode})

The distribution for the probability of cargo shifting at different sideways accelerations is estimated with the data from the inspections done in the SAFEDOR project. The different cargo securing arrangement has been studied and the expected acceleration when the cargo start to shift has been calculated.

The observations have been found to be lognormal distributed, see table 24.

Type of cargo/ Type of CTU	Normal distribution		Log normal distribution		No. of observa-tions
	Mean μ	Std dev σ	Mean μ	Std dev σ	
Low / type 1	4.386	0.235	1.477	0.049	2
Low / type 2	4.774	1.210	1.531	0.253	14
Low / type 3	5.120	1.324	1.599	0.264	45
Mid / type 1	5.658	1.541	1.701	0.246	13
Mid / type 2	6.385	2.519	1.789	0.347	20
Mid / type 3	5.171	1.277	1.615	0.238	84
High / type 1	5.200	1.403	1.616	0.249	12
High / type 2	4.938	1.155	1.572	0.219	14
High / type 3	5.695	2.319	1.676	0.348	13

Table 24 - Probability for cargo shifting depending on CTU and type of cargo

Probability of cargo damages at sideways acceleration (P_{3mode})

The probability of cargo damages at sideways acceleration was based on experience. Ongoing projects within the SIR-C group will give more accurate values in the future.

When the cargo starts to shift all the cargo will not be damaged. The proportion of damaged cargo is estimated to be normal distributed depending on the actual side acceleration. One basic assumption is that at the sideways acceleration a_t = 6.0 the proportion of damaged cargo is 50 %. In a normal distribution the mean value is μ =6.0.

The standard deviation is estimated to be σ ≈ 2.0. The result is presented in table 26.

Type of cargo/ Type of CTU	Mean μ	Std dev σ
Low / type 1	6.6	1.7
Low / type 2	6.4	2.0
Low / type 3	6.2	2.2
Mid / type 1	6.4	1.7
Mid / type 2	6.2	2.0
Mid / type 3	6.0	2.2
High / type 1	6.0	1.7
High / type 2	5.9	2.0
High / type 3	5.7	2.2

Table 26 - Distribution of cargo damages depending on cargo value and type of CTU

Probability of cargo damages (P_{mode})

Using the values of the above the following probability of cargo damages is calculated with *formula 1* and the result is presented in table 28;

	Road	Combi	Sea A	Sea B	Sea C
CTU Type1	0.001 %	0.097 %	0.002 %	0.033 %	0.386 %
CTU Type2	0.003 %	0.178 %	0.006 %	0.053 %	0.476 %
CTU Type3	0.004 %	0.238 %	0.006 %	0.067 %	0.591 %
Low value	0.002 %	0.129 %	0.003 %	0.040 %	0.433 %
Mid value	0.003 %	0.187 %	0.005 %	0.054 %	0.518 %
High value	0.006 %	0.336 %	0.011 %	0.092 %	0.736 %
Low type 1	0.002 %	0.177 %	0.001 %	0.042 %	0.520 %
Low type 2	0.004 %	0.225 %	0.006 %	0.063 %	0.563 %
Low type 3	0.004 %	0.228 %	0.006 %	0.064 %	0.563 %
Mid type 1	0.001 %	0.090 %	0.001 %	0.031 %	0.379 %
Mid type 2	0.002 %	0.123 %	0.004 %	0.038 %	0.370 %
Mid type 3	0.003 %	0.227 %	0.005 %	0.063 %	0.585 %
High type 1	0.002 %	0.131 %	0.002 %	0.041 %	0.450 %
High type 2	0.003 %	0.213 %	0.004 %	0.060 %	0.575 %
High type 3	0.005 %	0.234 %	0.010 %	0.068 %	0.537 %

Table 28 - Probability of cargo damages at different mode of transport

Cost for cargo damages

The cost of cargo damages C_{Dmode} expressed in SEK/ton is calculated with the formula 2;

$$C_{D\,mode} = P_{mode} \times V_{cargo} \qquad \textit{(formula 2)}$$

The average cargo value V_{cargo} is estimated for each type of cargo, see table 29.

Type of cargo	V_{cargo}	
Low	8	KSEK/ton
Mid	35	KSEK/ton
High	125	KSEK/ton

Table 29 - Average cargo value

With the cargo values above the cost of cargo damages (C_{Dmode}) is calculated and the result is presented in table 30;

	Road	Combi	Sea A	Sea B	Sea C
Low value	0.1	10.3	0.2	3.2	34.7
Mid value	1.0	65.5	1.6	19.1	181.3
High value	7.2	419.8	13.4	115.3	920.1
Low type 1	0.1	14.1	0.1	3.3	41.6
Low type 2	0.3	18.0	0.5	5.1	45.0
Low type 3	0.3	18.3	0.5	5.1	45.1
Mid type 1	0.4	31.3	0.5	10.9	132.7
Mid type 2	0.7	43.2	1.3	13.3	129.4
Mid type 3	1.2	79.5	1.8	22.1	204.8
High type 1	2.2	163.2	2.9	51.1	562.6
High type 2	3.8	266.8	5.4	74.5	718.3
High type 3	6.1	292.4	12.7	85.6	671.5

Table 30 - Cost for damaged cargo [SEK/ton]

If $L_{avgmode}$ is the average transport length at the actual mode of transport, see table 31, the cost of damaged cargo can be express in SEK/tonkm with formula 3;

$$C_{D\,mode} = \frac{P_{mode}}{L_{avg\,mode}} \times V_{cargo} \qquad \textit{(formula 3)}$$

Type of cargo	Average transport length
Road	100 km
Combi	500 km
Sea A	100 km
Sea B	1000 km
Sea C	6000 km

Table 31 - Average transport length

With the cargo values from table 29 the cost of damaged expressed in SEK/tonkm is presented in table 32;

	Road	Combi	Sea A	Sea B	Sea C
Low value	0.001	0.021	0.002	0.003	0.006
Mid value	0.010	0.131	0.016	0.019	0.030
High value	0.072	0.840	0.134	0.115	0.153
Low type 1	0.001	0.028	0.001	0.003	0.007
Low type 2	0.003	0.036	0.005	0.005	0.008
Low type 3	0.003	0.037	0.005	0.005	0.008
Mid type 1	0.004	0.063	0.005	0.011	0.022
Mid type 2	0.007	0.086	0.013	0.013	0.022
Mid type 3	0.012	0.159	0.018	0.022	0.034
High type 1	0.022	0.326	0.029	0.051	0.094
High type 2	0.038	0.534	0.054	0.074	0.120
High type 3	0.061	0.585	0.127	0.086	0.112

Table 32 - Cost for damaged cargo [SEK/tonkm]

Cost of cargo damages in an actual transport (chain of transport)

The estimated cost of cargo damages for an actual transport (chain of transport) can be calculated if the following data is known;

- Transport modes involved (road. sea A. sea B. sea C and/or combi)
- The transport length of the different transport modes (L_{mode})
- The type of cargo (low. mid or high value cargo)
- The value of the cargo (V_{cargo})
- The type of CTU (type 1. 2 or 3)

For a total chain of transport the formula for cost of cargo damages is;

(expressed in SEK/ton)

$$C_D = (P_{Road} + P_{SeaA} + P_{SeaB} + P_{SeaC} + P_{Combi}) \cdot V_{cargo} \qquad \textit{(formula 4)}$$

(expressed in SEK/tonkm)

$$C_D = (\frac{P_{Road}}{L_{Road}} + \frac{P_{SeaA}}{L_{SeaA}} + \frac{P_{SeaB}}{L_{SeaB}} + \frac{P_{SeaC}}{L_{SeaC}} + \frac{P_{Combi}}{L_{Combi}}) \cdot V_{cargo} \qquad \textit{(formula 5)}$$

The probability of cargo damages can be adjusted with a factor ε due to the length of the transport at each mode of transport. The estimation is that the probability of cargo damages is higher in the beginning and at the end of the transportation. A short transport should have a higher proportion of risk than a long transport. The adjusted probability of cargo damages P_a is calculated with the formula;

$$P_{a\,mode} = P_{mode} \times \varepsilon \qquad \textit{(formula 6)}$$

if $$\varepsilon = \sqrt{\frac{L_{mode}}{L_{avg\,mode}}} \qquad \textit{(formula 7)}$$

with L_{mode} = Transport length of the actual mode of transport
$L_{avg\,mode}$ = Average transport length at the actual mode of transport

The formula for adjusted cost of cargo damages is;

(expressed in SEK/ton)

$$C_{aD} = (P_{aRoad} + P_{aSeaA} + P_{aSeaB} + P_{aSeaC} + P_{aCombi}) \cdot V_{cargo} \qquad \textit{(formula 8)}$$

(expressed in SEK/tonkm)

$$C_{aD} = (\frac{P_{aRoad}}{L_{Road}} + \frac{P_{aSeaA}}{L_{SeaA}} + \frac{P_{aSeaB}}{L_{SeaB}} + \frac{P_{aSeaC}}{L_{SeaC}} + \frac{P_{aCombi}}{L_{Combi}}) \cdot V_{cargo} \qquad \textit{(formula 9)}$$

1. Preamble

1.1 Purpose and mission

The aim for analysis is to do a professional estimation of some basic data for the EFM-STAN model in the V-FUD SIR-C project ”MOS-Criteria” lead by BMT.

The basic data which are going to be analyzed is the risk of cargo damages, cost of cargo damages and cost of cargo securing with different mode of transports, Cargo Transport Units and types of cargo according to the following;

Actual modes of transport are;
- Road
- Sea area A
- Sea area B
- Sea area C
- Multimodal rail transport (Combi)

Actual Cargo Transport Units (CTU) are;
- CTU with rigid superstructure (freight containers and vehicle of box type)
- CTU with semi-rigid superstructure (vehicles with side boards and cover/stake body)
- CTU with non-rigid superstructure (container flats and curtainsiders)

Actual types of cargo in the analysis are:
- Low value cargo (< 10 kSEK/ton)
- Mid value cargo (10-50 kSEK/ton)
- High value cargo (50-200 kSEK/ton)

Definition of cargo damages (breakage)

In the official statistics over cargo damages the following causes are prevailing in the category “breakage”:

1. Damage during loading
2. Damage during discharging
3. Damage during unwrapping
4. Careless handling
5. Insufficient packing
6. Improper loading and stuffing
7. Improper cargo securing
8. Damages caused by defects in/on the cargo transport unit

From the above list of reason, items 1 – 4 may be categorised as handling damages while items 5 – 8 may be categorised as transport damages.

From the group of transport damages, items 5 – 7 primarily cause mechanical damage to the goods while reason for damages in group 8 mostly causes moist or temperature damages.

Deficiencies on the cargo transport unit may however also be the reason for mechanical damage to the goods e.g. obstacles projecting from surfaces or left nails on the floor that might impair.

This report will mainly focus on damages caused by category 5-7 (transport damages).

1.2 Delimitations and assumptions

The distribution of friction

The distribution of actual coefficient of friction is made from data from inspections of cargo securing made in the SAFEDOR[1] project. Most of the CTU was cargo secured for transport on road and sea A and/or sea B. The distribution of friction is assumed to be the same at sea C and railway transport.

Use of different of cargo methods

The distribution of use of different cargo securing methods is estimated from experience from inspections of cargo securing. More research has to be done to get better statistics on the distribution of use of cargo securing methods in different modes of transport and in different type of CTU and type of cargo.

Cargo shifting

One basic assumption and delimitation made in the calculations of the probability of cargo damages is that the cargo damages mainly occurs at sideways cargo shifting. This is not the whole truth especially at railway transports. More research has to be done to get better statistics on the probability of cargo shifting in all directions on different modes of transport.

Distribution of probability of maximum sideways accelerations

The distribution of probability of max sideways accelerations is partly based on estimations and partly from actual regulations. More research has to be done to get better statistics on the distribution of sideways acceleration at different modes of transport.

Distribution of probability of cargo shifting

The distribution of probability of cargo shifting is based on limit experiences from SAFEDOR project and estimations. More research has to be done to get better basic data of cargo shifting.

[1] SAFEDOR – Risks Regarding cargo shifting on RoPax vessels, MariTerm 2007; Sven Sökjer Petersen, Peter Andersson

Distribution of probability of damage cargo at cargo shifting

The distribution of probability of cargo damages at cargo shifting is based on pure estimations. More research has to be done to get better basic data of the probability of cargo damages at cargo shifting.

2. Modes of transport

The probability for cargo damages and the cost for cargo securing are depending on the modes of transports involved in the actual transport chain. The different modes of transport have different characteristic in acting forces caused by different movements during the transport.

In the following sections a description is given of the magnitude of the acting forces that can be expected during different modes of transport according to international standards and regulations. However, it should be in mind that the values mentioned are to be seen as extremes that do not occur in every transport but may arise on single occasions.

According to the International Maritime Organisation (IMO) Guidelines for Transport of Cargo Transport Units the transportations on sea is divided into three different sea areas depending on the magnitude of the forces.

Sea Area A: Baltic Sea to a boarder line from Lysekil, Sweden to Skagen, Denmark.

Sea Area B: North Sea, English Channel and Mediterranean

Sea Area C: Unrestricted waters

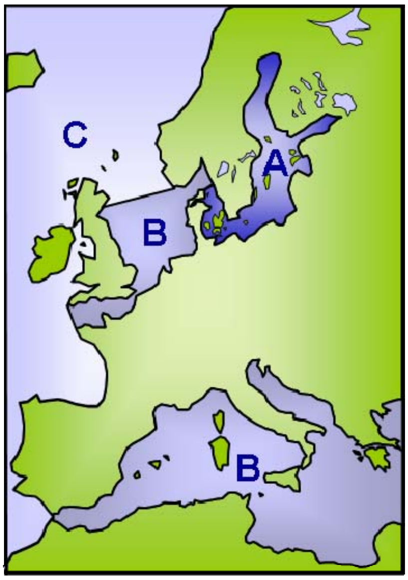


Figure 1 - Sea Areas

2.1 Regulations

Rules, regulations and standards for cargo securing exist on national as well as international level for road, sea and rail transports.

In this report the general requirements of cargo securing for transports in Europe are chosen.

Road

The regulations for cargo securing are not common in Europe but an EU Best Practice Guidelines was settled in year 2006. The EU Best practice Guidelines describe designing forces and principles for designing securing arrangements with different cargo securing methods.

Requirements on Cargo Transport Units (CTU) and securing equipment can be found in the international standards EN 12195-1, EN 283, EN 12642 L and XL.

Sea

There are international regulations for cargo securing described in the IMO/ILO/UN ECE Guidelines for Packing of Cargo Transport Units and in the IMO Model course 3.18 with Quick Lashing Guide.

Railway

In the International Unions for Railway – UIC's loading guidelines (RIV Appendix II) the following three levels of cargo securing requirements are found:

1. General forces arising during transport on rail in section 1, chapter 2.
2. General methods of loading and securing in section 1, chapter 5.
3. Specific instructions for cargo securing of different cargo types in section 2.

The general forces arising during transport are described in section 2.6.

As far as is understood these general forces are never used for real design of cargo securing arrangements. Instead the general methods or the specific instructions should be used.

According to UIC loading guidelines, section 1 chapter 1.2; any types of cargo securing are permitted, provided they meet the requirements of the general methods described in section 1. In reality it seems, however, to be so that securing arrangements according to section 2 is the only methods accepted by load securing inspectors. If the actual type of cargo is not included in section 2, an arrangement has to be agreed upon by the involved UIC member countries before the goods may be transported by rail.

If this procedure is intended to be used also for goods in combined cargo transport units, as trailers, swap bodies, containers etc. is unclear.

2.2 Road Transport

2.2.1 Active forces – Road Transport

The magnitude of the forces acting on cargo which can arise during road transport operations are, for international use, given in *EU Best Practice Guidelines*. However, national legislation or recommendations may require the use of other values. In most countries having cargo securing regulations for road transports it's stipulated that the cargo on a road vehicle must be secured in such a way that the cargo neither as a whole nor in parts can leave nor protrude the space meant for the cargo due to acting forces.

The acting forces to be taken into account according to the EU Best Practice Guidelines at a road transport are

- Forward: 1.0 × cargo weight
- Sideways: 0.5 × cargo weight
- Backward: 0.5 × cargo weight

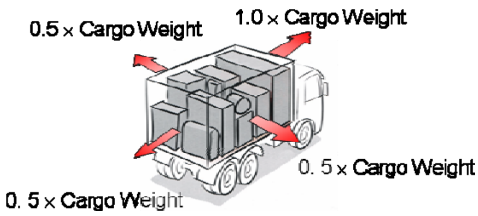


Figure 2 -Acting forces - Road

This stress mean that during road transport the cargo must be secured for forces equal to the full cargo weight forwards and half the cargo weight backwards and sideways. The regulations do not state any vertical force variation and the designing of the cargo securing assumes that the cargo presses with 1 × the cargo weight against the supporting surface.

2.3 Sea Area A

2.3.1 Active forces – Sea Area A

The acting forces to be taken into account according to the IMO/ILO/UN ECE Guidelines for Packing of Cargo Transport Units at a sea transport are

- Lengthways: 0.3 × cargo weight
- Sideways: 0.5 × cargo weight

Figure 3 - Acting sideway forces – Sea Area A

The designing side force in Sea area A is 0,5 × cargo weight combined with the gravitation acting downwards perpendicular to the deck, i.e. the same as stated for road transport. In other words the cargo securing according to road transport regulations is sufficient also for transportation on Sea area A.

At sea area A transport the longitudinal forces (forwards/backwards) is relatively limited (0.3 × cargo weight) compared with rail and road transport. When designing a cargo securing arrangement the longitudinal forces in lengthways direction is combined with static gravity force of 1.0 g acting downwards and a dynamic variation of ± 0.5 g.

2.4 Sea Area B

2.4.1 Active forces – Sea Area B

The acting forces to be taken into account according to the IMO/ILO/UN ECE Guidelines for Packing of Cargo Transport Units at a sea transport are

- Lengthways: 0.4 × cargo weight
- Sideways: 0.7 × cargo weight

Figure 4 - Acting sideway forces – Sea Area B

When designing a cargo securing arrangement the longitudinal forces in lengthways direction is combined with static gravity force of 1.0 g acting downwards and a dynamic variation of ± 0.7 g.

Most sides of superstructures on vehicles are designed for the acting force of 0.5 × cargo weight. Depending on the actual coefficients of friction the solitary side is not enough to block the cargo and the cargo arrangement has to be complemented with lashings.

2.5 Sea Area C

2.5.1 Active forces – Sea Area C

The acting forces to be taken into account according to the IMO/ILO/UN ECE Guidelines for Packing of Cargo Transport Units at a sea transport are

- Lengthways: 0.4 × cargo weight
- Sideways: 0.8 × cargo weight

Figure 5 - Acting sideway forces – Sea Area B

When designing a cargo securing arrangement the longitudinal forces in lengthways direction is combined with static gravity force of 1.0 g acting downwards and a dynamic variation of ± 0.8 g.

A CTU designed for the acting forces at sea area C is the ISO-standard freight container. All walls in the freight container can be used in blocking the cargo.

2.6 Railway transport

2.6.1 Active forces – Rail Transport

The general forces to be taken into account according to the International Union of Railways UIC at railway transport are

- Lengthways: Up to four times the weight of the load for goods that are rigidly secured
- Sideways: Up to 0.5 times the weight of the load
- Vertically: Up to 0.3 times the weight of the load (sliding only)

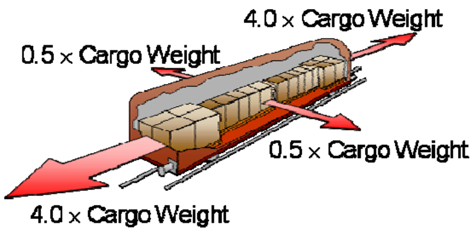


Figure 6 - Acting forces –Rail

2.6.2 Active forces – Intermodal Transport (Combi)

In this report an intermodal transport is a combined transport with several modes of transports in the transport chain. The cargo is loaded in the same cargo transport unit during the transport and a railway transport is included in the transport chain.

The general forces to be taken into account according to the International Union of Railways UIC at combined railway transport are;

- Lengthways: Up to 1.0 times the weight of the load for goods that can slide lengthways in the wagon
- Sideways: Up to 0.5 times the weight of the load
- Vertically: Up to 0.3 times the weight of the load

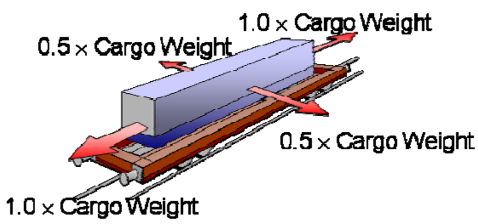


Figure 7 - Acting forces –Combi

2.7 Summary

In this report the value of the acting forces that could arise during transports, according to UIC (rail), IMO (sea) and EU Best Practice Guidelines (road), are summarised in the table below;

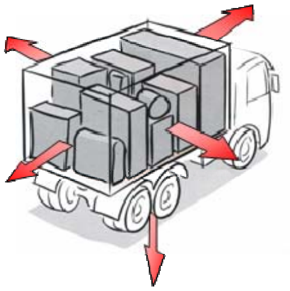


Figure 8 - Directions of Acting forces

Mode of transport	Forwards	Backwards	Sideways
Railway	4.0 g	4.0 g	0.5 g [d]
Rail (block train and combined transport)	1.0 g	1.0 g	0.5 g [d]
Road	1.0 g	0.5 g	0.5 g
Sea Baltic Sea	0.3 g [a]	0.3 g [a]	0.5 g
North Sea	0.3 g [b]	0.3 g [b]	0.7 g
Unrestricted	0.4 g [c]	0.4 g [c]	0.8 g
The above values should be combined with static gravity force of 1.0 g acting downwards and a dynamic variation of: a/ ± 0.5 g	b/ ± 0.7 g	c/ ± 0.8 g	d/ ± 0.3 g (at sliding only)

Table 1 - Acting forces at different directions and mode of transport

In the following sections the magnitude of the designing forces that can be expected during different modes of transport is taken to account. However, it should be in mind that the values mentioned are to be seen as extremes that do not occur in every transport but may arise on single occasions.

It is quite obvious that a trailer is not affected by a hard braking during every transport. It is just as obvious that the cargo must not launch like projectiles and maybe injure the driver or other road-user at an incident where hard braking is necessary.

The same applies for sea transport. Fortunately there are not continuously storms and large waves at sea, but when a storm occurs the cargo securing must be performed in such a way that the crew of the ship has a reasonable chance of salvaging both themselves, the ship and the cargo into port without damages.

However, when the cargo is loaded, it cannot be foreseen if the CTU will be subject to hard breaking, shunting bumps or sea rolling during the transport.

The general requirement must be;

The cargo must always be secured to sustain the worst occurrences in the entire transport chain.

3. Types of Cargo Transport Units (CTU)

Cargo Transport Units (CTU) used in intermodal transports are mainly

- Semi-trailers
- Swap-bodies
- Freight containers

The design of the CTUs superstructure is an important item regarding the efficiency of the cargo securing and the probability of breakage. In this report the superstructures are dived into three different groups depending on the strength of the CTUs side walls

3.1 Type 1 - CTU with rigid superstructure

Superstructures of type 1 have rigid walls. Common is that the superstructures are built according to some kind of international standard or regulation depending on which type of CTU and superstructure it is. Three different main combinations of CTU and superstructures have rigid sides;

1a.
Box type with side walls fulfilling the required strength in European standard

- EN 283 (swap body) or
- EN 12642 L (vehicles)

Figure 9 - Example of box type

1b.
All vehicle types with sides fulfilling the required strength in European standard

- EN 12642 XL

Figure 10 - Example of curtainsiders according to EN 12642 XL

1.c
Freight Containers built according to ISO-standards.

Figure 11 - Example of freight containers

The sides of the CTU of type 1 can be used as blocking device in sideways direction for all mode of transports except for sea area B and C where only freight containers built according to ISO- standards (type 1c) are strong enough.

3.2 Type 2 - CTU with semi-rigid superstructure

Superstructures of type 2 have some part of the side which can be seen as rigid. Common is that the superstructures are built according to some kind of international standard or regulation depending on which type of CTU and superstructure it is.

The superstructure consists of sideboard or equivalent with a height of at least 60 cm and cover/stake body. The superstructure shall fulfil the required strength in European standard

- EN 283 (swap body) or
- EN 12642 L (vehicles)

Figure 12 - Example of sideboards and cover/stake body

The sides of the CTU of type 2 can partly be used as at least bottom blocking device in sideways direction. The strength of the CTU sides are limited. This means that the weights of the cargo which can be blocked also are restricted.

3.3 Type 3 - CTU with non-rigid superstructure

Superstructures of type 3 have non-rigid sides. The superstructure can only be used as weather protection.

CTUs of type 3 have sides of the superstructure doesn't fulfil the required strength according to European standard
- EN 283 (swap body)
- EN 12642 L (vehicle)

or curtainsiders built according to
- EN 283 (swap body)
- EN 12642 L (vehicle)

Figure 13 - Example of Curtainsiders according to EN 12642 L

One reason to Curtainsiders built according EN 283 or EN 12642 L not can be used in sideways blocking is the high flexibility in the vehicle side. At a cargo shift the vehicle side could flex out more than 30 cm and movement of cargo centre is enough to tip the vehicle.
Furthermore the roof design is often so weak that it collapses at cargo shifting.

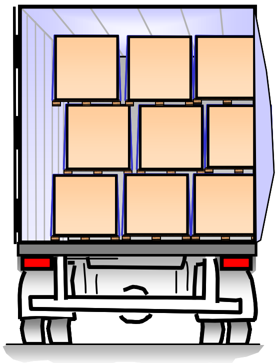


Figure 14 - Cargo shifting in a CTU of type 3

3.4 Comparison between demands on sides

In the figure below a comparison between different superstructures built according to different standards and which type of superstructures is shown;

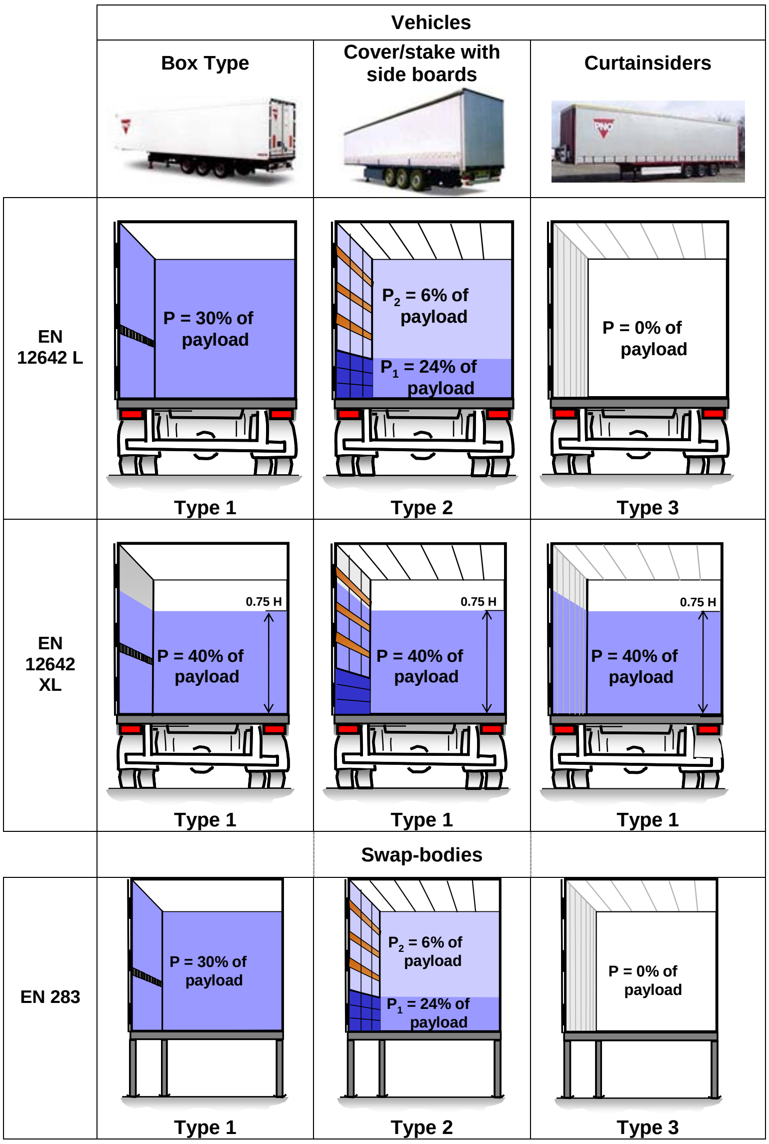


Figure 15 - Comparison between different superstructures

4. Types of Cargo

The cargo is divided into 3 different groups depending on the value of the cargo;

- Low value cargo < 10 kSEK/ton
- Mid value cargo 10-50 kSEK/ton
- High value cargo > 100 kSEK/ton

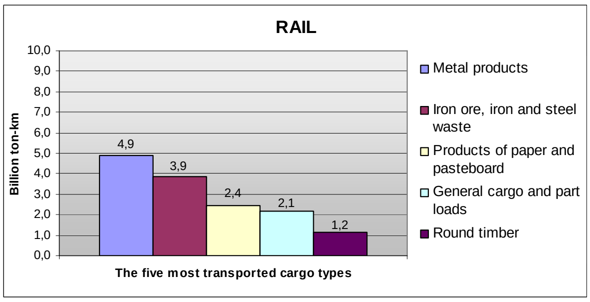
In Swedish transport statistics the goods are divided into 24 freight categories. These categories have, depending on the value of the goods, been classified into the three groups [SIKA-Statens institut för kommunikationsanalys].

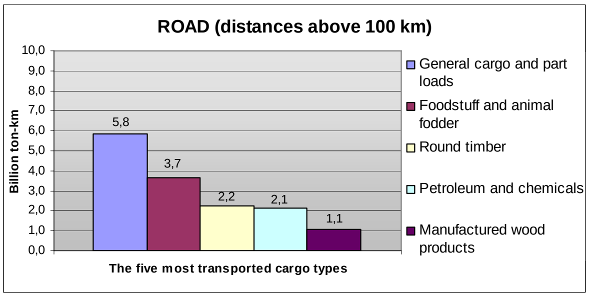
The categories are:

Freight category	Value group
Cereals	Low value
Potatoes, fruits and vegetables	Low value
Live animals, sugar beet	Low value
Round timber	Low value
Oil seeds and fats	Low value
Solid mineral fuels	Low value
Cement, lime, manufactured building materials	Low value
Misc. articles incl. packaging	Low value
Other waste incl. snow	Low value
Crude petroleum	Bulk cargo (Low value)
Petroleum products	Bulk cargo (Low value)
Iron ore, iron and steel waste	Bulk cargo (Low value)
Non-ferrous ores	Bulk cargo (Low value)
Crude and manufactured minerals	Bulk cargo (Low value)
Earth, sand and gravel	Bulk cargo (Low value)
Coal chemicals, tar	Bulk cargo (Low value)
Wood and cork	Middle high value
Manufactured wood products	Middle high value
Wood chip and waste wood	Middle high value
Textiles	Middle high value
Foodstuff and animal fodder	Middle high value
Metal products	Middle high value
Fertilisers	Middle high value
Chemicals	Middle high value
Pulp and waste paper	Middle high value
Products of paper and pasteboard	Middle high value
Transport equipment, machinery	High value
Products of metal	High value
Glass, glassware, ceramic products	High value
Leather textile, clothing, other manufactured articles	High value
General cargo and part loads	High value

Table 2 - Freight Categories

The five largest types of products measured in transport performance (for each of the three modes of transport) are shown in the diagrams below [SIKA].





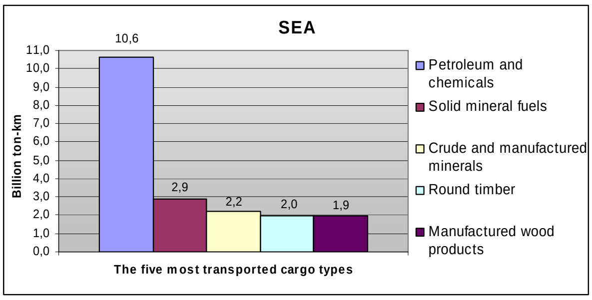


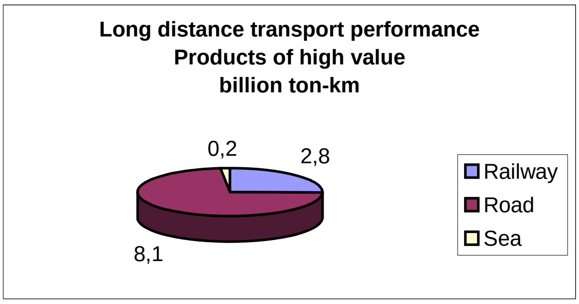
Diagram 1-3 - Most commonly transported types of goods for different modes of transport.

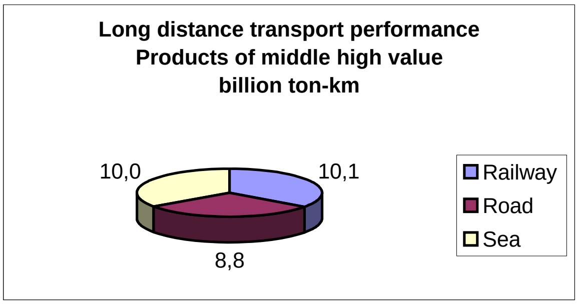
Scrutinising the above statistics gives clear evidence that road transports dominates the ”high value” goods sector.

In the same table it could also be noted that “low value goods” and goods in large volumes are the most commonly transported goods by sea transport. This could be explained by the fact that most oil and chemical products are considered as low value/bulk cargo and are transported in vast volumes by sea.

In the segment ”Products of middle high value” the breakdown between the various transport modes are quite evenly distributed.

Please note that in transport by rail the product group ”Misc. articles incl. packaging” is not specified in ”Part loads” i.e. the group as whole is to be found in ”Products of high value” while values in the group for road transports are divided in 90% for ”Products of high value” and the remaining 10% in ”Products of low value”.





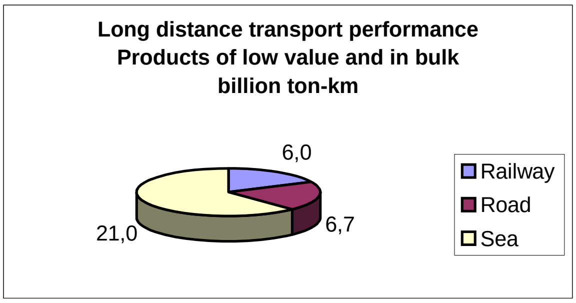


Diagram 4-6 - Long distance transport performance for high value products in billion ton-km.

From the figures in the statistics it can clearly be seen that only a small share (25%) of the goods of high value is transported by rail. One reason for this could be that the rail transport is considered as a harsh transport environmental for the goods compared with other means of transport.

5. Cost of typical types of securing arrangements

In this chapter the cost of the securing arrangements for different type of cargo transported at different modes of transport will be calculated. The securing arrangement for road and sea area A is the same and will be treated as one mode of transport (Road/Sea A). The examples of cargo securing arrangements are based on the regulations described in chapter 3. The cargo is supposed to be loaded against a headboard with required strength to prevent the cargo from sliding and tipping in forward direction. The securing arrangements described are to prevent sliding and tipping in sideways and backwards direction. The CTU platform material is wooden for all types of CTUs.

Examples of securing arrangements for different type of cargo, type of CTU and mode of transport are described in section 5.3 - 5.5. The cost for the different cargo securing arrangements is calculated and can be compared with the result in section 5.2.5.

5.1 Bases of the cost comparison

5.1.1 Lashcost (LSC-model)

The Transport Research Institute (TFK) in Sweden has developed the LASHCOST-model[2] (LSC) during 2001. The LSC-model is used as a model to calculate the cost (lashing cost) for the different securing arrangements in this chapter. The LSC-model divides the lashing cost in the following six basic elements (the labels refer to the TFK-report):

- Labour cost for cargo securing at loading and unloading - CLSL
- Cost for cargo securing equipment - CMES
- Cost for machines and handling equipment - CLLU
- Cost for Cargo Transport Unit (CTU) and vehicles - CLCV
- Capital cost of the cargo during handling and transport - CLTH
- Cost for cargo securing training - CLTS

Under each basic cost element there are several cost components defined in the LSC-model. Below is only the cost components considered described. A detailed description of the LSC-model can be found in the TFK-report.

All the costs are in Swedish Crowns SEK and expressed as cost per transportation and volume or weight unit.

[2] TFK Report 2001:3, Peter Bark, Ann-Sofi Granberg, Gunnar Janson and Rolf Nordström

Labor cost for cargo securing at loading and unloading - CLSL

LCLS – Cost for personnel who manually are loading and securing the cargo.

Man-hour × cost/man-hour

LLCU - Cost for personnel who manually are unloading and un-securing the cargo.

Man-hour × cost/man-hour

Cost for cargo securing equipment - CMES

PNDS – Purchase cost for one-way cargo securing equipment

Purchase cost per transportation

LRMS – Cost for re-usable cargo securing equipment.

Yearly cost / No. of transportations per year

Cost for machines and handling equipment - CLLU

Not considered in these analysis.

Cost for Cargo Transport Unit (CTU) and vehicles - CLCV

Not considered in these analysis.

Capital cost of the cargo during handling and transport - CLTH

Not considered in these analysis

Cost for cargo securing training - CLTS

Not considered in these analysis

5.1.2 Time consumption – lashings

The time consumption to perform the different alternatives of cargo securing is estimated to the following values:

– Scotches or wooden bars	2	min/scotch or bar
– Nails	0.5	min/nail
– Top-over lashing	5	min/lashing
– Loop lashing	10	min/lashing
– Spring lashing	10	min/lashing
– Straight/cross lashing	5	min/lashing
– Round-turn lashing	10	min/lashing
– H-brace (pre-manufactured)	5	min/H-brace
– Blocking with empty pallets	1	min/pallet

The time value includes securing and un-securing the different alternative methods.

5.1.3 Other presumptions

All other presumptions - man-hour cost, lashing costs etc, are taken from the LSC-model shown in the table below:

DESCRIPTION	Label	Unit	Value		
Labour cost					
Labour cost loading personnel	HLLS	SEK/h	183.5		
Labour cost un-loading personnel	HLUC	SEK/h	183.5		
Purchasing cost one way equipment					
One-way web lashing	PNDS2	SEK/m	3.5		
Locking to one-way web lashing	PNDS3	SEK/pcs	5		
Wooden bar	PNDS5	SEK/m	12		
Nails	PNDS8	SEK/pcs	0.8		
Edge protection	PDNS12	SEK/m	3		
Supporting edge beam	PNDS13	SEK/m	24		
Scotches	PNDS14	SEK/pcs	12		
H-brace	PNDS15	SEK/pcs	54		
Empty pallets	PNDS16	SEK/pcs	38.5		
Purchasing cost returnable equipment				**Label**	**Life time**
Web lashing with ratchet	PCRS2	SEK/pcs	90	LLMS2	1 year
Chain	PCRS3	SEK/m	30	LLMS3	1 year

Table 3 - Presumptions made in the LSC-model

Remarks:

- The returnable equipment is used 33 times/year.
- The model doesn't consider different prices for different strength of equipment
- The currency is SEK (Swedish Kronor); 9 SEK ≈ 1 EURO

5.1.4 Cost for different securing methods according to LSC-model

With the base data from the previous sections the cost for actual cargo securing methods according to the LSC-model are as follows:

Securing method	Cost per lashing [SEK]
Top-over lashing	18
Loop lashing	37
Straight lashing	37

Table 4 - Cost of different lashing methods

5.2 Cost comparison of cargo securing

Some assumption is done to simplify the cost comparison of cargo securing between different transport modes, type of CTU and type of cargo;

- The cargo securing taken into account is only to prevent sideways sliding.
  In the majority of cargo securing arrangements the cargo is blocked in length-ways direction to the headboard, front wall etc. In most cases it is the sideways sliding which determine the number of lashings.
- Four different methods to prevent the cargo from sideways sliding is taken into account;
    - top-over lashing
    - loop lashing
    - straight lashing
    - blocking against the side of CTU

5.2.1 The distribution of friction

Except the value of the designing forces, see chapter 2.7, and the dimensions of the cargo the coefficient of friction is an important factor to decide the number of lashing to prevent sideways sliding.

In the project SAFEDOR a numerous CTUs with a various type of cargo were inspected. The coefficient of friction was determined at the different CTUs and the result of the inspections was statistical calculated. The coefficient of friction was found normal distributed with an average μ = 0,441 and a standard deviation σ = 0,079.

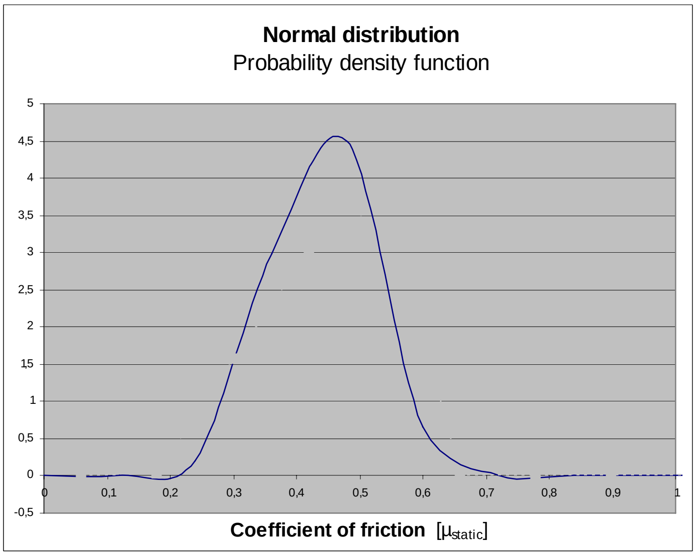


Diagram 7 - Probability of coefficient of friction

The probability for different interval of friction was calculated with a cumulative distribution function;

μ	< 0,2	0,2 - 0,3	0,3 - 0,4	0,4 - 0,5	0,5 - 0,6	> 0,7
Probability	0.001	0.036	0.265	0.471	0.206	0.022

Table 5 - Probability of friction

5.2.2 The effectiveness of lashing preventing sideways sliding

According to the regulation for the different modes of transport one lashing or one pair of lashings (loop and straight lashings) can prevent the following number of tons of cargo from sideways sliding.

[ton/lashing]	μ	0,2	0,3	0,4	0,5	0,6	0,7
Road/ Sea A	Top-over	0.5	1.2	3.2	No sliding	No sliding	No sliding
	Loop	4.2	5.5	7.7	No sliding	No sliding	No sliding
	Straight	2.6	3.8	5.8	No sliding	No sliding	No sliding
Sea B	Top-over	0.3	0.6	1.0	2.0	4.8	No sliding
	Loop	2.7	3.3	4.1	5.1	6.8	No sliding
	Straight	1.6	2.2	3.0	4.2	5.8	No sliding
Sea C	Top-over	0.2	0.4	0.8	1.3	2.4	5.5
	Loop	2.3	2.7	3.3	4.0	5.0	6.4
	Straight	1.4	1.8	2.4	3.2	4.2	5.8
Combi	Top-over	0.4	0.8	1.4	2.6	6.0	56.0
	Loop	3.7	4.5	5.6	7.0	9.1	12.6
	Straight	4.0	4.8	5.8	7.0	8.2	9.4

Table 6 - Tons of cargo prevented from sideways sliding – different lashing methods

5.2.3 The cost/ton for different lashing methods

With the cost for each lashing from the LSC-model, section 5.1.4, and the effectiveness of each lashing from the regulation, section 5.2.2, the cost for different lashing methods can be calculated. The average cost is calculated with distribution of friction from section 5.2.1.

[SEK/ton]	μ	0,2	0,3	0,4	0,5	0,6	0,7	Average cost
Road/ Sea A	Top-over	36.0	15.0	5.6	0.0	0.0	0.0	2.1
	Loop	8.8	6.7	4.8	0.0	0.0	0.0	1.5
	Straight	14.2	9.7	6.4	0.0	0.0	0.0	2.1
Sea B	Top-over	60.0	30.0	18.0	9.0	3.8	0.0	10.9
	Loop	13.7	11.2	9.0	7.3	5.4	0.0	7.3
	Straight	23.1	16.8	12.3	8.8	6.4	0.0	9.4
Sea C	Top-over	90.0	45.0	22.5	13.8	7.5	3.3	15.8
	Loop	16.1	13.7	11.2	9.3	7.4	5.8	9.5
	Straight	26.4	20.6	15.4	11.6	8.8	6.4	12.2
Combi	Top-over	45.0	22.5	12.9	6.9	3.0	0.3	8.1
	Loop	10.0	8.2	6.6	5.3	4.1	2.9	5.4
	Straight	9.3	7.7	6.4	5.3	4.5	3.9	5.5

Table 7 - Cost/ton – different lashing methods

5.2.4 Use of different of cargo securing methods

The use of different cargo methods to prevent sideways sliding for different modes of transport, CTU and type of cargo was estimated by experience to the following values:

CTU - type 1

	Method	Low value	Mid value	High value
Road/ Sea A	Top-over	15%	10%	5%
	Loop	15%	10%	5%
	Straight	0%	0%	0%
	Block	70%	80%	90%
Sea B	Top-over	15%	10%	5%
	Loop	15%	10%	5%
	Straight	10%	10%	10%
	Block	60%	70%	80%
Sea C	Top-over	30%	25%	20%
	Loop	15%	10%	5%
	Straight	15%	15%	15%
	Block	40%	50%	60%
Combi	Top-over	15%	10%	5%
	Loop	15%	10%	5%
	Straight	0%	0%	0%
	Block	70%	80%	90%

Table 8 - Use of different cargo securing – CTU Type 1

CTU - type 2

	Method	Low value	Mid value	High value
Road/ Sea A	Top-over	45%	45%	45%
	Loop	15%	10%	5%
	Straight	5%	5%	5%
	Block	35%	40%	45%
Sea B	Top-over	45%	45%	45%
	Loop	15%	10%	5%
	Straight	10%	10%	10%
	Block	30%	35%	40%
Sea C	Top-over	50%	50%	50%
	Loop	15%	10%	5%
	Straight	15%	15%	15%
	Block	20%	25%	30%
Combi	Top-over	45%	45%	45%
	Loop	15%	10%	5%
	Straight	5%	5%	5%
	Block	35%	40%	45%

Table 9 - Use of different cargo securing – CTU Type 2

CTU - type 3

	Method	Low value	Mid value	High value
Road/ Sea A	Top-over	80%	85%	90%
	Loop	15%	10%	5%
	Straight	5%	5%	5%
	Block	0%	0%	0%
Sea B	Top-over	75%	80%	85%
	Loop	15%	10%	5%
	Straight	10%	10%	10%
	Block	0%	0%	0%
Sea C	Top-over	70%	75%	80%
	Loop	15%	10%	5%
	Straight	15%	15%	15%
	Block	0%	0%	0%
Combi	Top-over	80%	85%	90%
	Loop	15%	10%	5%
	Straight	5%	5%	5%
	Block	0%	0%	0%

Table 10 - Use of different cargo securing – CTU Type 3

5.2.5 Result - Cost comparison cargo securing

With input from the previous sections the cost for cargo securing for different modes of transport, CTU and type of cargo was calculated:

[SEK/ton]	Type of CTU	Low value	Mid value	High value
Road/ Sea A	Type 1	0.5	0.4	0.2
	Type 2	1.3	1.2	1.1
	Type 3	2.0	2.0	2.0
Sea B	Type 1	3.7	2.8	1.8
	Type 2	7.0	6.6	6.2
	Type 3	10.2	10.4	10.6
Sea C	Type 1	8.0	6.7	5.5
	Type 2	11.2	10.7	10.2
	Type 3	14.3	14.6	15.0
Combi	Type 1	2.0	1.4	0.7
	Type 2	4.8	4.5	4.2
	Type 3	7.6	7.7	7.9

Table 11 - Cost of different cargo securing methods for different mode of transport

5.3 Example of securing of low value cargo

5.3.1 Example 1 - Low value cargo

The chosen cargo of low value cargo is big bags. Two big bags are loaded on one EUR-pallets in sections of two pallets. Each section has the following dimensions;

Height: H = 1.0 m
Breadth: B = 2.4 m
Length: L = 1.0 m
Weight: W = 1 ton

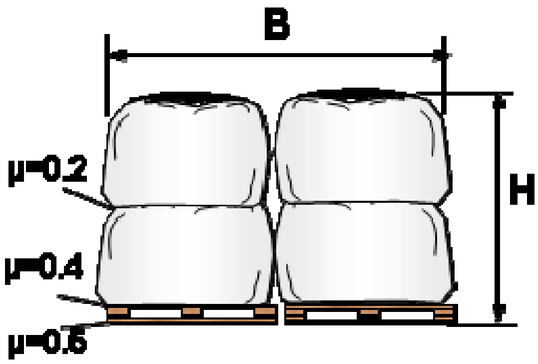


Figure 16 - Low value cargo section

The cargo is loaded in 11 sections with the total cargo weight of 11 tons.

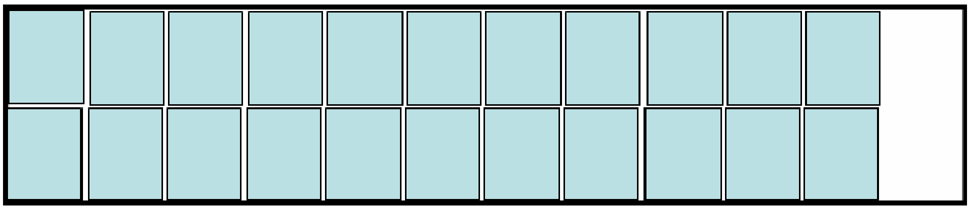


Figure 17 - Loading Pattern – Low Value Cargo

5.3.2 Securing arrangement Low value cargo – Road/Sea A

CTU – Type 1:
The cargo is blocked against the side walls which have enough strength to prevent sideways sliding and tipping. One top-over lashing is set on the last cargo section to prevent backward wandering.

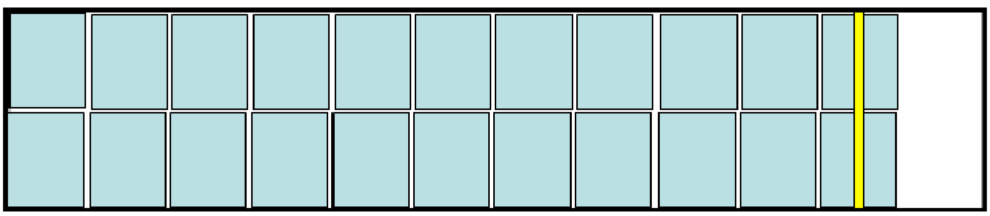


Figure 18 - Securing Arrangement – Low Value Cargo in CTU type 1 at Road/Sea A Transport

CTU – Type 2:
The cargo is blocked against the side boards which have enough strength to prevent sideways sliding and tipping. The second layer is prevented from sliding only if the side board has a minimum height of 60 cm. One top-over lashing is set on the last cargo section to prevent backward wandering.

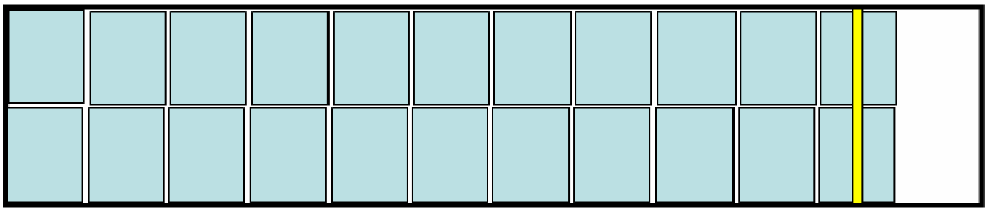


Figure 19 - Securing Arrangement – Low Value Cargo in CTU type 2 at Road/Sea A Transport

CTU – Type 3:
The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by one top-over lashing on each cargo section.

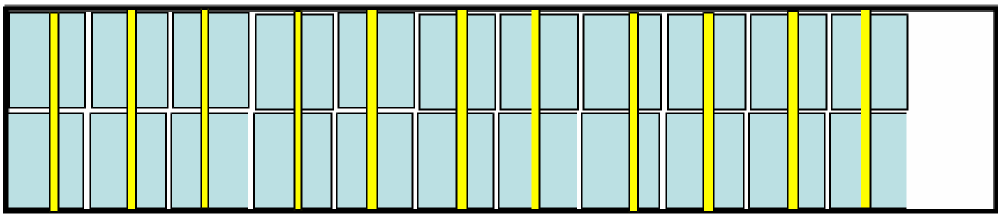


Figure 20 - Securing Arrangement – Low Value Cargo in CTU type 3 at Road/Sea A Transport

5.3.3 Securing arrangement Low value cargo – Sea B

CTU – Type 1:
The cargo is blocked against the side walls which have enough strength to prevent sideways sliding and tipping. One top-over lashing is set on the last cargo section to prevent backward wandering.

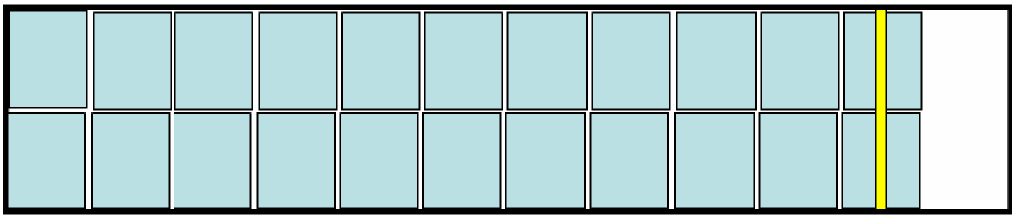


Figure 21 - Securing Arrangement – Low Value Cargo in CTU type 1 at Sea B Transport

CTU – Type 2:
The cargo is blocked against the side boards which have enough strength to prevent sideways sliding and tipping for the bottom layer. The top layer has to be secured by one top-over lashing/cargo section to prevent sideways sliding.

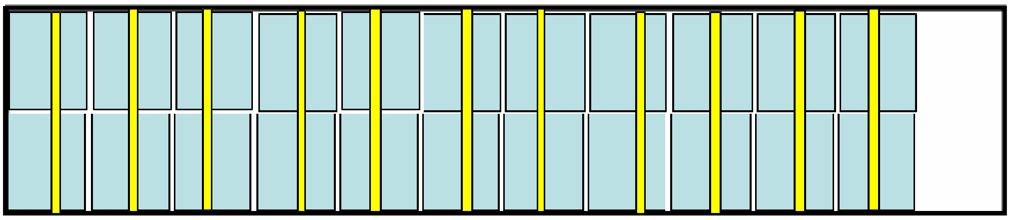


Figure 22 - Securing Arrangement – Low Value Cargo in CTU type21 at Sea B Transport

CTU – Type 3:
The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by two top-over lashings on each cargo section.

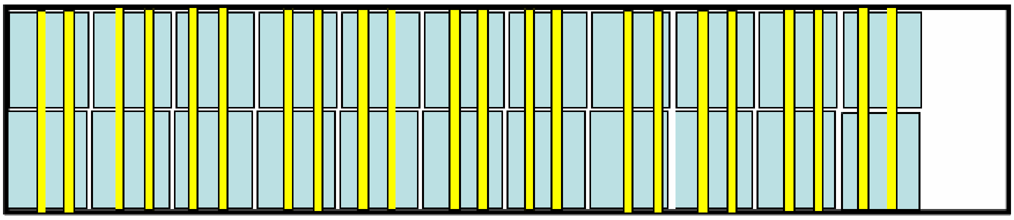


Figure 23 - Securing Arrangement – Low Value Cargo in CTU type 3 at Sea B Transport

5.3.4 Securing arrangement – Sea C

CTU – Type 1:
The cargo is blocked against the side walls but the strength of the walls is not enough to prevent sideways sliding. To support the side walls one top-over lashing/cargo section is set to prevent sideways sliding.

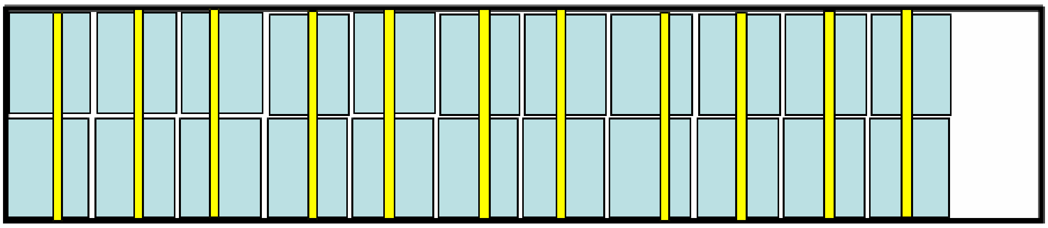


Figure 24 - Securing Arrangement – Low Value Cargo in CTU type 1 at Sea C Transport

CTU – Type 2:
The cargo is blocked against the side boards but the strength of the side board is not enough to prevent sideways sliding. The cargo has to be secured by two top-over lashing/cargo section to prevent sideways sliding.

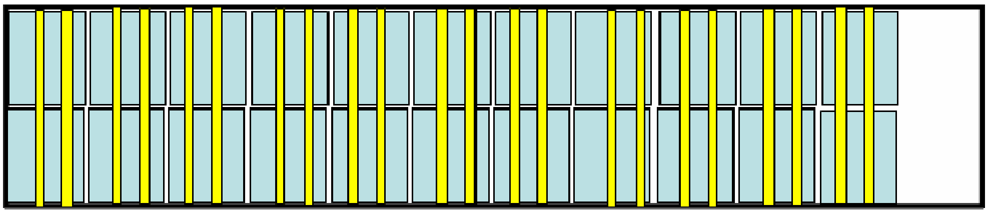


Figure 25 - Securing Arrangement – Low Value Cargo in CTU type 2 at Sea C Transport

CTU – Type 3:
The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by three top-over lashings on each cargo section.

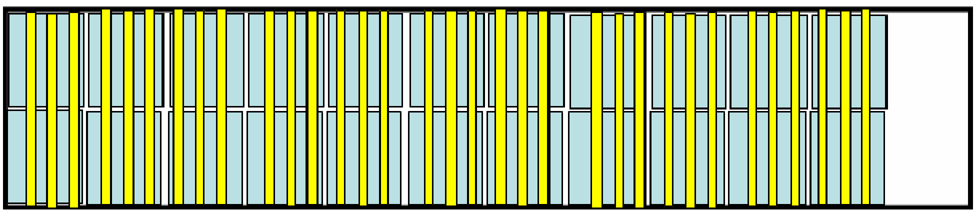


Figure 26 - Securing Arrangement – Low Value Cargo in CTU type 3 at Sea C Transport

5.3.5 Securing arrangement Low value cargo – Intermodal transport (Combi)

CTU – Type 1:
The cargo is blocked against the side walls which have enough strength to prevent sideways sliding and tipping. One top-over lashing is set on the last cargo section to prevent backward tipping and empty pallets block the cargo from backward sliding.

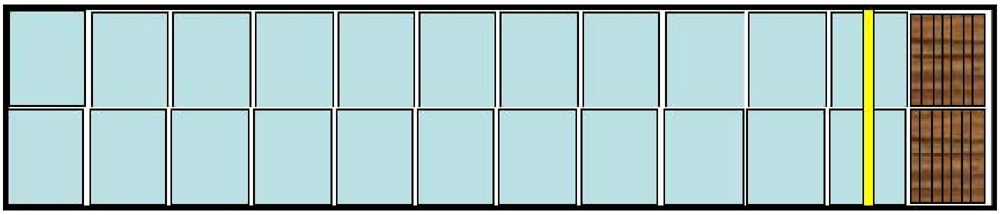


Figure 27 - Securing Arrangement – Low Value Cargo in CTU type 1 at Combi Transport

CTU – Type 2:
The cargo is blocked against the side boards which have enough strength to prevent sideways sliding and tipping. The second layer is prevented from sliding only if the side board has a minimum height of 60 cm. One top-over lashing is set on the last cargo section to prevent backward tipping and empty pallets block the cargo from backward sliding.

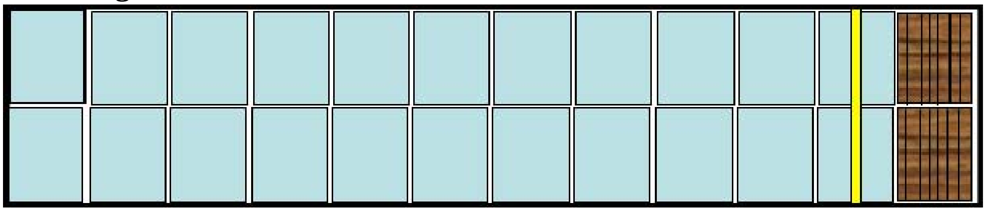


Figure 28 - Securing Arrangement – Low Value Cargo in CTU type 2 at Combi Transport

CTU – Type 3:
The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by one top-over lashing on each cargo section. Empty pallets block the cargo from backward sliding.

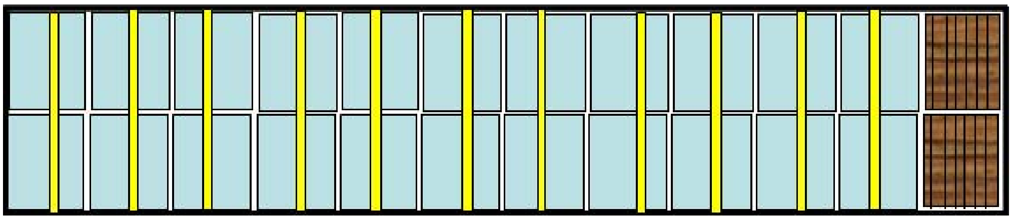


Figure 29 - Securing Arrangement – Low Value Cargo in CTU type 3 at Combi Transport

5.3.6 Input to LSC-model - Low value cargo

The securing arrangements above for low value cargo gives the following input to the LSC –model:

	Input	Road/ Sea A	Sea B	Sea C	Combi
Type 1	**Time consumption for no. of:**				
	- Top-over lashings	1	1	11	1
	- Pallets				4
	Time consumption [min]	**5**	**5**	**55**	**9**
	No. of returnable equipment				
	- Web lashing with ratchet	1	1	1	1
	- Pallets				4
Type 2	**Time consumption for no. of:**				
	- Top-over lashings	1	11	33	1
	- Pallets				4
	Time consumption [min]	**5**	**55**	**165**	**9**
	No. of returnable equipment				
	- Web lashing with ratchet	1	11	33	1
	- Pallets				4
Type 3	**Time consumption for no. of:**				
	- Top-over lashings	11	22	33	11
	- Pallets				4
	Time consumption [min]	**55**	**110**	**165**	**59**
	No. of returnable equipment				
	- Web lashing with ratchet	11	22	33	11
	- Pallets				4

Table 12 - Input to LSC Model – Low value cargo

5.3.7 Result of LSC-model – Low value cargo

Cost for cargo securing [SEK/ton]	Road/ Sea A	Sea B	Sea C	Combi
CTU Type 1	1.6	1.6	18.3	16.8
CTU Type 2	1.6	36.5	54.8	16.8
CTU Type 3	18.5	36.5	54.8	33.4

Table 13 - Result of LSC Model – Low value cargo

5.4 Example of securing of mid value cargo

5.4.1 Example 2 - Mid value cargo

The chosen cargo of mid value cargo is paper reels. One section consists of two paper reels standing on end. Each section has the following dimensions;

Height: H = 2.0 m
Breadth: B = ∅ 2.0 m
Weight: W = 2 ton

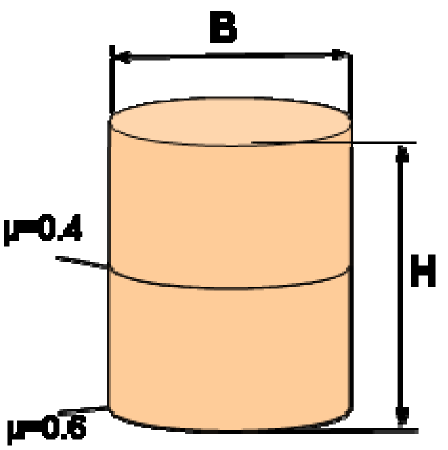


Figure 30 - Mid value cargo section

The cargo is loaded in a zigzag pattern in 6 sections with the total cargo weight of 12 tons. Rubber sheets with μ = 0.6 are placed between the paper reels and the CTU platform.

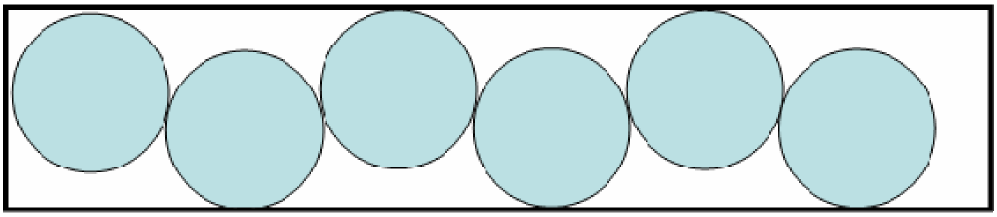


Figure 31 - Loading Pattern – Mid Value Cargo

5.4.2 Securing arrangement Mid value cargo – Road/Sea A

CTU – Type 1:
The cargo is blocked against the side walls which have enough strength to prevent sideways sliding and tipping. One top-over lashing is set on the last cargo section to prevent backward wandering.

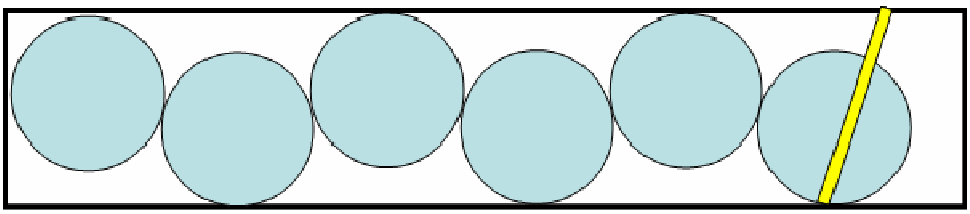


Figure 32 - Securing Arrangement – Mid value Cargo in CTU type 1 at Road/Sea A Transport

CTU – Type 2:
The bottom layer is blocked against the side boards which have enough strength to prevent sideways sliding. The top layer is prevented from sliding by one top-over lashing/cargo section.

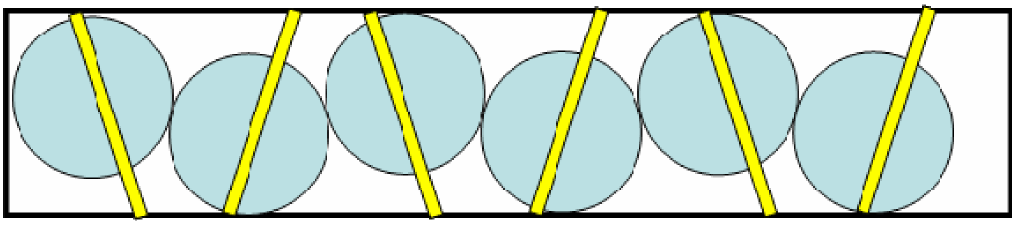


Figure 33 - Securing Arrangement – Mid value Cargo in CTU type 2 at Road/Sea A Transport

CTU – Type 3:
The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by one top-over lashing on each cargo section to prevent sideways sliding.

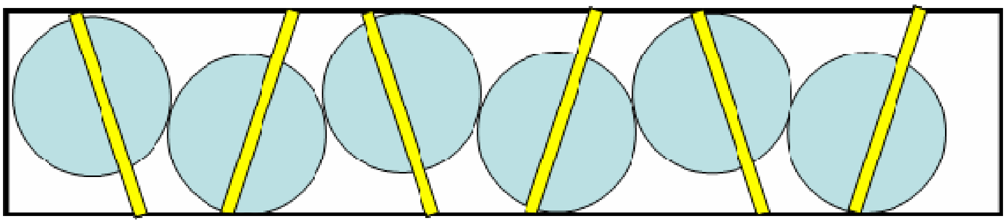


Figure 34 - Securing Arrangement – Mid value Cargo in CTU type 3 at Road/Sea A Transport

5.4.3 Securing arrangement Mid value cargo – Sea B

CTU – Type 1:
The cargo is blocked against the side walls which have enough strength to prevent sideways sliding and tipping. One top-over lashing is set on the last cargo section to prevent backward wandering.

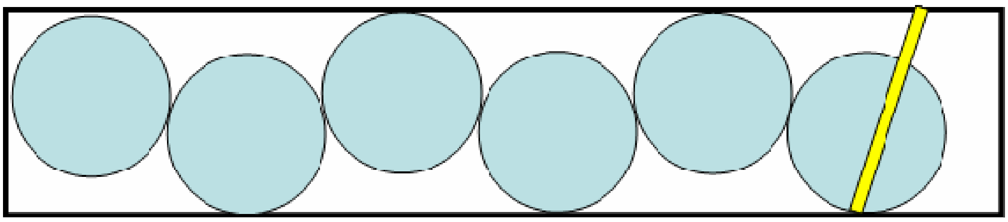


Figure 35 - Securing Arrangement – Mid value Cargo in CTU type 1 at Sea B Transport

CTU – Type 2:
The cargo is blocked against the side boards which have enough strength to prevent sideways sliding and tipping for the bottom layer. The top layer has to be secured by one top-over lashing/cargo section to prevent sideways sliding.

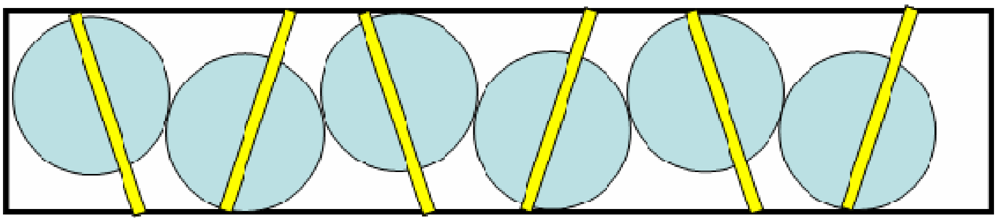


Figure 36 - Securing Arrangement – Mid value Cargo in CTU type 2 at Sea B Transport

CTU – Type 3:
The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by one top-over lashings on each cargo section.

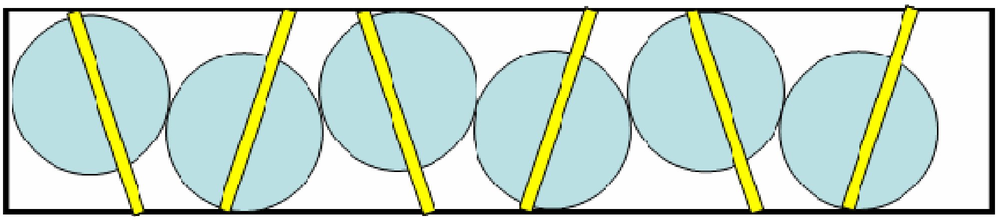


Figure 37 - Securing Arrangement – Mid value Cargo in CTU type 3 at Sea B Transport

5.4.4 Securing arrangement Mid value cargo – Sea C

CTU – Type 1:
The cargo is blocked against the side walls but the strength of the walls is not enough to prevent sideways sliding. To support the side walls one top-over lashing/cargo section is set to prevent sideways sliding.

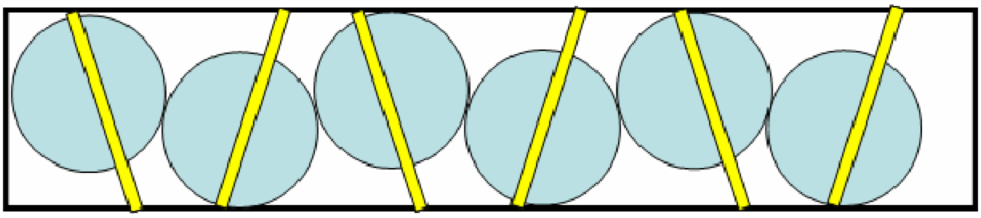


Figure 38 - Securing Arrangement – Mid value Cargo in CTU type 1 at Sea C Transport

CTU – Type 2:
The cargo is blocked against the side boards but the strength of the side board is not enough to prevent sideways sliding. The cargo has to be secured by two top-over lashing/cargo section to prevent sideways sliding.

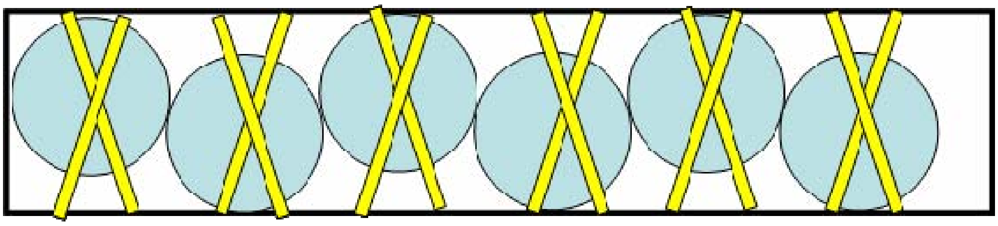


Figure 39 - Securing Arrangement – Mid value Cargo in CTU type 2 at Sea C Transport

CTU – Type 3:
The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by two top-over lashings on each cargo section.

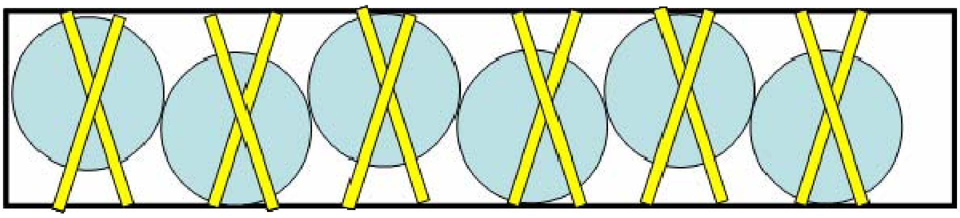


Figure 40 - Securing Arrangement – Mid value Cargo in CTU type 3 at Sea C Transport

5.4.5 Securing arrangement Mid value cargo – Intermodal transport (Combi)

CTU – Type 1:
The cargo is blocked against the side walls which have enough strength to prevent sideways sliding and tipping. One top-over lashing is set on the last cargo section to prevent backward tipping and three empty pallets to prevent backward sliding.

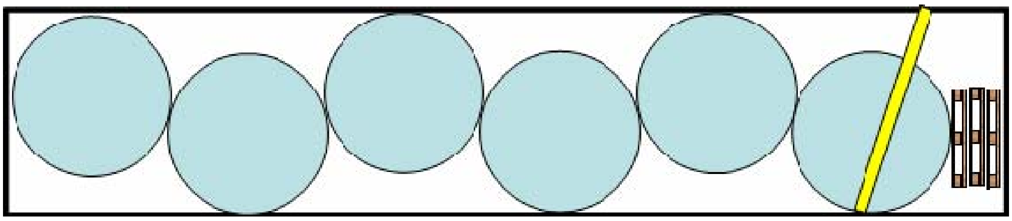


Figure 41 - Securing Arrangement – Mid value Cargo in CTU type 1 at Combi Transport

CTU – Type 2:
The bottom layer is blocked against the side boards which have enough strength to prevent sideways sliding. The top layer is prevented from sliding by one top-over lashing/cargo section. Three empty pallets are placed aft the last cargo section to prevent backward sliding.

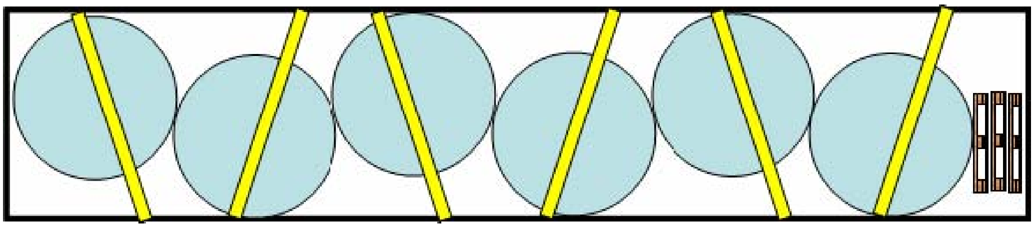


Figure 42 - Securing Arrangement – Mid value Cargo in CTU type 2 at Combi Transport

CTU – Type 3:
The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by one top-over lashing on each cargo section to prevent sideways sliding. Three empty pallets are placed aft the last cargo section to prevent backward sliding.

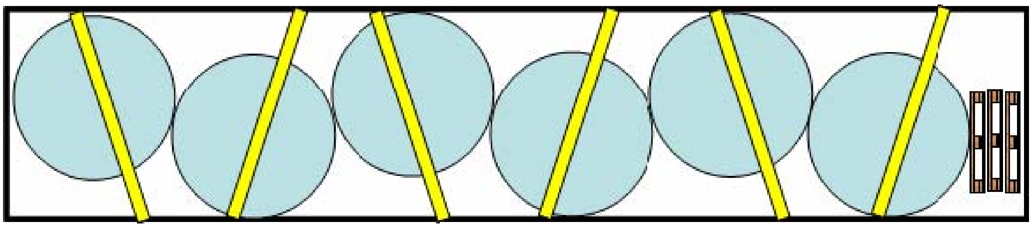


Figure 43 - Securing Arrangement – Mid value Cargo in CTU type 3 at Combi Transport

5.4.6 Input to LSC-model - Mid value cargo

The securing arrangements above for mid value cargo gives the following input to the LSC –model:

	Input	Road/ Sea A	Sea B	Sea C	Combi
Type 1	**Time consumption for no. of:**				
	- Top-over lashings	1	1	1	1
	- Pallets				3
	Time consumption [min]	**5**	**5**	**5**	**8**
	No. of returnable equipment				
	- Web lashing with ratchet	1	1	1	1
	- Pallets				3
Type 2	**Time consumption for no. of:**				
	- Top-over lashings	6	6	12	6
	- Pallets				3
	Time consumption [min]	**30**	**30**	**60**	**33**
	No. of returnable equipment				
	- Web lashing with ratchet	6	6	12	6
	- Pallets				3
Type 3	**Time consumption for no. of:**				
	- Top-over lashings	6	6	12	6
	- Pallets				3
	Time consumption [min]	**30**	**30**	**60**	**33**
	No. of returnable equipment				
	- Web lashing with ratchet	6	6	12	6
	- Pallets				3

Table 14 - Input to LSC Model – Mid value cargo

5.4.7 Result of LSC-model – Mid value cargo

Cost for cargo securing [SEK/ton]	Road/ Sea A	Sea B	Sea C	Combi
CTU Type 1	1.5	1.5	1.5	11.8
CTU Type 2	9.2	9.2	18.3	27.9
CTU Type 3	9.2	9.2	18.3	27.9

Table 15 - Result of LSC Model – Mid value cargo

5.5 Example of securing of high value cargo

5.5.1 Example 3 - High value cargo

The chosen cargo of high value cargo is cardboard boxes with a size of EUR-pallets. The cargo is loaded in section in 3 cargo rows and 3 cargo layers. Each section has the following dimensions;

Height: H = 2.2 m
Breadth: B = 2.4 m
Length: L = 1.2 m
Weight: W = 1 ton

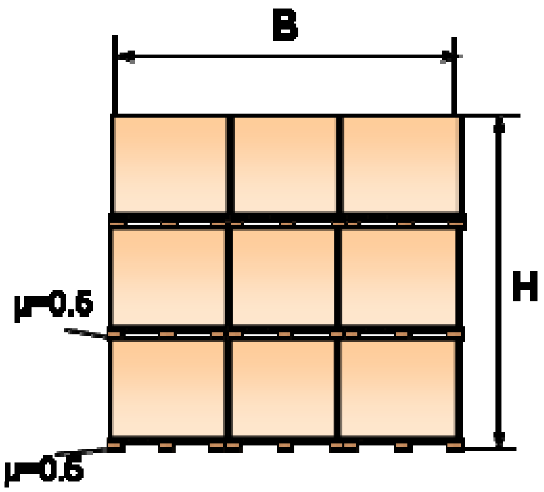


Figure 44 - High value cargo section

The cargo is loaded in 11 sections with the total cargo weight of 11 tons.

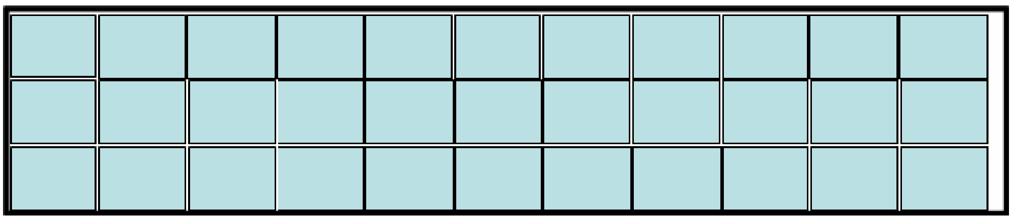


Figure 45 - Loading Pattern – High Value Cargo

5.5.2 Securing arrangement High value cargo – Road/Sea A

CTU – Type 1:
The cargo is blocked against the side walls if the cargo sections are full and no void between the cargo and the wall exist. Otherwise the cargo section has to be lashed or the void has to be filled by empty pallets, dunnage bags etc. One top-over lashing is set on the last cargo section to prevent backward wandering. An alternative is to place 4 empty pallets in the gap between the cargo and end wall.

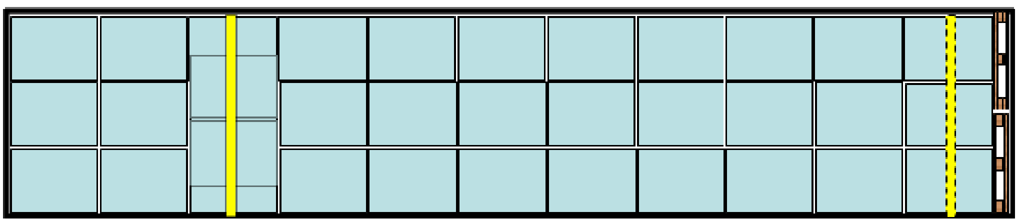


Figure 46 - Securing Arrangement – High value Cargo in CTU type 1 at Road/Sea A Transport

CTU – Type 2:

The bottom layer is blocked against the side boards which have enough strength to prevent sideways sliding. The upper layers are prevented from sliding by the friction μ = 0.5. If the friction is under μ=0.5 or the void between cargo and wall is too large the cargo section has to be lashed or the void has to be filled by empty pallets, dunnage bags etc. One top-over lashing is set on the last cargo section to prevent backward wandering.

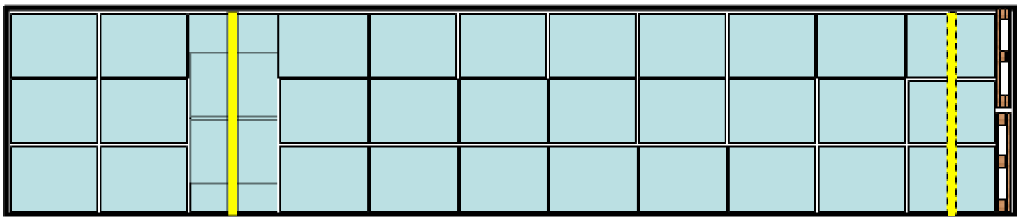


Figure 47 - Securing Arrangement – High value Cargo in CTU type 2 at Road/Sea A Transport

CTU – Type 3:

The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by one top-over lashing on each cargo section.

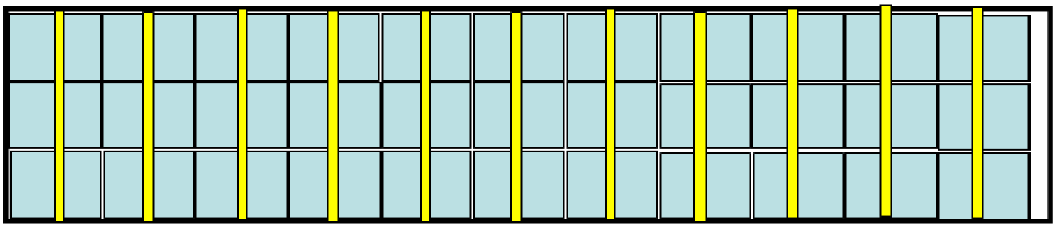


Figure 48 - Securing Arrangement – High value Cargo in CTU type 3 at Road/Sea A Transport

5.5.3 Securing arrangement High value cargo – Sea B

CTU – Type 1:

The cargo is blocked against the side walls if the cargo sections are full and no void between the cargo and the wall exist. Otherwise the cargo section has to be lashed or the void has to be filled by empty pallets, dunnage bags etc. One top-over lashing is set on the last cargo section to prevent backward wandering. An alternative is to place 4 empty pallets in the gap between the cargo and end wall.

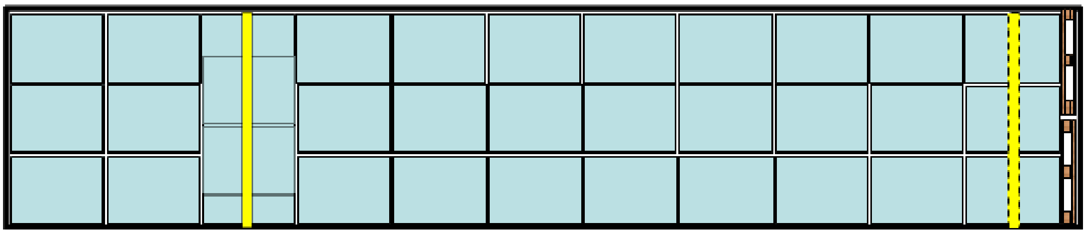


Figure 49 - Securing Arrangement – High value Cargo in CTU type 1 at Sea B Transport

CTU – Type 2:

The cargo is blocked against the side boards which have enough strength to prevent sideways sliding and tipping for the bottom layer. The upper layers have to be secured by one top-over lashing/cargo section to prevent sideways sliding.

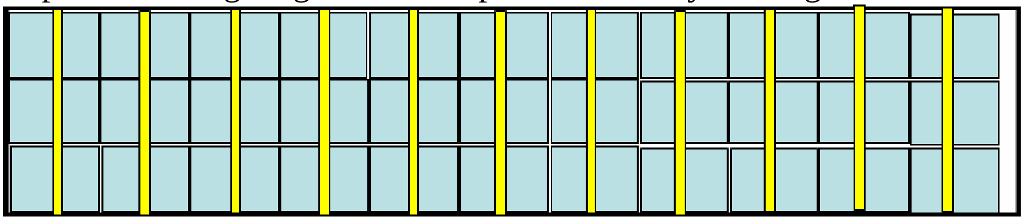


Figure 50 - Securing Arrangement – High value Cargo in CTU type 2 at Sea B Transport

CTU – Type 3:

The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by two top-over lashings on each cargo section to prevent sideways sliding.

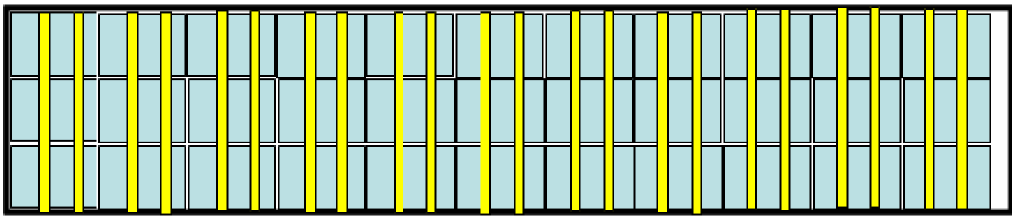


Figure 51 - Securing Arrangement – High value Cargo in CTU type 3 at Sea B Transport

5.5.4 Securing arrangement High value cargo – Sea C

CTU – Type 1:

The cargo is blocked against the side walls if the cargo sections are full and no void between the cargo and the wall exist. Otherwise the cargo section has to be lashed or the void has to be filled by empty pallets, dunnage bags etc. One top-over lashing is set on the last cargo section to prevent backward wandering. An alternative is to place 4 empty pallets in the gap between the cargo and end wall.

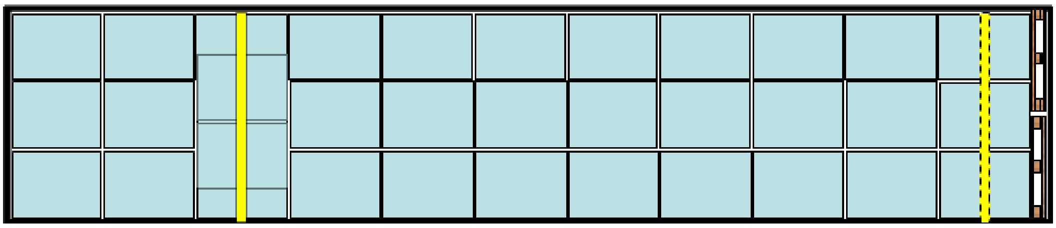


Figure 52 - Securing Arrangement – High value Cargo in CTU type 1 at Sea C Transport

CTU – Type 2:

The cargo is blocked against the side boards but the strength of the side board is not enough to prevent sideways sliding. The cargo has to be secured by one top-over lashing/cargo section to prevent sideways sliding and tipping.

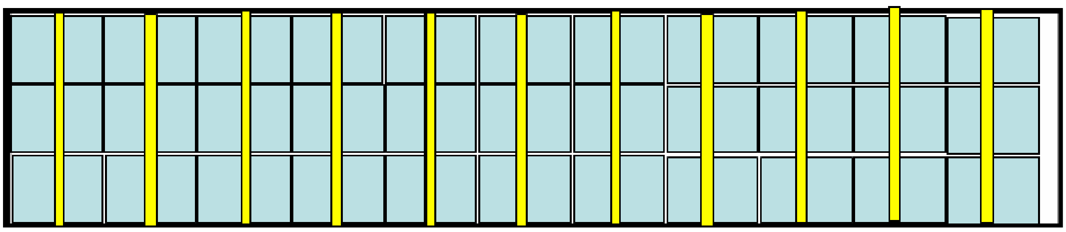


Figure 53 - Securing Arrangement – High value Cargo in CTU type 2 at Sea C Transport

CTU – Type 3:

The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by two top-over lashings on each cargo section to prevent sideways sliding and tipping.

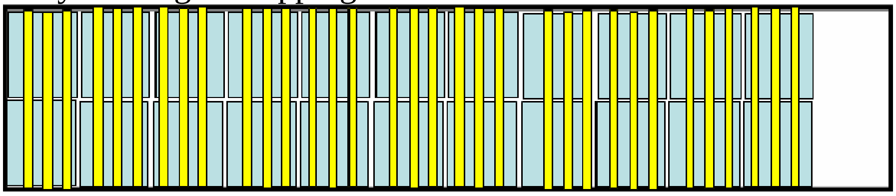


Figure 54 - Securing Arrangement – High value Cargo in CTU type 3 at Sea C Transport

5.5.5 Securing arrangement High value cargo – Intermodal transport (Combi)

CTU – Type 1:

The cargo is blocked against the side walls if the cargo sections are full and no void between the cargo and the wall exist. Otherwise the cargo section has to be lashed or the void has to be filled by empty pallets, dunnage bags etc. Four empty pallets are placed aft the last cargo section to prevent backward sliding and tipping.

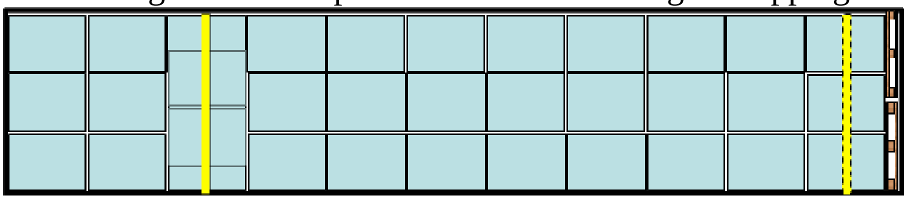


Figure 55 - Securing Arrangement – High value Cargo in CTU type 1 at Combi Transport

CTU – Type 2:

The bottom layer is blocked against the side boards which have enough strength to prevent sideways sliding. The upper layers are prevented from sliding by the friction $\mu = 0.5$. If the friction is under $\mu=0.5$ or the void between cargo and wall is too large the cargo section has to be lashed or the void has to be filled by empty pallets, dunnage bags etc. Four empty pallets are placed aft the last cargo section to prevent backward sliding and tipping.

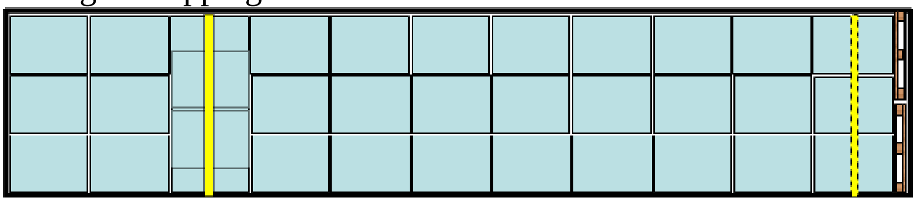


Figure 56 - Securing Arrangement – High value Cargo in CTU type 2 at Combi Transport

CTU – Type 3:

The walls of the cargo transport unit are too weak to be considered as blocking device. The cargo has to be secured by one top-over lashing on each cargo section. Four empty pallets are placed aft the last cargo section to prevent backward sliding and tipping.

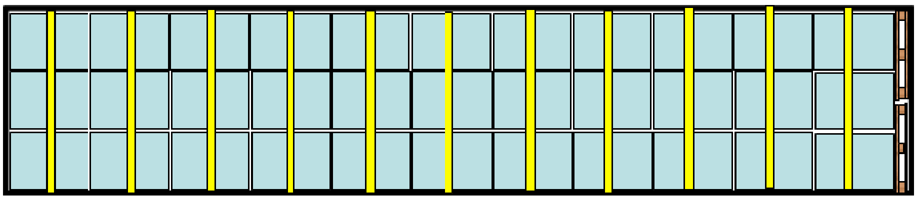


Figure 57 - Securing Arrangement – High value Cargo in CTU type 3 at Combi Transport

5.5.6 Input to LSC-model - High value cargo

The securing arrangements above for high value cargo gives the following input to the LSC –model:

	Input	Road/ Sea A	Sea B	Sea C	Combi
Type 1	**Time consumption for no. of:**				
	- Pallets	4	4	4	4
	Time consumption [min]	**4**	**4**	**4**	**4**
	No. of returnable equipment				
	- Pallets	4	4	4	4
Type 2	**Time consumption for no. of:**				
	- Top-over lashings		11	33	
	- Pallets	4			4
	Time consumption [min]	**4**	**55**	**165**	**4**
	No. of returnable equipment				
	- Web lashing with ratchet		11	33	
	- Pallets	4			4
Type 3	**Time consumption for no. of:**				
	- Top-over lashings	11	11	22	11
	- Pallets				4
	Time consumption [min]	**55**	**55**	**110**	**59**
	No. of returnable equipment				
	- Web lashing with ratchet	11	11	22	11
	- Pallets				4

Table 16 - Input to LSC Model – High value cargo

5.5.7 Result of LSC-model – High value cargo

Cost for cargo securing [SEK/ton]	Road/ Sea A	Sea B	Sea C	Combi
CTU Type 1	15.1	15.1	15.1	15.1
CTU Type 2	15.1	18.3	18.3	15.1
CTU Type 3	18.3	18.3	18.3	33.4

Table 17 - Result of LSC Model – High value cargo

6. Basic method for the calculation of cost of cargo damages

The following method is suggested to calculate the cost of cargo damages in different mode of transport with different CTUs and type of cargo.

Step 1:
The probability of expected maximum sideways accelerations during different mode of transport is estimated in chapter 7.

Step 2:
Next step is to estimate the distribution of the risk of cargo shifting at different sideways accelerations. The estimation is done for different type of CTUs and type of cargo in chapter 8.

Step3:
The proportion of damaged cargo at cargo shifting at different sideways acceleration is estimated depending on the type of cargo and type of CTU in chapter 9.

Step 4:
The risk of cargo damages is calculated with the formula below in chapter 10 with the values from chapter 7-9.

$$P_{mode} = \sum_{a=1}^{a=y} P_{1mode} \times P_{2mode} \times P_{3mode} \qquad \textit{(formula 1)}$$

where;

P_{mode} = Probability of cargo damages at actual mode of transport
a = Sideways acceleration
y = 5 (road, Sea A and Combi), 7 (sea B) or 8 (Sea C)
P_{1mode} = Probability of max sideways acceleration a in actual mode of transport
P_{2mode} = Probability of cargo shifting at sideways acceleration a in actual mode of transport
P_{3mode} = Probability of cargo damages at sideways acceleration a in actual mode of transport

Step 5:
When the risk of cargo damages has been calculated the cost caused by cargo damages can be calculated using average cargo values for the different type of cargo. The cost can be expressed both in SEK/ton and SEK/tonkm.

The estimated cost of cargo damages for an actual transport can then be calculated if the following data is known;

– Transport modes involved (road, sea A, sea B, sea C and/or combi)
– The transport length of the different transport modes
– The type of cargo (low, mid or high value cargo)
– The weight of the cargo
– The type of CTU (type 1, 2 or 3)

If V_{cargo} = average value of the cargo, the formula for cost of cargo damages in one mode of transport is;

(expressed in SEK/ton)

$$C_{D\,mode} = P_{mode} \times V_{cargo} \qquad \textit{(formula 2)}$$

(expressed in SEK/tonkm)

$$C_{D\,mode} = \frac{P_{mode}}{L_{avg\,mode}} \times V_{cargo} \qquad \textit{(formula 3)}$$

if

$L_{avg\,mode}$ = Average transport length at the actual mode of transport

For a total chain of transport the formula for cost of cargo damages is;

(expressed in SEK/ton)

$$C_D = (P_{Road} + P_{SeaA} + P_{SeaB} + P_{SeaC} + P_{Combi}) \cdot V_{cargo} \qquad \textit{(formula 4)}$$

(expressed in SEK/tonkm)

$$C_D = (\frac{P_{Road}}{L_{Road}} + \frac{P_{SeaA}}{L_{SeaA}} + \frac{P_{SeaB}}{L_{SeaB}} + \frac{P_{SeaC}}{L_{SeaC}} + \frac{P_{Combi}}{L_{Combi}}) \cdot V_{cargo} \qquad \textit{(formula 5)}$$

Step 6

The probability of cargo damages is adjusted with a factor ε due to the estimation that the probability of cargo damages is higher in the beginning and at the end of the transportation. A short transport should have a higher proportion of risk than a long transport. The adjusted probability of cargo damages P_a is calculated with the formula;

$$P_{a\,mode} = P_{mode} \times \varepsilon \qquad \textit{(formula 6)}$$

if

$$\varepsilon = \sqrt{\frac{L_{mode}}{L_{avg\,mode}}} \qquad \textit{(formula 7)}$$

with L_{mode} = Transport length of the actual mode of transport
$L_{avg\,mode}$ = Average transport length at the actual mode of transport

The formula for adjusted cost of cargo damages is;

(expressed in SEK/ton)

$$C_{aD} = (P_{aRoad} + P_{aSeaA} + P_{aSeaB} + P_{aSeaC} + P_{aCombi}) \cdot V_{cargo} \qquad \textit{(formula 8)}$$

(expressed in SEK/tonkm)

$$C_{aD} = (\frac{P_{aRoad}}{L_{Road}} + \frac{P_{aSeaA}}{L_{SeaA}} + \frac{P_{aSeaB}}{L_{SeaB}} + \frac{P_{aSeaC}}{L_{SeaC}} + \frac{P_{aCombi}}{L_{Combi}}) \cdot V_{cargo} \qquad \textit{(formula 9)}$$

7. Probability of maximum sideways acceleration

In this chapter the probability for expected maximum sideways acceleration in different modes of transport will be analyzed. All figures and assumptions are estimated. Some input data is coming from the project BREAKAGE[3] and ongoing projects within the SIR-C group will give more accurate values in the future. Statistics for different mode of transport is taken from SIKA.

7.1 Road Transport

At road transport the regulation for cargo securing is stipulating a dimensioning transverse force of 0.5 × cargo weight equal with the sideways acceleration of 5 m/s^2. Tests in the project VERIFY[4] showed that when the transverse forces reach over 0.5 × cargo weight the whole vehicle will tip.

The Swedish statistics over transports [SIKA] gives an average transport length on road of approximately 100 km/transport and each vehicle perform about 1000 transports annually.

The probability of max sideways acceleration is estimated as follows

Max Sideways Acceleration	Estimated Probability	Comments
1	0.8	80 % of the transports
2	0.2	Every 5th transport
3	0.003	3 times a year
4	0.0005	1 time every second year
5	0.0001	1 time every 10th year

Table 18 - Estimated probability of max sideways acceleration at Road transport

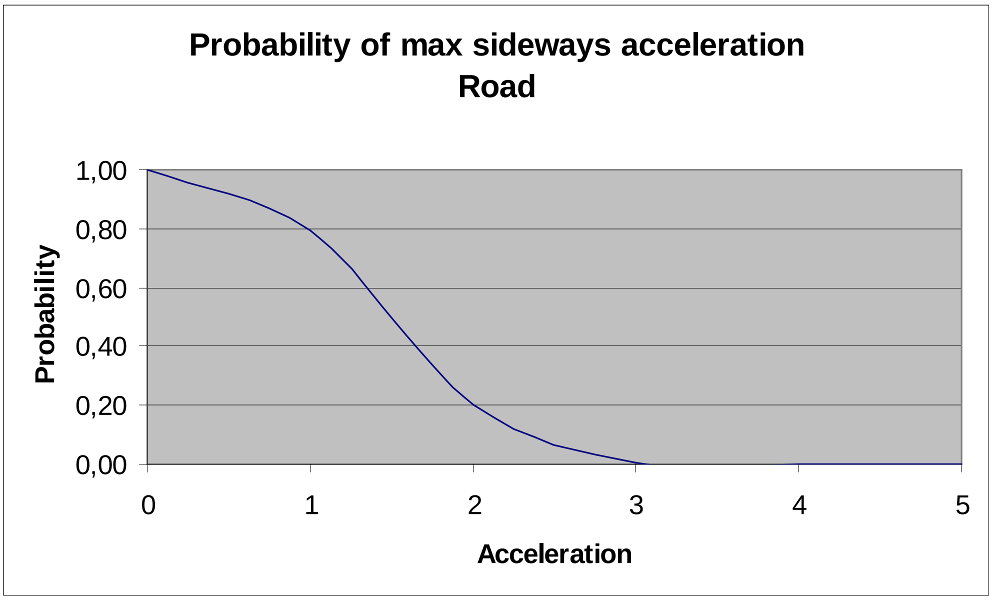


Diagram 8 - Probability of max sideways acceleration at Road transport

[3] BREAKAGE – Transport Quality on Railway Regarding Breakage, MariTerm April 2006
[4] TFK Report 2004:6, Verification of level of basic parameters important for dimensiong of cargo securing arrangements (VERIFY), TFK and MariTerm Sep 2004

7.2 Sea Area A

The cargo securing regulation for transport at sea A is stipulating a dimensioning transverse force of 0.5 × cargo weight equal with the sideways acceleration of 5 m/s^2. The probability of occurrence is once in 20 years.

The Swedish statistics over transports gives an average transport length more or less equal with road transport with an average transport length of approximately 100 km and each vessel perform about 1000 transports annually.

The probability of max sideways acceleration is estimated to be a little bit lower than for road transport due to the possibility to predict the forces with weather forecasts. The vessel (captain) has a choice to remain in harbour because of heavy weather.

Max Sideways Acceleration	Estimated Probability	Comments
1	0.82	82 % of the transports
2	0.17	Every 6th transport
3	0.01	10 times a year
4	0.001	Once a year
5	0.0001	1 time every 20th year

Table 19 - Estimated probability of max sideways acceleration at Sea A transport

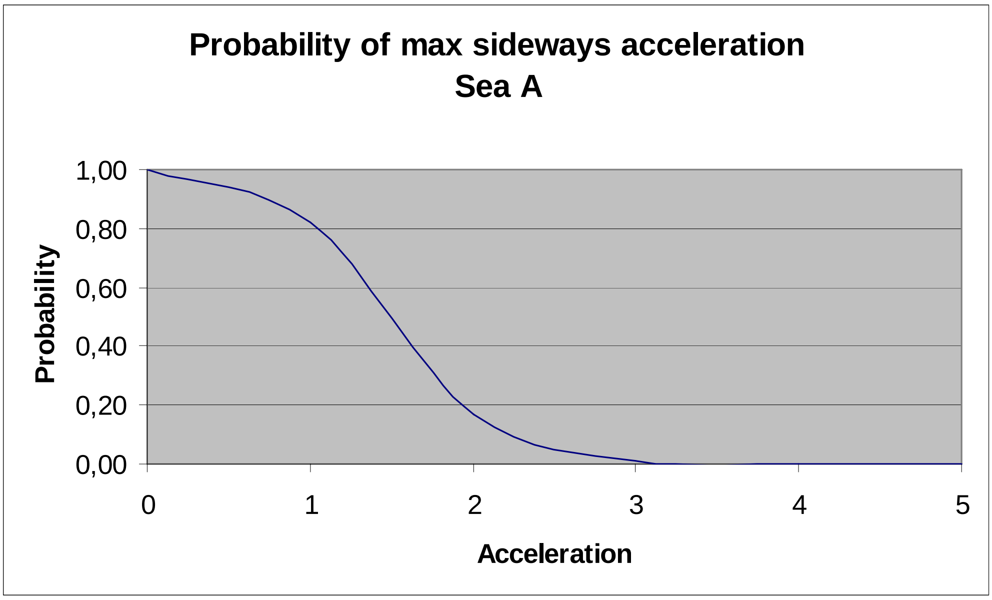


Diagram 9 - Probability of max sideways acceleration at Sea A transport

7.3 Sea Area B

The cargo securing regulation for transport at sea B is stipulating a dimensioning transverse force of 0.7 × cargo weight equal with the sideways acceleration of 7 m/s^2. The probability of occurrence is once in 20 years.

Then average transport length is estimated to approximately 1000 km and each vessel performs about 350 transports annually.

The probability of max sideways acceleration is estimated to be higher than Sea A due to the possibility to be surprised by intense weather is higher in Sea B transports.

Max Sideways Acceleration	Estimated Probability	Comments
1	0.77	77 % of the transports
2	0.2	Every 5th transport
3	0.02	7 times a year
4	0.007	Twice a year
5	0.001	1 time every 3rd year
6	0.0004	1 time every 7th year
7	0.0001	1 time every 20th year

Table 20 - Estimated probability of max sideways acceleration at Sea B transport

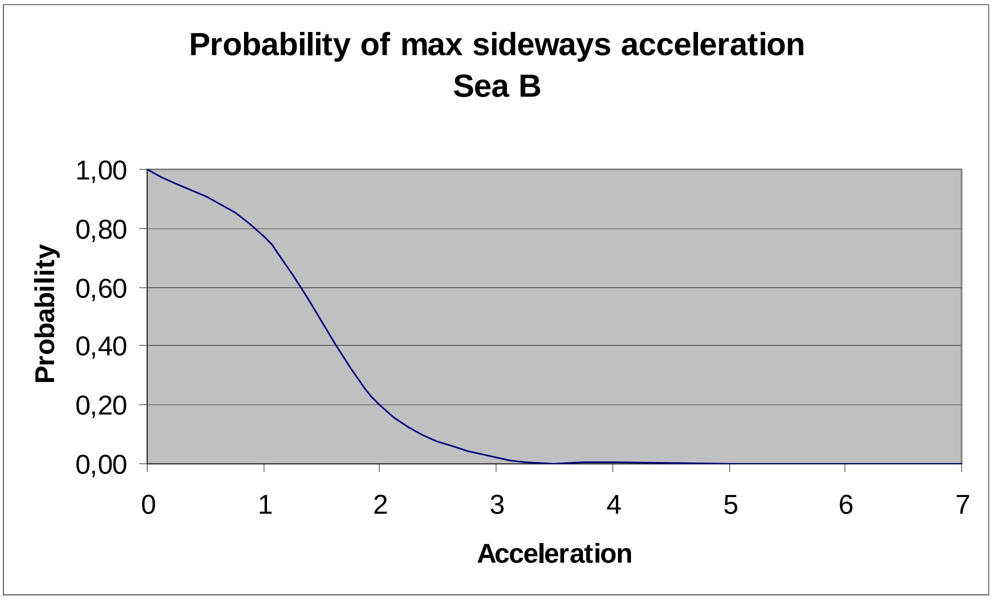


Diagram 10 - Probability of max sideways acceleration at Sea B transport

7.4 Sea Area C

The cargo securing regulation for transport at sea C is stipulating a dimensioning transverse force of 0.8 × cargo weight equal with the sideways acceleration of 8 m/s^2. The probability of occurrence is once in 20 years.

Then average transport length is estimated to approximately 6000 km and each vessel performs about 50 transports annually.

The probability of max sideways acceleration is estimated to be higher than Sea B due to the possibility to be surprised by intense weather is higher in Sea C transports.

Max Sideways Acceleration	Estimated Probability	Comments
1	0.71	71 % of the transports
2	0.2	Every 5th transport
3	0.05	2.5 times a year
4	0.02	Once a year
5	0.01	1 time every 2nd year
6	0.004	1 time every 5th year
7	0.002	1 time every 10th year
8	0.001	1 time every 20th year

Table 21 - Estimated probability of max sideways acceleration at Sea C transport

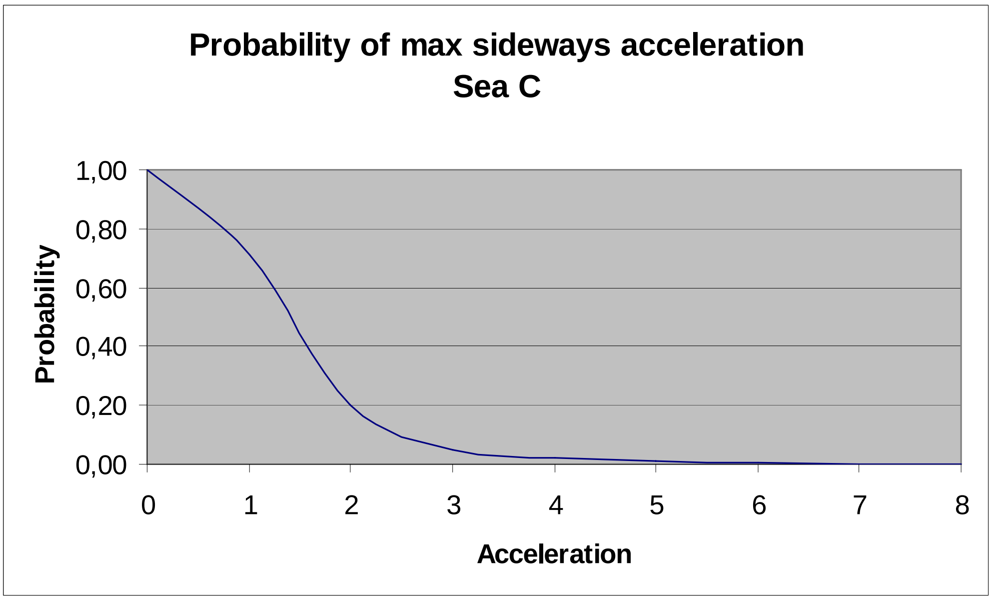


Diagram 11 - Probability of max sideways acceleration at Sea C transport

7.5 Intermodal Transport (Combi)

At combined railway transports the regulation for cargo securing is stipulating a dimensioning transverse force of 0.5 × cargo weight equal with the sideways acceleration of 5 m/s^2.

The Swedish statistics over transports gives an average transport length on combined railway transport of approximately 500 km/transport and each wagon perform annual about 300 transports.

The probability of max sideways acceleration is estimated with experience from tests performed in the project Breakage. One result from the Breakage project is that the acceleration of 5 m/s^2 is not as unusual as in road transports.

Max Sideways Acceleration	Estimated Probability	Comments
1	0.72	72 % of the transports
2	0.2	Every 5th transport
3	0.05	15 times a year
4	0.02	6 times a year
5	0.01	3 times a year

Table 22 - Estimated probability of max sideways acceleration at combi transport

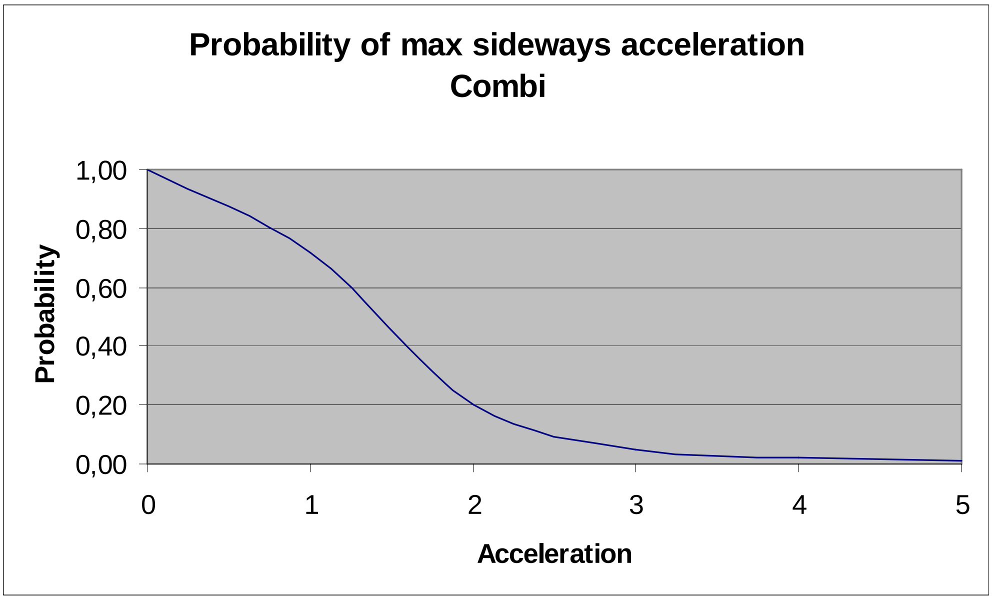


Diagram 12 - Probability of max sideways acceleration at Combi transport

7.6 Summary

The probability of expected maximum sideways acceleration is estimated as follows

Max Sideways Acceleration	Road	Sea A	Sea B	Sea C	Combi
1	0.8	0.82	0.77	0.71	0.72
2	0.2	0.17	0.2	0.2	0.2
3	0.003	0.01	0.02	0.05	0.05
4	0.0005	0.001	0.007	0.02	0.02
5	0.0001	0.0001	0.001	0.01	0.01
6			0.0004	0.004	
7			0.0001	0.002	
8				0.001	

Table 23 - Estimated probability of max sideways acceleration at different mode of transport

8. Probability of cargo shifting

The distribution for the probability of cargo shifting at different sideways accelerations is estimated with the data from the inspections done in the SAFEDOR project. The different cargo securing arrangement has been studied and the expected acceleration when the cargo start to shift has been calculated.

The observations have been found to be lognormal distributed.

8.1 Different type of CTU

8.1.1 CTU Type 1

CTU Type 1
- Number of observations: 27

Normal distribution
- Mean value: $a_t = 5.330$
- Standard deviation $\sigma = 1.448$

Lognormal distribution
- Mean value: $a_t = 1.642$
- Standard deviation $\sigma = 0.243$

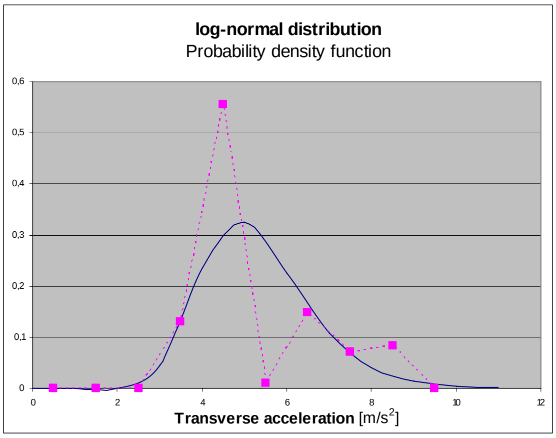


Diagram 13 - Probability of cargo shifting in CTU type 1

8.1.2 CTU Type 2

CTU Type 2
- Number of observations: 48

Normal distribution
- Mean value: $a_t = 5.448$
- Standard deviation $\sigma = 2.030$

Lognormal distribution
- Mean value: $a_t = 1.648$
- Standard deviation $\sigma = 0.317$

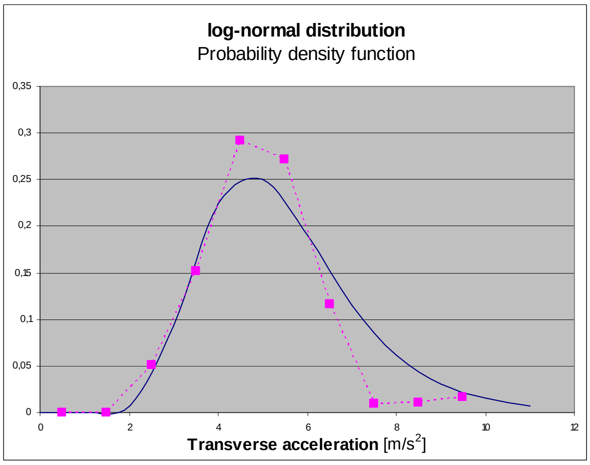


Diagram 14 - Probability of cargo shifting in CTU type 2

8.1.3 CTU Type 3

CTU Type 1
- Number of observations: 142

Normal distribution
- Mean value: $a_t = 5.185$
- Standard deviation $\sigma = 1.384$

Lognormal distribution
- Mean value: $a_t = 1.613$
- Standard deviation $\sigma = 0.256$

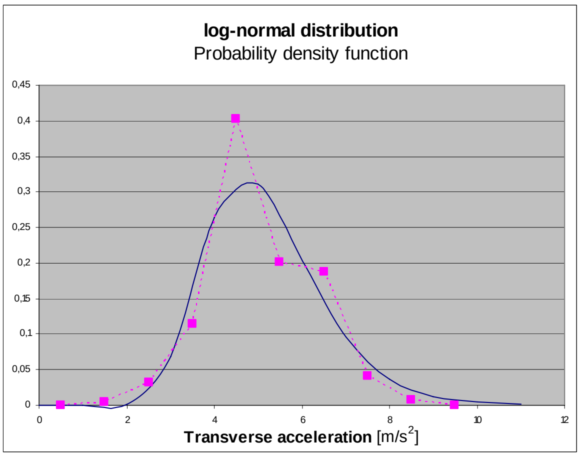


Diagram 15 - Probability of cargo shifting in CTU type 3

8.2 Different type of cargo

8.2.1 Low value cargo

Low value cargo
- Number of observations: 61

Normal distribution
- Mean value: $a_t = 4.974$
- Standard deviation $\sigma = 1.274$

Lognormal distribution
- Mean value: $a_t = 1.572$
- Standard deviation $\sigma = 0.258$

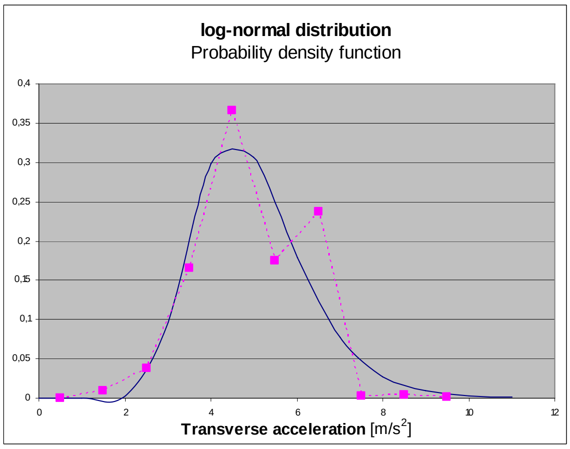


Diagram 16 - Probability of cargo shifting – Low cargo value

8.2.2 Mid value cargo

Mid value cargo
- Number of observations: 117

Normal distribution
- Mean value: $a_t = 5.504$
- Standard deviation $\sigma = 1.744$

Lognormal distribution
- Mean value: $a_t = 1.664$
- Standard deviation $\sigma = 0.277$

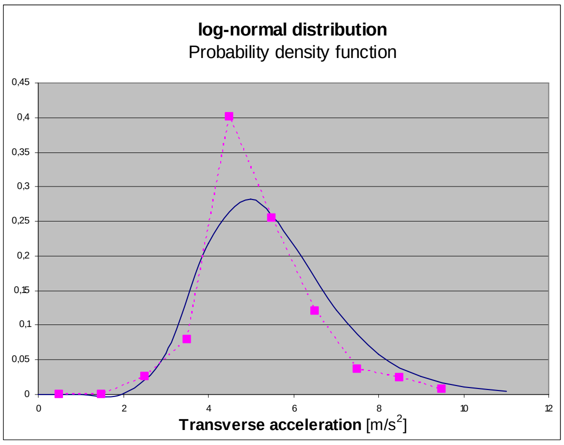


Diagram 17 - Probability of cargo shifting – Mid cargo value

8.2.3 High value cargo

High value cargo
- Number of observations: 39

Normal distribution
- Mean value: $a_t = 5.233$
- Standard deviation $\sigma = 1.650$

Lognormal distribution
- Mean value: $a_t = 1.615$
- Standard deviation $\sigma = 0.273$

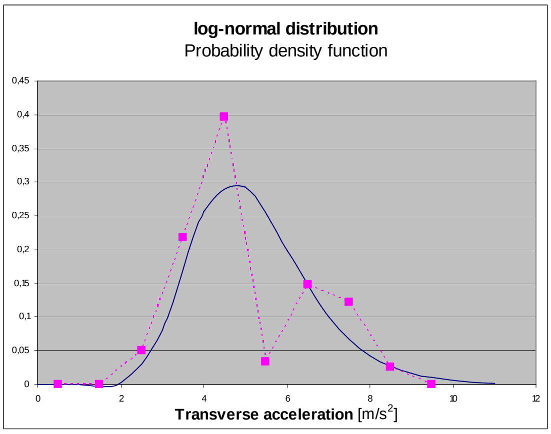


Diagram 18 - Probability of cargo shifting – High cargo value

8.3 Combination of different type of CTU and type of cargo

The probability for cargo shifting depending on CTU, section 8.1, and type of cargo, section 8.2 is combined with the following input to the normal distribution and log-normal distribution of probability for cargo shifting;

Type of cargo/ Type of CTU	Normal distribution		Log normal distribution		No. of observa-tions
	Mean μ	Std dev σ	Mean μ	Std dev σ	
Low / type 1	4.386	0.235	1.477	0.049	2
Low / type 2	4.774	1.210	1.531	0.253	14
Low / type 3	5.120	1.324	1.599	0.264	45
Mid / type 1	5.658	1.541	1.701	0.246	13
Mid / type 2	6.385	2.519	1.789	0.347	20
Mid / type 3	5.171	1.277	1.615	0.238	84
High / type 1	5.200	1.403	1.616	0.249	12
High / type 2	4.938	1.155	1.572	0.219	14
High / type 3	5.695	2.319	1.676	0.348	13

Table 24 - Probability for cargo shifting depending on CTU and type of cargo

With the distribution above the following proportion of damaged shifting is found at different sideways accelerations:

Acceleration	1	2	3	4	5	6	7	8	9
CTU Type1	0.0 %	0.0 %	1.3 %	14.7 %	44.7 %	73.1 %	89.4%	96.4 %	98.9 %
CTU Type2	0.0 %	0.1 %	4.1 %	20.4 %	45.2 %	67.5 %	82.7%	91.4 %	95.9 %
CTU Type3	0.0 %	0.0 %	2.2 %	18.8 %	49.4 %	75.7 %	90.3%	96.6 %	98.9 %
Low value	0.0 %	0.0 %	3.3 %	23.6 %	55.8 %	80.3 %	92.7%	97.6 %	99.2 %
Mid value	0.0 %	0.0 %	2.1 %	15.8 %	42.1 %	67.7 %	84.5%	93.3 %	97.3 %
High value	0.0 %	0.0 %	2.9 %	20.0 %	49.1 %	74.1 %	88.7%	95.6 %	98.4 %
Low type 1	0.0 %	0.0 %	0.0 %	3.1 %	99.7 %	100.0%	100.0%	100.0%	100.0%
Low type 2	0.0 %	0.0 %	4.4 %	28.3 %	62.1 %	84.8 %	94.9%	98.5 %	99.6 %
Low type 3	0.0 %	0.0 %	2.9 %	21.0 %	51.5 %	76.7 %	90.5%	96.5 %	98.8 %
Mid type 1	0.0 %	0.0 %	0.7 %	10.1 %	35.5 %	64.4 %	84.0%	93.8 %	97.8 %
Mid type 2	0.0 %	0.1 %	2.3 %	12.3 %	30.3 %	50.4 %	67.5%	79.9 %	88.0 %
Mid type 3	0.0 %	0.0 %	1.5 %	16.8 %	49.1 %	77.2 %	91.8%	97.5 %	99.3 %
High type 1	0.0 %	0.0 %	1.9 %	17.8 %	48.9 %	76.0 %	90.7%	96.9 %	99.0 %
High type 2	0.0 %	0.0 %	1.5 %	19.8 %	56.8 %	84.2 %	95.6%	99.0 %	99.8 %
High type 3	0.0 %	0.2 %	4.9 %	20.3 %	42.4 %	63.0 %	78.1%	87.7 %	93.3 %
All units	0.0 %	0,0%	2.7 %	19.0 %	47.5 %	72.7 %	87.8%	95.1%	98.2 %

Table 25 - Proportion of cargo shifting at different sideways accelerations

9. Probability of damaged cargo at cargo shifting

In this chapter the probability of damaged cargo by cargo shifting will be analyzed. All figures are estimated from experience. Ongoing projects within the SIR-C group will give more accurate values in the future.

When the cargo starts to shift all the cargo will not be damaged. The proportion of damaged cargo is estimated to be normal distributed depending on the actual side acceleration. One basic assumption is that at the sideways acceleration a_t = 6.0 the proportion of damaged cargo is 50 %. In a normal distribution the mean value is μ =6.0.

The standard deviation is estimated to be $\sigma \approx 2.0$.

9.1 Different type of CTU

9.1.1 CTU Type 1

A CTU of type 1 has a side/wall designed to manage stresses up to 0.5 × the cargo weight (sideways acceleration = 5 m/s^2). The side/wall will in some cases be able to minimise the effect of the cargo shifting. The result should be that the mean value should be greater than μ = 6.0 and the standard deviation less than σ = 2.0.

CTU Type 1
The proportion of damaged cargo is estimated to be normal distributed with a mean value of a_t = 6.6 and a standard deviation σ = 1.7.

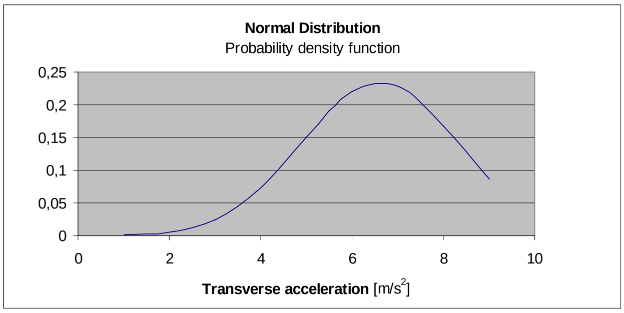


Diagram 19 - Probability of damaged cargo – CTU Type 1

9.1.2 CTU Type 2

A CTU of type 2 has a side board designed to manage stresses up to 0.5 × the cargo weight (sideways acceleration = 5 m/s^2). The side board will in some cases be able to minimise the effect of the cargo shifting. This effect will drastically decrease for cargo layers over the side board. The result should be that the mean value should be greater than μ = 6.0 but less than for CTU Type 1.

CTU Type 2
The proportion of damaged cargo is estimated to be normal distributed with a mean value of a_t = 6.3 and a standard deviation σ = 2.0.

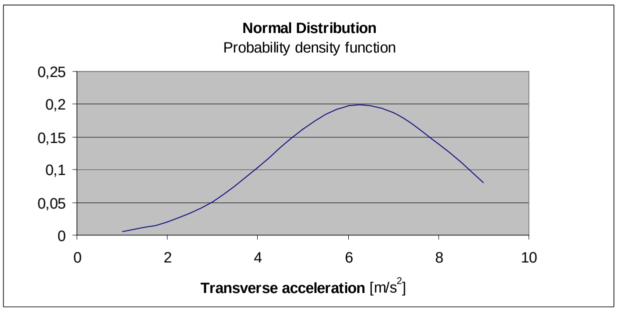


Diagram 20 - Probability of damaged cargo – CTU Type 2

9.1.3 CTU Type 3

The side/wall of a CTU of type 3 has a limited or no strength to manage stresses up to 0.5 × the cargo weight (sideways acceleration = 5 m/s^2). For instance, open vehicles or freight container racks have no side or wall to block the cargo to prevent sideways motions. The ability to minimise cargo damages caused by cargo shifting is restricted.

The effect should be that the mean value should be around μ = 6.0.

CTU Type 3
The proportion of damaged cargo is estimated to be normal distributed with a mean value of a_t = 6.0 and a standard deviation σ = 2.2.

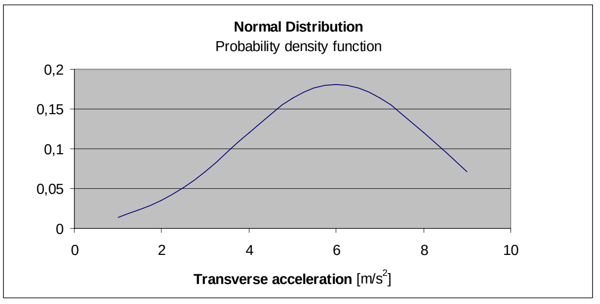


Diagram 21- Probability of damaged cargo – CTU Type 3

9.2 Different type of cargo

9.2.1 Low value cargo

Some types of low valued cargo; like round timber, cement, potatoes etc, will not be damaged in an extensive degree due to cargo shifting.

The result should be that the mean value should be greater than μ = 6.6 and the standard deviation less than σ = 2.0.

Low value cargo
The proportion of damaged cargo is estimated to be normal distributed with a mean value of a_t = 6.6 and a standard deviation σ = 1.7.

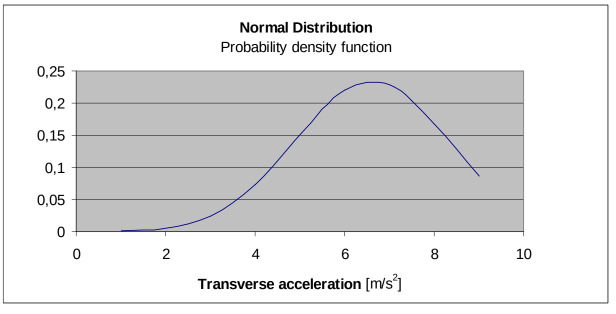


Diagram 22 - Probability of damaged cargo - Low value cargo

9.2.2 Mid value cargo

Mid value cargo is estimated to be equal to the basic assumption.

Mid value cargo
The proportion of damaged cargo is estimated to be normal distributed with a mean value of a_t = 6.0 and a standard deviation σ = 2.0.

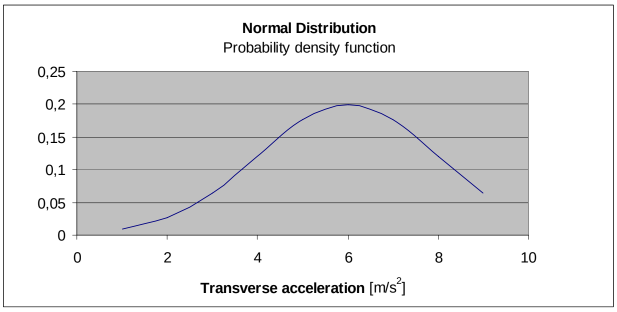


Diagram 23 - Probability of damaged cargo - Mid value cargo

9.2.3 High value cargo

Some types of high valued cargo; like machinery, glass and general cargo, could be severe damaged even at low cargo shifting.

The effect should be that the mean value should be less than μ = 6.0.

High value cargo
The proportion of damaged cargo is estimated to be normal distributed with a mean value of a_t = 5.4 and a standard deviation σ = 2.2.

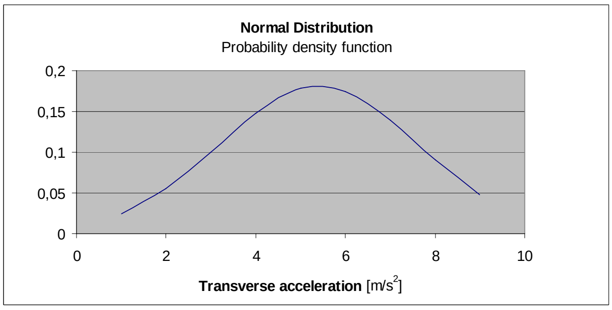


Diagram 24 - Probability of damaged cargo - High value cargo

9.3 Combination of different type of CTU and type of cargo

The different proportion of damaged cargo depending on CTU, section 9.1, and type of cargo, section 9.2, is combined with the following input to the normal distribution of the proportion of damaged cargo;

Type of cargo/ Type of CTU	Mean μ	Std dev σ
Low / type 1	6.6	1.7
Low / type 2	6.4	2.0
Low / type 3	6.2	2.2
Mid / type 1	6.4	1.7
Mid / type 2	6.2	2.0
Mid / type 3	6.0	2.2
High / type 1	6.0	1.7
High / type 2	5.9	2.0
High / type 3	5.7	2.2

Table 26 - Distribution of cargo damages depending on cargo value and type of CTU

With the distribution above the following proportion of damaged cargo is found at different sideways accelerations:

Acceleration	1	2	3	4	5	6	7	8	9
CTU Type1	0.0 %	0.3 %	1.7 %	6.3 %	17.3 %	36.2 %	59.3 %	79.5 %	92.1 %
CTU Type2	0.4 %	1.6 %	4.9 %	12.5 %	25.8 %	44.0 %	63.7 %	80.2 %	91.1 %
CTU Type3	1.2 %	3.5 %	8.6 %	18.2 %	32.5 %	50.0 %	67.5 %	81.8 %	91.4 %
Low value	0.0 %	0.3 %	1.7 %	6.3 %	17.3 %	36.2 %	59.3 %	79.5 %	92.1 %
Mid value	0.6 %	2.3 %	6.7 %	15.9 %	30.9 %	50.0 %	69.1 %	84.1 %	93.3 %
High value	2.3 %	6.1 %	13.8 %	26.2 %	42.8 %	60.7 %	76.6 %	88.1 %	94.9 %
Low / type 1	0.0 %	0.3 %	1.7 %	6.3 %	17.3 %	36.2 %	59.3 %	79.5 %	92.1 %
Low / type 2	0.3 %	1.4 %	4.5 %	11.5 %	24.2 %	42.1 %	61.8 %	78.8 %	90.3 %
Low / type 3	0.9 %	2.8 %	7.3 %	15.9 %	29.3 %	46.4 %	64.2 %	79.3 %	89.8 %
Mid / type 1	0.1 %	0.5 %	2.3 %	7.9 %	20.5 %	40.7 %	63.8 %	82.7 %	93.7 %
Mid / type 2	0.5 %	1.8 %	5.5 %	13.6 %	27.4 %	46.0 %	65.5 %	81.6 %	91.9 %
Mid / type 3	1.2 %	3.5 %	8.6 %	18.2 %	32.5 %	50.0 %	67.5 %	81.8 %	91.4 %
High / type 1	0.1 %	0.5 %	2.3 %	7.9 %	20.5 %	40.7 %	63.8 %	82.7 %	93.7 %
High / type 2	0.5 %	1.8 %	5.5 %	13.6 %	27.4 %	46.0 %	65.5 %	81.6 %	91.9 %
High / type 3	1.2 %	3.5 %	8.6 %	18.2 %	32.5%	50.0 %	67.5 %	81.8 %	91.4 %

Table 27 - Proportion of damaged cargo at different sideways accelerations

10. The risk of cargo damages

The risk of cargo damages in different mode of transport, type of CTU and type of cargo is a combination of the probability of sideways accelerations (chapter 7), risk of cargo shifting (chapter 8) and the risk of cargo damages at different accelerations (chapter 9).

The risk of cargo damages at different mode of transport (P_{mode}) can be calculated with the formula below using the values from chapter 7-9.

$$P_{\mathrm{mod}\,e} = \sum_{a=1}^{a=y} P_{1\,\mathrm{mod}\,e} \times P_{2\,\mathrm{mod}\,e} \times P_{3\,\mathrm{mod}\,e} \qquad \textit{(formula 1)}$$

where;

P_{mode} = Probability of cargo damages at actual mode of transport
a = Sideways acceleration
y = 5 (road, Sea A and Combi), 7 (sea B) or 8 (Sea C)
$P_{1\,\mathrm{mod}\,e}$ = Probability of sideways acceleration a in actual mode of transport
$P_{2\,\mathrm{mod}\,e}$ = Probability of cargo shifting at sideways acceleration a in actual mode of transport
$P_{3\,\mathrm{mod}\,e}$ = Probability of cargo damages at sideways acceleration a in actual mode of transport

Using the values from the previous chapter the following probability of cargo damages is calculated;

	Road	Combi	Sea A	Sea B	Sea C
CTU Type1	0.001 %	0.097 %	0.002 %	0.033 %	0.386 %
CTU Type2	0.003 %	0.178 %	0.006 %	0.053 %	0.476 %
CTU Type3	0.004 %	0.238 %	0.006 %	0.067 %	0.591 %
Low value	0.002 %	0.129 %	0.003 %	0.040 %	0.433 %
Mid value	0.003 %	0.187 %	0.005 %	0.054 %	0.518 %
High value	0.006 %	0.336 %	0.011 %	0.092 %	0.736 %
Low type 1	0.002 %	0.177 %	0.001 %	0.042 %	0.520 %
Low type 2	0.004 %	0.225 %	0.006 %	0.063 %	0.563 %
Low type 3	0.004 %	0.228 %	0.006 %	0.064 %	0.563 %
Mid type 1	0.001 %	0.090 %	0.001 %	0.031 %	0.379 %
Mid type 2	0.002 %	0.123 %	0.004 %	0.038 %	0.370 %
Mid type 3	0.003 %	0.227 %	0.005 %	0.063 %	0.585 %
High type 1	0.002 %	0.131 %	0.002 %	0.041 %	0.450 %
High type 2	0.003 %	0.213 %	0.004 %	0.060 %	0.575 %
High type 3	0.005 %	0.234 %	0.010 %	0.068 %	0.537 %

Table 28 - Probability of cargo damages at different mode of transport

11. Cost of cargo damages

11.1 Cost of cargo damages in SEK/ton

When calculating the cost of cargo damages the average value for each type of cargo (V_{cargo}) has to be estimated;

Type of cargo	V_{cargo}	
Low	8	KSEK/ton
Mid	35	KSEK/ton
High	125	KSEK/ton

Table 29 - Average cargo value

Expressed in SEK/ton the formula for the cost of damaged cargo is

$$C_{D\,mode} = P_{mode} \times V_{cargo} \qquad \textit{(formula 2)}$$

With the distribution in chapter 10 the cost of cargo damages at different mode of transports expressed in SEK/ton is as follows;

	Road	Combi	Sea A	Sea B	Sea C
Low value	0.1	10.3	0.2	3.2	34.7
Mid value	1.0	65.5	1.6	19.1	181.3
High value	7.2	419.8	13.4	115.3	920.1
Low type 1	0.1	14.1	0.1	3.3	41.6
Low type 2	0.3	18.0	0.5	5.1	45.0
Low type 3	0.3	18.3	0.5	5.1	45.1
Mid type 1	0.4	31.3	0.5	10.9	132.7
Mid type 2	0.7	43.2	1.3	13.3	129.4
Mid type 3	1.2	79.5	1.8	22.1	204.8
High type 1	2.2	163.2	2.9	51.1	562.6
High type 2	3.8	266.8	5.4	74.5	718.3
High type 3	6.1	292.4	12.7	85.6	671.5

Table 30 - Cost for damaged cargo [SEK/ton]

11.2 Cost of cargo damages in SEK/tonkm

When calculating the cost of cargo damages in SEK/tonkm the average transport length $L_{avgmode}$ for each mode of transport is used, see chapter 7;

Type of cargo	Average transport length
Road	100 km
Combi	500 km
Sea A	100 km
Sea B	1000 km
Sea C	6000 km

Table 31 - Average transport length

Expressed in SEK/tonkm the formula for the cost of cargo damages is

$$C_{D\,mode} = \frac{P_{mode}}{L_{avg\,mode}} \times V_{cargo} \qquad \textit{(formula 3)}$$

With the cost of cargo damages in SEK/ton, see section 11.1, the cost of cargo damages at different mode of transports expressed in SEK/tonkm is as follows;

	Road	Combi	Sea A	Sea B	Sea C
Low value	0.001	0.021	0.002	0.003	0.006
Mid value	0.010	0.131	0.016	0.019	0.030
High value	0.072	0.840	0.134	0.115	0.153
Low type 1	0.001	0.028	0.001	0.003	0.007
Low type 2	0.003	0.036	0.005	0.005	0.008
Low type 3	0.003	0.037	0.005	0.005	0.008
Mid type 1	0.004	0.063	0.005	0.011	0.022
Mid type 2	0.007	0.086	0.013	0.013	0.022
Mid type 3	0.012	0.159	0.018	0.022	0.034
High type 1	0.022	0.326	0.029	0.051	0.094
High type 2	0.038	0.534	0.054	0.074	0.120
High type 3	0.061	0.585	0.127	0.086	0.112

Table 32 - Cost for damaged cargo [SEK/tonkm]

11.3 Examples of calculating the cost of cargo damages

11.3.1 Example 1

The estimated cost of cargo damages for an actual transport can then be calculated if the following data is known;

- Transport modes involved (road. sea A. sea B. sea C and/or combi)
- The transport length of the different transport modes
- The type of cargo (low. mid or high value cargo)
- The weight of the cargo
- The type of CTU (type 1. 2 or 3)

Example 1:

20 ton of a mid value cargo is transported in a vehicle with a cover stake superstructure (CTU type 2). The following modes of transports are involved;

Road	Combi	Sea A	Sea B	Sea C	TOTAL
50	400	50	0	0	500

Table 33 - Transport length [km] - Example 1

The formula for cost of cargo damages expressed in SEK/ton is

$$C_D = (P_{Road} + P_{SeaA} + P_{SeaB} + P_{SeaC} + P_{Combi}) \cdot V_{cargo} \qquad \textit{(formula 4)}$$

and expressed in SEK/tonkm is

$$C_D = (\frac{P_{Road}}{L_{Road}} + \frac{P_{SeaA}}{L_{SeaA}} + \frac{P_{SeaB}}{L_{SeaB}} + \frac{P_{SeaC}}{L_{SeaC}} + \frac{P_{Combi}}{L_{Combi}}) \cdot V_{cargo} \qquad \textit{(formula 5)}$$

With the figures for mid value cargo in a CTU type 2 in section 11.2 and the actual length of transport the following cost of cargo damages can be calculated;

	Cost for damaged cargo [SEK/ton]					TOTAL		
	Road	Combi	Sea A	Sea B	Sea C	SEK /ton	SEK/ tonkm	SEK
Mid type 2	0.36	34.53	0.64	0.00	0.00	35.53	0.071	711

Table 34 - Cost of cargo damages – Example 1

In chapter 6 an adjustment of the probability of cargo damages with a factor ε can be done due to the estimation that the probability of cargo damages is higher in the beginning and at the end of the transportation. The adjusted probability of cargo damages P_a is calculated with the formula;

$$P_{a\,mode} = P_{mode} \times \varepsilon \qquad \textit{(formula 6)}$$

if $$\varepsilon = \sqrt{\frac{L_{mode}}{L_{avg\,mode}}} \qquad \textit{(formula 7)}$$

with L_{mode} = Transport length of the actual mode of transport

$L_{avg\,mode}$ = Average transport length at the actual mode of transport

The formula for adjusted cost of cargo damages is;

(expressed in SEK/ton)

$$C_{aD} = (P_{aRoad} + P_{aSeaA} + P_{aSeaB} + P_{aSeaC} + P_{aCombi}) \cdot V_{cargo} \qquad \textit{(formula 8)}$$

(expressed in SEK/tonkm)

$$C_{aD} = \left(\frac{P_{aRoad}}{L_{Road}} + \frac{P_{aSeaA}}{L_{SeaA}} + \frac{P_{aSeaB}}{L_{SeaB}} + \frac{P_{aSeaC}}{L_{SeaC}} + \frac{P_{aCombi}}{L_{Combi}}\right) \cdot V_{cargo} \qquad \textit{(formula 9)}$$

If the values for each mode of transport are adjusted with the formula above using the average transport length mentioned in section 11.2, the adjusted cost of damaged cargo is;

	Adjusted cost for damaged cargo [SEK/ton]					TOTAL		
	Road	Combi	Sea A	Sea B	Sea C	SEK /ton	SEK/ tonkm	SEK
Mid type 2	0.26	30.9	0.5	0.0	0.00	31.59	0.063	632

Table 35 - Cotst of cargo damages – Example 1

Conclusion: The total value of the cargo is 700 000 SEK (20 ton × 35 000 SEK) and the cost for damaged cargo is 632 SEK about 0.09 % of the total cargo value.

11.3.2 Example 2

The same principle method in example 1 is used in example 2.

Example 2:

25 ton of a low value cargo is transported in a freight container (CTU type 1). The following modes of transports are involved;

Road	Combi	Sea A	Sea B	Sea C	TOTAL
50	1000	100	250	3000	4400

Table 36 - Transport length [km] – Example 2

With the figures for low value cargo in a CTU type 1 in section 11.2 and the actual length of transport the following cost of cargo damages can be calculated;

	Cost for damaged cargo [SEK/ton]					TOTAL		
	Road	Combi	Sea A	Sea B	Sea C	SEK /ton	SEK/ tonkm	SEK
Low type 1	0.07	28.27	0.08	0.83	20.78	50.04	0.011	1 251

Table 37 - Cost of cargo damages – Example 2

If the values for each mode of transport are adjusted with the same formula as the section above using the average transport length mentioned in section 11.2. the adjusted cost of damaged cargo is;

	Adjusted cost for damaged cargo [SEK/ton]					TOTAL		
	Road	Combi	Sea A	Sea B	Sea C	SEK /ton	SEK/ tonkm	SEK
Low type 1	0.05	40.0	0.1	0.4	14.70	55.23	0.013	1 381

Table 38 - Adjusted cost of cargo damages – Example 2

Conclusion: The total value of the cargo is 200 000 SEK (25 ton × 8000 SEK) and the cost for damaged cargo is 1 381 SEK about 0.7 % of the total cargo value.