RoadMind for FreeCAD 1.1



RoadMind is a specialized workbench for heavy lift engineers, transport planners, and SPMT operators. It connects your 3D transport model directly to the calculations that keep it safe — stability, axle load, lashing, and documentation, all inside a single FreeCAD document.

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Important Notes – Intended Use, Verification and Liability

Intended Use

RoadMind is software designed to support engineering tasks in the field of heavy haulage with SPMT (Self-Propelled Modular Transporter), in particular SPMT configuration, axle load distribution, stability calculation, tipping checks, cargo securing and related static calculations.

The software serves exclusively as an aid for qualified users. It neither replaces the professional assessment of an experienced heavy haulage engineer nor the approval by the responsible planner, nor any verifications, approvals or documentation required by authorities or clients.

Verification of Calculation Results

All calculations produced with RoadMind are based on the input data provided or imported by the user. The user is solely responsible for its correctness, completeness and up-to-dateness.

Before using the calculation results for operational decisions, transport approvals, axle load permits or any other safety-relevant applications, all results must be independently verified by the responsible engineer.

In particular, the calculation results must be compared with the valid and approved documents for the respective transport. These include in particular:

- the manufacturer's documentation and operating limits of the SPMT modules used, including axle load limits, hydraulic capacity, platform heights and permissible travel speeds,
- the valid certificates and inspection reports for SPMT modules, axles, hydraulic systems and control systems,
- the manufacturer's documentation and valid certificates for lifting gear, lashing equipment, chains, ratchet straps, shackles, stoppers and other load handling and cargo securing devices,
- the approved load limits and support conditions of the cargo, including lifting points, saddle supports and centre of gravity data provided by the cargo manufacturer,
- the results of the route survey, including ground bearing pressure, bridge and culvert classification, gradients, slopes, curve radii and clear passage heights,
- the requirements of the competent approval authorities for abnormal and heavy haulage transports,
- the provisions of the applicable road traffic regulations and the relevant European regulatory frameworks,

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- the guidelines of ALE (Association of Heavy Transport and Lifting) and ESTA (European Association of Abnormal Road Transport and Mobile Cranes),
- the standards EN 12195-1 and EN 12195-2 for cargo securing,
- as well as all other applicable national and international regulations.

Any deviations between the calculation results of RoadMind and the approved documents or the manufacturer's specifications must be fully clarified before the results are used. In case of doubt, the approved original documents, the manufacturer's specifications and the requirements of the competent authorities and clients shall always take precedence.

Liability

RoadMind has been developed with the greatest possible care and implemented and tested on the basis of recognised engineering methods and international regulations.

Nevertheless, no guarantee can be given that the software will operate without errors in every individual case or that it will deliver suitable results for every application.

To the extent permitted by law, the author or licensor assumes no liability for direct or indirect damage, consequential damage, financial loss, business interruption, personal injury or property damage, or loss of profit arising from the use or non-use of the software.

Liability for intent, gross negligence and in cases mandatorily prescribed by law remains unaffected.

By installing or using the software, the user accepts these provisions.

Concluding Remark

RoadMind was developed to support the planning, calculation, verification and documentation of heavy haulage transports with SPMT. The software consolidates calculations and technical information from various sources and supports the engineer in the preparation, verification and traceable documentation of technical decisions.

RoadMind neither replaces the approved manufacturer's documentation nor the verifications, approvals or professional responsibility of the responsible engineer required under the applicable regulations.

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Chapter 1 – Introduction

1.1 Purpose and Scope

RoadMind is a FreeCAD workbench for planning and calculating heavy haulage transports with SPMT (Self-Propelled Modular Transporter). It covers the entire planning workflow: from capturing the cargo, through SPMT configuration and stability verification, to lashing calculation, technical drawing and PDF report.

The workbench is intended for the **planning engineer**, not for the operator on site. It provides the figures an experienced heavy haulage engineer needs to assess and release a transport configuration.

1.2 Limitations of Use

RoadMind is **not** a substitute for:

- the geotechnical assessment of the ground
- the structural analysis of the cargo itself (deformation, stresses, lifting points)
- consultation with the SPMT manufacturer regarding axle loads, hydraulics and operating limits
- the route survey (bridges, bottlenecks, ground conditions)
- permit planning under road traffic regulations
- dynamic analysis of the transport (vibrations, resonances)

RoadMind is a **planning tool**. It provides the figures for the initial design stages and for documentation. Approval and responsibility for execution remain with the responsible engineer.

1.3 Standards and Guidelines

The calculations follow:

- **ALE Engineering Guidelines, Section 03 Transport** – for tipping angles, capacity factors and the 2° reserve
- **ESTA Best-Practice Guideline for SPMTs** – for load assumptions and operating limits
- **EN 12195-1** – for lashing calculation (ratchet straps, chains)
- **EN 12195-2** – for lashing capacities (LC values)

The standards and guidelines are **not** interpreted by RoadMind. RoadMind applies the values stated in the guidelines directly. Responsibility for the correct application of the guidelines remains with the user.

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1.4 Coordinate System and Sign Convention

All calculations in RoadMind use a consistent coordinate system:

- **x = 0** at the front edge of the cargo, **+x** towards the rear
- **y = 0** at the centreline, **+y** to the left, **−y** to the right
- **z = 0** at ground level, **+z** upwards

Accelerations:

- **a_x > 0** – acceleration towards the rear (braking is negative)
- **a_y > 0** – acceleration to the left
- **a_x = 0.8 g** – typical assumption for forward acceleration
- **a_x = −0.5 g** – typical assumption for braking
- **a_y = ±0.5 g** – typical assumption for cornering

Slopes:

- **Slope long > 0** – uphill (downhill is negative)
- **Slope lat > 0** – slope to the right

Wind:

- **Wind lateral > 0** – wind from the right
- **Wind long > 0** – wind from the rear

Lashing:

- **Fwd** – secures against forward sliding
- **Aft** – secures against rearward sliding
- **Left** – secures against sliding to the right
- **Right** – secures against sliding to the left

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Chapter 2 – Installation and Licence

2.1 System Requirements

RoadMind runs on:

- **FreeCAD 1.1** or later (Windows, Linux, macOS)
- Python 3.11 or later
- SQLite (included in FreeCAD)
- reportlab (included in FreeCAD or installable via pip)

2.2 Installation

Installation is performed via the RoadMind installer, which copies the workbench into the FreeCAD module directory:

- **Windows:** `%APPDATA%\FreeCAD\v1-1\Mod\RoadMind\`
- **Linux:** `~/.local/share/FreeCAD/v1-1/Mod/RoadMind/`
- **macOS:** `~/Library/Application Support/FreeCAD/v1-1/Mod/RoadMind/`

FreeCAD must be restarted after installation. The workbench then appears under **Tools → Workbenches → RoadMind**.

2.3 Licence

RoadMind is commercial software. The licence is bound to a single workstation (single seat).

- **28-day trial:** All functions available, no registration, no watermarks.
- **Full version:** €990 one-time, incl. 12 months of updates and e-mail support.
- **Update extension:** €350/year after the initial 12 months.

The licence file is copied to `%APPDATA%\FreeCAD\RoadMind\license.json` (Windows) or `~/.FreeCAD/RoadMind/license.json` (Linux/macOS). FreeCAD must then be restarted.

Limitations:

- Licence verification is offline. Moving to another computer is not possible without a new licence.
- The licence is non-transferable.

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Chapter 3 – The Workflow

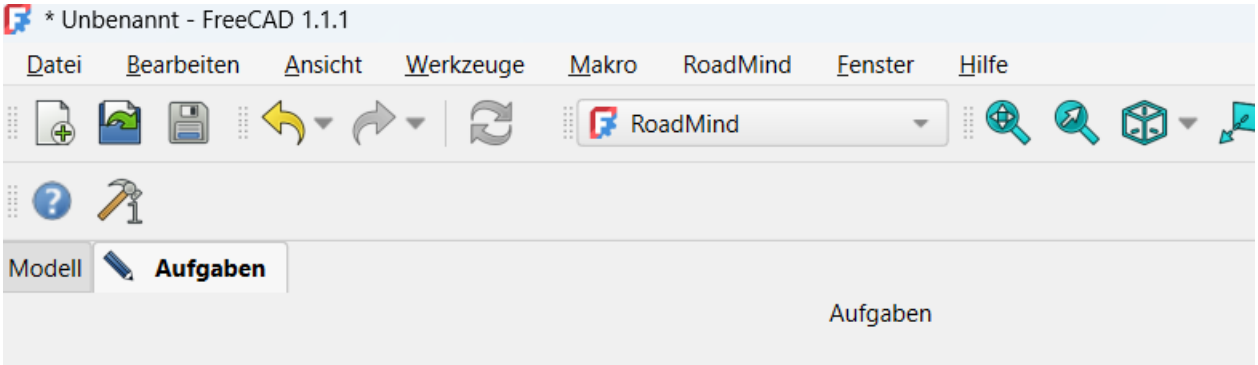
3.1 Overview

RoadMind follows a fixed workflow:

1. **Create or import cargo** – box, cylinder or STEP file
2. **Position saddles** – contact points of the cargo on the SPMT
3. **Configure SPMT** – select modules, enter load cases, calculate
4. **Generate 3D model** – SPMT modules, saddles and cargo in the FreeCAD document
5. **Plan lashing** – place lash points, define lashings, calculate balance
6. **Create drawing** – A2 TechDraw drawing with all views
7. **Export report** – A4 PDF with all calculation results
8. **Save setup** – all inputs and results as a FreeCAD object

3.2 Workflow in Detail

First of all, load Roadmind workbench:



start RoadMind by clicking : 

Step 1 – Cargo: The cargo can be created as a box, cylinder or STEP file. Mass, dimensions and COG are derived automatically from the geometry. For boxes and cylinders, mass and COG can be overridden manually.

Step 2 – Saddles: The saddles are the contact points between SPMT and cargo. They are created as separate objects in the document. Position (x) and height are used for the calculation.

Step 3 – SPMT: SPMT models are loaded from a SQLite database. The user selects a model or lets RoadMind automatically choose the appropriate one. Load cases (acceleration, curve, slope, wind) are entered. A click on "Calculate" starts the calculation.

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Step 4 – 3D: "Generate SPMT in FreeCAD" creates the SPMT modules as 3D objects in the document. The modules are positioned automatically; cargo and saddles are set to the correct height.

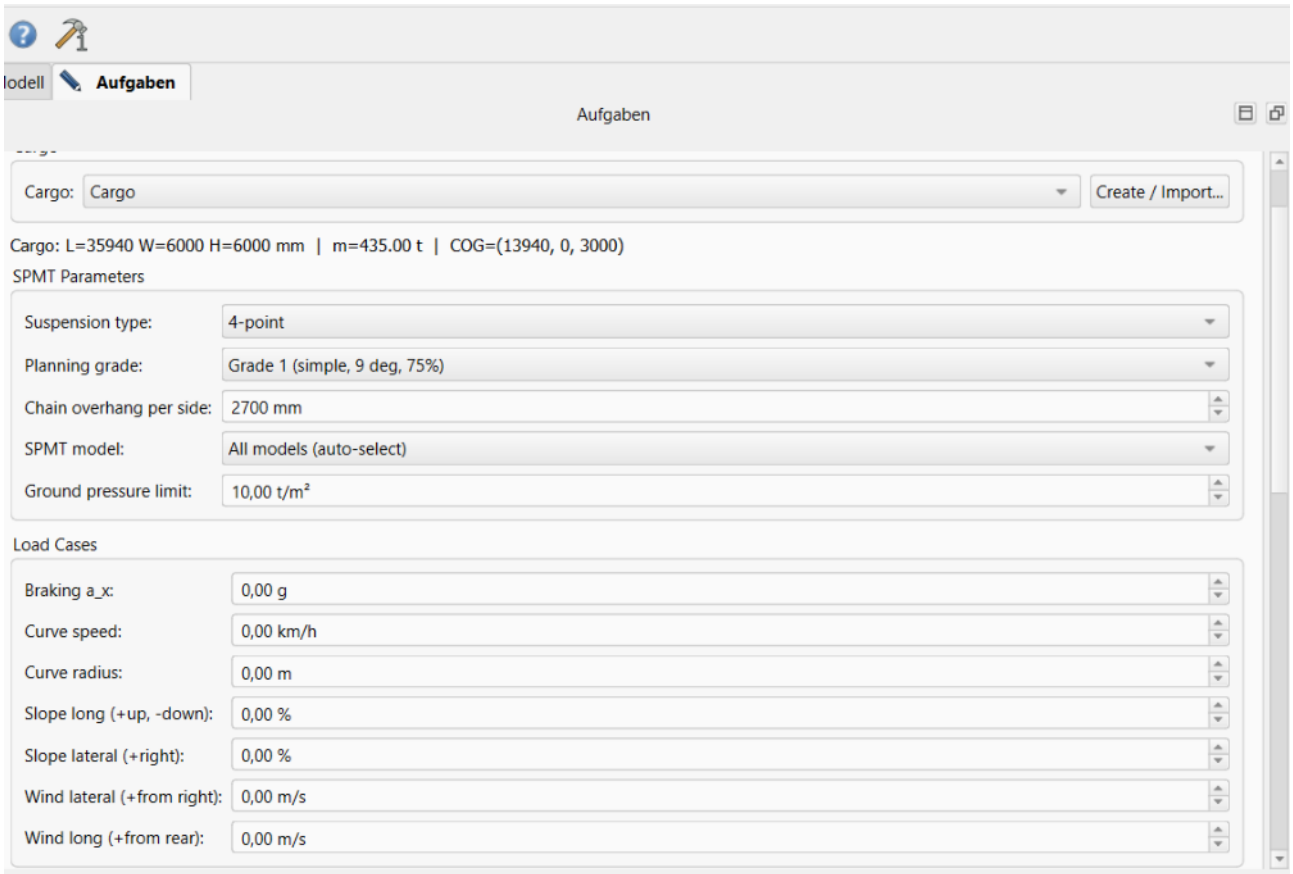
Step 5 – Lashing: The lashing editor opens as a separate window. Lash points are placed by clicking on the 3D model. Lashings connect SPMT points with cargo points. The balance of forces is calculated automatically after placement.

Step 6 – Drawing: "Create Drawing" generates an A2 TechDraw drawing. It contains four orthographic views (front, side, top and isometric) as well as a second top view with the stability polygon and the COG.

Step 7 – Report: The PDF report is generated via "Export PDF...". It contains all calculation results: cargo data, saddle positions, SPMT configuration, stability, axle loads, reactions and the self-check.

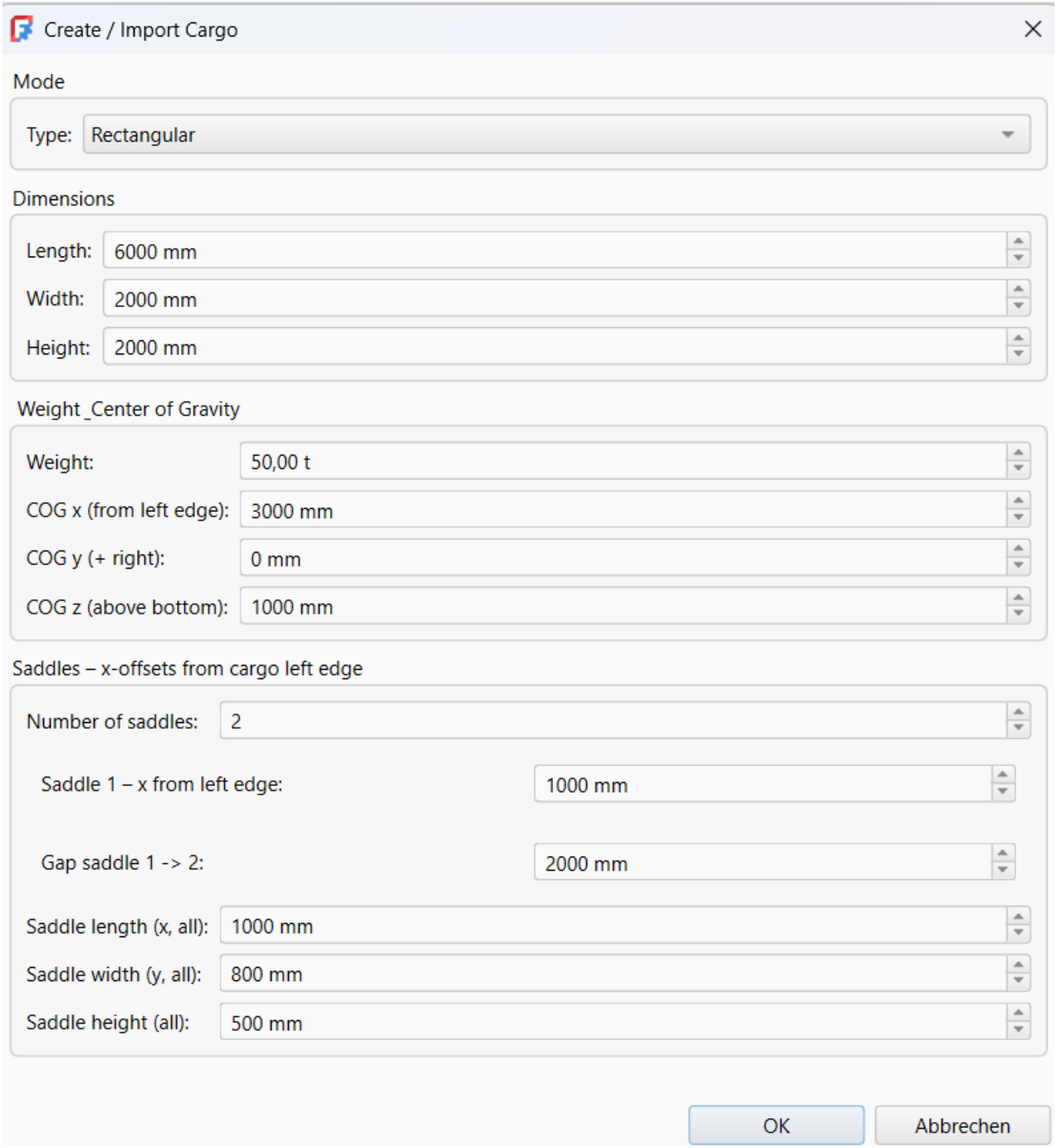
Step 8 – Setup: "Save Setup..." stores all inputs and results in a FreeCAD object. On loading, the task panel is populated with the stored values.

Taskpanel which will open:



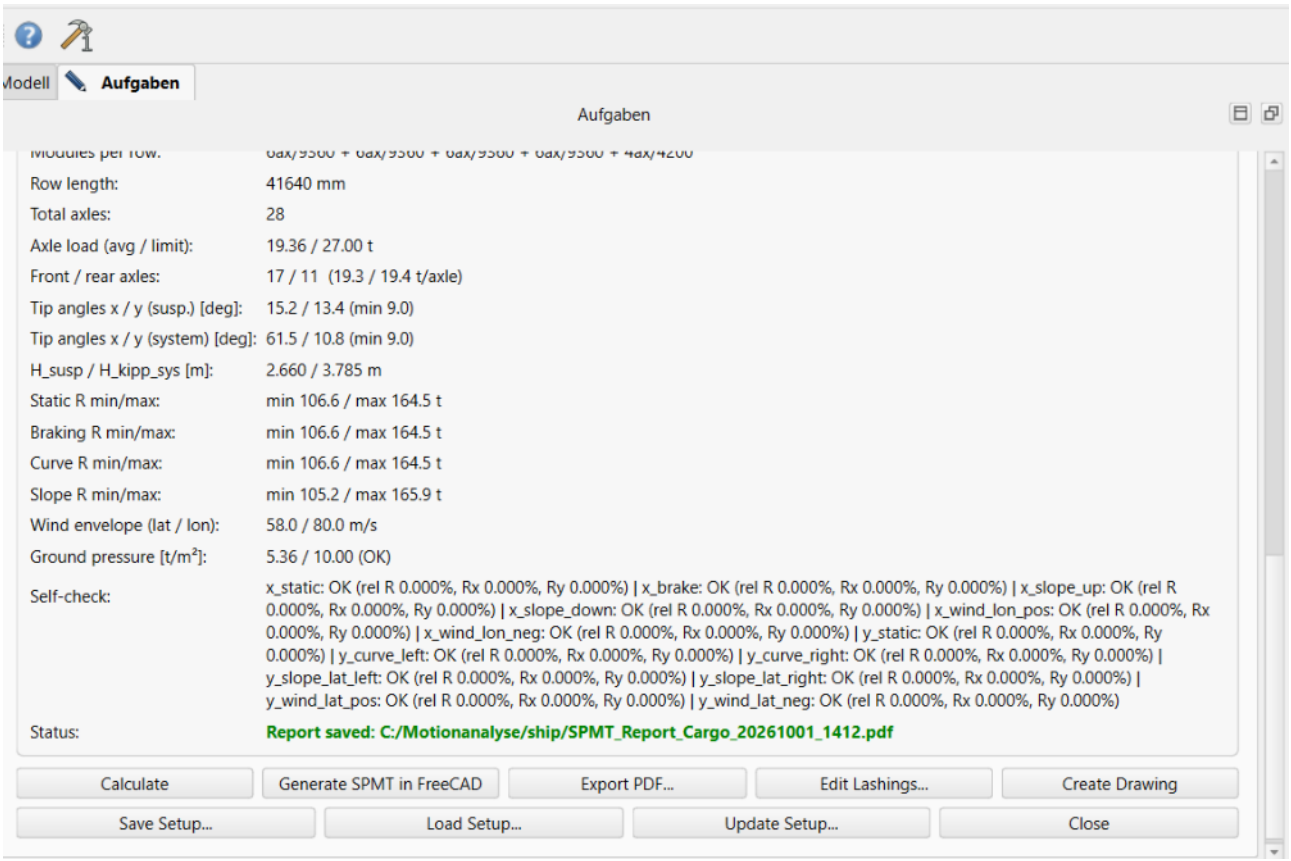
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and the Taskpanel to create the cargo:

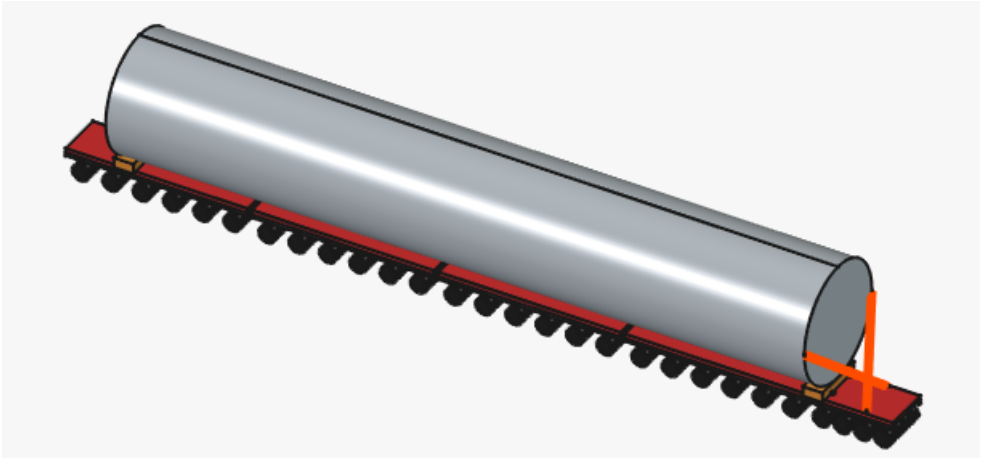


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and the calculation and additional action lower part of TaskPanel:



on the view page, the result:



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3.3 Limitations

- The workflow is **sequential**. Returning to an earlier step is possible but requires recalculation.
- 3D generation assumes that cargo and saddles are correctly positioned. Subsequent movement of the cargo in the 3D model is **not** reflected in the calculation.
- The lashing calculation is independent of the SPMT calculation. Changes to the SPMT configuration do not require recalculation of the lashing, but not vice versa.

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Chapter 4 – Creating or Importing Cargo

4.1 Overview

The cargo is the starting point of every SPMT plan. RoadMind supports three types:

1. **Box** – rectangular cargo (e.g. transformer, machine part)
2. **Cylinder** – cylindrical cargo (e.g. tank, pipe)
3. **Import** – STEP/IGES/STL file (any geometry)

4.2 Box

A box is the simplest cargo shape. It is defined by length, width and height. RoadMind derives from this:

- **Volume** = L × W × H
- **Mass** = volume × density (density entered manually)
- **COG** = geometric centre, optionally shiftable manually

The COG of a box is the centroid of the cuboid. If the mass is not uniformly distributed (e.g. a transformer with a heavy core), the COG must be entered manually. RoadMind uses the manually entered value when set.

4.3 Cylinder

A cylinder is defined by diameter and length. The COG is at the geometric centre. For horizontal cylinders (axis horizontal), the height of the COG equals the radius.

4.4 Import

STEP, IGES and STL files can be imported. After import:

- the mass is entered manually (RoadMind cannot derive it from the geometry)
- the COG is entered manually or taken from the geometry

For imported parts, the **position of the coordinate system** is decisive. RoadMind assumes that the imported part is located with its local origin at the FreeCAD origin. If this is not the case, the part must be moved after import.

4.5 The COG – What It Really Is

The COG (centre of gravity) is **the most important input parameter** for the SPMT calculation. An error of 100 mm in the COG can shift the axle load distribution by several tonnes.

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The COG is specified in RoadMind **relative to the bottom of the cargo**, not absolutely above ground. The z coordinate of the COG is therefore the distance from the bottom of the cargo to the centre of gravity.

The absolute height above ground is determined in the calculation:

```
cog_z_abs = cog_z_local + saddle_height + platform_height    (4.1)
```

Note: When the cargo is mounted on the SPMT, the COG of the **cargo** does not change. The COG of the **overall system** (cargo + SPMT) is at a different location.

4.6 Limitations

- RoadMind does **not** derive the COG from the mass distribution. It must be entered correctly by the user.
- For imported parts, the coordinate position is often unclear. Verification in the 3D model is essential.
- The COG is assumed to be **point-shaped**. For elongated cargo with distributed mass, this is a simplification.
- The mass is a **nominal mass**. Manufacturing tolerances, attachments and packaging are not automatically included.

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Chapter 5 – SPMT Parameters

5.1 Overview

The SPMT configuration is loaded from a SQLite database. The database contains per model:

- **Manufacturer** and **model name**
- **Number of axles** (axle_lines)
- **Platform length** (platform_length_mm)
- **Platform width** (platform_width_mm)
- **Platform height** (platform_height_mm)
- **Frame thickness** (frame_thickness_mm)
- **Tyre radius** (tire_radius_mm)
- **Tyre width** (tire_width_mm)
- **Turntable diameter** (turntable_dia_mm)
- **Dead weight** (dead_weight_tonnes)
- **Maximum axle load** (max_axle_load_tonnes)

5.2 Manufacturer Geometry

RoadMind knows the transverse spacing of the suspension points for the common manufacturers:

Manufacturer	**Track [mm]**	**y_half [mm]**
Scheuerle	1450	725
KAMAG	1450	725
Goldhofer	1450	725
Goldhofer PST/ES-E 285	1810	905
Cometto	1800	900
Nicolas Euro	1820	910
Nicolas AWL	2190	1095
Nicolas 365	2150	1075

The y_half value is the distance of an outer suspension point from the centreline for one row. For multiple rows it is shifted by (module width + coupling gap) per additional row.

5.3 Module Selection

RoadMind selects the modules automatically. The algorithm:

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1. **Minimum length** = saddle span + 2 × overhang (default 700 mm)
2. **Sorting** of modules by length, descending
3. **Number of long modules** = rounded up (minimum length / longest module)
4. **Remaining length** = minimum length − (number of long modules − 1) × longest module
5. **Shortest module** from the remainder that covers the remaining length

If the remaining length is not covered by any shorter module, an additional long module is added.

5.4 Number of Rows

The number of rows (n_files) is determined iteratively:

- Start at n_files = 1
- Calculation of all criteria (axle load, tipping angle, hydraulics, ground pressure, overall system)
- If all criteria are met → done
- Otherwise n_files = 2, then 3, up to a maximum of 8
- If no count meets all criteria, the configuration with the **fewest violations** is selected

5.5 Load Cases

RoadMind evaluates each load case **signed**, i.e. with sign. This captures the extreme values in both directions.

Standard load cases:

Load case	**a_x**	**a_y**
Static	0	0
Braking	−0.8 g	0
Braking (soft)	−0.5 g	0
Curve left	0	+0.5 g
Curve right	0	−0.5 g
Slope up	+0.35 g	0
Slope down	−0.35 g	0
Wind lateral	0	±a_wind
Wind longitudinal	±a_wind	0

The slope acceleration is calculated from the slope angle:

```
a_slope = sin(atan((slope_pct + 3.49) / 100))                (5.1)
```


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The value 3.49 % corresponds to the ESTA reserve of 2°.

5.6 Planning Grades

RoadMind distinguishes two planning grades:

Grade 1 (standard):

- Tipping angle ≥ 9.0°
- Capacity factor 0.75 (75 % of nominal capacity)
- For simple transports on firm ground with direct coupling

Grade 2 (complex):

- Tipping angle ≥ 7.0°
- Capacity factor 0.90 (90 % of nominal capacity)
- For barge transports, ballasting, dynamic loads

The choice of planning grade is the user's responsibility. In case of doubt, Grade 1 should be selected.

5.7 Limitations

- The database contains **example models**. The user must enter the models of their actual fleet.
- The manufacturer geometry is an **approximation**. Exact values must be obtained from the manufacturer.
- The load cases are **suggestions**. The actual loads depend on the transport route.
- Module selection does **not** take into account whether modules are available or operational.

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Chapter 6 – Drawing and Report

6.1 Drawing

The TechDraw drawing is generated with "Create Drawing". It contains:

- **Front view** (looking along +Y): cargo with SPMT, COG height dimension
- **Side view** (looking along +X): cargo with SPMT, dimensions
- **Top view** (looking along +Z): cargo with SPMT, saddle spacings, length dimensions
- **Isometric view**: 3D representation, scaled to the width of the title block
- **Second top view** (below the first): SPMT modules only with stability polygon, COG and load-case envelope

The format is A2 landscape (594 × 420 mm). The scale is selected automatically (1:1 to 1:1000) so that all views fit into their cells.

6.2 Stability Polygon in the Drawing

In the second top view, the stability polygon is drawn as model geometry:

- **Rectangle** (black) – for 4-point suspension
- **Triangle** (black) – for 3-point suspension
- **COG cross** (red) – position of the cargo COG, 3 m above the cargo bottom
- **Load-case envelope** (grey, dashed) – region in which the COG moves under all load cases

The envelope shows at a glance how far the COG deviates from its rest position under the extreme load cases. The closer it comes to the polygon edge, the more critical the configuration.

6.3 Report

The PDF report is generated with "Export PDF...". It is A4 portrait and contains:

- **Header:** cargo, date, planning grade, support type, status, limiting factor
- **Cargo:** mass, COG coordinates, saddle height
- **Saddle positions:** x coordinates of all saddles
- **SPMT configuration:** chain, axles, rows, platform geometry, weights
- **Stability (suspension):** H_susp, r_poly, slope, tipping angles, criteria
- **Stability (overall system):** H_kipp_sys, tipping angles, criterion
- **Slope/curve/wind:** all inputs and wind envelope
- **Axle load:** average, limit, nominal capacity

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- **Suspension points:** x and y coordinates
- **Reactions per load case:** R values at each point
- **Self-check:** deviation between numerical and analytical solution

6.4 Limitations

- The drawing is a **planning drawing**, not a manufacturing drawing. It does not replace a technical drawing with tolerances.
- The report contains **calculated values**, not measured ones. It documents the planning, not the approval.
- The wind envelope is stated as a **constant value**. The actual wind load depends on gusts and direction changes.
- The report has **no page numbers** and **no table of contents**. It must be supplemented manually for documentation.

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Chapter 7 – Calculation Basis

7.0 Overview

This chapter describes which quantities RoadMind calculates, on what mathematical basis, with what assumptions, and where the limits of the method lie. It is intended as a reference for the reviewing engineer, not as an introduction to SPMT planning.

All calculations follow the coordinate system defined in Chapter 4:

- x = 0 at the front edge of the cargo, +x towards the rear
- y = 0 at the centreline, +y to the left
- z = 0 at ground level, +z upwards

Forces are given in tonnes [t], moments in tonne-metres [t·m], lengths in millimetres [mm], angles in degrees [°]. Accelerations are given as multiples of gravitational acceleration g (1 g = 9.81 m/s²).

All calculations are performed per **number of rows** (n_files). RoadMind searches for the smallest number of rows for which all criteria are met. If no number meets all criteria, the configuration with the fewest violations is selected — the status is then explicitly marked as "NOT OK".

7.1 Suspension Points

What Is Calculated

RoadMind derives the suspension points that span the stability polygon from the saddle positions and the SPMT geometry. 3-point suspension produces a triangle, 4-point suspension a rectangle.

Derivation

Let the saddle positions be $x_1 < x_2 < \ldots < x_n$. Let the cargo centre of gravity be at x_{COG}. The suspension points are not applied directly at the saddle positions, but at the **midpoints between saddle and COG** — this corresponds to the actual load transfer when the SPMT modules are distributed over the entire chain length and the load is introduced via the saddles.

The front suspension point is at:

$$x_{fore} = (x_1 + x_{COG}) / 2 \qquad (7.1)$$

The rear suspension point is at:

$$x_{aft} = (x_{COG} + x_n) / 2 \qquad (7.2)$$

The lateral distance y_half is derived from the number of rows n_files and the module width b. For n_files = 1, y_half is half the manufacturer's track (e.g. 725 mm for Scheuerle). For n_files > 1, each additional row shifts by (b + 300 mm):

$$y_{half} = y_0 + (n_{files} - 1) \cdot (b + g) \qquad (7.3)$$

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with y_0 = half track for one row, b = module width, g = 300 mm coupling gap.

The suspension points are then:

3-point:

```
P_1 = (x_fore, 0)
P_2 = (x_aft, −y_half)
P_3 = (x_aft, +y_half)
```

4-point:

```
P_1 = (x_fore, −y_half)
P_2 = (x_fore, +y_half)
P_3 = (x_aft, −y_half)
P_4 = (x_aft, +y_half)
```

Assumptions

- The load is distributed evenly over all axles of a row. This is approximately true for SPMT with hydraulic levelling.
- The coupling gap between two modules is 300 mm. This corresponds to the standard coupling for Scheuerle/KAMAG/Goldhofer.
- The COG lies between the two outer saddles. Otherwise the suspension points shift such that the polygon becomes smaller — the calculation is then conservative.

Limitations

- The method does **not** verify whether the actual hydraulic load distribution matches the assumed one. If individual axles are switched off or levelling is locked, the real load distribution can deviate significantly.
- For more than two saddles (e.g. three or four support points on the cargo), the load distribution between the saddles is not explicitly solved. RoadMind implicitly assumes that the saddle positions dominate the suspension points.
- The polygon describes only the **geometry** of the suspension, not the stiffness of the system. For very soft cargo (e.g. long beams), the real deformation can influence the tipping behaviour.

Example 96 t Transformer

Cargo: 12 × 3 × 3.5 m, 96 t, COG centred at x_COG = 6000 mm. Saddles: two at x_1 = 2000 mm and x_2 = 10000 mm. SPMT: Scheuerle Gen3, 2 rows, module width 2430 mm, y_0 = 725 mm.

```
x_fore = (2000 + 6000) / 2 = 4000 mm
x_aft  = (6000 + 10000) / 2 = 8000 mm
y_half = 725 + (2 − 1) · (2430 + 300) = 3455 mm
```

The stability rectangle therefore has the corners:

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```
P_1 = (4000, −3455)    P_2 = (4000, +3455)
P_3 = (8000, −3455)    P_4 = (8000, +3455)
```

7.2 Stability Margin

What Is Calculated

The stability margin is the smallest perpendicular distance from the (static or shifted) COG to an edge of the stability polygon. It is the central measure of tipping risk.

Derivation

Let the stability polygon be given by the ordered corner points P_1 … P_n (sorted counter-clockwise). Let p be the COG point to be checked. For each polygon side between P_i and P_{i+1}, the **signed** perpendicular distance is calculated:

```
d_i = (e_x · (p_y − y_i) − e_y · (p_x − x_i)) / |e|          (7.4)
```

with e = P_{i+1} − P_i the edge vector. The sign is positive if p lies on the inside of the edge, and negative if p lies outside.

The stability margin is the minimum over all edges:

```
r = min(d_1, d_2, …, d_n)                                    (7.5)
```

RoadMind calculates this value for **each load case** and for **both signs of the shift** (i.e. +x and −x, +y and −y). The minimum over all load cases and both directions is the governing margin in x or y respectively.

Separate Evaluation in x and y

For tipping about the longitudinal axis (y direction), only the **y edges** of the polygon are relevant; for tipping about the transverse axis (x direction), only the **x edges**. RoadMind classifies each edge by its orientation:

- An edge with |e_x| ≥ |e_y| is predominantly x-parallel → it contributes to the **y margin**
- An edge with |e_x| < |e_y| is predominantly y-parallel → it contributes to the **x margin**

This is important because a narrow, long configuration has a very different margin in the x direction than in the y direction.

COG Shift Due to Acceleration

For a load case with acceleration a_x in the x direction and a_y in the y direction, the effective COG shifts by:

```
Δx = a_x · H_susp                                            (7.6)
Δy = a_y · H_susp                                            (7.7)
```

with H_susp the effective lever arm between COG and suspension plane. The shifted COG is then at (x_COG + Δx, y_COG + Δy) — this is the point whose margin is calculated.

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Assumptions

- The acceleration acts as a **quasi-static** load. Dynamic effects (vibrations, resonances) are not considered.
- The COG of the cargo and the COG of the SPMT are treated separately and weighted by mass. The calculation assumes that both masses are rigidly coupled.
- For wind, the wind force is applied as a full load on the exposed area, without considering pressure distribution, gusts or dynamic effects.

Limitations

- The margin is a **geometric** criterion. It says nothing about the deformation of the system.
- For very tall structures, the wind application point can be significantly above the COG — in that case the tipping moment is greater than the calculation shows. RoadMind assumes that the wind application point is at COG height. This is acceptable for compact cargo, but conservative in the wrong direction for tall, light cargo.
- The tipping edge is **not** the outer module edge, but the line through the suspension points. This is the conservative assumption. In reality, the tipping edge can be closer to the module centre if the hydraulics fail.

Example 96 t Transformer

COG: (6000, 0, 1500) mm above cargo bottom. Saddle height: 500 mm. SPMT platform height: 1500 mm. H_susp = COG above suspension plane = 1500 + 500 = 2000 mm = 2.0 m.

Load case "Curve left" with a_y = 0.5 g:

```
Δy = 0.5 · 2.0 = 1.0 m = 1000 mm
```

Shifted COG: (6000, 1000). The nearest edge is the left edge of the rectangle at y = +3455. The distance is:

```
r_y = 3455 − 1000 = 2455 mm
```

The y margin is therefore 2455 mm in the "Curve left" load case.

7.3 Tip Angle

What Is Calculated

The tip angle is the angle by which the entire configuration would have to tilt for the COG to move over the tipping edge. It is the engineering measure of tipping safety.

Derivation

If the COG is at distance r from the tipping edge and the suspension plane is tilted by angle α, the COG moves by r · cos(α) towards the tipping edge. The tipping edge is reached when:

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```
tan(α) = r / H_susp                                                    (7.8)
```

The tip angle is therefore:

```
α = atan(r / H_susp)                                                   (7.9)
```

RoadMind calculates this angle **separately for x and y**:

```
α_x = atan(r_x / H_susp)                                               (7.10)
α_y = atan(r_y / H_susp)                                               (7.11)
```

with r_x and r_y the minima from Section 7.2.

Required Tip Angles

RoadMind checks against two planning grades corresponding to the ALE guidelines and the ESTA recommendation:

Planning grade	**Required tip angle**
Grade 1 (simple, firm ground, direct coupling)	9.0°
Grade 2 (on barge, ballasting, complex configurations)	7.0°

The values result from a base value (7° or 5°) plus a reserve of 2°.

Assumptions

- The tipping axis lies in the suspension plane. This is the conservative assumption.
- The stiffness of the system is not considered. The system is assumed to be rigid.
- The COG is assumed to be point-shaped.

Limitations

- The tip angle is a **static** criterion. It does not account for dynamic amplification due to vibrations.
- For very tall structures or very flexible cargo, the actual tipping risk can be significantly higher than the calculated angle. In such cases, an explicit dynamic analysis is required, which RoadMind does not provide.
- The angle says nothing about the **speed** at which tipping occurs. A system with a large tip angle can still tip quickly once it becomes unstable.

Example 96 t Transformer

With H_susp = 2000 mm and r_y = 2455 mm in the "Curve left" load case:

```
α_y = atan(2455 / 2000) = 50.8°
```


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This is the tip angle in the "Curve left" load case. In the static load case (a = 0), r_y = 3455 mm and therefore α_y = atan(3455/2000) = 59.9°.

For planning grade Grade 1 (minimum 9°), both values are more than sufficient.

7.4 Reaction Forces

What Is Calculated

RoadMind calculates the vertical reaction forces at each suspension point for each load case. These are the forces that the SPMT must support at the suspension points.

Derivation

The reaction forces R_i at the suspension points P_i must satisfy three equilibrium conditions:

Force equilibrium in z:

$$\Sigma R_i = W_{total} \tag{7.12}$$

Moment equilibrium about the y-axis:

$$\Sigma R_i \cdot x_i = W_{total} \cdot x_{COG} + M_y \tag{7.13}$$

Moment equilibrium about the x-axis:

$$\Sigma R_i \cdot y_i = W_{total} \cdot y_{COG} + M_x \tag{7.14}$$

The moments M_x and M_y arise from the accelerations:

$$M_y = -W_{total} \cdot a_x \cdot H_{susp} \tag{7.15}$$
$$M_x = +W_{total} \cdot a_y \cdot H_{susp} \tag{7.16}$$

Sign convention: With a_x > 0 (acceleration towards the rear), the inertial force acts towards the front, and the moment shifts the load forward. With a_y > 0 (acceleration to the left), the inertial force acts to the right, and the moment shifts the load to the right.

Static Determinacy

3-point suspension: Three supports, three equations (7.12–7.14) — the system is statically determinate. The solution is unique:

$$A \cdot R = b \tag{7.17}$$

with A the 3×3 matrix of point coordinates and b the right-hand side vector. RoadMind solves this system directly with `numpy.linalg.solve`.

4-point suspension: Four supports, only three equations — the system is statically indeterminate. There are infinitely many solutions. RoadMind uses the **minimum-norm solution**, i.e. the solution with the smallest sum of squares of reaction forces:

$$R = A^T \cdot (A \cdot A^T)^{-1} \cdot b \tag{7.18}$$

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This is the mathematically "smoothest" solution. It is not necessarily the physically correct one — the actual load distribution depends on the stiffness of the system.

Assumptions

- The suspension points are **point-shaped**. This is approximately true for SPMT with hydraulic levelling.
- For 4-point, the minimum-norm solution is used. This is a **modelling assumption**, not a physical prediction.
- The stiffness of the modules and the cargo is not considered.

Limitations

- **For 4-point, the reaction distribution is not unique.** If one point fails (e.g. hydraulic failure), the load distributes differently than calculated. The minimum-norm solution is a compromise, not a guarantee.
- For very different module stiffnesses (e.g. a combination of short and long modules), the actual load distribution can deviate significantly from the calculated one.
- The reactions are **vertical forces**. Horizontal forces (e.g. from wind) are not carried by the suspension points but through the lashings and friction.

Example 96 t Transformer

W_total = 96 t (cargo) + 2 · 2 · 11.5 t (SPMT) = 96 + 46 = 142 t H_susp = 2.0 m

Static load case (a = 0):

```
Σ R = 142 t
Σ R · x = 142 · 6000 = 852,000 t·mm
Σ R · y = 0
```

With the four points P_1 = (4000, −3455), P_2 = (4000, +3455), P_3 = (8000, −3455), P_4 = (8000, +3455):

```
R_1 = R_2 = 35.5 t
R_3 = R_4 = 35.5 t
```

For 4-point suspension, the load therefore distributes evenly over all four points because the COG is exactly in the centre.

7.5 Axle Load Distribution

What Is Calculated

RoadMind distributes the total load over the front and rear axles so that both saddles are evenly loaded and no axle is overloaded.

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Derivation

The load on the front saddle results from the moment equilibrium about the rear saddle:

```
F_fore = W_total · (x_aft − x_COG) / (x_aft − x_fore)        (7.19)
```

The load on the rear saddle:

```
F_aft = W_total · (x_COG − x_fore) / (x_aft − x_fore)        (7.20)
```

RoadMind then searches for the number of axles n_fore and n_aft = n_total − n_fore such that:

```
F_fore / n_fore ≤ cap_per_axle                               (7.21)
F_aft / n_aft ≤ cap_per_axle                                 (7.22)
F_fore / n_fore ≥ min_axle_load                              (7.23)
F_aft / n_aft ≥ min_axle_load                                (7.24)
```

The optimisation minimises the maximum utilisation:

```
util = max(F_fore / (n_fore · cap_per_axle),
           F_aft / (n_aft · cap_per_axle))                   (7.25)
```

The constraint min_axle_load ensures that each axle carries a minimum load. This is required for traction — an axle without load cannot steer.

Assumptions

- The load distributes evenly over the axles of a saddle. This is approximately true for SPMT with hydraulic levelling.
- The axles are distributed only by **load**, not by geometric position. In reality, the axles are at fixed positions; RoadMind assumes that the assignment to the saddles is freely selectable.
- The capacity per axle is `max_axle_load · capacity_factor`, i.e. 75 % for Grade 1 and 90 % for Grade 2.

Limitations

- **The axle distribution is a planning quantity, not a measured value.** In reality, the SPMT display shows the actual axle loads. These can deviate from the calculation if the hydraulics are not properly levelled.
- If a hydraulic group fails, the load distribution changes abruptly. RoadMind does **not** check what happens if an axle or hydraulic group fails. Explicit failure analysis is required for such cases.
- The `capacity_factor` is a flat reserve. It does **not** account for the actual number of load cycles, dynamic load peaks or fatigue.

Example 96 t Transformer

W_total = 142 t, x_fore = 4000, x_aft = 8000, x_COG = 6000:

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```
F_fore = 142 · (8000 − 6000) / (8000 − 4000) = 142 · 0.5 = 71 t
F_aft  = 142 · (6000 − 4000) / (8000 − 4000) = 142 · 0.5 = 71 t
```

Both saddles carry 71 t. With 4-axle modules and 2 modules per saddle (i.e. 8 axles per saddle):

```
Load per axle = 71 / 8 = 8.9 t
```

With Grade 1 (75 %) and max_axle_load = 12 t:

```
cap_per_axle = 9.0 t
8.9 t < 9.0 t → OK
```

With 6-axle modules and 2 modules per saddle (12 axles per saddle):

```
Load per axle = 71 / 12 = 5.9 t → well below 9.0 t → OK
```

7.6 Ground Pressure

What Is Calculated

RoadMind calculates the mean ground pressure under the entire SPMT configuration and compares it with the permissible limit value.

Derivation

The contact area results from the chain length L_row multiplied by the total width of all rows:

```
A_contact = L_row · (n_files · b)                                    (7.26)
```

with L_row = chain length [m], b = module width [m].

The mean ground pressure is then:

```
p_ground = W_total / A_contact                                       (7.27)
```

RoadMind compares p_ground with the permissible limit value p_max from the route survey (default: 10 t/m² per ALE 3.10).

Assumptions

- The load distributes **evenly** over the entire contact area. This is a rough simplification.
- The contact area is assumed to be a **rectangle** resulting from the chain length and the module width. The actual contact area is the sum of the tyre contact patches.
- The tyres are assumed to be rigid — there is no sinking depth, no deformation.

Limitations

- **The mean ground pressure is not a peak pressure.** In reality, significantly higher pressures occur under individual tyres than the mean. The mean pressure is only meaningful if the ground yields uniformly and the load can distribute.

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- For soft ground (sand, silt), the **peak pressure** under the most heavily loaded tyre is decisive. RoadMind does not provide this value.
- For route surveys, the mean pressure is often sufficient; for assessing ground pressure on sensitive surfaces (e.g. hall floors, bridges), it is too coarse.
- The limit value p_max is a **planning value**. It does not replace the geotechnical assessment of the actual subsoil.

Example 96 t Transformer

Chain length L_row = 12 m, n_files = 2, module width b = 2.43 m:

```
A_contact = 12 · (2 · 2.43) = 58.3 m²
p_ground = 142 / 58.3 = 2.44 t/m²
```

With a limit value of 10 t/m², this is well within the green range.

7.7 Wind Envelope

What Is Calculated

The wind envelope is the maximum wind speed at which the configuration is still **fully** valid — i.e. not only that the margin remains positive, but that the tip angle is still above the required value.

Derivation

The wind force on an exposed area A at wind speed v is:

```
F_wind = 0.0625 · A · v²                                    (7.28)
```

The factor 0.0625 results from the air density ρ = 1.25 kg/m³ and the drag coefficient c_w = 1.0:

```
F_wind = 0.5 · ρ · c_w · A · v² / 1000                      (7.29)
       = 0.5 · 1.25 · 1.0 · A · v² / 1000 = 0.000625 · A · v²
```

in tonnes, with A in m² and v in m/s.

The wind acceleration is then:

```
a_wind = F_wind / W_total                                   (7.30)
```

RoadMind iteratively searches for the largest wind speed at which both the margin is positive and the tip angle is above the required value, **and** all reaction forces remain within the capacity limits.

The iteration runs in steps of 0.5 m/s up to a maximum of 80 m/s.

Assumptions

- The wind application point is at COG height. This is a simplification.
- The drag coefficient c_w = 1.0 applies to compact, cuboid cargo. For other shapes (e.g. cylindrical tanks, lattice structures), the value is too high or too low.

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- The wind force is applied as a static load. Gusts, resonances and dynamic effects are not considered.
- The wind direction is assumed to be perpendicular to the exposed area.

Limitations

- **In reality, the wind application point is often above the COG.** For tall, light cargo (e.g. containers, tanks), the wind application point can be significantly higher. The tipping risk is then greater than calculated. In such cases, an explicit 3D wind load calculation is required.
- **The wind speed is assumed to be constant.** Gusts with peaks significantly above the mean are not captured. EN 1991-1-4 gives gust factors that are not considered here.
- **The wind direction is assumed to be constant.** A sudden change in wind direction can significantly alter the load distribution.
- The iteration provides a **conservative** value: the first speed at which a criterion is violated is the upper limit. The actual value can be lower if several criteria fail simultaneously.

Example 96 t Transformer

Cargo: 12 m × 3.5 m (long side), wind exposure area A = 42 m². W_total = 142 t. H_susp = 2.0 m, r_y = 3455 mm (static).

Wind force at v = 20 m/s:

```
F_wind = 0.0625 · 42 · 400 = 1050 kg = 1.05 t
```

Wind acceleration:

```
a_wind = 1.05 / 142 = 0.0074 g
```

COG shift:

```
Δy = 0.0074 · 2.0 = 0.0148 m = 14.8 mm
```

This is negligibly small. For the transformer, the wind envelope will therefore be very high — limited by the tip angle. RoadMind outputs it in the console; in the example it is above 60 m/s.

7.8 Overall System Tipping (Tipping System A)

What Is Calculated

In addition to tipping about the suspension points, RoadMind checks tipping of the **overall system** (cargo + SPMT) about the SPMT support edge. This is the more conservative consideration.

Derivation

The effective lever arm for the overall system is:

```
H_kipp = cog_z_sys_abs − z_kipp                                    (7.31)
```


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with:

- `cog_z_sys_abs` = combined COG of cargo and SPMT above ground
- `z_kipp` = height of the tipping point above ground. Standard: 375 mm (normal travel) or 225 mm (lowered).

The combined COG is:

```
cog_z_sys_abs = (W_cargo · cog_z_abs + W_spmt · cog_spmt_abs)
                / W_total                                          (7.32)
```

with:

- `cog_z_abs` = COG of cargo above ground
- `cog_spmt_abs` = COG of SPMT above ground. RoadMind assumes 50 % of the platform height.

The tip angle for the overall system is then:

```
α_x_sys = atan(r_x / H_kipp)                                       (7.33)
α_y_sys = atan(r_y / H_kipp)                                       (7.34)
```

with r_x and r_y the minima from Section 7.2 (unshifted COG).

Assumptions

- The tipping point is at 375 mm (normal travel) or 225 mm (lowered). This corresponds to the ALE guidelines.
- The SPMT COG is at 50 % of the platform height. This is an empirical value.
- The stiffness of the system is assumed to be rigid.

Limitations

- Overall system tipping is **more conservative** than suspension tipping. If only the overall system fails, the configuration may still be drivable in reality — but only if the hydraulics are functioning correctly and levelling is active.
- For very tall structures (e.g. towers, chimneys), overall system tipping is often the governing criterion.
- The choice between 375 mm and 225 mm depends on the operating mode. RoadMind assumes 375 mm by default; the value can be adjusted via `tip_point_height_mm`.

Example 96 t Transformer

W_cargo = 96 t, W_spmt = 46 t, W_total = 142 t cog_z_abs = 1500 + 500 + 1500 = 3500 mm cog_spmt_abs = 0.5 · 1500 = 750 mm z_kipp = 375 mm

```
cog_z_sys_abs = (96 · 3500 + 46 · 750) / 142
              = (336,000 + 34,500) / 142
              = 2609 mm = 2.609 m
```


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```
H_kipp = 2609 − 375 = 2234 mm = 2.234 m
```

In the static load case, r_y = 3455 mm:

```
α_y_sys = atan(3455 / 2234) = 57.1°
```

This is well above the required value of 9° (Grade 1).

7.9 Summary of Assumptions and Limitations

The following table summarises the central assumptions and limitations of all calculations.

Area	**Assumption**	**Limitation**
Suspension points	Even load distribution over all axles of a row	Does not apply when levelling is locked
Suspension points	Coupling gap 300 mm	Manufacturer-dependent
Stability margin	Rigidly coupled masses	Does not apply to very flexible cargo
Stability margin	Wind application point at COG height	Too optimistic for tall, light cargo
Tip angle	Rigidly assumed tipping axis	Neglects stiffness and damping
Reactions 3-point	Statically determinate	Unique, but only with ideal point supports
Reactions 4-point	Minimum-norm solution	Not unique; real distribution depends on stiffness
Axle load distribution	Even distribution over all axles	Does not apply to hydraulic failure
Axle load distribution	Axles freely assignable	In reality bound to fixed positions
Ground pressure	Even contact area	Peak pressure under tyres higher
Ground pressure	Limit value from route survey	Does not replace geotechnical assessment
Wind envelope	Constant wind, c_w = 1.0	Gusts, shape factors, direction changes not captured
Overall system	SPMT COG at 50 % platform height	Empirical value, not measured
All	Static load assumption	Dynamics, resonance, fatigue not captured

Important: RoadMind is a planning tool. It does not replace the engineering assessment by an experienced heavy haulage engineer, the route survey, or consultation with the SPMT manufacturer.

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The calculations follow the ALE guidelines and the ESTA recommendation, but responsibility for the execution of the transport remains with the executing company.

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Hier Kapitel 8–11 auf Englisch.

Chapter 8 – Lashing and Cargo Securing

8.1 Overview

The lashing calculation verifies whether the cargo is adequately secured against sliding and tipping on the SPMT. It follows the **Advanced Calculation Method** of EN 12195-1 and the requirements of the ALE/ESTA guidelines for heavy haulage.

RoadMind distinguishes two separate verifications:

- **Balance of Forces (sliding)** – secures the cargo against horizontal sliding
- **Tipping System B (tipping on the SPMT)** – secures the cargo against tipping about the saddle edge

Both verifications are performed in parallel. A lashing may be sufficient for the sliding check but not for the tipping check – and vice versa.

8.2 Lash Points

Lash points are the connection points between SPMT and cargo. They are placed as separate 3D objects in the model.

A lash point has:

- **Role:** `SPMTAttachment` (on the SPMT) or `CargoAttachment` (on the cargo)
- **Position:** (x, y, z) in world coordinates
- **Allowable load:** allowable load in kN
- **Reference object:** the object to which the lash point is attached

RoadMind distinguishes the roles because a lashing must **always** connect an SPMT point with a cargo point. Two SPMT points or two cargo points cannot be connected.

Limitations:

- The allowable load is a **nominal value**. It must be confirmed by the manufacturer of the attachment point. RoadMind does not verify the attachment of the point itself.
- The position is a **point in space**. In reality, each attachment point has an extent and a defined pull direction. Directional dependence is not captured.

8.3 Lashing Types

RoadMind knows eight lashing types with their LC values (Lashing Capacity) according to EN 12195-2:

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Type	LC [daN]	LC [kN]
Chain 13 mm	10,000	100
SpanSet 24 mm (LC 400)	400	4
SpanSet 35 mm (LC 1000)	1,000	10
SpanSet 50 mm (LC 2000)	2,000	20
SpanSet 50 mm (LC 2500)	2,500	25
SpanSet 55 mm (LC 5000)	5,000	50
Chain (LC 10000)	10,000	100
Chain (LC 25000)	25,000	250

The LC is the **permissible tensile force** of the lashing, not the breaking load. It already includes the safety factor specified in EN 12195-2.

Limitations:

- The LC values are **nominal values**. They apply to new, undamaged lashings. Wear, ageing and damage reduce the LC.
- The LC applies only to **axial tensile loading**. Transverse loading, bending or twisting reduce the capacity.
- The values are **manufacturer-dependent**. The table contains typical values; the user must use the LC of their actual lashings.

8.4 Geometry and Force Resolution

A lashing connects an SPMT point with a cargo point. The vector between the two points defines the **pull direction** of the lashing:

$$v = P_{cargo} - P_{spmt} \tag{8.1}$$

The length of the vector:

$$L = |v| \tag{8.2}$$

The angles:

$$\alpha_{vert} = \operatorname{atan}\left(\frac{|v_z|}{\sqrt{v_x^2 + v_y^2}}\right) \tag{8.3}$$

$$\alpha_{hor} = \operatorname{atan}\left(\frac{v_y}{v_x}\right) \tag{8.4}$$

The force components on the cargo (reaction force, opposite to the pull direction):

$$F_x = -LC \cdot \frac{v_x}{L} \tag{8.5}$$

$$F_y = -LC \cdot \frac{v_y}{L} \tag{8.6}$$

$$F_z = -LC \cdot \frac{v_z}{L} \tag{8.7}$$

with LC the effective lashing capacity.

The **effective lashing capacity** is the minimum of:

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- LC of the lashing
- allowable load of the SPMT attachment point
- allowable load of the cargo attachment point

LC_eff = min(LC_lashing, LC_spmt, LC_cargo) (8.8)

The weakest point in the system determines the capacity.

Limitations:

- The force resolution assumes that the lashing is **straight** under tension. Slack or pre-tension are not captured.
- The **pre-tension** of a lashing is not considered. It is often more important for sliding resistance than the LC.
- The force resolution does **not** account for the deformation of the lashing under load (elongation, settling).

8.5 Balance of Forces (Sliding)

What Is Calculated

The balance of forces verifies for each of the four directions (Fwd, Aft, Left, Right) whether the available securing exceeds the required securing.

Derivation

The required securing force in direction i is:

$$F_{req,i} = W_{total} \cdot a_i \quad (8.9)$$

with a_i the acceleration in direction i. For Fwd/Aft, a_i = 0.8 g or 0.5 g; for Left/Right, a_i = 0.5 g.

The available securing is composed of three components:

1. Friction:

$$F_{friction} = \mu \cdot N \quad (8.10)$$

with μ the friction coefficient and N the normal force. The normal force is the weight force **minus** the sum of the vertical lashing forces:

$$N = W_{total} - \Sigma F_{z,lashing} \quad (8.11)$$

If lashings pull upwards (F_z < 0), they reduce the normal force and therefore friction. This is a **critical effect** that is often overlooked.

2. Lashings:

For each direction, the sum of lashing components in that direction is formed. For Fwd:

$$F_{lashing,Fwd} = \Sigma \max(0, F_{x,lashing}) \quad (8.12)$$

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For Aft:

```
F_lashing,Aft = Σ max(0, −F_x,lashing)                    (8.13)
```

Analogously for Left/Right with F_y.

3. Stoppers:

Stoppers are **rigid** blocks (timber chocks, steel blocks). They are applied with their LC:

```
F_stopper,i = Σ LC_stopper,i                              (8.14)
```

Note: Stoppers have a safety factor f = 1.0 (per ALE guidelines). If a stopper is present in direction i, the lashings in that direction are **not** counted – the stopper takes the load alone. This is the conservative assumption: a lashing alongside a stopper cannot act simultaneously.

The available securing in direction i is then:

```
F_avail,i = F_friction + F_lashing,i + F_stopper,i        (8.15)
F_avail,i = F_friction + F_stopper,i (if stopper present)
F_avail,i = F_friction + F_lashing,i (if no stopper)
```

The verification is satisfied when:

```
F_avail,i ≥ F_req,i                                       (8.16)
```

Assumptions

- Friction acts **uniformly** in all directions. This is a simplification – for anisotropic friction pairings (e.g. steel on timber), the friction coefficient may differ in different directions.
- The friction coefficient μ is a **nominal value**. It depends on surface, moisture and pre-tension.
- The lashings are applied at their **full LC**, without consideration of pre-tension or settling behaviour.
- Stoppers are applied with **f = 1.0**, i.e. without additional safety factor.

Limitations

- **Friction is the most important factor – and the most uncertain.** A friction coefficient of 0.30 (neoprene on steel) can drop to 0.15 when wet. RoadMind uses the entered value; the choice is the user's responsibility.
- **Steel on steel is to be avoided** (ALE guideline). RoadMind warns at μ ≤ 0.11 but does not enforce a change.
- **Pre-tension is not captured.** In reality, lashings must be tensioned to the specified pre-tension. A lashing that is not pre-tensioned only acts after a certain displacement.
- **The friction coefficient can be improved by intermediate layers.** RoadMind does not capture these automatically; the user must enter the increased μ value.

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Example 96 t Transformer

W_total = 142 t, μ = 0.30. Four lashings with 50 kN LC each, vertical 45°, horizontal 0°. No stoppers.

Normal force per (8.11):

```
N = 142 − 4 · (50 · sin(45°)) / 9.81
  = 142 − 4 · (50 · 0.707) / 9.81
  = 142 − 14.4 = 127.6 t
```

Friction per (8.10):

```
F_friction = 0.30 · 127.6 = 38.3 t
```

Lashing components in Fwd direction (F_x = 50 · cos(45°) = 35.4 kN = 3.6 t per lashing):

```
F_lashing,Fwd = 4 · 3.6 = 14.4 t
```

Available securing Fwd:

```
F_avail,Fwd = 38.3 + 14.4 = 52.7 t
```

Required securing Fwd:

```
F_req,Fwd = 142 · 0.8 = 113.6 t
```

Result: 52.7 t < 113.6 t → NOT OK.

This is a typical result: with four normal lashings, a 96 t cargo cannot be secured against 0.8 g. Either stoppers, more lashings, or a combination of both are required.

8.6 Tipping System B (Tipping on the SPMT)

What Is Calculated

Tipping System B verifies whether the cargo tips about the **saddle edge** under transverse acceleration. This is a pure moment verification.

Derivation

The **tipping moment** from the transverse acceleration is:

```
M_tip = W_cargo · a_y · H_cargo                                    (8.17)
```

with:

- W_cargo = mass of the cargo [t]
- a_y = transverse acceleration [g]
- H_cargo = COG of the cargo above saddle bottom [m]

The **restoring moment** from the weight force is:

```
M_gravity = W_cargo · b_half                                       (8.18)
```


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with b_half = half support width [m]. The support width is the minimum of saddle width and platform width:

```
b_half = min(saddle_width, platform_width) / 2                (8.19)
```

The **lashing moment** results from the forces of the lashings about the tipping edge:

```
M_lashing = Σ (r_y · F_z − r_z · F_y)                         (8.20)
```

with r = distance between lash point and tipping edge, F = force components of the lashing. The sign is defined such that a **restoring** effect is positive.

The **total restoring moment**:

```
M_restore = M_gravity + M_lashing                             (8.21)
```

The verification is satisfied when:

```
M_restore ≥ M_tip                                             (8.22)
```

The **utilisation** is:

```
util = M_tip / M_restore                                      (8.23)
```

The **critical transverse acceleration** (at which the cargo tips):

```
a_crit = M_restore / (W_cargo · H_cargo)                      (8.24)
```

When Tipping System B Is Binding

RoadMind compares the critical transverse acceleration of Tipping System B with the critical transverse acceleration of the overall system (Tipping System A, Section 7.8).

Tipping System B is binding when a_crit_B < a_crit_A. The verification per Tipping System B is then decisive for approval.

Tipping System B is informational when a_crit_B ≥ a_crit_A. The overall system is then decisive, and Tipping System B is output for information only.

Limitations:

- Tipping System B only checks tipping **about the longitudinal axis** (transverse tilt). Tipping about the transverse axis (longitudinal tilt) is not checked. It is generally uncritical because the support width in the longitudinal direction is larger.
- The **deformation** of the cargo and the saddles is not captured.
- The **pre-tension** of the lashings is not captured. A lashing that is not pre-tensioned only acts after a certain tipping movement.
- The tipping edge is assumed to be a **sharp line**. In reality, the edge is rounded or deformed.

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Example 96 t Transformer

W_cargo = 96 t, H_cargo = 1500 + 500 = 2000 mm = 2.0 m Saddle width = 600 mm, platform width = 2430 mm b_half = min(600, 2430) / 2 = 300 mm = 0.3 m a_y = 0.5 g

M_tip per (8.17):

```
M_tip = 96 · 0.5 · 2.0 = 96 t·m
```

M_gravity per (8.18):

```
M_gravity = 96 · 0.3 = 28.8 t·m
```

Without lashings:

```
M_restore = 28.8 t·m
util = 96 / 28.8 = 3.33 → 333 %
```

a_crit per (8.24):

```
a_crit = 28.8 / (96 · 2.0) = 0.15 g
```

Result: The cargo would tip at a transverse acceleration of 0.15 g. This is well below 0.5 g. Additional lashings are required.

With four lashings of 50 kN each (vertical 45°, on the longitudinal sides of the cargo):

Assume each lashing provides a restoring moment of 0.5 t·m:

```
M_lashing = 4 · 0.5 = 2.0 t·m
M_restore = 28.8 + 2.0 = 30.8 t·m
util = 96 / 30.8 = 3.12 → 312 %
a_crit = 30.8 / 192 = 0.16 g
```

Result: Even with four lashings, the tipping risk is significant. Either **stoppers** (acting as direct blocking), a **wider support**, or a **reduction in transverse acceleration** (slower cornering) is required.

8.7 Stoppers

Stoppers are rigid blocks that secure the cargo against sliding in one direction. RoadMind knows three materials:

- **Steel** – steel block, LC as entered
- **Chain / D-Ring** – chain or D-ring, LC as entered
- **Timber chock** – timber chock, LC as entered

Stoppers are placed in the 3D model. They have:

- **Direction:** Fwd, Aft, Left or Right
- **LC:** allowable load in kN
- **Material:** for the BOM report

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Stoppers are applied with **f = 1.0**, i.e. without additional safety factor. The justification: stoppers are designed to take the load directly; they are not held by friction or pre-tension.

Limitations:

- **Stoppers must be in positive contact.** A stopper with clearance only acts after a displacement equal to the clearance.
- **Stoppers can damage the cargo.** For sensitive surfaces, an intermediate layer is required.
- **Stoppers are only as good as their attachment.** A stopper that is not attached to the SPMT can slip away.

8.8 Bill of Materials

RoadMind generates a BOM (Bill of Materials) with all lashings and stoppers:

- Lashing type, LC, quantity
- Stopper material, LC, quantity

The BOM appears in the PDF report and can be used for procurement.

Limitations:

- The BOM contains **no** wear parts, spare parts or tools.
- The BOM contains **no** attachment points on the SPMT or on the cargo – these must be procured separately.

8.9 Summary of Lashing Limitations

Area	**Assumption**	**Limitation**
Lash points	Point-shaped, with nominal load	Attachment not verified
Lashing types	LC per EN 12195-2	Wear, ageing not captured
Geometry	Straight under tension	Slack, pre-tension not captured
Force resolution	Static, without deformation	Elongation, settling not captured
Balance of forces	Uniform friction	Friction coefficient uncertain, anisotropic
Balance of forces	Stopper f = 1.0	Clearance, attachment not captured
Tipping System B	Tipping about longitudinal axis	Tipping about transverse axis not checked
Tipping System B	Sharp tipping edge	Rounding, deformation not captured
All	Static load assumption	Dynamics, resonance not

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Area	Assumption	Limitation
		captured

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Chapter 9 – Saving and Loading Setups

9.1 Overview

RoadMind stores the entire planning state – inputs, results, lashings, stoppers and the last lashing balance – in a single FreeCAD object named `SPMT_Setup`. This allows multiple transport variants to be kept in one document and switched between.

9.2 Saving

"Save Setup..." opens a dialog:

- **Setup name:** freely selectable (default: name of the cargo)
- **Version:** e.g. "Rev A", "Rev B"
- **Notes:** free text for remarks

After saving, an `SPMT_Setup` object is created. It contains:

- **Inputs:** cargo mass, COG, saddle positions, SPMT parameters, load cases
- **Results:** all results from `SPMTCalculator.result`
- **Lashings:** all lashing objects with their parameters
- **Stoppers:** all stopper objects
- **Lashing balance:** the result of the last balance calculation
- **References:** to the cargo, saddle and lashing objects in the document
- **Metadata:** creation date, last modification, version, notes

9.3 Loading

"Load Setup..." opens a list of all `SPMT_Setup` objects in the document. The user selects one. RoadMind:

- populates the task panel with the stored values
- restores the last calculation state
- loads the stored lashings and stoppers (if they still exist in the document)
- shows in the status bar whether the stored lashing balance passed

9.4 Updating

"Update Setup..." overwrites an existing setup with the current state. The dialog warns that the previous values will be lost.

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9.5 References

Setup objects store **names** (not objects) of cargo, saddle and lashing objects. If an object is deleted or renamed, the setup can no longer resolve the reference. On loading, RoadMind then indicates which references are missing.

Limitations:

- A setup is **bound to the document**. It cannot easily be transferred to another FreeCAD document.
- If a referenced object is deleted, the reference is **lost**. The setup stores the numbers, but not the geometry.
- The setup stores **no** 3D models. The SPMT modules must be regenerated after loading.

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Chapter 10 – Limitations and Responsibility

10.1 What RoadMind Does Not Verify

RoadMind is a planning tool. It does **not** verify:

- the **attachment** of the lash points to the SPMT or to the cargo
- the **load capacity** of the attachment points on the cargo
- the **deformation** of the cargo under its own weight and acceleration
- the **stability** of the cargo on the saddles (sliding on the saddle)
- the **load capacity** of the ground under the SPMT
- the **load capacity** of bridges and culverts along the route
- **traffic regulations** (weight, axle load, height, width)
- the **permitability** of the transport
- **dynamic** loads (vibrations, resonances, impact)
- **fatigue** of components
- the **operating limits** of the SPMT (hydraulics, steering, drive)

10.2 When an Engineer Must Be Involved

RoadMind provides figures. Approval always requires an **engineering assessment**. An engineer must be involved in particular when:

- the COG is **not centred** (asymmetric load)
- the cargo is **tall** (height > width)
- the cargo is **light** (wind exposure)
- the route is **complex** (gradients, curves, bridges)
- the configuration requires **multiple rows**
- Tipping System B is **binding**
- the tipping angles are **close** to the limit values
- the balance of forces is only **marginally** satisfied
- the actual axle loads **cannot be measured**

10.3 Responsibility

Responsibility for the execution of the transport lies with the executing company. RoadMind is a tool that supports planning but does not replace it.

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The user is responsible for:

- the correct entry of all data
- the selection of the correct planning grade
- the selection of the correct friction coefficients
- the selection of the correct lashings
- the verification of the calculation results
- the approval of the configuration
- compliance with legal requirements
- consultation with the SPMT manufacturer
- the route survey
- training of the operating personnel

10.4 Disclaimer

The calculations in RoadMind follow the published guidelines (ALE, ESTA, EN 12195). They are a **planning aid**, not an approval. The user bears sole responsibility for the use of the results.

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Chapter 11 – Appendix

11.1 Symbols and Units

Symbol	Meaning	Unit
W	Weight force	t
m	Mass	t
a	Acceleration	g
g	Gravitational acceleration	9.81 m/s²
H	Lever arm	m
r	Distance	mm
α	Angle	°
μ	Friction coefficient	–
LC	Lashing Capacity	kN
F	Force	t or kN
M	Moment	t·m
x, y, z	Coordinates	mm
p	Pressure	t/m²

11.2 Detailed Example Calculation

Input Data

Cargo:

- Type: box
- Length: 12,000 mm
- Width: 3,000 mm
- Height: 3,500 mm
- Mass: 96 t
- COG: (6000, 0, 1500) mm above cargo bottom

Saddles:

- Number: 2
- Position: x = 2000 mm and x = 10000 mm
- Height: 500 mm

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- Width: 600 mm

SPMT:

- Manufacturer: Scheuerle Gen3
- Platform width: 2430 mm
- Platform height: 1500 mm
- Dead weight per module: 11.5 t
- Maximum axle load: 12 t
- Overhang: 700 mm

Load cases:

- Grade 1 (9°, 75 %)
- a_x_brake = −0.5 g
- a_y_curve = 0.5 g (curve left)
- Slope long = 0 %
- Slope lat = 0 %
- Wind = 0 m/s

Step 1 – Saddle Span and Minimum Length

```
Span = 10000 − 2000 = 8000 mm
Min_length = 8000 + 2 · 700 = 9400 mm
```

Step 2 – Module Selection

Longest module in the database: 6-axle, 8400 mm. Number of long modules:

```
n_long = ceil(9400 / 8400) = 2
```

Remaining length:

```
Rest = 9400 − 8400 = 1000 mm
```

Shortest module covering the remaining length: 2-axle, 2800 mm. So:

```
Combo = [6-axle, 6-axle, 2-axle]  (not quite right, because n_long = 2)
Correction: n_long = 2, so Combo = [6-axle, 4-axle] with L = 8400 + 5600 = 14000
mm
```

RoadMind selects the combination that covers the minimum length with the fewest axles.

Step 3 – Number of Rows

n_files = 1:

- W_spmt = 1 · (11.5 + 11.5) = 23 t

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- W_total = 96 + 23 = 119 t
- Total axles = 1 · 10 = 10
- y_half = 725 mm
- Suspension points: P1 = (4000, −725), P2 = (4000, +725), P3 = (8000, −725), P4 = (8000, +725)
- Stability margin in y: 725 mm
- H_susp = 1500 + 500 = 2000 mm = 2.0 m
- Tip angle y: atan(725/2000) = 19.9° → above 9° → OK
- Tip angle x: r_x = 2000 mm (half span), atan(2000/2000) = 45° → OK
- Axle load: 119/10 = 11.9 t > 12 · 0.75 = 9 t → **NOT OK**
- Ground pressure: 119 / (14 · 2.43) = 3.5 t/m² → OK

n_files = 2:

- W_spmt = 46 t
- W_total = 142 t
- Total axles = 20
- y_half = 725 + (2430 + 300) = 3455 mm
- Suspension points: P1 = (4000, −3455), P2 = (4000, +3455), P3 = (8000, −3455), P4 = (8000, +3455)
- Stability margin in y: 3455 mm
- H_susp = 2.0 m
- Tip angle y: atan(3455/2000) = 59.9° → OK
- Tip angle x: 45° → OK
- Axle load: 142/20 = 7.1 t < 9 t → OK
- Ground pressure: 142 / (14 · 4.86) = 2.1 t/m² → OK
- Hydraulics: 142 / 20 = 7.1 t/axle → OK

Result: n_files = 2 satisfies all criteria.

Step 4 – Reactions (Static)

```
Σ R = 142 t
Σ R · x = 142 · 6000 = 852,000 t·mm
Σ R · y = 0
```

With 4-point solution (minimum norm):

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```
R1 = R2 = 35.5 t (front)
R3 = R4 = 35.5 t (rear)
```

Step 5 – Reactions (Curve Left, a_y = 0.5 g)

```
M_x = 142 · 0.5 · 2.0 = 142 t·m = 142,000 t·mm
Σ R · y = 0 + 142,000 = 142,000 t·mm
Σ R · x = 852,000 t·mm
Σ R = 142 t
```

Solution:

```
R1 = 30.9 t  (front right)
R2 = 40.1 t  (front left)
R3 = 30.9 t  (rear right)
R4 = 40.1 t  (rear left)
```

The left points carry more load because the cargo tips to the left.

Step 6 – Tipping System B

```
b_half = min(600, 2430) / 2 = 300 mm = 0.3 m
H_cargo = 1500 + 500 = 2000 mm = 2.0 m
M_tip = 96 · 0.5 · 2.0 = 96 t·m
M_gravity = 96 · 0.3 = 28.8 t·m
M_restore = 28.8 t·m (without lashings)
a_crit = 28.8 / (96 · 2.0) = 0.15 g
```

Result: Tipping System B is binding because a_crit_B = 0.15 g < a_crit_A.

Step 7 – Overall System

```
cog_z_abs = 1500 + 500 + 1500 = 3500 mm
cog_spmt_abs = 0.5 · 1500 = 750 mm
cog_z_sys_abs = (96 · 3500 + 46 · 750) / 142 = 2609 mm
z_kipp = 375 mm
H_kipp = 2609 − 375 = 2234 mm = 2.234 m
Tip angle y: atan(3455/2234) = 57.1° → OK
Tip angle x: atan(2000/2234) = 41.8° → OK
```

Step 8 – Lashing

Four lashings with 50 kN LC, vertical 45°, horizontal 0°:

```
F_friction = 0.30 · (142 − 4 · 50 · 0.707 / 9.81) = 0.30 · 127.6 = 38.3 t
F_lashing,Fwd = 4 · 50 · 0.707 / 9.81 = 14.4 t
F_avail,Fwd = 38.3 + 14.4 = 52.7 t
F_req,Fwd = 142 · 0.8 = 113.6 t
```

Result: NOT OK. Additional securing required.

11.3 References

- **ALE Engineering Guidelines, Section 03 Transport.** Heavy Transport Association, latest edition.

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- **ESTA Best-Practice Guideline for SPMTs.** European Association of Abnormal Road Transport and Mobile Cranes, latest edition.
- **EN 12195-1:** Load restraint assemblies on road vehicles – Calculation of lashing forces.
- **EN 12195-2:** Load restraint assemblies on road vehicles – Web lashing made from man-made fibres.
- **IMO CSS Annex 13:** Code of Safe Practice for Cargo Stowage and Securing.

11.4 Glossary

Term	**Meaning**
SPMT	Self-Propelled Modular Transporter
COG	Centre of Gravity
LC	Lashing Capacity
MSL	Maximum Securing Load
Suspension Point	Support point at which the SPMT carries the load
Stability Polygon	Polygon formed by the suspension points
Stability Margin	Smallest distance from the COG to the polygon edge
Tip Angle	Tipping angle at which the COG moves over the tipping edge
H_susp	Lever arm between COG and suspension plane
H_kipp_sys	Lever arm between overall COG and tipping point
Tipping System A	Tipping of the overall system (cargo + SPMT)
Tipping System B	Tipping of the cargo on the SPMT
Envelope	Region in which the COG moves under load cases
n_files	Number of rows (transverse module rows)
Grade 1	Planning grade for simple transports (9°, 75 %)
Grade 2	Planning grade for complex transports (7°, 90 %)
Friction coefficient μ	Ratio of friction force to normal force
Stopper	Rigid blocking against sliding
Balance of Forces	Equilibrium of forces in all directions

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Chapter 12 – Appendix Example Results

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SPMT Transport Calculation Report

Cargo:	Cargo
Date:	2026-10-01 18:38
Planning grade:	1 (tip >= 9.0 deg, capacity factor 75 %)
Support type:	4point
Status:	OK
Limiting factor:	none

Cargo

Mass [t]	435.00
COG x [mm]	13940
COG y [mm]	0
COG z above cargo bottom [mm]	3000
COG z above ground [mm]	5000
COG z above suspension plane [mm]	3500
Saddle height [mm]	500

Saddle positions (x, from cargo front edge)

Saddle	x [mm]
1	0
2	35450

SPMT configuration

Saddle span [mm]	35450
Chain overhang per side [mm]	2700
Min chain length [mm]	40850
Modules per row	6ax/9360 + 6ax/9360 + 6ax/9360 + 6ax/9360 + 4ax/4200
Row length [mm]	41640
Axles per row	28
Files (rows)	1
Total axles	28
Platform width [mm]	2430
Platform height [mm]	1500
y_half [mm]	725
SPMT dead weight [t]	107.12
Total weight [t]	542.12

Stability (suspension)

H_susp (COG above suspension plane) [m]	2.660
r_poly (min edge dist) [m]	0.725
slope_x / slope_y [%]	27.25 / 23.77

ALE op limit x / y [%]	13.63 / 11.88
Tip angle x / y (suspension) [deg]	15.24 / 13.37
Required tip angle [deg]	9.0
Geometric OK x	yes
Geometric OK y	yes
Hydraulic OK	yes
Axle OK	yes

Stability (overall system, tipping point 225 mm above ground, ALE 3.6.5)

H_kipp_sys (COG above ground - 225 mm) [m]	3.785
Tip angle x / y (overall system) [deg]	61.49 / 10.84
Required tip angle [deg]	9.0
Overall system OK	yes

Slope / Curve / Wind

Slope long (user) [%]	0.00
Slope lateral (user) [%]	0.00
Slope long effective (incl. ESTA +2 deg) [%]	3.49
Slope lateral effective (incl. ESTA +2 deg) [%]	3.49
Curve a_y [g]	0.000
Slope a_x [g]	0.035
Wind speed lat / lon [m/s]	0.0 / 0.0
Wind area lat / lon [m2]	None / None
Wind accel lat / lon [g]	0.0000 / 0.0000
Wind envelope lateral [m/s]	58.0
Wind envelope longitudinal [m/s]	80.0

Axle load

Average axle load [t]	19.36
Axle load limit [t]	27.00
Nominal max axle load [t]	36.00

Suspension points

#	x [mm]	y [mm]
P1	6970	-725
P2	6970	725
P3	24695	-725
P4	24695	725

Reactions per load case

Case	P1 [t]	P2 [t]	P3 [t]	P4 [t]

Static	164.5	164.5	106.6	106.6
Braking	164.5	164.5	106.6	106.6
Curve	164.5	164.5	106.6	106.6
Slope	165.9	165.9	105.2	105.2

Reaction self-check (numeric vs analytical)

Case	dSum_R [t]	rel [%]	dSum_Rx [t*m]	rel [%]	dSum_Ry [t*m]	rel [%]

Report generated by RoadMind. Criteria follow ESTA Best-Practice Guideline for SPMTs and the ALE Engineering Guidelines (Section 03 Transport). Suspension stability uses the suspension-point polygon; overall-system tipping assumes the tipping point 225 mm above ground. The 2 deg ESTA slope reserve is always added to every slope. This report is a planning aid, not a certification.

SPMT LASHING CALCULATION

Balance of Forces · ESTA / ALE Acceleration Envelope · Restraint per certified LC (EN 12195-2), used directly; no additional reduction factor.

OVERALL RESULT: PASS

Cargo	**Cargo**	Envelope Fwd	**0.8 g**
Mass	**435.000 t**	Envelope Aft	**0.5 g**
Normal force N	**447.342 t**	Envelope Left/Right	**0.5 g**
Friction μ	**0.60**	Sum Fz (lashings)	**-12.34 t**
Date	**2026-10-01 18:39**	Kippsystem B	**informational / binding (see below)**

Securing Arrangement – Lashings

Dir	Lashing	LC daN	LC kN	α vert °	α hor °	Fx kN	Fy kN	Fz kN	Restr kN
Right	Lashing 1 (Cargo Point 3 -> SPMT Point 1)	10000	100.0	38.0	-115.6	+34.0	+71.1	-61.5	**71.1**
Left	Lashing 2 (Cargo Point 4 -> SPMT Point 2)	10000	100.0	36.6	117.1	+36.6	-71.5	-59.6	**71.5**

Stoppers / Blocking Devices (f = 1.0)

Dir	Stopper	Material	LC kN
Fwd	Stopper 1 (Fwd)	Steel	500.0
Fwd	Stopper 2 (Fwd)	Steel	500.0

Balance of Forces (Sliding)

Direction	Req t	Friction t	Lashings t	Stopper t	Avail t	Source	Status
Fwd	348.00	268.40	0.00	101.94	**370.34**	Stopper(2) + Friction	**OK**
Aft	217.50	268.40	0.00	0.00	**268.40**	Lashings + Friction	**OK**
Left	217.50	268.40	7.25	0.00	**275.65**	Lashings + Friction	**OK**
Right	217.50	268.40	7.29	0.00	**275.69**	Lashings + Friction	**OK**

Kippsystem B – Cargo Tipping on the SPMT

Saddle width: 2800 mm | Platform width: 2430 mm | H_cargo: 3000 mm (cargo COG above saddle bottom) | Tipping edge: +/-1215 mm

n_files = 1 -> Kippsystem A (overall system) is governing. Kippsystem B is informational only.

Side	M_tip (0.5 g) t·m	M_gravity t·m	M_lashings t·m	M_restore t·m	Util (0.5 g)	a_crit g	Status
Left	652.50	528.53	+14.52	**543.05**	120.2%	**0.416**	informational
Right	652.50	528.53	+15.47	**543.99**	119.9%	**0.417**	informational

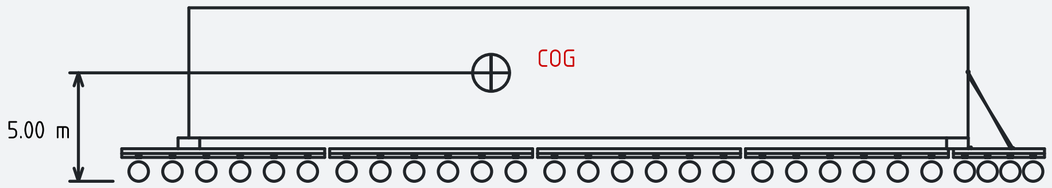
Bill of Materials

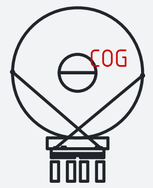
Item	Count
Chain 13 mm | LC=10000 daN	**2**
Stopper Fwd | Steel | LC=500 kN	**2**

*Envelope: Fwd 0.8 g, Aft 0.5 g, Left/Right 0.5 g. Effective restraint = min(lashing LC, both point loads); no additional safety factor (EN 12195-1). Stopper: f = 1.0; lashings alongside a stopper count 0 for sliding. Kippsystem B: moment balance about the saddle edge, with the gravity restoring moment m * half_base.*

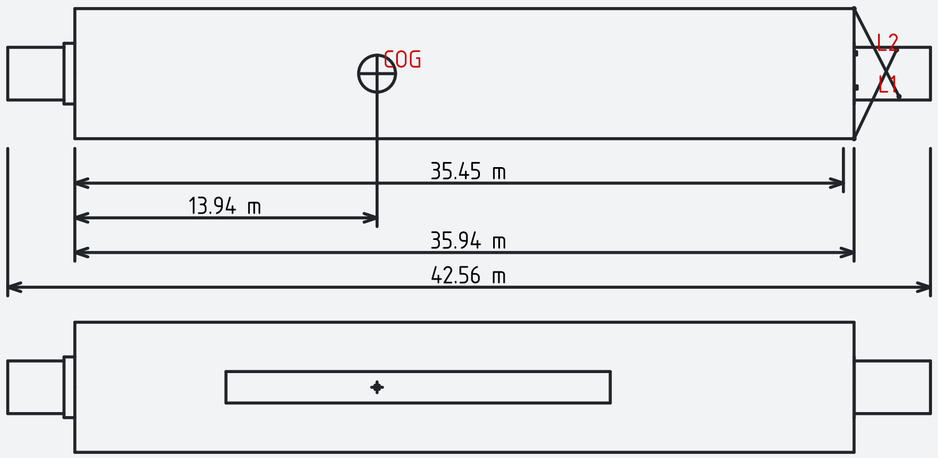
roadexpedition

Length: 42.56 m
Width: 6.10 m
Height: 8.00 m
Weight: 435 t

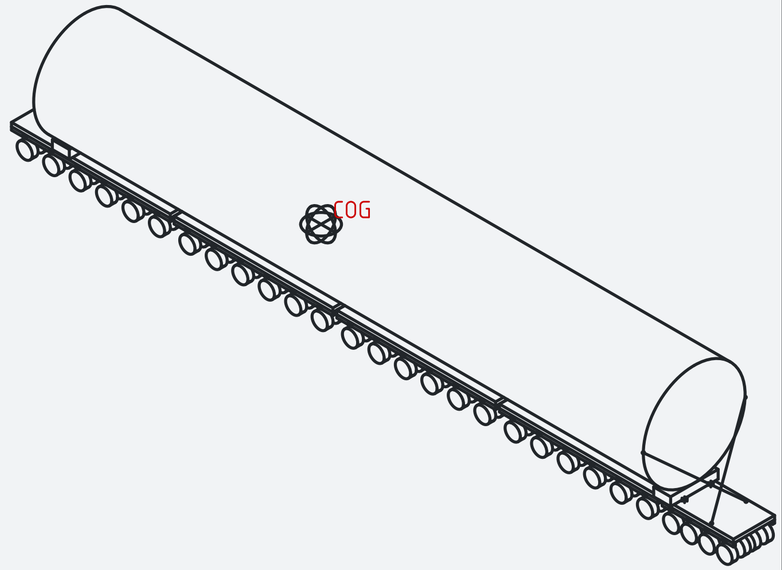




COG (cargo): x=13940 y=0 z=5001 mm



4-point suspension | tip x=15.2° y=13.4° (min 9.0°) | r_poly=0.72 m



Title: **SPMT Transport**		
Cargo: Cargo		Drawn by: -
Date: 2026-10-01	Scale: 1:200	Sheet: 1/1