DESIGN OF METHODOLOGY FOR THE VERIFICATION OF LOAD DISTRIBUTION IN A CONTAINER

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Abstract

The paper presents a sophisticated interactive tool supporting the decision-making of loading parties and vehicle operators – Methodology for the verification of load distribution in a container. The methodology allows us to standardize procedures used by loading parties, and ensures safe loading and transport of container units. Using a spreadsheet (table editor), it offers a simple, quick, affordable and universally applicable solution. The procedures featured in the Methodology are generalised and allow verifying load distribution in any ISO series 1 storage container. The procedures presented are generally algebraically described and accompanied by a calculation flow diagram. Safe handling and transport of a container unit is ensured by keeping the deviation of the actual centre of gravity from the optimum centre of gravity in acceptable limits. A model example of loading of one of the most commonly used containers – ISO 1 C – is also part of the Methodology.

Keywords: container, methodology, decisions, distribution, centre of gravity, pallet unit.

JEL classification: B_{49}, L_{62}.

1. Introduction

When the armies of the North Atlantic Treaty Organization (NATO) member states employ a container transport system and emphasis is put on the swiftness of the transport and supply system, the need for information support for the management of material flow is becoming more and more urgent. Programme applications dealing with specific process logistic actions are very expensive, as their development depends on specific requirements, environment and other aspects.

Fields, such as the verification of container loading for the purpose of safe handling and transport, are not, as a rule, software-supported in economically less developed countries. In such cases, in particular basic algorithms and practical knowledge gained during previous loadings are applied.

Armed Forces of the Czech Republic (ACR) also lacked an exact procedure for container loading as well as a binding methodological instruction for the creation of container units. In today's situation, when the budget of the Ministry of Defence (MoD) is being reduced, the purchase of a suitable programme application or the extension of the existing MoD and ACR Logistics Information System by the function in question cannot be reckoned on in near future.

Armies using software products for container loading must have an alternative variant at hand in case of the system failure during crisis.

For the above-stated reasons, the interactive tool allowing us to standardize, simplify and speed up the process of loading is an efficient solution.

2. Basic assumptions

For the purpose of the verification of load distribution in a container, the authors have worked up a single methodological procedure that can be applied using *a worksheet (table editor)*.

The resulting methodological procedure has taken into consideration following requirements arising from the experience of loading parties:

- *simplicity*;
- *affordability*, i.e. with low or zero initial economic difficulty;
- *universal applicability* to various types of containers;
- *unity* of procedures for the verification of load distribution in a container;
- *applicability* by the lowest levels of command and management.

The goal of the Methodology for the verification of load distribution in a container (further in the text referred to as "Methodology") is to ensure proper load weight distribution for the purpose of safe handling of container units. Otherwise, damages to persons or property or other losses relating to the interruption of material flow may result. The methodology complies with *STANAG 2828*, and meets the above-listed requirements.

As a model, the methodology is adapted to the most commonly used container in ACR – ISO 1 C, produced by DAHER KARBOX, s. r. o. company. The container of this type has smaller dimensions (5,870 x 2,330 mm) compared to the dimensions of commonly commercially available ISO 1 C containers in Europe and the USA (as a rule 5,897 x 2,350 mm).

The entire process of the verification of load distribution is generalized, and the Methodology may be applied to any type of ISO series 1 storage container. For the purpose of calculation, Microsoft Excel 97-2007 spreadsheet has been utilised. The calculation of a model example for the most common type of container in ACR (ISO 1 C) and pallets (1,200 x 800 mm) is also part of the methodology.

3. Methodological procedure for the verification of load distribution

3.1. Input data

For the verification, whether a container unit is loaded in compliance with the requirements for safe handling, information about the load (material, pallet units, etc.) and transport equipment (a container, pallets, crates, etc.) must be obtained.

For the purpose of calculation, following data is required:

- *the weight of individual pallet units* can be determined by weighing a complete pallet unit or by technical calculation, i.e. by the summation of the weight of material, all packaging and transport equipment (crates, pallets, etc.);

- *position of the centre of gravity of each pallet unit* – on normally produced pallet units containing a single type of material, the centre of gravity is generally assumed to be in the centre of the pallet unit; in other cases, the method of identification of the centre of gravity is the same as for the container (further in the text);

- *dimensions* (length and width) *of the loading area of a container* – data is provided by the producer; for the most common types of containers utilised by ACR – ISO 1 C storage containers – the data can be found on www.karbox.cz;

- *the coordinates of the centres of gravity* of pallet units in the container coordinate system can be obtained by measuring the distances of individual pallet units from container walls or by drawing them in a created coordinate axis (refer to fig. 1 and 2).

3.2. The creation of a container coordinate system

A container coordinate system can be created by simple drawing on a paper, preferably of A4 size (refer to fig. 1).

As it is a scheme of a load plan, where the coordinates of individual pallet units are also drawn, a printed load plan of a container unit can be used.

The ideal scale for the drawing of an ISO 1 C container loading area (5,870 x 2,330 mm) is 1:25 allowing us to schematically depict two containers on one sheet of paper of A4 size. The origin of the coordinate system (point 0) is located in the lower right corner of the door space for the ISO 1 C (ISO 1 CC) container.

Fig. 1. Coordinate system of a container loading area

3.3. Plotting pallet units

For better orientation in the scheme, four walls of the container can be maintained. Then, pallet units are to be plotted on the drawing according to their actual placement in the container. Example of determining the first pallet unit coordinates is shown in fig. 2.

Fig. 2. Plotting the first pallet unit

If the centre of gravity is in the centre of a pallet unit (the red spot), the coordinates can be determined by simple calculation. Fig. 2 shows a pallet unit with standard dimensions

1,200 x 800 mm (bold black line) that is placed 65 mm far from the left wall (of the door space) and 32 mm from a side wall. The coordinates are then as follows:

x: 65 + 800/2 = 465 mm

y: 32 + 1,200/2 = 632 mm

Coordinates of other pallet units shall be determined in the same way, and then drawn in the scheme.

On the condition that the centre of gravity of a pallet unit is elsewhere (refer to fig. 2 – green line), the distance from the actual centre of gravity (the green spot) shall be determined.

Fig. 3 shows an example of the distribution of pallet units sized 1,200 x 800 x 1,600 mm in an ISO 1 C container.

Further information (designation, dimensions, weight, etc.) facilitating the orientation in the scheme and further calculation can be part of the plotting of individual pallet units.

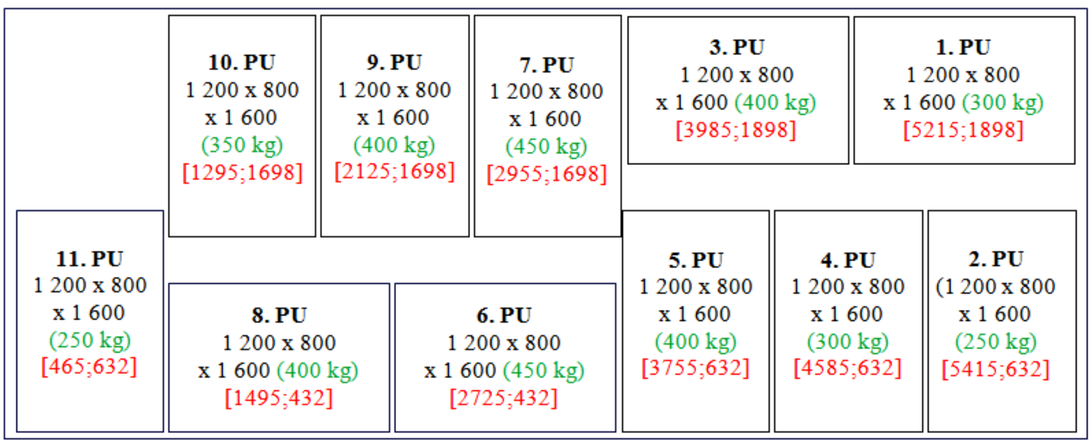

Fig. 3. Example of a container unit load plan with all data

The next step is the determination of the container optimum (theoretical) centre of gravity coordinates. The centre of the container loaded area can be considered as the ideal position of the centre of gravity. In case of ISO 1 C container, the calculation of the optimum centre of gravity coordinates T_{opt}: [x_{opt}; y_{opt}] is as follows:

x_{opt}: 5,870/2 = 2,935 mm

y_{opt}: 2,330/2 = 1,165 mm

3.4. Entering values in the table

The values are entered in a Microsoft Excel sheet named "METHODOLOGY OF THE VERIFICATION OF LOAD DISTRIBUTION IN A CONTAINER" that is available from the main author upon request. Only the fields containing red or blue text in the "METHODOLOGY" sheet are to be filled in. The table is shown in fig. 4.

CONTAINER DESIGNATION

PU designation	x_i	y_i	m_i (kg)
Pallet unit 1	0	0	0
Pallet unit 2	0	0	0
Pallet unit 3	0	0	0
Pallet unit 4	0	0	0
Pallet unit 5	0	0	0
Pallet unit 6	0	0	0
Pallet unit 7	0	0	0
Pallet unit 8	0	0	0
Pallet unit 9	0	0	0
Pallet unit 10	0	0	0
Pallet unit 11	0	0	0
m_C	–	–	0
Acceptable deviation in axis x (%)	10		
Acceptable deviation in axis y (%)	10		

Operation	Result
Σm_i	0
$\Sigma x_i m_i$	0
$\Sigma y_i m_i$	0
x	#DIV/0!
y	#DIV/0!
x_{opt}	2 935
y_{opt}	1 165
Deviation in axis x (%)	**#DIV/0!**
Deviation in axis y (%)	**#DIV/0!**

Fig. 4. Tables for the calculation of load distribution in a container

Designation (name) of the container is entered in cell B 2.

In the upper table, coordinates of pallet units x_i and y_i (columns C and D) and their weight m_i (column E) are to be filled in. Cell E 16 is not to be filled in; it contains a mathematical formula for the summation of weight of all pallet units in a container. The last two lines of the upper table contain pre-set values of deviation (10 %); in standard cases, the value is left unchanged.

In the lower table, only the coordinates of the optimum centre of gravity (cells C 26 and C 27) are to be filled in. The cells contain pre-set values for commonly utilised ISO 1 C or ISO 1 CC storage containers.

The remaining part of the lower table contains mathematical formulas that automatically calculate the deviation from the optimum centre of gravity.

The results (values of deviations in axes x and y) in cells C 28 and C 29 are subject to conditional formatting that **highlights unacceptable deviation value with red colour**. In such cases, the distribution of load proposed is not possible, and the arrangement of the pallet units must be changed.

3.5. Algebraic description of the centre of gravity calculation

Mathematical formulas for the calculation of the centre of gravity are provided in the following algebraic notation and flow diagram (refer to fig. 5).

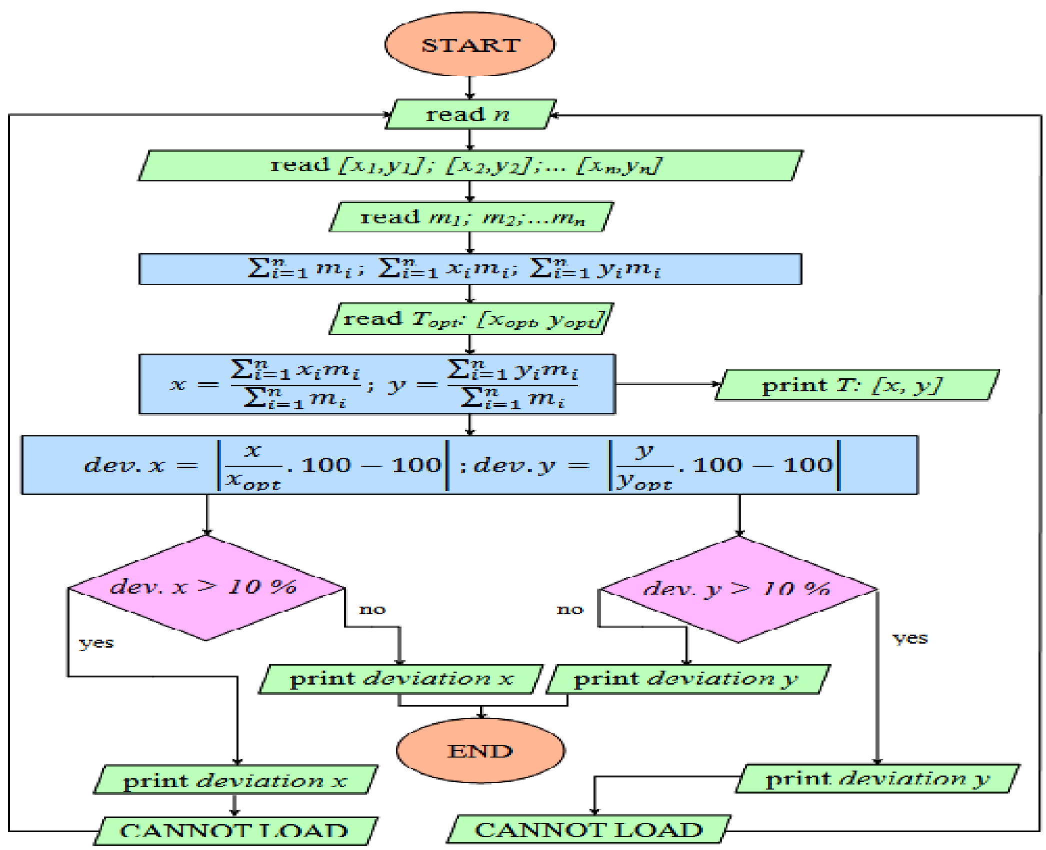

Fig. 5. Flow diagram for the verification of load distribution in a container

For the calculation of coordinates of the centre of gravity T: [x; y] following relations are used:

$$x = \frac{\sum_{i=1}^{n} x_i m_i}{\sum_{i=1}^{n} m_i} \quad (1),$$

$$y = \frac{\sum_{i=1}^{n} y_i m_i}{\sum_{i=1}^{n} m_i},\ i \in N, \quad (2),$$

where n is the number of pallet units; x_i is coordinate x of i-th pallet unit and m_i is its weight. Analogically, y_i is coordinate y of i-th pallet unit.

The position of the centre of gravity (T) only has information value in relation to the optimum centre of gravity (T_{opt}) and the determination of the deviation. In NATO member states (e.g. USA, Germany), the recommended deviation is max. ± 10 %, which ensures even distribution of load in a container and safe handling of a container unit.

For the purpose of calculation, even deviations lesser than ± 10 % can be used on the condition that stricter handling requirements are applied.

The relations for the determination of a deviation are as follows:

$$Deviation\ x\ (\%) = \left| \frac{x}{x_{opt}} .100 - 100 \right| \quad (3),$$

$$Devitation\ y\ (\%) = \left| \frac{y}{y_{opt}} .100 - 100 \right| \quad (4),$$

Entering values from fig. 3 is shown in sheet "MODEL EXAMPLE" in the upper table. In the lower table, a complete calculation of the container unit centre of gravity deviation from the optimum centre of gravity (refer to fig. 6) is provided.

CONTAINER 1

PU designation	x_i	y_i	m_i (kg)
Pallet unit 1	5 215	1 898	300
Pallet unit 2	5 415	632	250
Pallet unit 3	3 985	1 898	400
Pallet unit 4	4 585	632	300
Pallet unit 5	3 755	632	400
Pallet unit 6	2 725	432	450
Pallet unit 7	2 955	1 698	450
Pallet unit 8	1 495	432	400
Pallet unit 9	2 125	1 698	400
Pallet unit 10	1 295	1 698	350
Pallet unit 11	465	632	250
m_c			3 950
Acceptable deviation in axis x (%)	10		
Acceptable deviation in axis y (%)	10		

Operation	Result
Σm_i	3 950
$\Sigma x_i m_i$	11 963 250
$\Sigma y_i m_i$	4 491 800
x	3 029
y	1 137
x_{opt}	2 935
y_{opt}	1 165
Deviation in axis x (%)	**3,19**
Deviation in axis y (%)	**2,39**

Fig. 6. Model example of the verification of load distribution in a container

In the model example for the container unit designated as "Container 1", the deviations are in acceptable range (0-10 %), i.e. they are depicted in black and bold. Otherwise, they would be in red and bold. The resulting deviations are in the last two lines of the lower table in fig. 6, where there is 3.19% deviation from axis x and 2.39% deviation from axis y.

The procedure is schematically broken down in the above-provided flow diagram. Provided that the condition of the deviation value is not met (e.g. ± 10 %), the arrangement of pallet units in the container or their weight, need to be changed.

4. Conclusion

The methodology presented represents a very simple, effective and affordable tool for the verification of load weight distribution in storage containers of various types and is designed to support decision-making of loading parties.

Analogically, the methodological procedure can serve to identify the position of the centre of gravity of an unevenly loaded pallet unit. The axis of coordinates will then be created with regard to the loading area of a pallet (e.g. for EURO pallet, it is, without overlap, 1,200 x 800 mm).

The methodology is intended for a wide range of users who are responsible for the creation of container units in the armies of NATO member states.

As a result, the container unit is produced with regard to the safety of handling and transport. Hence, the danger of injury during handling or exclusion from, e.g. air transport due to insufficient balance of a handling unit, is prevented.

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