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# DESIGN SOLUTION OF HANDLING EQUIPMENT FOR INTEROPERATIONAL TRANSPORT OF INJECTION MOLDS

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***Abstract:***
*This article focuses on the design of a transport device specifically tailored for handling such heavy molds. The objective is to create a device that can securely and easily handle molds of various sizes, transporting them between the press and the mold warehouse, or vice versa, from the mold warehouse to the injection press. This article was created based on the requirement of a company working for the automotive industry. This company produces large-sized plastic moldings such as dashboard, car door trim and the like. These moldings are produced on large-size injection molding machines, with massive injection molds. One of the problems with this business was the handling of these massive forms, which can weigh tens of tons. The strength calculation of the structure is carried out using Finite Element Method (FEM) in the conclusion.*

***Key words:***
*Transport, handling equipment, design, inter-operative transport*

## 1 INTRODUCTION

The transportation and storage of materials during the assembly process pose a significant obstacle to its further development. The automotive industry plays a crucial role in driving the growth of the Slovak economy (Sinay et al., 2018). To meet the demands of flexible and automated production, there is a need to develop advanced technical solutions for inter-operative transportation and storage (Verebová, 2016). The efficient and seamless connection of assembly workplaces, systems, and their functions through material flow is of utmost importance.

Transport machinery and handling equipment play a crucial role in all sectors of the national economy through their dedication and functionality. In every production process, the involvement of handling, transportation, and supporting tasks is essential, as only their combined and coordinated efforts lead to the creation of a finished product (Xie et al., 2015). Material handling holds significant importance in any industrial operation. Economic studies have evaluated the value of each individual sub-operation and work task that precedes and follows one another, which are accomplished through the utilization of transport and handling equipment. Therefore, the realization of production relies not only on operational and technological aspects but also incorporates an average handling cost ranging from 10 to 30%. In modern engineering production, effective material handling and suitable transportation means are indispensable requirements (Ambriško et al., 2015).

The automotive sector has long been a driving force behind the Slovak economy, providing direct employment to around 120,000 individuals. When considering the expenditures made by both companies and individuals involved in passenger car production, the number of jobs dependent on the industry rises to 200,000. In the previous year, automobile manufacturing alone contributed to approximately 44% of the Slovak industry, with passenger car exports accounting for 35% of total domestic exports. For several years, Slovakia has held the top position in terms of the number of cars produced per thousand inhabitants (Kališ, 2018).

This article was written in response to the needs of a company operating within the automotive industry. The company specializes in manufacturing oversized plastic moldings, including items such as dashboards and car door trims. These moldings are produced using large-scale injection molding machines and require substantial injection molds. One of the challenges faced by this company pertains to the handling of these sizable molds, which can weigh tens of tons.

## 2 DEFINITION OF EQUIPMENT CHARACTERISTICS AND REQUIREMENTS

The objective was to create a transport device that could move a mold between an injection molding machine and a warehouse, as well as vice versa, from the warehouse to the machine. The specific injection molding machine in question was the Engel duo 1500, which possessed a clamping force of 1500 tons. This machine was capable of accommodating the largest mold size of 1400 x 700 x 3750 mm, weighing up to 30 tons. Therefore, the design of a transport device, referred to as a trolley, became necessary. This trolley needed to have a lifting capacity of 30 tons and be equipped with an adjustable locking mechanism to accommodate molds of various sizes.

The design of the transport truck drew inspiration from various road vehicles. Specifically, it took cues from low loaders used for transporting heavy civilian and military equipment, as well as automated forklift trucks with advanced control systems. Additionally, construction solutions commonly employed in trucks played a role in shaping the design of the transport truck.

The design and assembly of the load-bearing structure should be capable of withstanding all anticipated loads and influences that may occur during construction and operation throughout its intended service life, ensuring a suitable level of reliability. It should fulfill the specified usability requirements set for the load-bearing structure or its individual elements. The dimensioning of the load-bearing structure should ensure sufficient strength, durability, and usability (Michlowicz, 2011).

There are two categories of limit states that we are aware of: the ultimate limit states and the serviceability limit states.

The ultimate limit state refers to the condition before the structure's complete collapse. It is necessary to assess the load-bearing structure for ultimate limit states in this context:

1. loss of stability of the structure or any part thereof,

2. failure of excessive deformation, transformation of the load-bearing structure or some of its parts into a movable mechanism, various types of material failure, loss of stability of the supports of the structure or foundations,
3. fatigue or other time-dependent effects.

The serviceability limit state pertains to the performance of a particular structure or load-bearing components under regular operating conditions (Takosoglu, et al., 2012). This involves evaluating significant sags or cracks. The examination of these limit states should take into account the following considerations:

1. deformations that alter the structure's appearance or impact its serviceability,
2. vibration that impairs the functionality of the structure,
3. permanent damage that could negatively impact the structure's longevity or overall performance.

The structure's design, with respect to limit states, should be grounded on simulation models representing the structure and its loads under specific conditions. It is imperative to ensure that none of the limit states are surpassed during this verification process (Pekarčíková, et al., 2019).

# 3 DESIGN OF TRANSPORT TROLLEY

## 3.1 Supporting steel frame

Transport truck frames or load-bearing structures can be fabricated by welding or riveting bent sheets or rolled steel profiles. These steel profiles typically come in various shapes like I, O, U, Z, and others. Additionally, some vehicle frames are constructed using round, square, rectangular, or similar tubes with varying wall thicknesses (Medvecká-Beňová, 2017).

The trolley's supporting steel structure (Figure 1) is constructed using welded UPE 300 steel profiles, 15 mm thick steel plates, and smaller 15 mm thick steel plates. In order to decrease the overall height of the trolley, the UPE profiles at both ends are reduced by 185 mm. The individual components are joined together using corner welds. The bottom plates are designed to accommodate the spring bed. Relief holes are cut into the UPE profiles. The entire beam weighs 2.1 tons and measures 4500 x 1800 x 315 mm. The material used for the UPE profiles and sheets is steel S355.

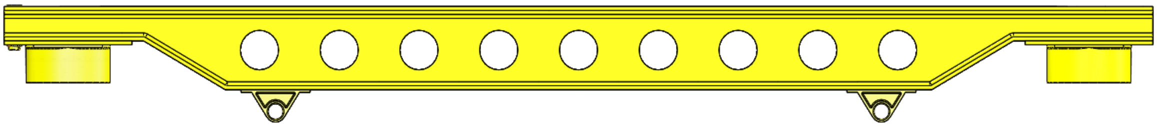


***Fig.1*** *Model of supporting steel frame - front view*

Frequently, there arises a need to modify lifting platforms, cranes, and similar devices over time. In such situations, the vehicle frame requires reinforcement at specific critical points. To achieve this, various reinforcements (profiles) are often welded to the most stressed areas of the frame.

### 3.2 Transport truck front axle

Driving the vehicle serves the purpose of maintaining or altering its direction of travel as needed. During cornering, each wheel traces a circle with a distinct radius but shares the same center. To ensure safe steering while cornering, it is essential to adhere to the correct steering geometry. For proper wheel alignment, the extended axes of all rotating wheels should intersect at a single point, known as the theoretical corner of the vehicle. In the case of two-axle vehicles with front-wheel steering, this theoretical corner is positioned on the extended rear axle axis, also known as the pole line (Czech, 2017).

For Ackermann's regulation geometry (1), (2) (Figure 2) the following equations apply:

$$cotg\ \beta_1 = \frac{R + \frac{s}{2}}{L} \tag{1}$$

$$cotg\ \beta_2 = \frac{R - \frac{s}{2}}{L} \tag{2}$$

*where: R- theoretical turning radius (m),,*
*s - pin axis distance (m),*
*L - axles distance (m),*
$\beta_1$, $\beta_2$ *- outer and inner wheel angles (°).*

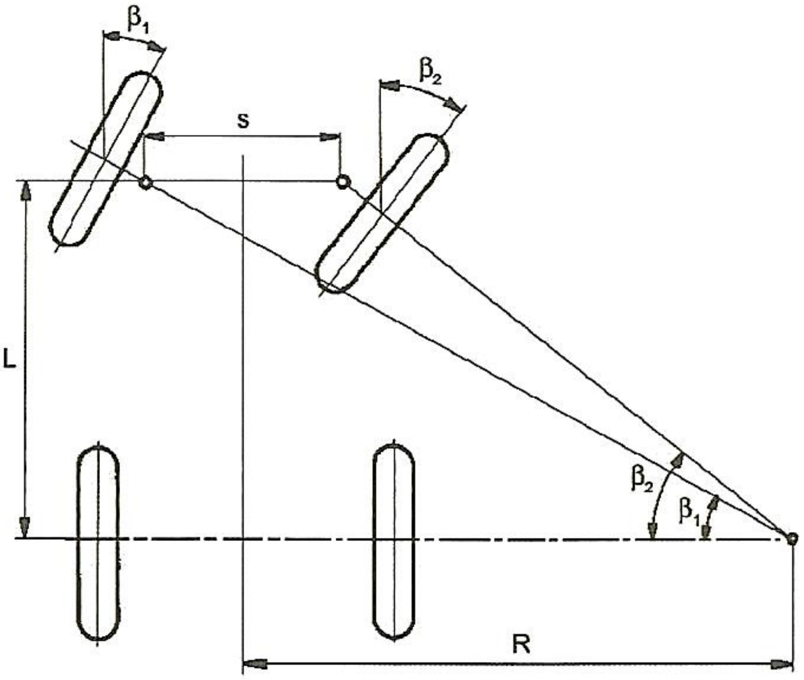


***Fig.2*** *Theoretical car steering geometry*
*Source: (Grabara, et al., 2010)*

The steering mechanism is operated by a trolley, which is powered by the towing vehicle. At full turning, the angle between the wheels is approximately 4°, and the wheel's turning radius measures around 4.5 meters (Figure 3).

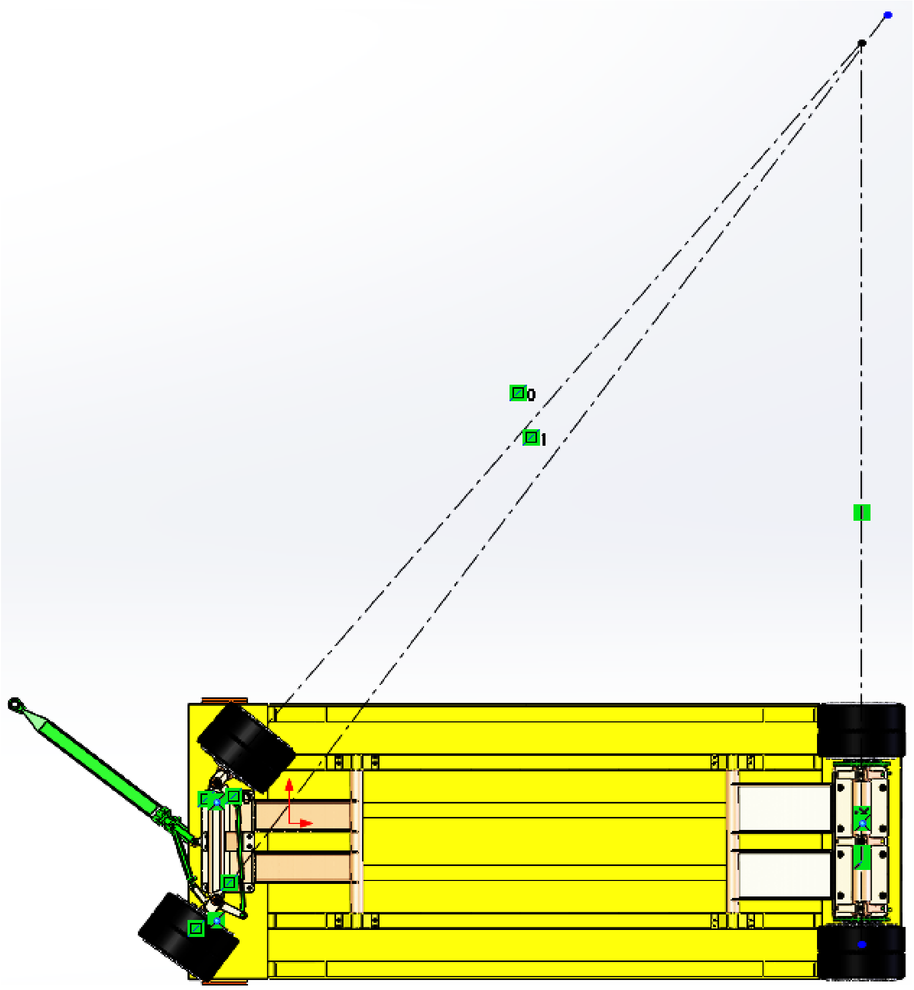


***Fig.3*** *Axle kinematics*

## 3.3 Transport truck rear axle

The rear axle (Figure 4) was designed as a fixed axle with rotating wheels. A spring bed is directly mounted on the axle. The rear axle wheels are equipped with separate track brakes for braking.

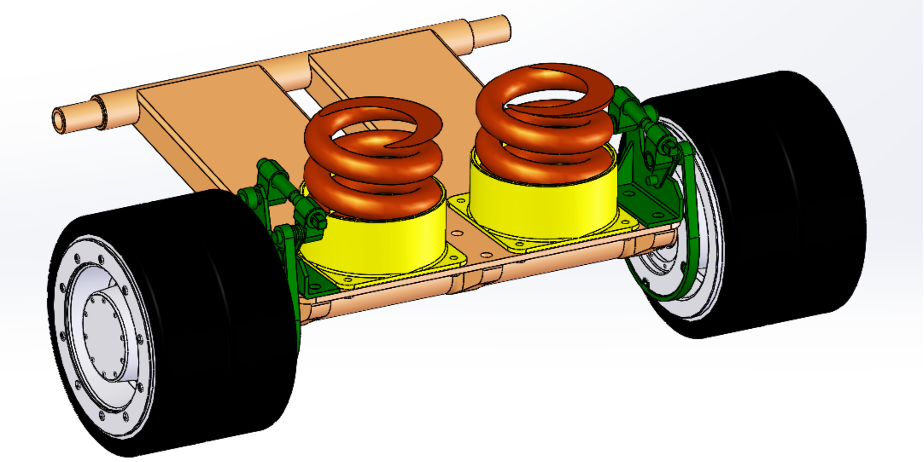


***Fig.4*** *Rear axle*

The wheel is designed as a hub with a pair of wheeled tires pressed onto it. The wheel rings consist of steel rings with vulcanized rubber. Each wheel has a load-bearing capacity of 6.4 tons, allowing a pair of hubs to carry 12.8 tons. The manufacturer guarantees the wheel's strength up to a speed of 6 km/h. To support the wheel's load and forces, two sets of cylindrical roller bearings are utilized. The first set includes a pair of NJ220EDM bearings arranged in an "X" configuration, capable of absorbing both radial and axial forces. The second set consists of a pair of NU218EDM bearings that only absorb radial forces. Four bearings per wheel are used to evenly distribute the load to the pivot. To secure the inner set of bearings, an KM nut and MB washer are used as they are not subject to axial forces, while the outer set is secured with retaining rings. Grease is considered as the lubricant for the bearings.

## 3.4 Locking mechanism

The front locking mechanism (Figure 5) operates on the concept of a sliding wall with similar sliding clamps as the rear detent. The construction of the front jig is comparable to the rear jig, both being welded from 15mm sheets. However, the front jig can be adjusted along the beam to accommodate molds of different sizes. To minimize sliding resistance, the front locking fixture includes recesses on the lower plate and is equipped with a sliding guide featuring side locks.

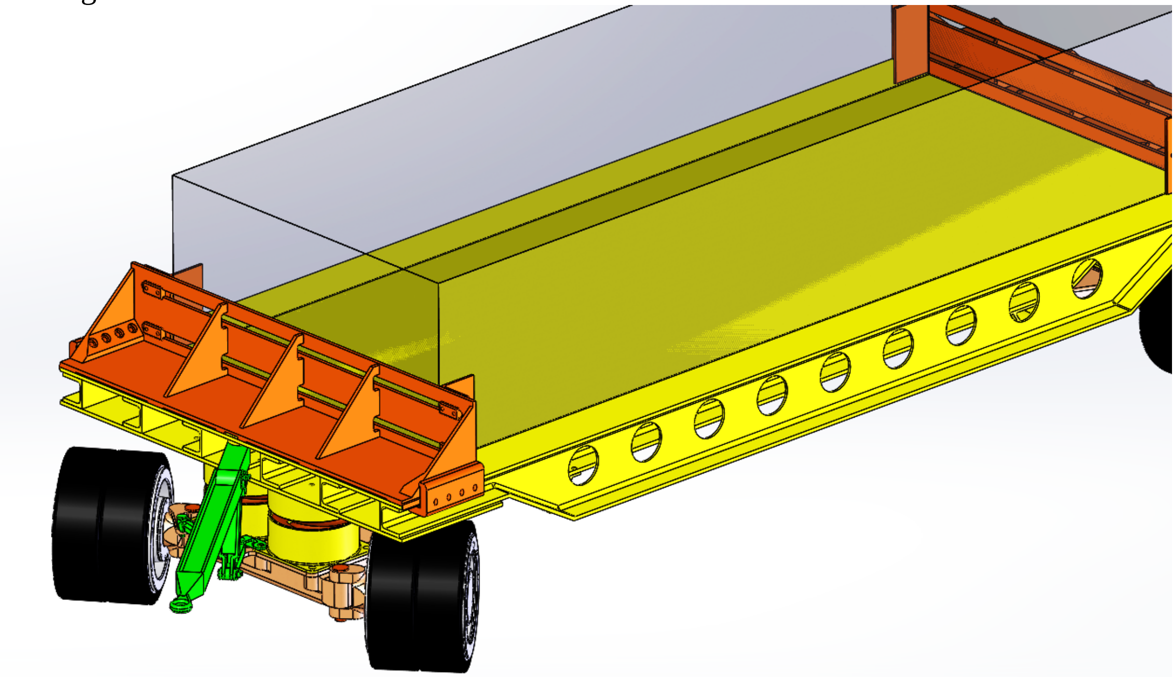


***Fig.5*** *Front locking device*

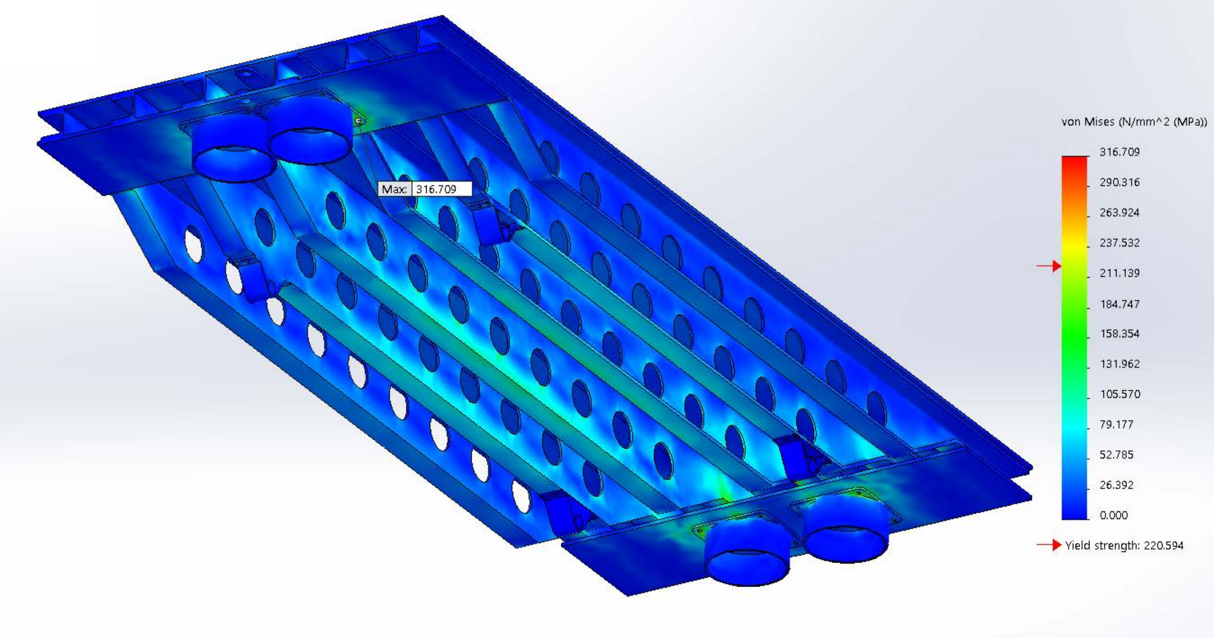
The process of securing the mold is as follows:

1. Position the mold on the trolley, ensuring it makes contact with the rear detent wall and aligns approximately at the center of the vehicle's width.
2. Push the side jigs of the rear jig towards the mold and fasten them securely by tightening the screws.
3. Move the front locking fixture towards the mold and secure its sliding lock on both sides by tightening it firmly.
4. Slide the side jigs of the front jig towards the mold and fix them in place by tightening the screws firmly.

## 4 CALCULATION AND ANALYSIS OF THE STRENGTH AND DESIGN OF THE TRANSPORT EQUIPMENT

The main beam bears a continuous load, which represents the weight of the mold. As a safety measure, calculations considered a weight of 60 tons, accounting for a potential fall from zero height, which could lead to a double overload.

The Finite Element Method (FEM) analysis confirmed that the beam meets the required strength standards. The beam is made from S355 steel with a yield point Re = 355 MPa, as depicted in Figure 6. Under a simulated load of 60 tons, the maximum local stress levels on the beam reach approximately 160 MPa. However, the peak stress of 316 MPa is not practically relevant since it arises from a constraint that restricts rotation and is not encountered in actual conditions.



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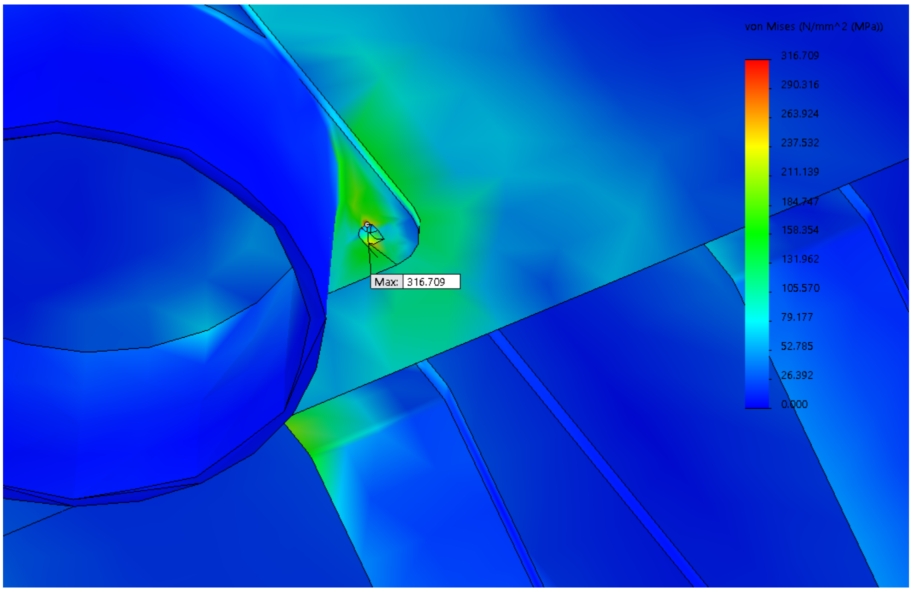

***Fig.6*** *Results of FEM beam simulation*

## 5 CONCLUSIONS

The purpose of inter-operational transport and handling equipment is to facilitate the material flow between different assembly workstations and systems. It plays a crucial role in handling heavy equipment, such as large-scale injection molds used for producing plastic moldings like dashboards, car door trim, and more.

The design of the transport equipment used for carrying large molds is of significant importance. The designed handling trolley is capable of securely and effortlessly accommodating molds of various sizes, transporting them between the press and the mold store, or vice versa, from the mold store to the injection molding machine. The load-bearing structure proposed is adequately rigid to withstand significant bends and additional loads, while being reasonably lightweight. Rigid axles have been incorporated, capable of enduring double the overload of the structure without incurring damage. The front axle steering adheres to Ackermann's geometry, ensuring the wheels follow the appropriate trajectory during turning. The proposal includes mechanical adjustable locking for injection mold preparation of varying sizes. The structural strength calculation was carried out using the finite element method.

The potential impact of implementing the proposed transport equipment on the inter-operation transport system is a subject for further research.

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