

Article

Modern Design of Carrier for Overhead Conveyor

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Abstract: Modern industry should apply modern design in the construction of production facilities. This is typically the case with belt production, where parts are moved towards the worker, or when moving parts from the factory to the warehouse and shipping area. There is a relatively high energy consumption associated with moving these parts. The size of the consumption is mainly determined not only by the size of the transported components and the transport technology, but also by the design of the hoppers used for transport. One way to reduce material handling costs is to make the equipment used for moving parts more efficient. A more efficient carrier should, above all, be lighter. Topological optimization can serve very well for this weight reduction. Of course, the reduction in weight not only has an effect on lower power consumption, but also on the wear of other components. Hence, later in this article, we try to quantify these impacts and assess how much benefit the use of a modern designed carrier can bring. It is also important to consider the cost of producing new carriers versus modifying existing ones. The paper describes the application of the modern designed carrier and compares it with the existing carriers as well as modified existing carriers.

Keywords: topology optimization; efficient production; transportation of material; overhead conveyor



Citation: Hruzík, L.; Struž, J.; Trochta, M.; Klapetek, L.; Pišťáček, D. Modern Design of Carrier for Overhead Conveyor. *Appl. Sci.* **2024**, *14*, 5352. <https://doi.org/10.3390/app14125352>

Academic Editor: Arkadiusz Gola

Received: 7 May 2024

Revised: 17 June 2024

Accepted: 18 June 2024

Published: 20 June 2024



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1. Introduction

The technical problem solved in this article is based on the application of an overhead conveyor, which serves as an inter-operational conveyor for the transport of wheels between single production stations and possibly warehouse areas.

Although nowadays a relatively high emphasis is placed on the efficiency of any operation, in the case of overhead conveyors, the emphasis on the design of the carrier is very often oversized from a safety point of view, based on the experience of previously used carriers.

Using previously tested designs is inexpensive, especially in the design phase. The disadvantage of these designs is often the weight and therefore, with the longer operation time of the equipment, the carrier design becomes inefficient mainly due to higher power consumption. This is where there is room for the application of new methods and the creation of a new modern carrier design that will be more efficient, especially due to the lower power consumption of the conveyor.

1.1. Overhead Conveyor

Several commercial software can be used to simulate and design conveyors; here are examples of using one of them [1–3]. Since overhead conveyors are already relatively well known, there are analytical calculations for their design and dimensions. They are described, for example, in [4]. Overhead conveyors can be classified into several groups according to their shape and the number of tracks, if any. For the more loaded overhead wire rope conveyors, the so-called two-track conveyors are used, which are heavier and more complicated in design. They have the advantage of separating the load from gravity and the rope or chain tension [5] Light conveyors can also be used to transport lighter

loads. In this case, the lightest conveyor seems to be the overhead rope. An example of the calculation of such a rope can be found, for example, in [6]. The operation of the conveyors themselves and thus the loading and unloading of loads can be realized either by human operators or automatically. Automatic used is an example of this application, where lifts are used for loading. If more complex handling is required, a robotic arm can be used, for example, as described in [7].

It is still a lifting device often operated by and over the heads of workers. Despite the relatively well-known design of these overhead conveyors, the safety of this equipment needs to be addressed. In the current configuration of the production line, it is an overhead conveyor that is enclosed from below and from the sides by a steel net, so that both the load and parts of the conveyors do not fall down to the places where the production line personnel are working. Hand-in-hand with safety is the regular inspection of individual conveyor components. In recent years, this inspection has also been automated and we can use modern methods, such as those described in [8,9].

1.2. Boundary Conditions

The external boundary conditions are defined mainly by the conveyor construction. The maximum internal space of the carrier must correspond to the actual design. The maximum space is defined by the largest wheel to be loaded with a gap on each side of the wheel so that the wheel and carrier do not collide during loading.

Another critical parameter is the maximum weight of the carrier. This condition is defined in two ways. One parameter is the maximum load of the conveyors, where a maximum load of 100 lb, or 45.35 kg, is possible per conveyor carriage. Both the weight of the carrier and the weight of the aluminum wheel to be transported must be included in this maximum weight. The maximum weight of the largest and heaviest billet aluminum wheel is about 35 kg. The maximum possible weight of the carrier is therefore about 10 kg.

The second perspective is that point of the company operating the application, which would like to reduce the weight to 50% of the weight of the original carrier. The original carrier weighs approximately 24.2 kg and is shown on Figure 1.



Figure 1. Original carrier.

The weight of the original carrier was not only taken from the drawing, but the carriers were weighed. The original carriers operated at this facility were of two types, therefore both were weighed, as seen in Figure 2, and the higher weight was considered.



Figure 2. Original carrier.

1.3. Motivation

There are several motivations for performing topological optimization.

- To achieve the applicability of the equipment without making further structural modifications to the overhead conveyor.
- Reducing operating costs in terms of electricity consumption.
- Reducing operating costs in terms of wear and tear.

Achieving the applicability of the device is one of the basic requirements, therefore it is necessary to meet the conditions of the client for this technical problem, which enable the operation of the whole device.

The weight reduction is manifested in more ways than one. One of them is the financial intensity, either in the form of electricity consumption or in the form of prices of parts, which wear more due to the higher weight of the suspension. Another negative impact of more frequent maintenance is the need to shut down the equipment during maintenance and the financial burden on the maintenance staff.

2. Materials and Methods

For a better orientation in the article and also in the procedure of how the different methods followed each other, a diagram was created Figure 3, which describes the design procedure.

The diagram in Figure 3 describes the process of solving this problem. The process can be divided into two branches, namely to create new carriers or to optimize existing carriers. There were several decision parameters namely price, manufactured and most importantly the stress and fatigue properties of the carrier. Furthermore, one of the concepts was selected and developed, which was then also used to measure the consumption of the transport equipment on which the carriers are suspended.

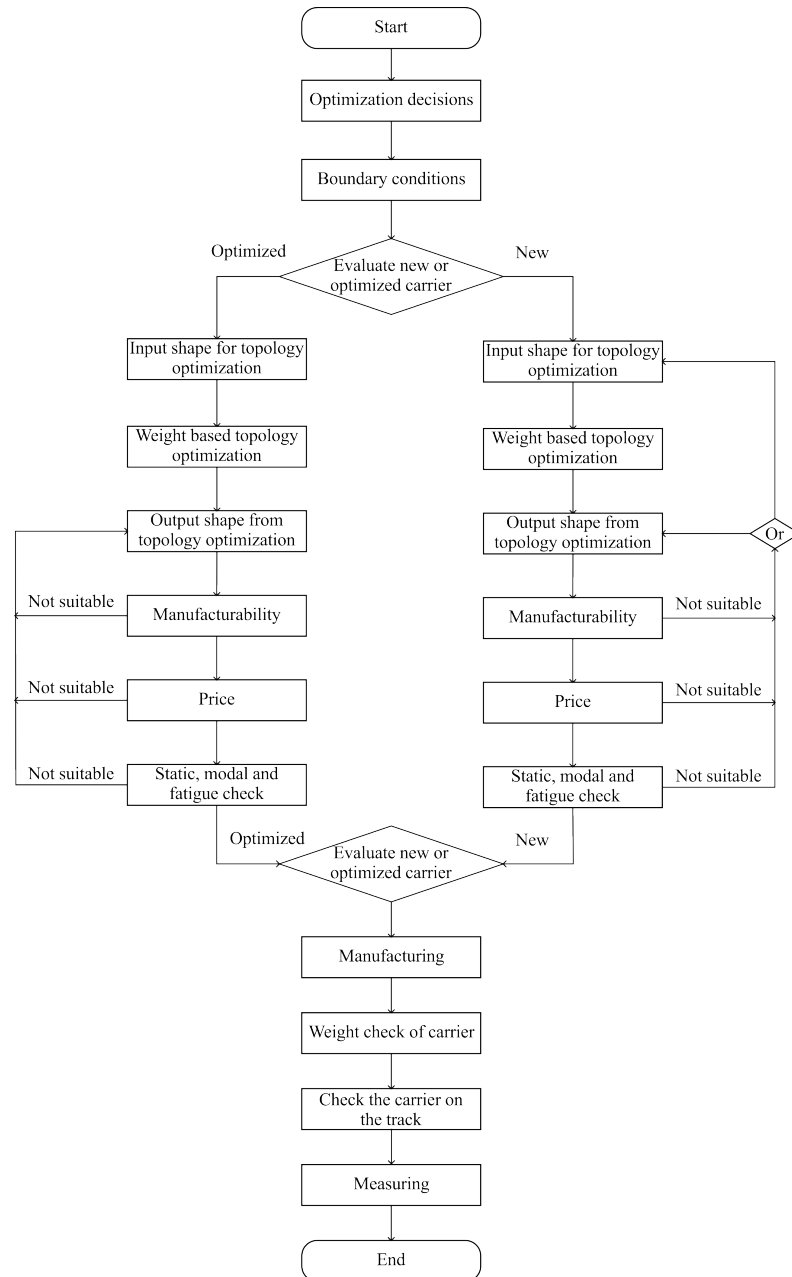


Figure 3. Process diagram of this research.

2.1. Theory of Topology Optimization

Topological optimization is the main optimization method used in this article and in this application. Topological optimization is a very powerful tool that can be applied in a variety of ways. Probably the most common is the variant where weight reduction is the criterion. The general properties of topological optimization are discussed in, for example [10]. The mathematical subtext of stress based topology optimization on the academic example is described, for example, in [11–17]. More complex shapes are used, for example, in additive technologies and are discussed in [18,19].

It is also very common today to use topological optimization to create relatively complex shapes, but they still have to be manufactured in conventional ways. This case is described, for example, in [20,21]. This article deals with a similar issue. Of course, topological optimization is implemented for various reasons.

An example of a relatively advanced topological optimization is that of a component based on the contact between other components. This is dealt with in, for example [22,23].

The next step is multibody dynamic [24]. The disadvantage of this optimization is its relatively high complexity. In this case, we also have a combination of different components according to the current production on the line, which would further deteriorate the functionality of this topological optimization, which depends on mutual contact. The opposite can be the optimization described in [25]; in this optimization the mechanism is optimized in terms of its elasticity, so that it is as rigid as possible and at the same time achieves the desired deformation. A very similar issue, however, applies to automotive parts where the arm is topologically optimized and then the natural frequencies are controlled [26].

Topological optimizations, which are generally used to lighten structures, are very much used in the aerospace industry. About topological optimization in the aerospace industry [27]. Due to the pressure to reduce weight, materials such as composites etc. are very often used today. Even these composites are very often lightened further and topological optimization as in [28]. Today, in homogeneous materials are often used in technical practice, an example of which could be a laminate element. Topological optimization of in homogeneous materials is, for example, the subject of [29]. For the sake of completeness, it is very good to add that the optimization can be used for the flow as shown, for example, in [30].

Topology optimization is an iterative process. Workflow of this project is described for example in [31]. For example, the following Figure 4 image is taken from this article. Similar diagrams are also shown, for example, in [16,18].

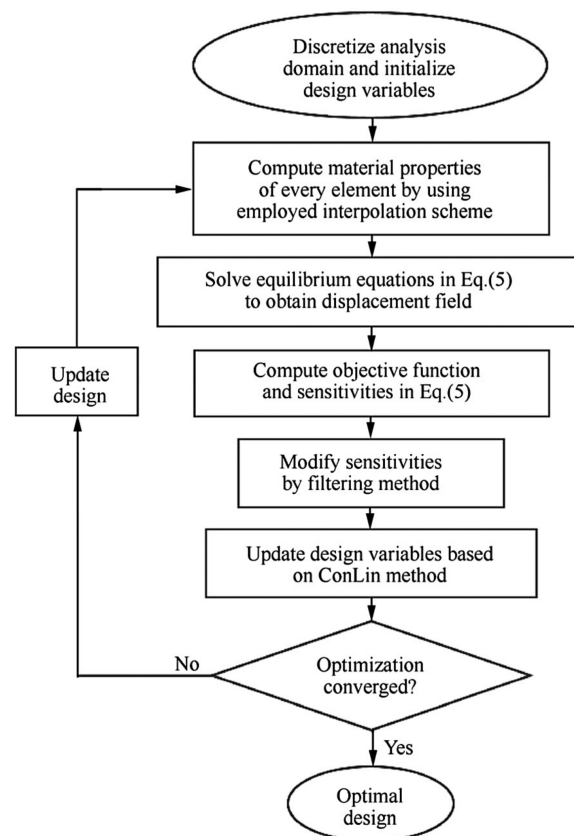


Figure 4. Topology optimization process diagram [31].

2.2. Optimization of Original Carrier

One possible solution to this technical problem is to modify the original carrier. Thus, topological optimization was used for the modification. The optimization module in Ansys was used. An example of a setup directly for this software is given, for example, in [32]. Further examples and a theoretical analysis of the solver used in Ansys Workbench 2023

R2 from Ansys manufacturer from Canonsburg, PA, USA are given, for example, in the following articles [33–36].

For topological optimization purposes, the currently used carrier had to be remodeled in 3D from a drawing, which was the only documentation provided with the carrier. The original carrier in the form of a 3D model is shown in Figure 5. This original carrier was subjected to topological optimization to determine the areas where it would be best to remove material.

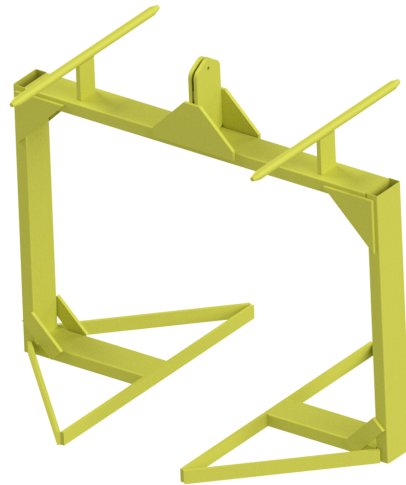


Figure 5. Original carrier 3D model.

The carrier was further modified for topological optimization. Elements that were not used in the analysis were removed due to their very low, or rather negligible, loading, but at the same time the necessity of using these elements. These are mainly the guide rods, which ideally are not loaded at all.

This topological optimization is performed on the basis of a very important premise. If this optimization is advantageous, the existing carriers would be modified. This modification would consist of creating holes in the existing profiles. Modification by changing the thickness of the profile is very difficult or even unrealistic, or even very costly. For this reason, a model was used in which steel blanks and plates were used as planar components with an associated thickness. A representation of the model can be seen in Figure 6.

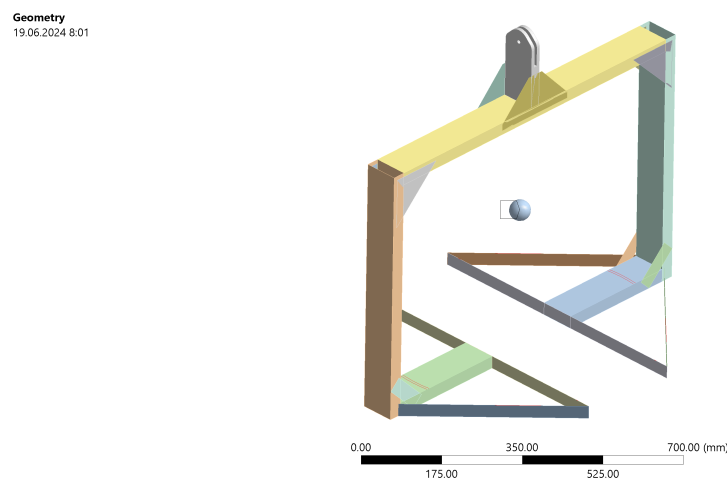


Figure 6. Model of original carrier for Ansys.

In this geometry, the weight of the load is missing. This mass has been replaced by a mass point, which has been placed at the centre of gravity of the transported object. A

mass of 35 kg was considered. The representation of the mass point relative to the carrier is shown in Figure 7.

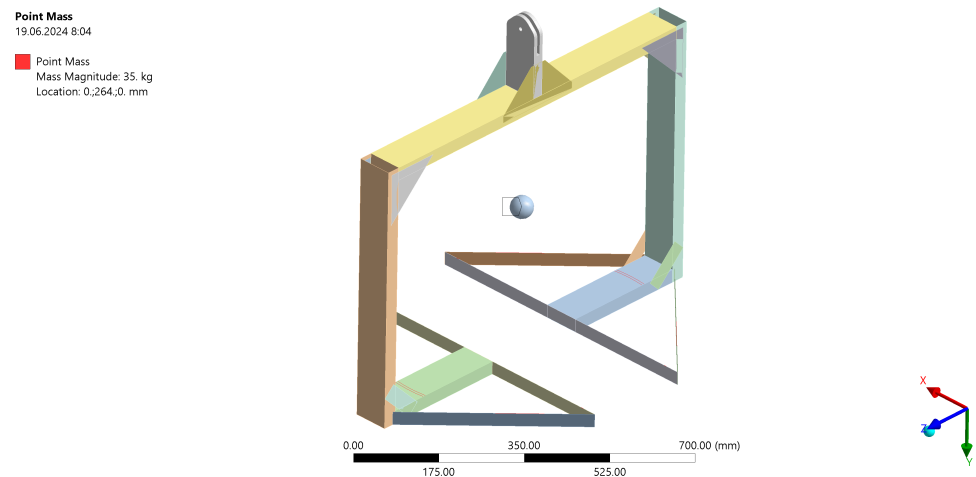


Figure 7. Model of original carrier with point mass.

The mesh and its size were chosen with respect to the needs of topological optimization. A coarse mesh could cause poor performance especially in topological optimization, a mesh that is too fine on the other hand greatly increases computation time. A representation of the model mesh for topological optimization is shown in Figure 8.

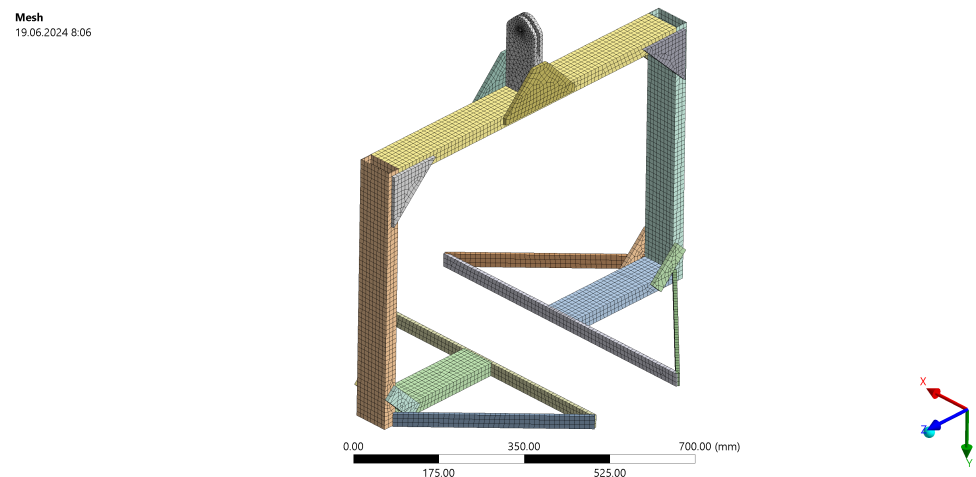


Figure 8. Mesh of the original carrier.

The mesh element size was set to 10 mm. This size is sufficient for the needs of modal analysis and subsequent topological optimization. The model was solved as a combination of shell and solid elements. Parameters of the mesh see on Table 1.

Table 1. Parameters of mesh.

Elements	Number of Elements
TriShell3	122
QuadShell4	7092
Tet10	7893

2.2.1. Modal Analysis

Due to the use of the carrier as a moving component, which is also dynamically excited, it is necessary to check the natural frequencies. These natural frequencies also describe

the stiffness of the carrier. To fix the carrier in space, a fixed support is considered in the upper eye of the carrier. The first 6 natural frequencies have been determined. The natural frequencies are shown in Figure 9.

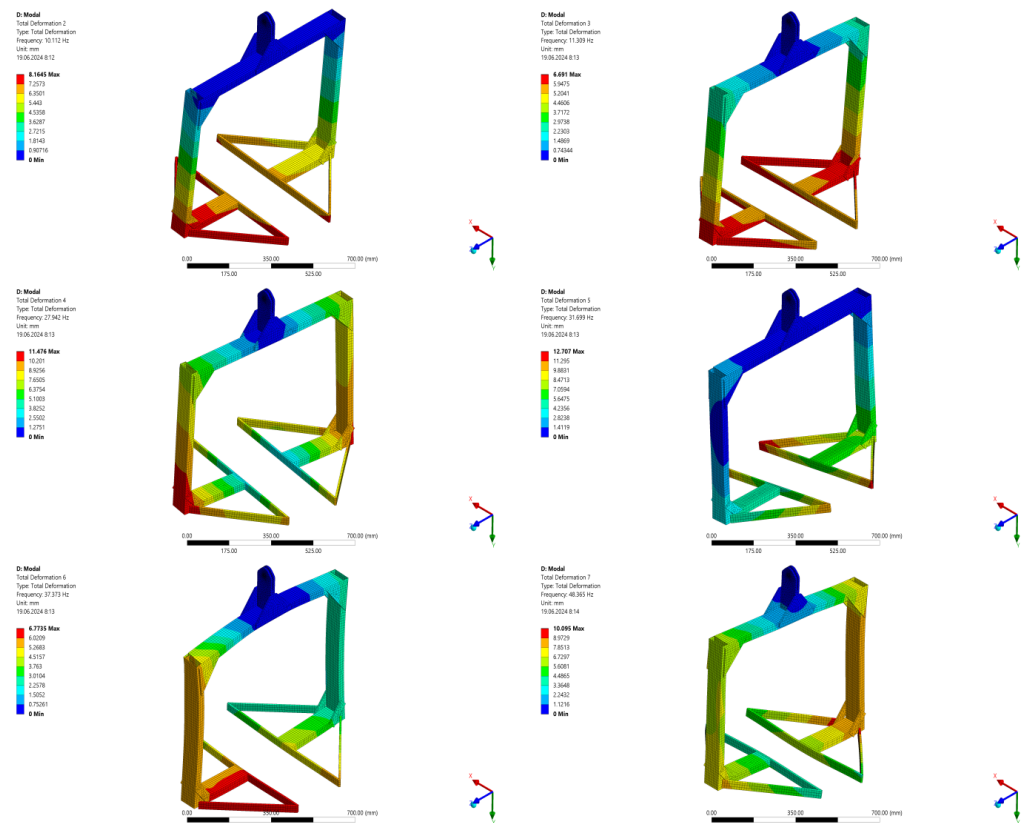


Figure 9. Natural frequencies of original carrier.

Modal analysis is particularly useful for determining the directions in which the carrier is least stiff. In the case of the carrier in Figure 9, it is also to determine the stiffness of the original carrier.

2.2.2. Static Analysis

For topological optimization, a static analysis must first be performed. Again, the boundary condition of fixed support in the upper mesh of the carrier was used for fixing in space. The load was defined using the standard Earth Gravity function in the vertical direction. Boundary conditions are described in Figure 10.

After the static analysis, we continue with the topological optimization, where we determine the areas in which material can or cannot be removed and the optimization condition. The optimization condition has been set as a minimization of the mass with a criterion of 50%. The areas to be optimized are shown in Figure 11.

The result of the topological optimization is shown in Figure 12. The figure shows that for topological optimization, it is good to remove quite a lot of material at the top of the carrier. Further, take in the corners and joints of the profiles, possibly on the bottom profile. For example, the inclined bottom plates, which only bear the load in the event of some unexpected tilting of the load, are already very thinned as assumed in this analysis.

The result of this topological optimization was used as a sample for the modification of the original carrier. The carrier was modified primarily with respect to the manufacturing technology so that the modification cost was as low as possible, and the carrier stiffness was as high as possible.

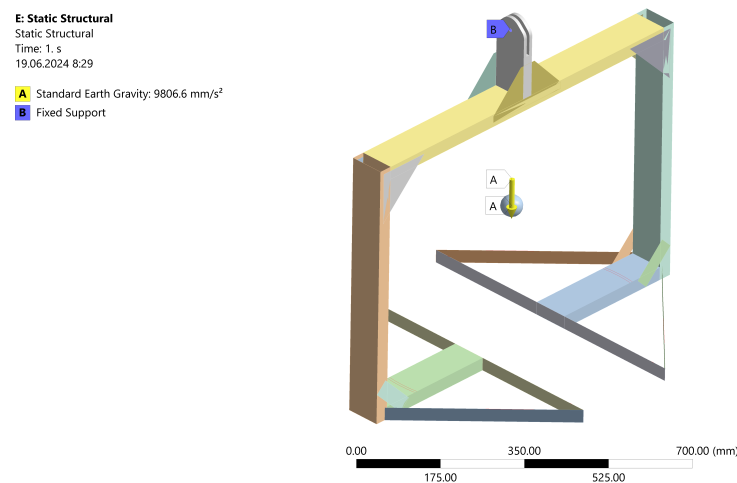


Figure 10. Boundary conditions of the topology optimization.

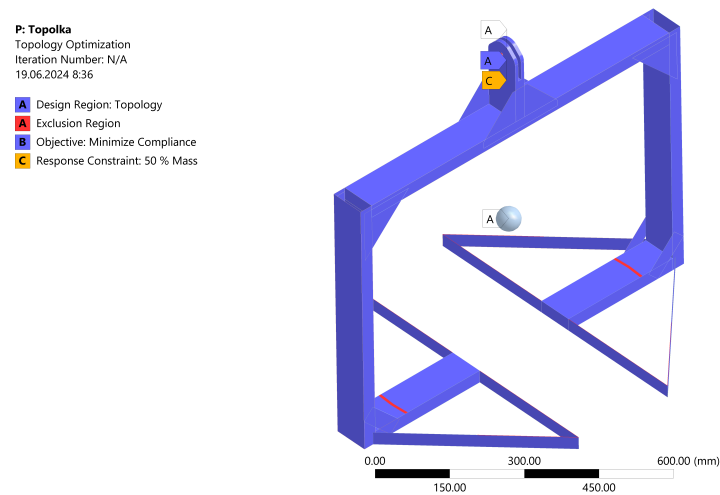


Figure 11. Topology optimization settings.

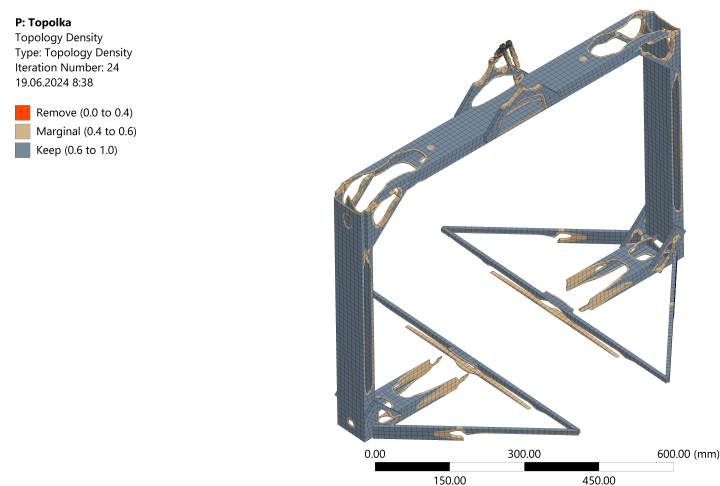


Figure 12. Result of topology optimization.

2.2.3. Modified Carrier

A lot of variants of different modifications of the existing carrier have been created, from the variants with drilled holes and no modifications in the upper part of the carrier, to the finally chosen variant. The final variant is a variant created with the consultation of the company commissioning this work. This modified carrier is shown in Figure 13.

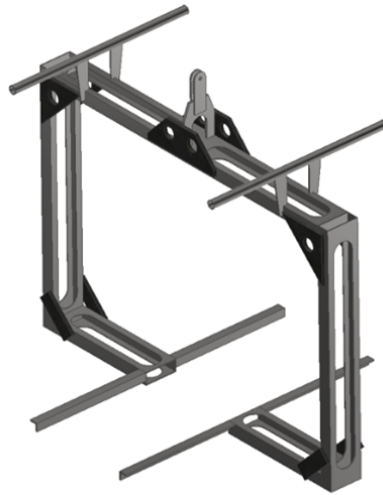


Figure 13. Modified carrier.

The optimized carrier was also designed as a component composed of surfaces with an assigned thickness. The considered load is replaced by a mass point at the center of gravity of the transported object, see Figure 14.

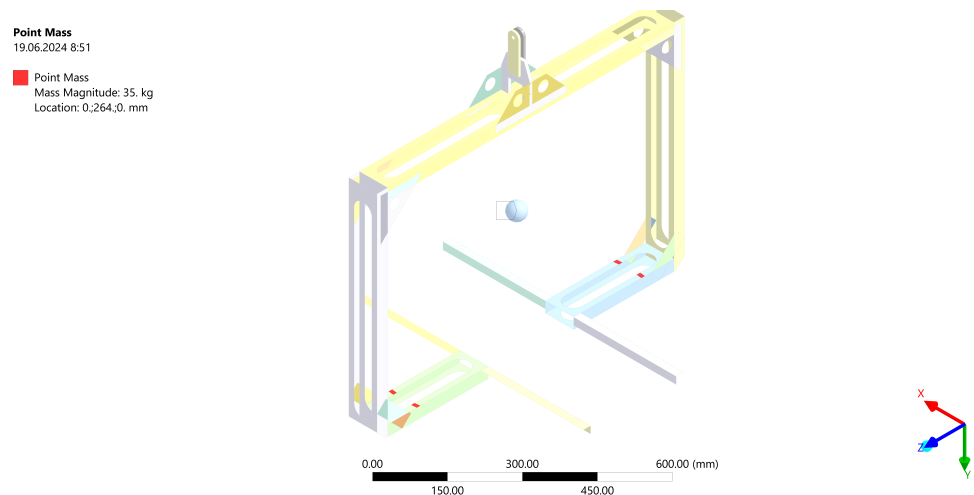


Figure 14. Model of optimized carrier for Ansys.

The mesh setup is defined in the same way as in the case of analyses performed before topological optimization. First, the optimized carrier was examined in terms of natural frequencies. The natural frequencies have already decreased as expected, and the lightened carrier is less rigid than the original one. The display of the natural frequencies is in Figure 15.

A static check of this carrier followed. The boundary conditions are essentially the same as the original carrier, hence the fixed support used on the cylindrical bore at the top of the carrier. This is a device that is loaded dynamically, It is possible that minor impacts will occur when loading the wheels. The static check was therefore carried out with twice the gravity. The results of the total deformation and the stress reduction are shown in Figure 16.

The carrier is a dynamically loaded component, and it is therefore necessary to check this component for material fatigue. There are more dynamic forces acting on the carrier, but it is a problem to quantify them. However, the fatigue from loading and unloading of the loads carried is dominant. A check has therefore been made regarding the permanent strength, because it is not certain for how many years the carrier will be in service. This is a transient load cycle with an amplitude of 1 g vertically. The result is therefore the safety with respect to the permanent strength, and is shown in Figure 17.

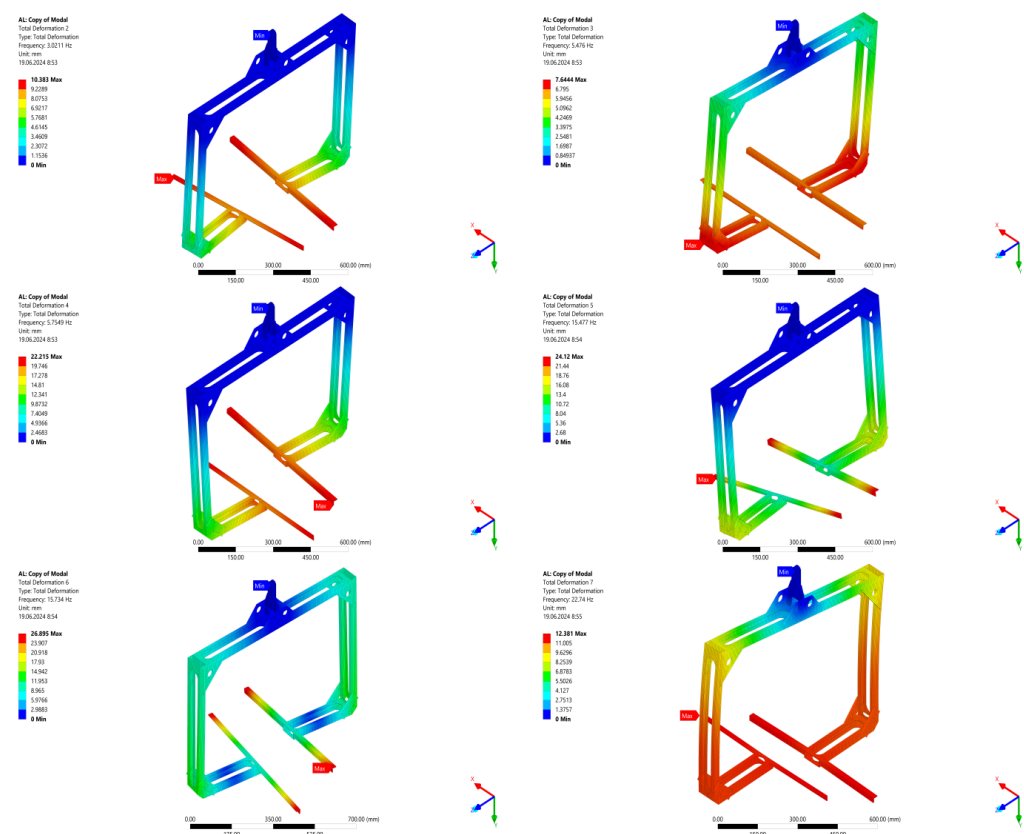


Figure 15. Natural frequencies of optimized carrier.

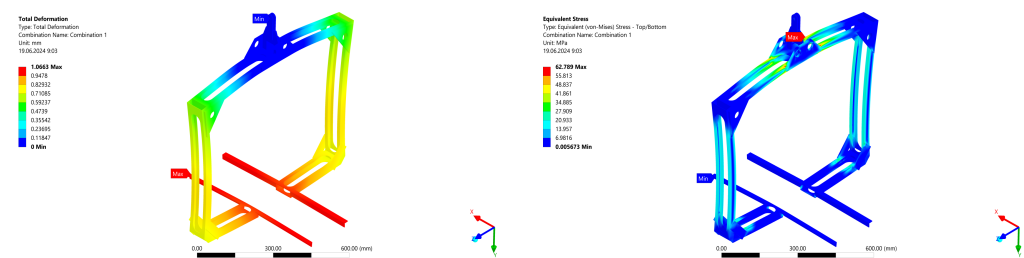


Figure 16. Total deformation and Von Mises stress of optimized carrier.

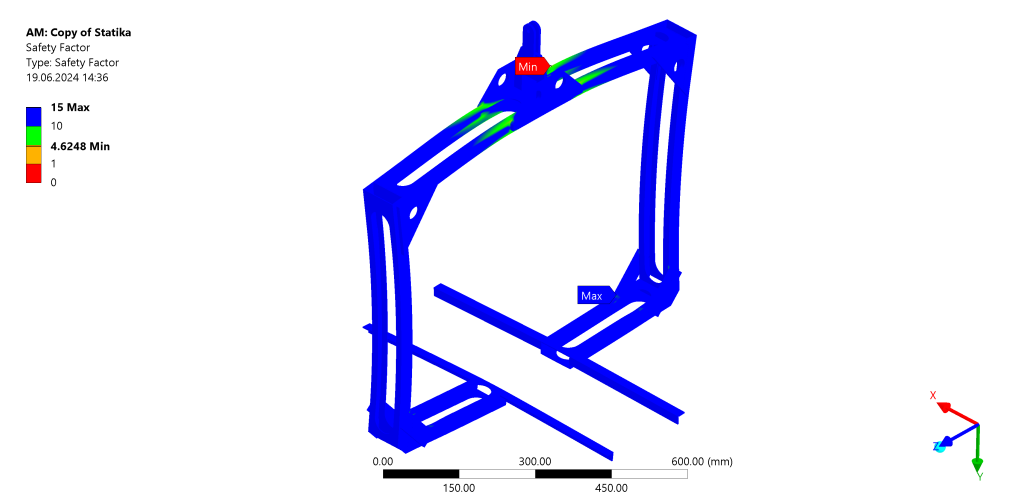


Figure 17. Fatigue stress factor.

2.3. New Carrier

Several carrier designs were created, where the final version of the design was created in consultation with company representatives, especially regarding manufacturability.

2.3.1. Topology Optimization

For the new carrier design, several topological optimizations were again performed. First, a topological optimization was made to a very generic carrier design, which basically satisfied only the necessary dimensions with respect to the size of the load. This was followed by a slightly more refined topological optimization, which has a shape already specified. The models of the topological optimizations are shown in Figure 18.

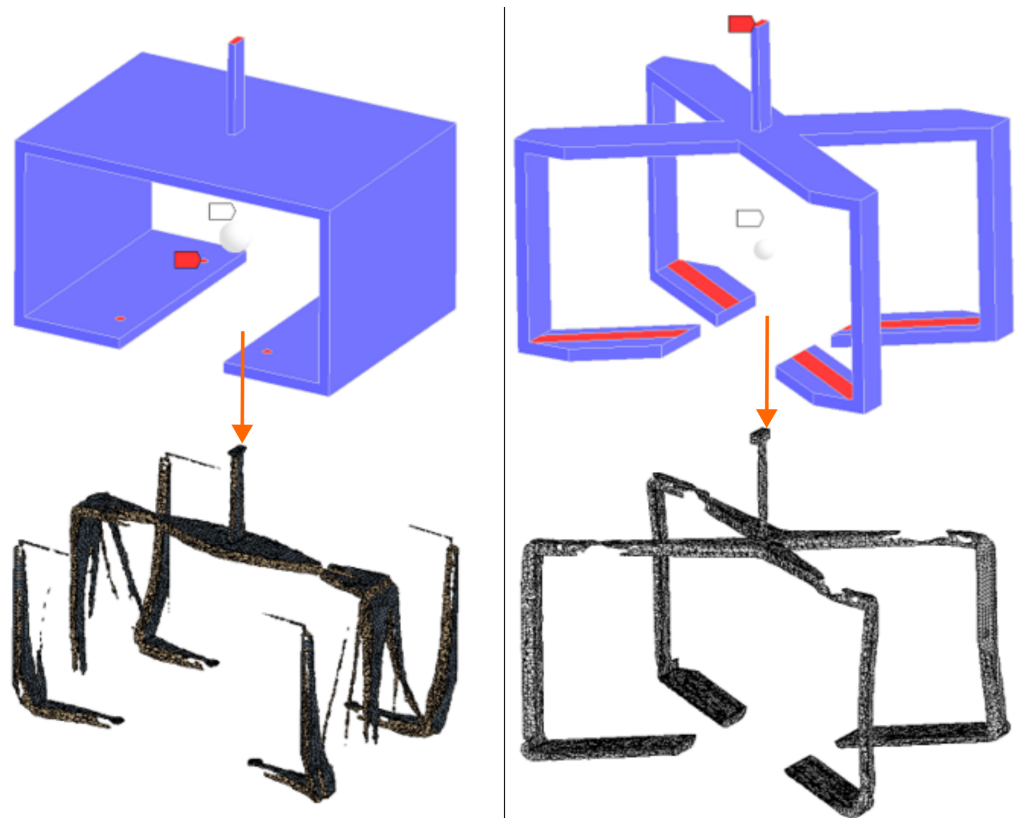


Figure 18. Topology optimization for new carrier.

From these optimized shapes, a new design was created in consultation with the company that applies the carrier. We came to the conclusion that for reasons of production technology and manufacturability with regard to cost, it would be ideal to design the new design from sheet metal, as opposed to the original design, which was from metallurgical blanks. It was also necessary to consider the material benefits, with the lowest weight being a carrier made from aluminum alloy. However, due to technology, it was decided that a steel alloy was more suitable. A design was created, and 5 pieces were produced. The prototypes were used to verify the price and take to verify the functionality and possible collisions with the track, for which there is no complete drawing documentation. The design that was selected about the technology and the company's requirements is shown on Figure 19.

This design was excellent considering its weight, which was under 10 kg. However, during testing it became clear that it would be ideal to stiffen the carrier further. In addition, the reinforcements were positive for production purposes, as the reinforcements made the carrier easier to weld. The unresolved question is therefore whether the modified carrier, which was very similar in natural frequency to the unreinforced new design, but which had to be further modified and reinforced, would work.



Figure 19. New carrier.

The result of these required modifications is shown on Figure 20. The carrier thus modified has a weight of 11.75 kg. The carrier was further subjected to strength calculations so that we could guarantee its proper function.

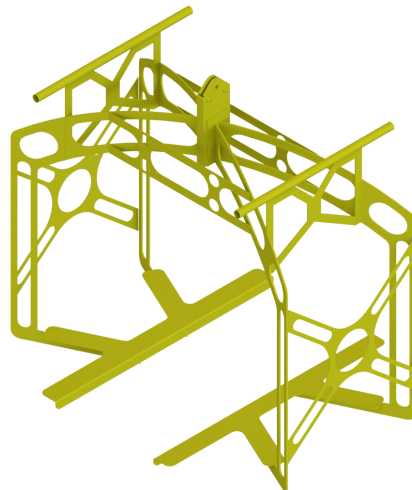


Figure 20. Modified new carrier.

The mass of the load has been replaced by a mass point at the centre of gravity of the load. The mass point was connected to the contact surfaces of the load and the carrier. The mass of the load is 35 kg. The plates have been replaced by surfaces with an associated material thickness. In space, the carrier is fixed again using the fixed support function in the upper eye of the carrier. The geometry with mass point and mesh is shown in Figure 21.

The mesh element size was set to 5 mm. This size is sufficient for the needs of static structural analysis. Parameters of the mesh see on Table 2. The model was solved as a combination of shell and solid elements.

Table 2. Mesh parameters of modified new carrier.

Elements	Number of Elements
TriShell3	584
QuadShell4	39,539
Hex20	528

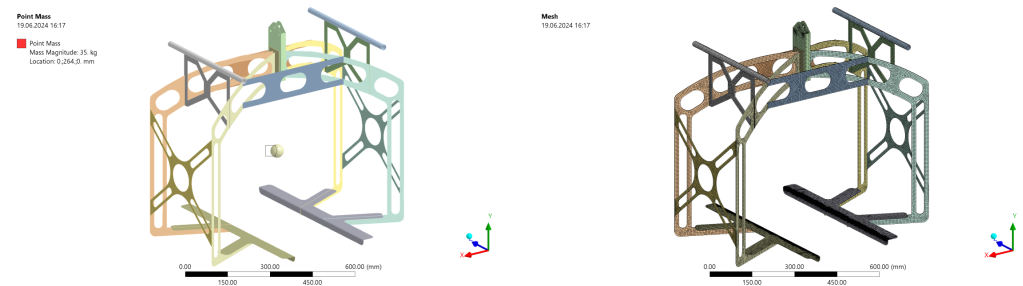


Figure 21. Geometry and mesh of modified new carrier.

2.3.2. Modal Analysis

As in the case of the original carrier modification, a modal analysis was first performed. Ideally, the first natural frequency should be as high as possible and therefore the carrier as rigid as possible. The results are shown in Figure 22.

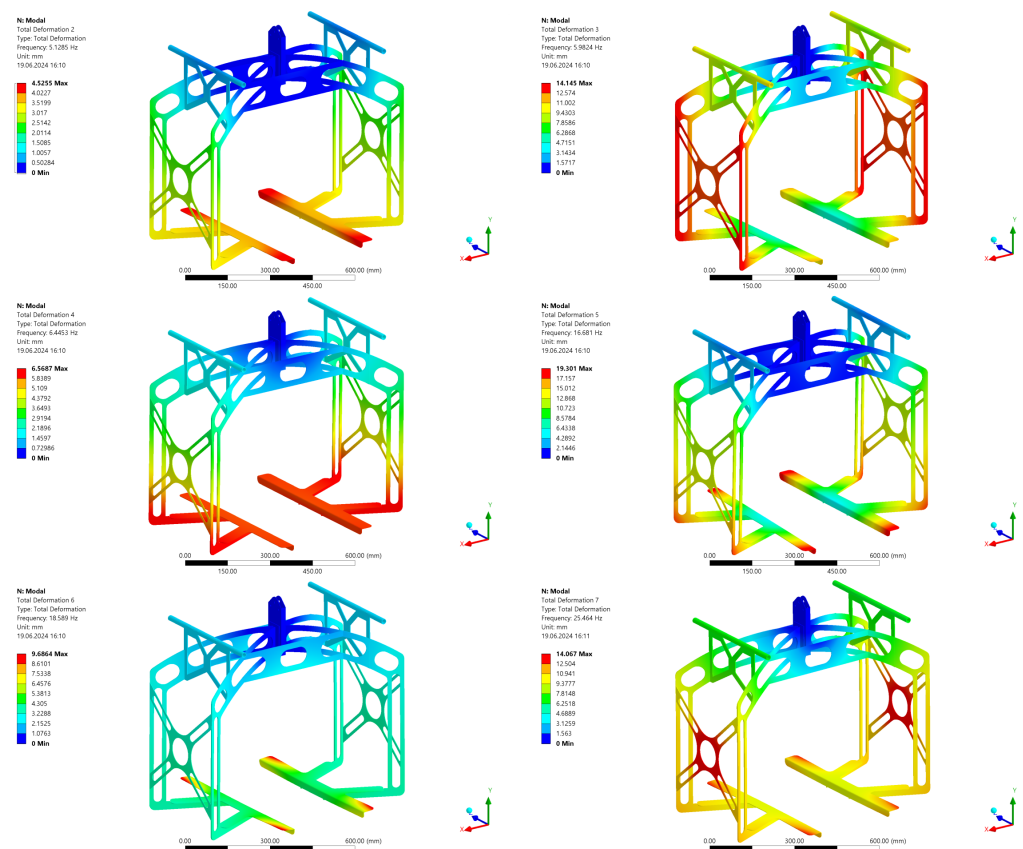


Figure 22. Modal analysis of a modified new carrier.

2.3.3. Strength Analysis

The strength control is set in the same way as for the optimized carrier. Again, we consider that shocks may occur, so the load for a single overload is defined as 2 g acceleration vertically. The results are shown in Figure 23.

Again, a material fatigue check was considered. The load from the loading of the loads was considered as a load cycle, thus a load of 1 g vertically downwards. This is a passing load cycle. Safety was determined with respect to the fatigue limit, hence the unlimited lifetime, with the safety results shown in Figure 24.

The new carrier also features an optimized upper carrier mount that has the ability to adjust the width due to manufacturing tolerances of both the carrier and the ropeway mount. Fine tuning is possible by means of defining plates, and any fine-tuning is realized by means of a preloaded bolt that holds the carrier. The upper grip is shown in Figure 25.

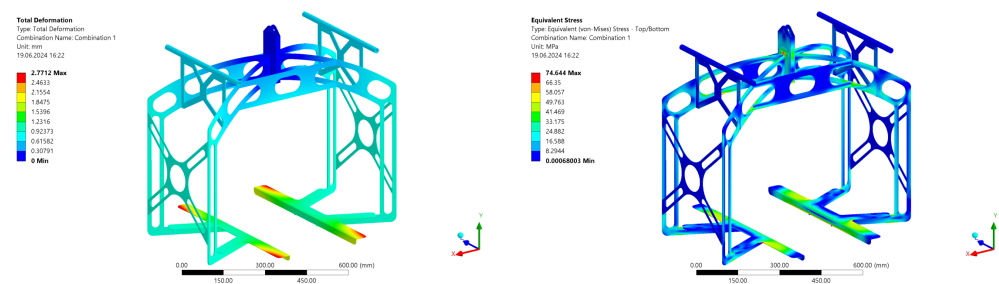


Figure 23. Static analysis of a modified new carrier.

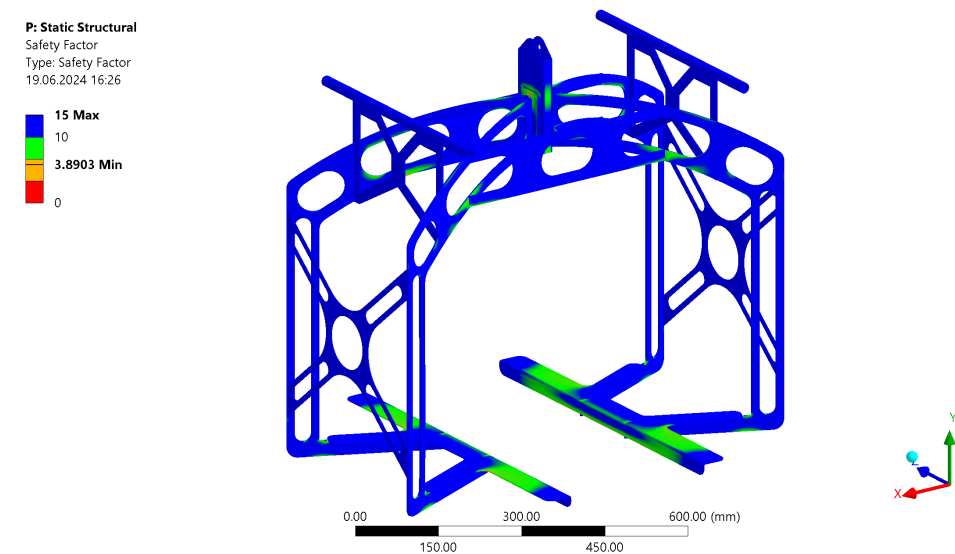


Figure 24. Fatigue safety factor.

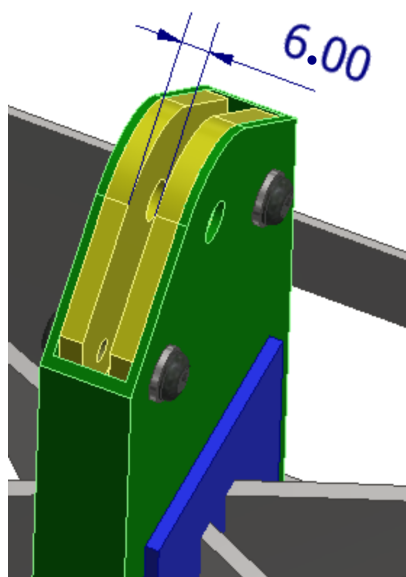


Figure 25. Modified upper mount.

2.4. Choice of Solutions

We are now in a situation where we need to assess the economics and benefits of each option and evaluate whether to go down the route of modifying the original carrier or producing new carriers. Probably the main indicator is the economic aspect, because after the braces have been added to the new solution, the resulting weight of the modified carrier and the new carrier is basically the same. For comparison, here are their parameters in Table 3.

Table 3. Comparison of selected parameters of carriers.

Carrier	Weight	Max. Von Mises Stress	Maximal Deformation	Min. Fatigue Safety Factor	First Natural Frequency
Optimized carrier	11.02 kg	62.79 MPa	1.1 mm	4.6	3.02 Hz
New carrier	11.75 kg	74.64 MPa	2.7 mm	3.9	5.13 Hz

It is evident from the tabulated values that, for example, the weight of the modified and the new carrier is comparable. The advantage of the modified carrier is lower deformation, but this may be due to slightly different settings of the calculation model. As far as the stiffness of the carrier is concerned without influence on the direction of loading, it is expressed by the first natural frequency, according to which the new carrier is stiffer. The safety with respect to the fatigue limit is sufficient in both cases. The parameter that will decide on the chosen variant will therefore be manufacturability and financial costs.

Manufacturing Costs

It was necessary to assess whether new carriers would be produced or whether existing carriers would be modified. The manufacturability parameter is very difficult to quantify, so the cost of production is usually used, in our case the cost of the carrier. The determination of the production price and the final decision was made by the company that will operate the new carrier. The result is perhaps surprising, because the production of the new carrier is cheaper than the modification of the existing carrier. For this reason, it was decided to produce the new carrier in full 176 units. The weight of the new carrier produced is shown on Figure 26.

**Figure 26.** Weight of the new carrier.

3. Results

To verify whether the modifications made sense, several measurements were needed. The priority was to resolve the load capacity so that a billet wheel weighing 35 kg could be transported without increased operating costs caused by wear and tear on the overloaded overhead conveyor. The results in the form of improved performance are described below and are broken down into several subsections.

3.1. Load Capacity

The very first point was met in terms of the client's specifications and the weight was reduced to less than half of the original. Unfortunately, after consultation with the client, the condition that the heaviest wheel and carrier together should weigh up to 45 kg could not be met. This condition was finally dropped because the heaviest wheels weighing 35 kg are very few and rarely carried. Weight is described in Table 4.

Table 4. Comparison weight of carriers.

Carrier	Weight
Original carrier	24.20 kg
New carrier	11.75 kg

The condition was to reduce weight by at least 50%, and the resulting weight reduction is 62%. The condition has therefore been met. Considering the number of carriers, the total weight saving is already considerable. The total number of carriers is 176, so the total weight saved on the conveyor is 2193 kg.

3.2. Measuring Electricity Consumption

The electricity consumption was measured by the company that used the conveyor. Consumption measurement is very common in technical practice [37,38]. The measurements were carried out on an empty conveyor. It is assumed here that the conveyor consumption will increase linearly with increasing load.

First, measurements were made on the conveyor, where all the original carriers were replaced with new carriers, see Figure 27. The carriers were then loaded with the difference in weight by which the carriers were lightened and the consumption measurement was again taken to represent the consumption before conveyor optimization.



Figure 27. Overhead conveyor with new carrier.

The consumption value indicated in Table 5. Is the value of consumption when considering three shift operation.

Table 5. Comparison of selected parameters of carriers.

Carrier	Weight of All Carriers	Weekly Consumption	Consumption for 50 Weeks
Original carrier	4259 kg	124 kWh	6208 kWh
New carrier	2068 kg	64 kWh	3200 kWh

In the context of the total consumption of a factory like this, which is quite demanding in terms of energy, the savings are not essential in the overall calculation. In percentage terms, however, the saving is not insignificant and is 48.5%.

Associated with the reduction in electric energy consumption is a reduction in CO₂ emissions. The emission reduction savings have been calculated by the conveyor operating company with respect to its energy mix. The saving, assuming continuous operation for 50 weeks per year, is 1931 kg CO₂.

3.3. Savings in Maintenance

The radical reduction in weight will of course have a positive effect on maintenance. The assumption was that there would be a positive impact on maintenance due to the lower wear and tear on the individual conveyor components. Lower wear due to lower weight should increase maintenance intervals.

However, there was another positive impact that was unexpected. Due to the reduction of the weight of the carrier and the change in the shape of the carrier, the handling of the carrier has been easier. When replacing the carriers on the line, it originally required the cooperation of three workers to change the carrier. After this change, the cooperation of two workers is already sufficient, which has a positive impact on the time of changing the carriers and therefore on the finances.

4. Conclusions

In this article, the design process of a modern carrier and the advantages of using it were described. The main purpose was to reduce weight and thus increase usability, increase efficiency, and reduce power consumption in wheel production. Today, due to the higher price of electricity, a window is opening for the use of computing technology for the design of modern carriers that reduces the consumption of electricity.

More advanced computational methods such as topological optimization are ideally used in the first design phase, but they also bring their advantages in the case of the reconstruction of existing devices. Another option is to use machine learning and generative design [39]. The positive effect on weight is very fundamentally linked to production technology, where methods that were previously not applicable are nowadays definitely common in technical practice. It is the advantages of these methods that need to be taken into account in the design of the carrier. In this case, it is mainly the use of sheet metal cut-outs. Nowadays, for example, 3D printing is also often used, which, however, does not make economic sense for this application.

The use of a lighter carrier has a very positive impact on the wear of the overhead conveyor and the consumption of electric energy. Both ultimately have an impact on the now much-discussed carbon emission footprint. Of course, in addition to the ecological impact, this has a primarily economic impact.

Another positive impact of the new carrier is the impact on maintenance with regard to the number of operators required to change the carrier. Due to the lower weight and better shape, the number of changeover workers was reduced from three to two. This has a major impact on reducing maintenance costs and also on the speed of carrier replacement.

In general, it can be said that the optimization of the conveyor and carrier has had a very positive impact on the entire production line and on the economy and efficiency

of production. It is definitely a good idea nowadays to use modern methods in carrier design to achieve a modern carrier design that is more efficient. This is confirmed by the information from this solution, where a new carrier that is more effective is also cheaper to produce than modifying an existing design.

Author Contributions: Conceptualization, L.H. and J.S.; methodology, L.H. and M.T.; validation, L.H., L.K. and D.P.; formal analysis, L.H.; investigation, L.H., J.S. and M.T.; resources, L.H.; data curation, L.H.; writing—original draft preparation, L.H.; writing—review and editing, L.H.; visualization, L.H.; supervision, M.T. and J.S.; project administration, M.T.; funding acquisition, L.H. All authors have read and agreed to the published version of the manuscript.

Funding: This work was financially supported by [Fakulta strojní, Vysoká Škola Bánská—Technická Univerzita Ostrava] (Grant number [SP2024/031]).

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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