Lightweight Design Concept Methodology of the Extended Market Wagon: A Shift2Rail Project

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Abstract

The Extended Market Wagon (EMW) presented in this study is a design concept developed within the FR8RAIL-4 project, which is part of the Shift2Rail IP-5 program. FR8RAIL-4 focuses on increasing the efficiency of rail freight transportation by employing new technologies and strategies such as new lightweight wagon designs, novel running gear, wagon intelligence and wagon automation in order to deliver goods safely, reliably and cost-efficiently. The challenges addressed in this research primarily relate to the conceptualization and design of a robust yet lightweight innovative wagon structure that can be implemented using conventional manufacturing methods. This lightweight design must be achieved while balancing the above goals with the necessity for simplicity and low life-cycle-costs.

A further goal of the study is to demonstrate the use of the described methods and design in the course of dramatically shortened design cycles and in flexible response to changing requirements. The Extended Market Wagon (EMW) is one of the demonstration parts of the FR8RAIL-4 project which addresses technical solutions for these requirements and also challenges. Therefore, the results of the study are to be applied as a technical 1:1 scale demonstrator, in accordance with the EU Annual Work Plan 2020. I It will be tested on track under real world conditions.

Keywords: lightweight design, structural topology optimization, freight, shift2rail, FR8RAIL

1. Introduction

Reducing greenhouse gas emissions from the freight transportation sector has become a crucial goal of the European Union as it committed to reduce them by 80-95% by 2050 [1]. This goal can be accomplished by shifting traffic from carbon-intensive modes such as air and road to more environmentally friendly transportation modes, such as rail. The European Commission reported that at least 30% of the total freight volume should be diverted to low carbon modes by 2030 in order to achieve this reduction goal [2]. To amplify the carbon emission reductions, the efficiency of the rail freight transportation can also be increased by employing new technologies and strategies such as new lightweight wagon designs, novel running gear and wagon intelligence and automation systems in order to deliver goods safely, reliably and cost-efficiently. FR8RAIL-4 is one of the most recent projects of the Shift2Rail IP-5 program that addresses these challenges and seeks to increase the technical readiness of these technologies up to technology readiness level (TRL) 7 in parallel to EU Annual Work Plan 2020. One of the main challenges in this project is to propose a novel freight wagon design concept called the Extended Market Wagon (EMW). It features several innovative components: a lightweight undercarriage structure, a novel running gear design and aerodynamically optimized cladding as well as operational measures to reduce drag.

In this paper, the structural lightweight design approach of the EMW is presented. In order to achieve the lightweight design, a finite element (FE)-based topology optimization method is employed. The results are analyzed for their load paths and lightweight design potential and then converted into a wagon design with manufacturing costs in mind while also considering current material availability.

1.1 Requirements

The initial concept of the EMW was decided based on the pre-requirements which are given in Table-1 below. According to that, a two-axle wagon which compliance with G2 profile was selected. It is also required to have a loading level under 1000 mm in order to transport Swap Bodies. The selection of the loading level influences the design of the concept significantly since the wheelset dimension and also coupling height must be selected accordingly. Furthermore, a short coupling length was called for during the design process in order to reduce drag and increase the capacity of a given length of train. The EMW is planned to be operated as a block train of permanently coupled wagon pairs.

Parameter	Concept	Parameter-cont.	Concept
profile-type UIC	G2	**coupling**	1 fixed center coupling & 1 automatic center coupler DAC type 5 per wagon
train weight	1600 t w/o Loco	**buffer**	No buffer
train length	730 m w/o Loco	**aerodynamics**	full coverage of chassis
no. of wagons/platforms	22 double wagon-units/44 for 2 Swap Bodies Type C	**braking**	disc brake, safe life 1.2 Mill. km
Loading height	< 1000 mm for loading High Cube Swap Bodies	**brake system**	EBC (Electronic brake control)
maximum speed	140 km/h loaded	**type of operation**	Block train, in P2P or CTL mode
noise emission 100 km/h	69 dB(A)	**WOBU**	train integrity, locking of load, automatic decoupling
payload/dead weight ratio	5 to 6	**telematics**	GNSS Positioning, GPRS/LTE mobile communication, freight train bus
tare weight	approx. 500 – 600 kg/m => 8.3 to 10 t for 1 wagon	**energy consumption**	10 % less in operation at 100 km/h
max. weight	2700 kg/m	**energy supply transport**	8 kW, 400 V 3~AC
axle load	max. 22.5 to / average 15 to.	**energy supply drive**	./.
operation without empty body	no	**energy supply OBU**	1 kW*, Storage 1 kWh**
wheelset	safe life axle > 1.2 Mill. km including bearings; wheel disc; wheel Ø 850 mm	**primary damping**	hydraulic
running gear	2 axle chassis, steering frame with pivot radius „0“	**primary suspension**	air springs approx. Ø 300 mm

Table 1: Technical Specification of EMW

The selected main wagon dimensions are given in Figure -1 below.

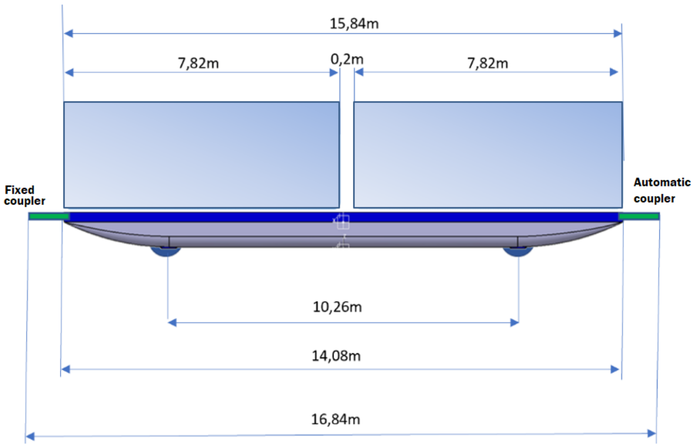

Figure 1: The EMW's main dimensions

1.2 Receiving optimal load paths via topology optimization

The topology optimization method was employed in order to develop a lightweight chassis. It is a powerful design tool that is used to obtain the chosen functional performance and it has been widely used to improve structural performance in engineering fields such as in the aerospace and automobile industries. To do that, a three-dimensional design space of EMW was generated using the CAD program CATIA and then transferred to the Altair Hypermesh pre-processor for element discretization. The whole geometry was modelled using 8 node brick elements. The boundary conditions and relevant load cases based on European norms were applied to the model and the optimized load paths were then iteratively calculated using the solver OptiStruct. The objective for the optimization problem was defined as minimization of the compliance, which, since compliance is the inverse of stiffness, corresponds to a maximization of the stiffness.

For the static topology optimization, boundary conditions were implemented and forces and load cases (See Table 2) were derived from EN 12663-1 [1]. In order to increase the competitiveness and service range of wagon, beside the 20-foot Swap body containers, also the standard containers size of 20-foot, 40-foot and 45-foot were also considered as a payload. The maximum allowed payload per container is considered as 17 tonnes.

Load Case	Description	
1 / 9	Compressive load + mass incl. payload	for 20 Swap Bodies and 20-foot- / 45-foot Container
2 /10	Tension load + mass incl. payload	
3 /11	Mass with payload and safety factor of 1.3	
4 / 12	one-sided lifting	
5 / 13	Lifting on both sides	
6 / 14	Staggered lifting	
7 / 15	Acceleration payload in x-direction with 5g	
8 / 16	Acceleration payload in y-direction with 1g	
17	Acceleration payload in z-direction	Same for all container sizes
18	Acceleration bogie in x-direction with 5g	
19	Acceleration bogie in y-direction with 1g	

Table 2: Load cases of the topology optimization

Furthermore, several load patterns and various load cases such as, bogie traction were also applied in order to obtain realistic load patterns. In Figure 2-a below, a number of the force application points and constraint points are given.

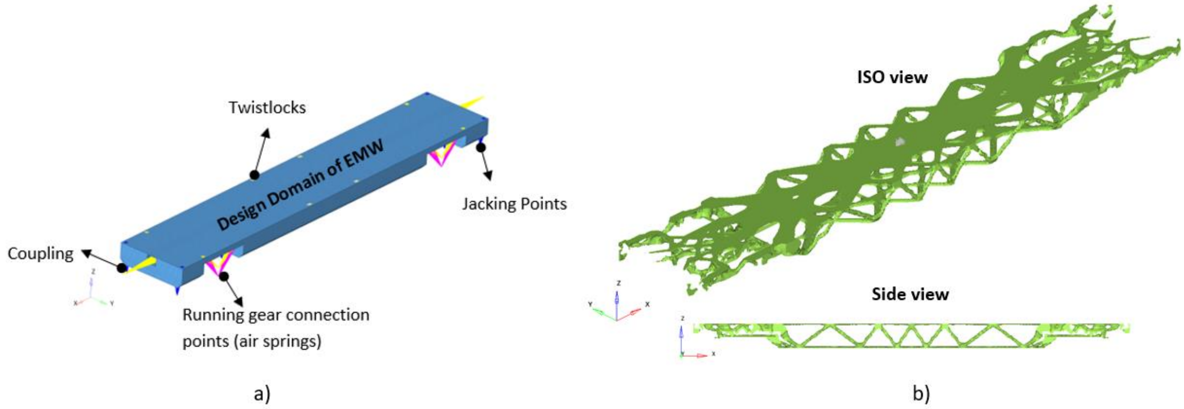

Figure 2: a) Model setup for topology optimization b) Topology optimization result of EMW

By configuring the EMW design structure in this way, the maximum allowed payload of EMW and specific energy efficiency can be optimized. The topology optimization result is given in Figure 2-b.

1.3 Computer aided design

The result of the topology optimization serves as the basis for the wagon design in CAD. This design has the challenge of balancing the competing and sometimes contradictory demands of being light, robust, reparable, cost-efficient as well as easy to manufacture. Additionally, the timeframe of the project demands a rapid development and manufacturing cycle, which poses a further challenge in the development of the concept.

From the topology optimization result (**Figure 3**, a skeleton is first extracted according to the load paths within the structure. The skeleton serves as the base reference for subsequent design steps. The wagon features a sheet metal design with few cast parts for load introduction. For the planned prototype, these parts will likely be milled due to cost reasons at a small scale.

In a first iteration, the sides of the wagon were planned to feature bent hollow rectangular profiles following the topology optimization result. The stress and strength calculations showed this design as viable and advantageous. However, due to the strict manufacturing timeframe and tight market availability of such steel profiles, a sheet metal web with topology-optimized contours and comparable properties was substituted.

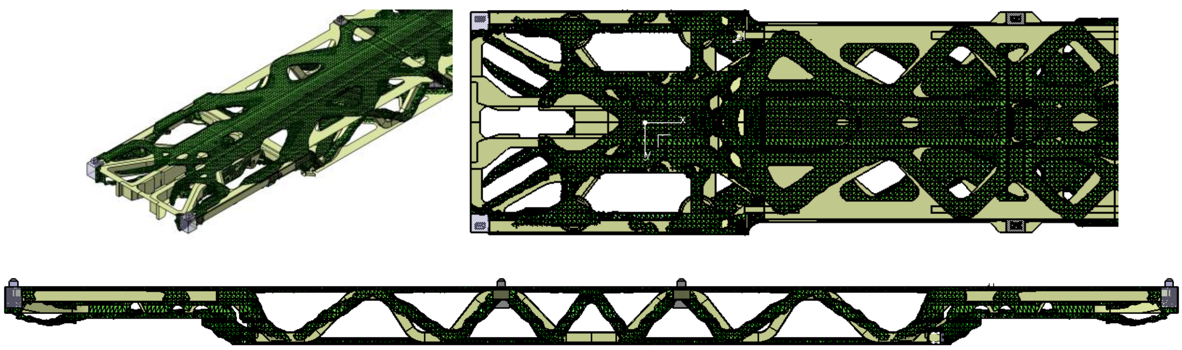

Figure 3: Comparison of topology optimization (green) and the CAD concept design

In the running gear areas, the loads acting on the couplers are transferred from the centre to the main frame members on either side of the wagon. The design of these as well as the top and bottom sheets in the running gear areas provide a continuous path for longitudinal forces to flow through the wagon. The main longitudinal and lateral frames are stiffened by the lightweight webs in order to prevent buckling under extreme loads and increase the natural frequencies. The automatic twist locks are integrated into the beam profiles on either side. They are mounted to receivers which are welded into the structure as load-bearing members. There is also space reserved for integration of the wagon on-board units (WOBU) which contain necessary electronics. The prototype will feature different couplers on either end. The strength of the resulting design has been verified according to FEM analysis results. The manufacturing candidate design of the EMW is given in **Figure 4**.

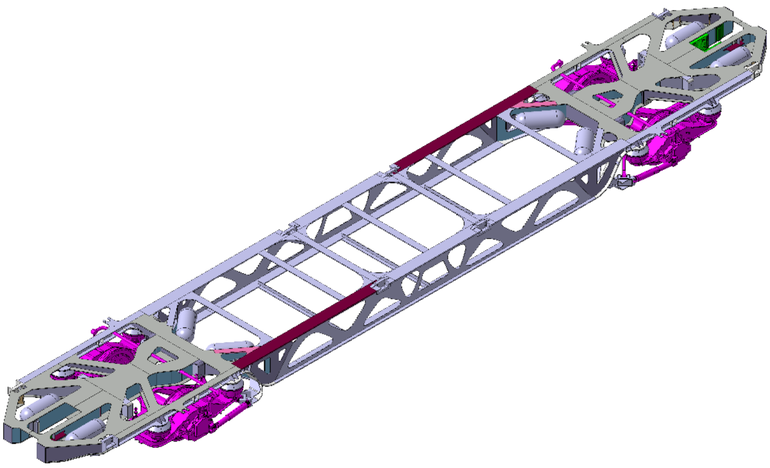

Figure 4: Manufacturing candidate design of the EMW

3. Results

By configuring the EMW design structure in this way, the maximum allowed payload of EMW and specific energy efficiency can be optimized structurally. The EMW design masses approximately 10 500 kg, which is approximately 16 % lighter than wagons with comparable functionality [4], which allows a maximum payload and a reduced specific energy requirement.

5. Conclusion

The presented lightweight mechanical design approach of the Extended Market Wagon supports the strategy for reducing greenhouse gas emissions in the freight transportation sector. Low vehicle mass, high payload and high specific energy efficiency with reduced aerodynamic drag, together with technologies that enable highly flexible operation and a high degree of automation will allow a new generation of freight wagons to complement current rail freight offerings while promoting the decarbonization of the freight sector through the displacement of current fossil-fueled road freight traffic.

Using these tools, a novel lightweight wagon design can be generated with an expected weight reduction of up to 16 % in comparison to similar class wagons such as LGS 580 [4]. This allows greater payloads and efficiencies, which are key factors toward increasing the competitiveness of rail freight transportation.

As a next step of this work, it will be manufactured and presented at the InnoTrans 2022. After exhibition, the dynamic stability and mechanical characteristics of the EMW will be also tested under real conditions.

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