Front Loading of Rolling Stock Design – WMATA7000 as a Case Study

Over the years, performance requirements of rolling stock design have become increasingly demanding. At the same time, the design of railway vehicles must be tailored to the existing facilities of railway companies, and manufacturers are increasingly asked to deliver on short lead-times. These trends were clearly evident in the project signed with the Washington Metropolitan Area Transit Authority (WMATA) in 2010 for the WMATA7000. To meet the challenging requirements, Kawasaki front-loaded design resources from the early stages of the project, which enabled it to achieve total optimization of design and delivery on a short lead time without delay.

Introduction

The performance required for rolling stock, such as safety, comfortable cabin environment, and operability, has grown more sophisticated with time. On the other hand, there are many constraints, such as space and weight, because new rolling stock is to be installed on the existing equipment of railway companies. The required performance significantly varies among railway companies. In addition, lead-time is becoming shorter and shorter.

For rolling stock, design items such as required performance and constraints that conflict with each other must be satisfied while ensuring entire projects progress without delay. To this end, front loading is effective for total optimization design and for shortening development and design periods. With front loading, sufficient resources are applied at the initial stage of projects.

1 Front-loading in rolling stock design

The rough flow of a rolling stock project is design, the purchase of raw materials and parts, production of pilot cars, various tests using pilot cars, and the mass production of cars. Any delay in the design may delay entire projects or force us to start subsequent steps even when the designs are not complete, which may result in reworking. Such reworking results in further delays in project schedules and deterioration of quality.

To avoid this, in front loading, importance is attached to the initial stage (the front) and thereby focusing resources in that stage (loading) to understand issues early, thus advancing development processes smoothly while also aiming at shortening lead-time, improving quality, and minimizing costs. In this report, we will introduce the WMATA7000 as an example case.

2 Outline of the WMATA7000 along with its design issues

Washington Metropolitan Area Transit Authority (WMATA) operates railways on six lines that extend into Maryland and Virginia with Washington, D.C. as its center. WMATA has approximately 1,300 cars from the 1000 to 6000 Series (six types). The operational start of the 1000 to 6000 Series varies from series to series, but they are compatible with each other so that train sets can be coupled for operation. The designs have also been standardized.

We received an order for 748 cars of the 7000 Series to replace existing cars and to add new cars. WMATA wanted to use stainless steel carbody structures (aluminum was used in the past), rooftop integrated air conditioning units, and Ethernet networks in the rolling stock. It also wanted to increase indicators in rolling stock and wanted the designs for the car interior and exterior to be novel. The requested items for the 7000 Series were new even for WMATA, so the series had high expectations as new rolling stock. Table 1 below shows the main specifications of the WMATA7000.

Issues with the WMATA7000 are listed below.

- WMATA was a new customer for us, so all of the rolling stock had to be optimized by making various conditions—such as car size, required conditions (e.g. strength, noise, and riding comfort), track conditions,

Table 1 Main specifications of WMATA7000

Car model		A Car, B Car
Dimensions	Total length [mm]	22,860 (75 feet)
	Maximum car width [mm]	3,092 (10 feet 1–3/4 inches)
	Maximum roof height [mm]	3,302 (10 feet 10 inches)
	Floor height [mm]	1,016 (40 inches)
Maximum speed [km/h]		120 (75 mph)
Acceleration [km/h/s]		4.5 + 0.3–0.0 (2.8 + 0.2–0.0 mph/s)
Deceleration [km/h/s]		4.8 ± 0.3 (3.0 ± 0.2 mph/s) (normal) 5.1 (3.2 mph/s) (emergency)
Carbody structure material		Stainless steel, low alloy high-tensile steel
Current collection method		DC700V, third rail
Braking		Air brake with regenerative braking Parking brake
Bogie		Air suspension bogie with bolster (inboard bogie) Axle box suspension: Laminated rubber
Side sliding door		Double-door with door pockets, three doors on one side Linear motor type door operator
Air conditioning unit		Rooftop integrated installation
Onboard network		ETN (Ethernet), TCN (MVB and WTB)

and the equipment to be installed on rolling stock—compatible with WMATA specifications.

- New cars had to be compatible with existing equipment. In addition, rig space had to be secured and weight had to be reduced because the equipment to be installed was increased to improve functions in comparison with existing cars.
- Detailed designs had to be completed one and a half years from when we received the order because the project's lead-time was tight.

3 Front-loading for the WMATA7000

In order to solve the issues in Section 2, we promoted front loading as discussed below.

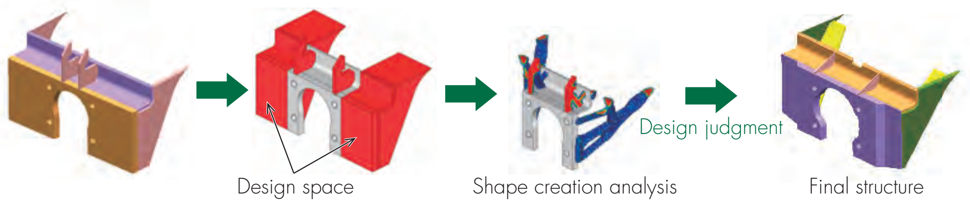
- The people in charge, who usually worked in each design section separately, were gathered in one place to do concentrated design.
- The Corporate Technology Division, which had a variety of key technologies, participated in the project from the beginning along with the Rolling Stock Company, which was the main entity for the development.
- Design resources were applied from the bidding stage as well as the initial stage after receiving the order to satisfy the high-level technical requirements, save weight, save space, shorten lead-time, and lower the price.
- The carbody structure, collision resistance, thin floor structure, air conditioning systems, noise, vibration, running performance and bogie strength, and electrical part systems were given primary consideration because they required time for discussion and they significantly affected downstream processes.
- Great importance was attached to concurrent engineering (a method in which design and production planning processes are carried out simultaneously) from the initial stage of development with an eye toward manufacturing.
- Design review was optimized and labor was reduced thanks to the introduction of new materials as well as structural developments and new development methods using advanced simulations.

(1) Carbody structure considerations (optimization calculation)

Weight saving is an important task in designing rolling stock. In the past, designers determined the thickness and shape of parts based on previous experience when designing carbody structures, identified sections where the strength was excessive or insufficient by analysis, corrected thickness and shape, and then performed analysis again. These processes had to be repeated several times.

This time, we used software to calculate the optimal thickness and shape and used the lists of increased and reduced thicknesses and optimal shapes obtained from the calculations, thus reducing the number of corrections to thickness and shape and the number of times the analysis had to be repeated (Fig. 1). Additionally, we were able to start the next step, designing part installation, quickly because carbody structure designs were completed early.

(a) Optimization of the thickness of carbody structures



(b) Optimizing the shape of the coupler bracket

Fig. 1 Investigation of carbody structure (optimization analysis)

(2) Carbody structure considerations (collision)

High collision resistance is required in designs for North America. The design suitability was verified and evaluated by collision analysis in order to meet various conditions, such as absorption of collision energy, securing survival space when leading cars were deformed due to collision, derailing, and running aground (Fig. 2).

In addition, we carried out crash tests for collision energy absorber elements and collision tests for frame structures. We verified the analysis results and incorporated the results in our designs. Thanks to the work and tests above, the collision resistance structure was determined at an early stage, making it possible to start the production of carbody structures without delay.

(3) Thin floor structure

The space under the WMATA7000 floors was small, so the floor structure had to be made thinner to secure space for the installation of underfloor equipment, pipes, and wires. In addition, after the floor structure was determined, designs for underfloor equipment, pipes, and wires were started, so the floor structure had to be determined quickly. Usually, thinner floor structures act against stiffness, strength, fire-resistant and heat-insulating properties, and sound insulation performance. However, we developed a new thin corrugated floor structure that can satisfy the performance required while reducing floor thickness. The new floor structure made it possible to secure space to rig underfloor equipment, pipes, and wires (Fig. 3).

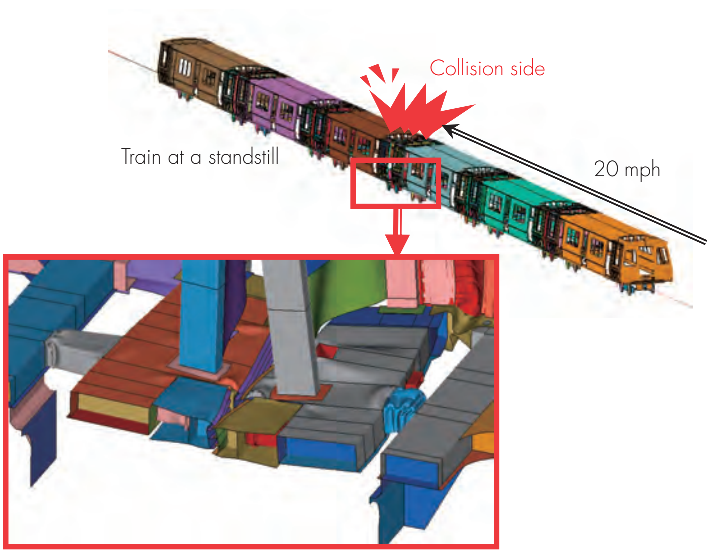


Fig. 2 Investigation of carbody structure (collision analysis)

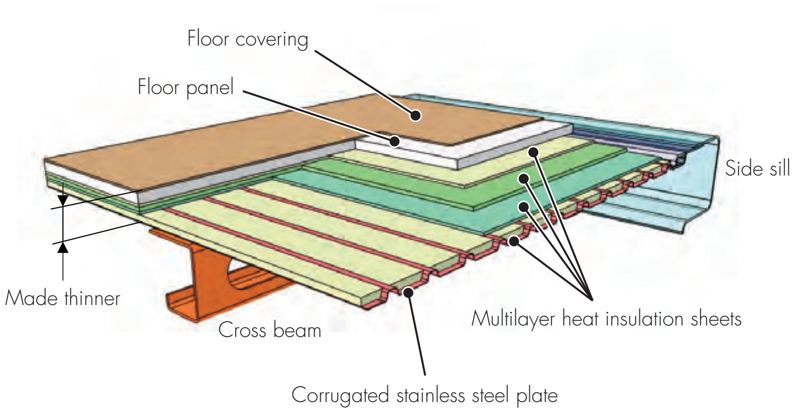


Fig. 3 Investigation of floor construction

(4) Air conditioning system (Optimization of air quantity and temperature in cars and reduction of noise)

Ducts had to be designed so that the specified air quantity was achieved based on the performance of the air conditioning units and spaces in the ceiling cavities. At the same time, air conditioning temperature distribution had to be optimized and noise had to be reduced. Rooftop integrated air conditioning units, which are easy to maintain, were used for the WMATA7000 (the separate type, where units were installed on the rooftops and underfloor, were used in existing cars). However, the size of the new cars was the same as existing cars, so the air conditioning units and ducts had to be installed in very limited spaces in the ceiling cavities.

Therefore, by making full use of simulations using computational fluid dynamics (CFD) analysis, we were able to study designs that could optimize air quantity distribution in the air conditioning ducts and passages, make the temperature distribution in cars appropriate, and reduce noise (Fig. 4). An actual car was used in a test for the final evaluation of the air conditioning system in a climatic testing room. Any problems found at that time would have affected the designs and production of other sections. However, the early-stage simulation prevented large-scale reworking.

(5) Interior Noise

Interior noise is judged based on the results of measurements at the actual sites after cars are delivered. If the noise levels at that time are beyond the specifications, the cars must be redesigned, which would affect the delivery schedule. Therefore, the statistical energy analysis (SEA method) was used to simulate noise prior to the delivery of the WMATA7000 (Fig. 5). Rolling noise around bogies under the influence of rails was required as input data for such simulations, so we used existing cars to get measurements and used the obtained data for the simulations. The noise levels were within the specifications in the measurements conducted after the WMATA7000 cars were completed, so no rework was required.

(6) Carbody design (cab design)

When cabs are designed, considerations are necessary to ensure the operability of equipment and to secure a forward view for drivers with different physical features based on ergonomics. In the past, two-dimensional drawings were used for such verification, but there were limitations on the verifiable scope. Therefore, three-dimensional models were used for the WMATA7000 to verify in detail the operational range and view in consideration of the differences in the physical features of

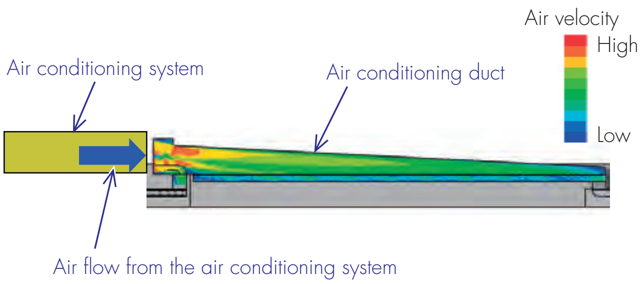


Fig. 4 Investigation of HVAC system (air distribution)

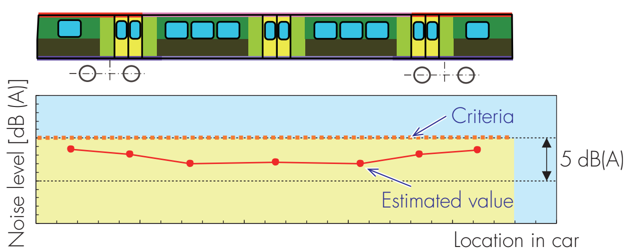


Fig. 5 Investigation of interior noise

drivers (Fig. 6). We were able to check details using the simulation results prior to the production of a mockup, thus shortening the design period and making it easy to carry out visual checks, enabling us to obtain customer approval earlier.

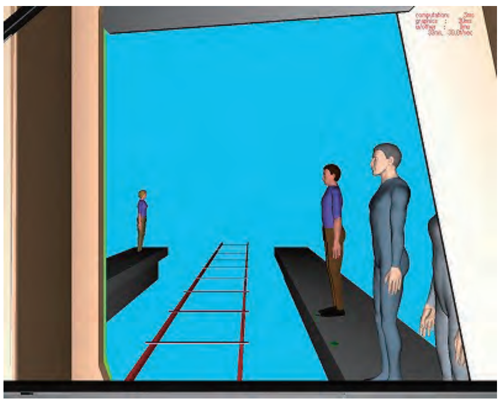
(7) Bogies (running simulation)

In bogie design, it is necessary to check if the running performance reaches required levels and if running safety is ensured in running simulations in the design stage beforehand. Many items and conditions need to be evaluated, but bogies are to be designed in a detailed way based on the simulation results, so such evaluation needs to be carried out effectively in the initial stages of projects. We carried out many simulations for each of the combined conditions in an efficient way and incorporated the results in the bogie designs (Fig. 7).

(8) Bogies (consideration of strength)

Various loads are applied to bogies. Static strength and fatigue strength must be closely inspected for all combinations of a variety of loads in order to secure safety. We have developed a new system that combines various loads to calculate the strength and optimizes thickness based on the results and used it to design the bogie frames and bogie bolsters for the WMATA7000 (Fig. 8). This system made it possible to reduce the weight of the components while maintaining sufficient strength and it allowed us to shorten the design period and to continue to the next process smoothly.

(a) Verification of operation range



(b) Verification of view

Fig. 6 Carbody design (cab)

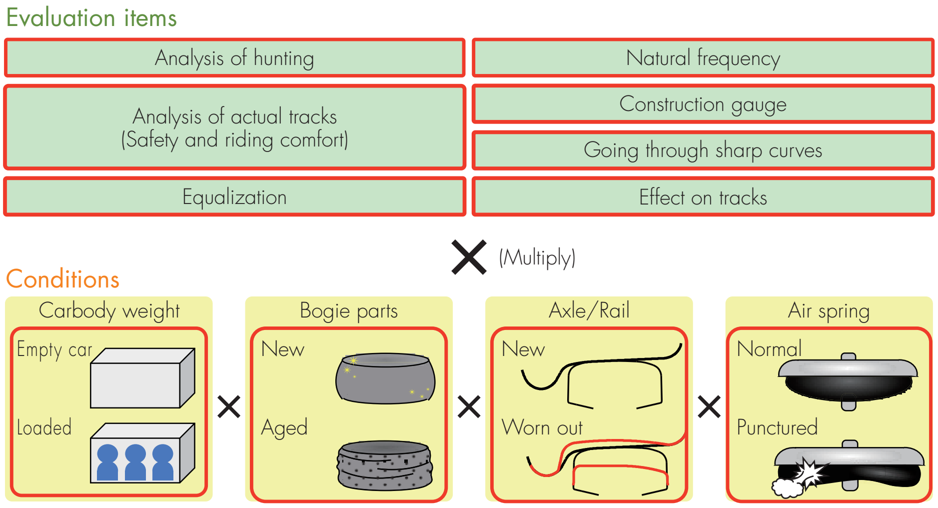


Fig. 7 Bogie design (running simulation)

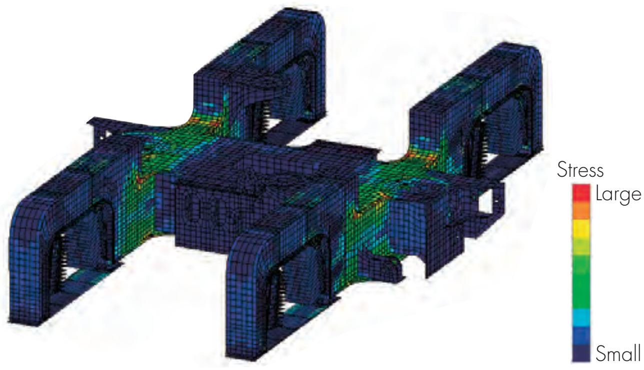


Fig. 8 Bogie design (strength investigation)

(9) System design

The amount of equipment to be installed on the WMATA7000 was greater than existing cars, including network devices and passenger information system. Advanced functions were also required. If the specifications for the equipment are changed after being decided, designs for installing such equipment must be reviewed. To avoid this, we had focused meetings with equipment manufacturers from the start of the project and designers working on the system and equipment installation (designs of car bodies, rigs, and bogies) engaged in detailed discussions about the designs while continuing the design work, which reduced the amount of rework required.

(10) Concurrent engineering

Even when designs satisfy customer specifications, if difficulties are encountered in manufacturing the products, they must be redone. Therefore, we used concurrent engineering wherein manufacturability was discussed with the engineering sections from the beginning of the WMATA7000 project.

Conclusion

In this report, we introduced a project with front loading in rolling stock design using the WMATA7000 as an example. Applying design resources from the start of the project allowed us to complete the designs in a shorter period of time without much rework. In addition, it was highly effective for total optimization. Furthermore, newly developed simulation techniques and the like significantly contributed to energy saving and optimization. We will apply these methods in the future as well to the new model rolling stock for other companies that we are currently researching in order to satisfy requests that are growing more and more advanced.

The WMATA7000 cars went into service in April 2015 after finishing the designs, the manufacturing of prototype cars, and various tests. Currently we are manufacturing and delivering mass production cars.

Last but not least, we would express our appreciation to everyone at WMATA and the equipment manufacturers for their cooperation from the initial design stage.


Homare Inagaki
North America Project Department,
Project Management Division,
Rolling Stock Company


Yuji Toya
Overseas Engineering Department 1,
Engineering Division,
Rolling Stock Company


Tomoe Tanaka
Overseas Engineering Department 1,
Engineering Division,
Rolling Stock Company


Keiichiro Kamura
Bogie Engineering Department,
Engineering Division,
Rolling Stock Company


Hiroshi Yano
Mechanical System Research Department,
Technical Institute,
Corporate Technology Division


Hideaki Ezaki
Electromechanical System Department,
System Technology Development Center,
Corporate Technology Division