Innovation in the development of CVT unit systems and their applications in projects

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Abstract

As the demands for automobile performance increase, the requirements for the development of CVT units are becoming more complex. In addition, many tradeoffs are involved in their development, making it difficult for development to proceed without rework. In response to these challenges, JATCO established a system architecture analysis method that applies Quality Function Deployment[1].

This report describes the issues that were identified in the application of the method to actual projects to complete development and the measures taken against the issues.

1. Introduction

In recent years, the requirements for the development of new CVT units have become increasingly diverse and complex owing to the need for more compact units to meet stricter vehicle crash safety requirements as well as the increased demand for improved exhaust emissions and fuel consumption. Under these circumstances, smooth development using conventional methods has become difficult. To address this situation, we introduced a systems engineering (SE) method[2] to perform development with a holistic view of the entire vehicle, powertrain, and CVT, thereby realizing a smooth development process with no rework and successfully achieving mass production. This report provides an example.

2. Issues identified when the method is applied to actual projects

For the smooth development of a new CVT unit, it is necessary to follow the V-process of SE. In particular, the first process, that is, system design, in which vehicle requirements are translated into unit requirements, is important, and its success or failure affects all downstream processes (Fig. 1). Therefore, the key points for high-quality development are whether all issues can be identified without omission and to clearly allocate requirements in the design review, which is the final step in the system design process.

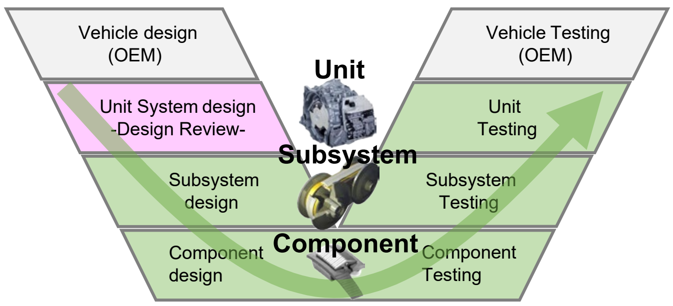

Fig. 1 V-shaped development process

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In the system design stage, it is important to consider a set of processes to identify changes, extract issues, examine issues, and review the design (Fig. 2).

The following section describes the issues that arise in each process and their solutions when applying a requirements traceability matrix to a real project.

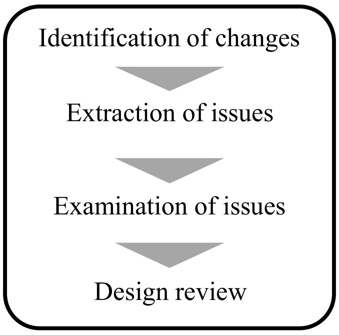

Fig. 2 The system design process until the design review

2.1 Identification of changes

Identifying changes is an important step when conducting projects. By utilizing the requirements traceability matrix, it is possible to ensure the completeness of the list of requirement items, assuming that the changes, which are the input information (customer requirements), are clearly identified. However, the following issues arose in its application to actual projects.

2.1.1 Issues in understanding requirements

There were cases in which, among the customer requirements, some requirement items were missing or the values of some requirements were unspecified. These issues were overcome by introducing a requirement management tool, setting out the company's in-house performance requirement items that were necessary for development, and having the customer present the target values for these requirement items, thereby preventing missing requirement items. Additionally, misunderstandings arising from a lack of communication were prevented by creating records of the agreed-upon parties as well as the dates and times of agreements.

To allocate vehicle requirements to unit requirements and unit requirements to subsystem requirements, a planning drawing framework (Fig. 3) was developed, and requirements–function–logic (RFL) at each level was managed using planning drawings, thereby preventing unclear allocations.

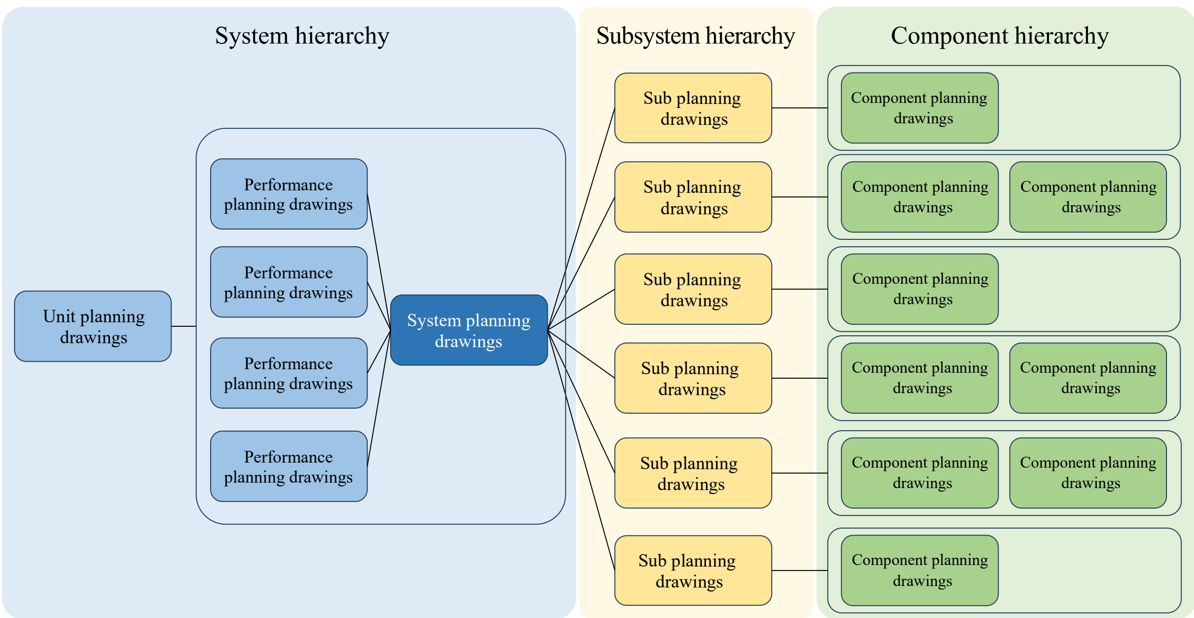

Fig. 3 The framework of planning drawings

2.1.2 Issues in understanding specifications

In the early development stages, it was easy to identify changes because the specifications were determined based on the performance requirements. However, specifications are frequently changed in later development stages to meet production requirements, supplier requirements, cost targets, and weight targets, making it less easy to identify all changes. To solve this problem, a drawing-based change identification and listing system was introduced into the drawing-release process, and a process gate was added to check for changes (Fig. 4).

2.2 Extraction of issues related to changes

By utilizing the requirements traceability matrix, it was possible to extract all impacts of the changes. This made it possible to efficiently extract the issues raised by experts and avoid any issues caused by variations in individual abilities. However, the following issues became apparent during the actual application of the project.

2.2.1 Insufficient issue extraction owing to delays in updating information

The extraction of issues in the requirements traceability matrix was based on the existing CVT system configuration, and it was not always possible to cover all issues, owing to delays in updating information, such as issues associated with the introduction of new systems and the horizontal deployment of specification changes in other models.

In response, a process (Fig. 5) was introduced to examine whether issues should be added based on the latest information in each functional design using the items extracted from the changes and the requirements traceability matrix as a base. This process prevented any issues from being overlooked and enabled the regular updating of the requirements traceability matrix.

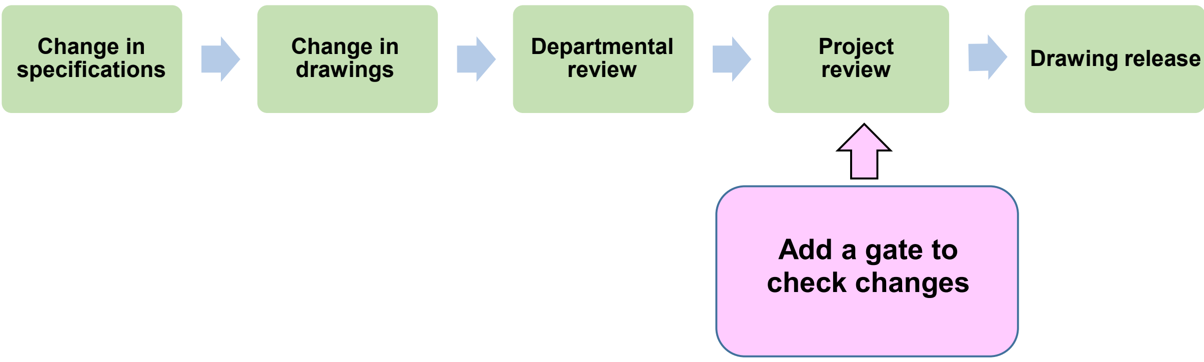

Fig. 4 Improving the drawing process

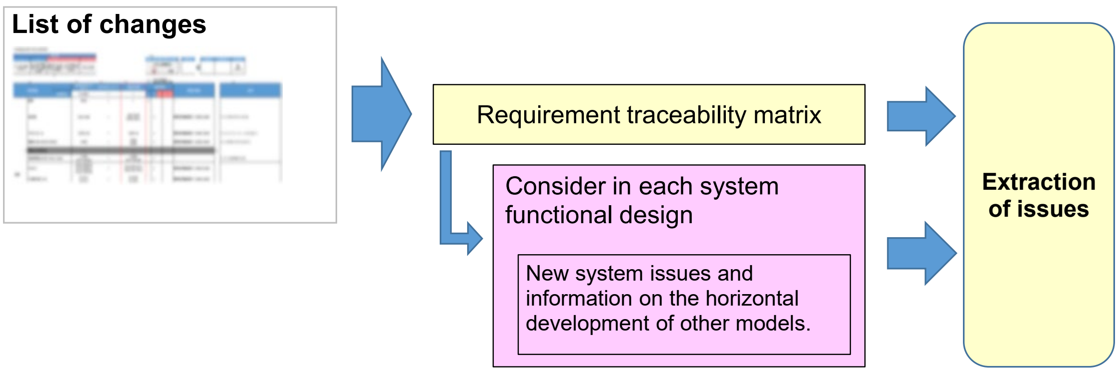

Fig. 5 The issue extraction process

2.2.2 Overextraction of issues

The requirements traceability matrix was designed to allow for the extraction of all items that might be generally affected so that no issues would be missed. This resulted in a significant number of extracted items, and there was a concern that the resources required for the subsequent examination of these issues would be excessive. In response to this concern, the changes extracted from the requirements traceability matrix were assessed by each design department, and if they were judged to have no obvious impact on the performance, they were excluded. This approach prevents an unreasonable increase in the number of items extracted from the matrix, thereby allowing time for the examination of important issues.

2.3 Examination of issues

The extracted issues were examined for each functional design, and the specifications were determined. At this point, requirement mediation was necessary for tradeoffs between functions, and substantial rework occurred when the specifications were not determined in an appropriate order.

The requirements traceability matrix was used to factor in the sequential order of design (extraction of key specifications), visualize the tradeoffs, and numerically evaluate the complexity of the system architecture (interface score). This approach clarifies the priorities of the functions and efficiently resolves tradeoffs.

Specifically, the tradeoff requirements for the changes were identified, and their complexity was quantified to enable a comparison with other changes. In addition, the issues were examined according to their priority, which was determined by evaluating them using the complexity and magnitude of the impact on key specifications and the unit layout on two axes, thus enabling the efficient resolution of complex tradeoffs (Fig. 6).

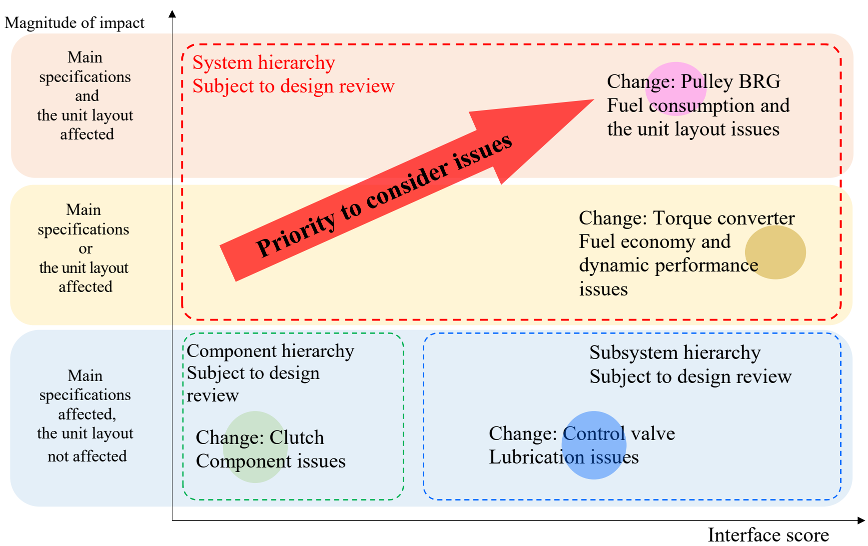

Fig. 6 Implementation of an Interface Score (Priority of issue study)

2.4 Review of issue examination

In this project, A level of meeting was assigned based on the presence of system issues extracted from the requirements traceability matrix, evaluation of the interface score, and magnitude of the impact on main specifications and the unit layout. This allowed us to focus on the most important issues (Fig. 7).

2.5 Examples of applications in actual project development

Five examples of project development applications are described below (Fig. 8).

(1) During the development process, a major specification change occurred in the belt, which is a key component of the CVT.

(2) In response to (1), the system issues were extracted. Based on the requirements traceability matrix, it was decided that fuel efficiency and dynamics (Wide-open-throttle start), which are the most important issues and have a high potential to affect the unit layout, would be addressed as priority 1 and that other issues would be addressed after the fuel efficiency and dynamic performance were resolved.

(3) The ratio coverage must be expanded to ensure fuel economy and dynamic performance. To expand the coverage ratio, it was necessary to change the design of the pulley, which is another key component of the CVT.

(4) System issues were extracted based on (3). Based on the requirements traceability matrix and other issues from (2) + prioritization, the durability of the pulley strength was reassigned as the new priority 1, and the unit layout, dynamics (highest speed), and operability issues were reassigned as the new priority 2.

(5) A level of meeting was determined according to the magnitude of the impact of the system on the issues identified in (4).

The above approach makes it possible to focus on the necessary review processes, depending on the importance of the issues in the project.

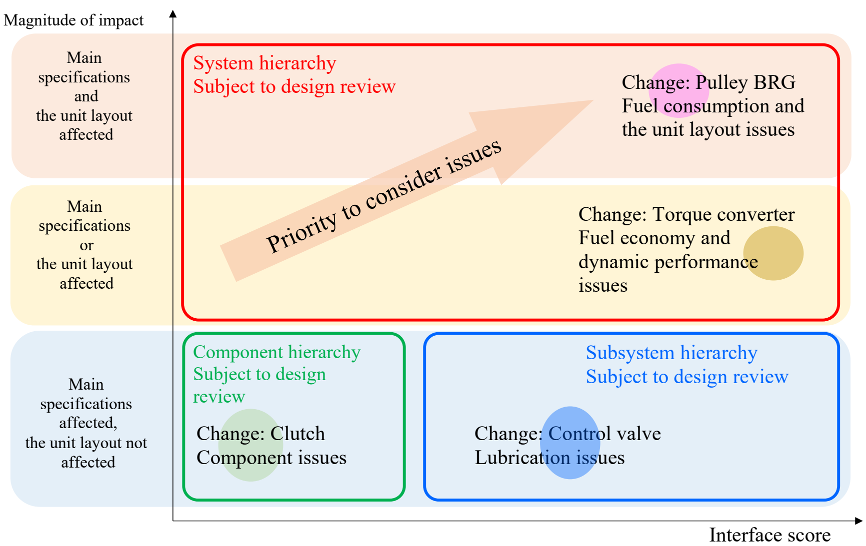

Fig. 7 Implementation of an Interface Score (Decide review level)

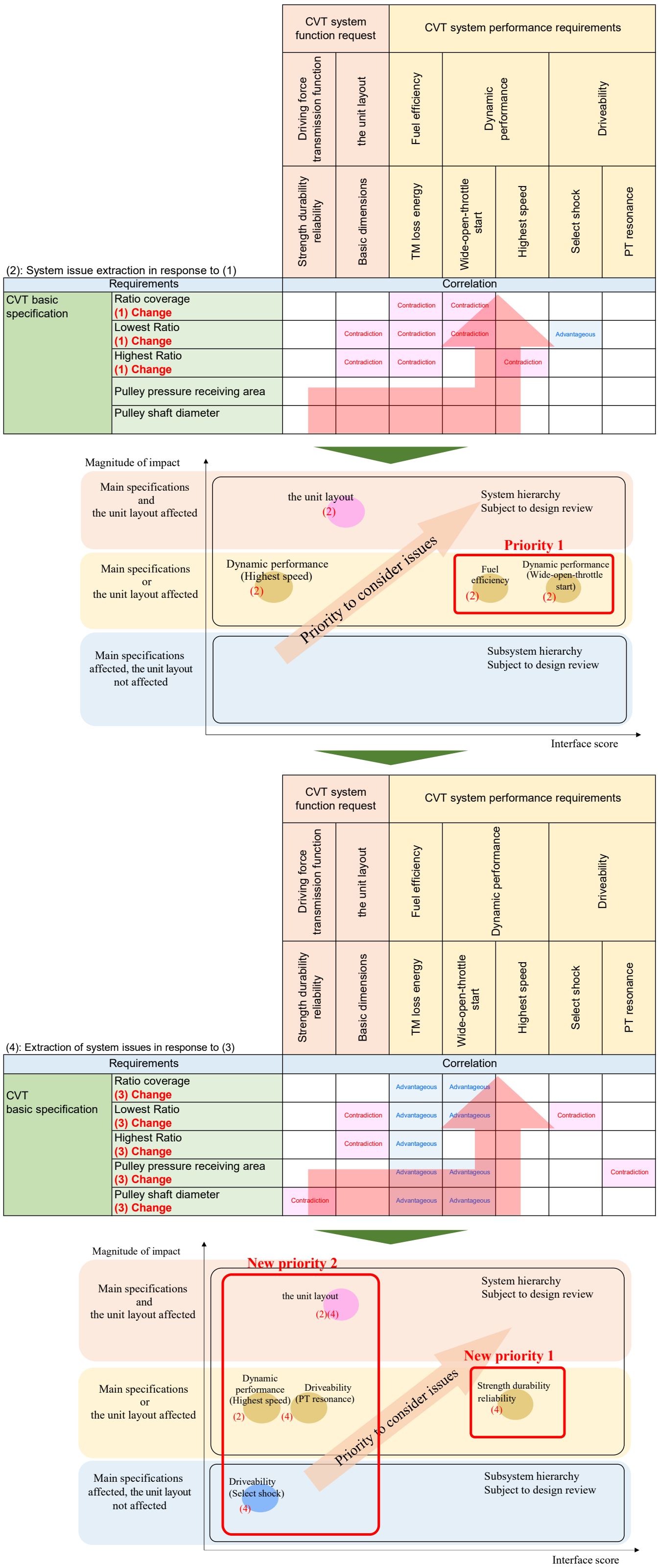

Fig. 8 Case study of project application

3. Outcome of the innovation in the system review

By applying the method described in this paper, the project contributed to the acquisition of the NCAP 5-star for an applicable car model by downsizing the unit size. This method also enabled the expansion of the ratio coverage, which contributed to improved fuel efficiency and dynamic performance by 13%, compared with those of the previous model (Fig. 9).

In addition, the development costs were reduced by approximately 14%, compared with those of the previous model.

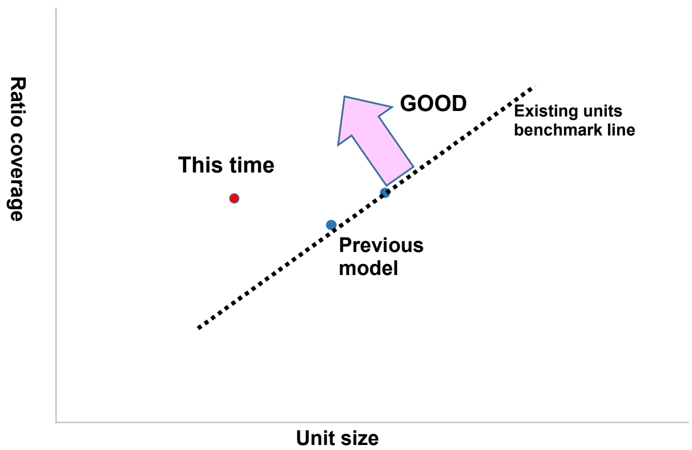

Fig. 9 Ratio coverage vs. Unit size

4. Discussion

This study describes an innovative method for developing CVT systems. In the future, to further improve quality, the application of this method will be expanded as follows.

4.1 Application to the development of electrification units

Although the system is not as complex as a CVT, it is necessary to develop one that encompasses not only the reduction gear but also the prime mover. Because the tradeoffs with vehicles will further increase, the present method can be used to achieve efficient and high-quality development.

However, it is also important to improve the accuracy of the requirements traceability matrix and create an environment in which the requirements traceability matrix can be visualized and discussed among the parties involved.

4.2. Application to the development of AT and CVT units

In the development of existing AT and CVT units, there are many system issues, such as recent regulations and the addition of new devices. The proposed method enables the efficient development of a wide variety of applications.

4.3. Cultivation of system human resources

As Japan's birth rate declines and its population ages, it is becoming increasingly difficult to pass on technology and cultivate human resources through on-the-job training, as was done in the past. By applying the proposed method, even inexperienced engineers can identify system issues and prioritize them, thereby enabling early human resource development.

5. Summary

This paper presents a case study of the application of the requirements traceability matrix to a project and discusses issues and their solutions in each process (Table 1).

The use of the requirements traceability matrix made it possible to prevent project issues from being overlooked and develop highly efficient and high-quality units.

Table 1 Issues and solutions in each process

Process	Issue	Solution
Identification of changes	Understanding of requirements	• Requirement management tool • Framework of planning drawing • RFL
	Understanding of specifications	• Identifications of changes based on drawings, listing • Addition of a process gate to the drawing release process (check for changes)
Issue extraction	Insufficient issue extraction owing to delays in updating information	Process for considering whether or not to add an issue
	Overextraction of issues	Performance impact assessment process
Examination of issues	Rework owing to tradeoffs between functions	Prioritized by complexity and impact on key specifications and the unit layout
Design review	Review of issue examination	Assigning a level of meeting for the examination of extracted issues

6. References

(1) Fuyuku Katsu and Yasushi Hattori, "Implementation of a system architecture analysis method in the automotive transmission development process," JATCO Technical Review No. 19 (2020).

(2) Takashi Nakazawa, "New Engine Development Using Systems Engineering," Journal of the Japan Society of Mechanical Engineers, Vol. 119, No. 1177 (2016).

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