Development of power train ECU for AZ line※1 engine

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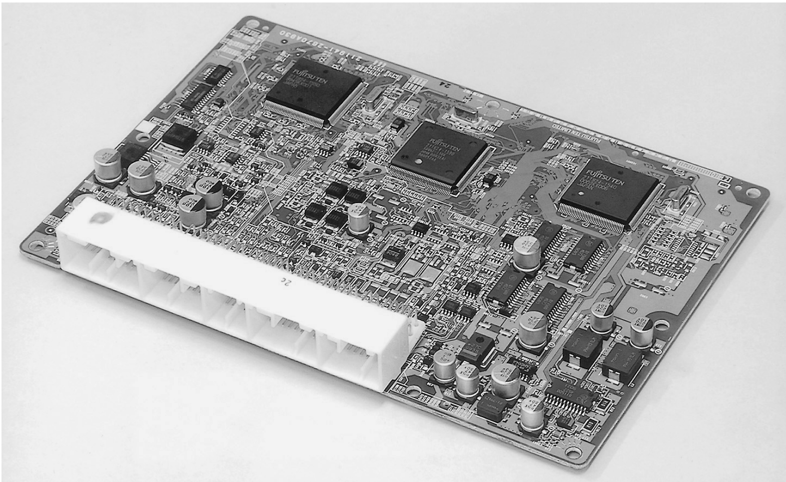

Abstract

Motor industry is globalizing rapidly in recent years, and the requests for short-term product development and cost reduction are increasing, with intensifying competition. Therefore, the demand for on-vehicle equipment quality is becoming much higher than ever before.

To correspond to such market factors, we reexamined each conventional operation step in the power train control field, from development to production. We then started the introduction and application of new technology and construction methods.

In this article, we introduce the improvements toward the ease of manufacturing by surface mounting all electric parts, and new inspection methods without using the ICT (in-circuit tester). In addition, improvements in software development technique are introduced.

※1: 2000cc engine (1AZ-FE, 1AZ-FSE), which is loaded on the RAV4 ('00/5) and the Opa ('00/8) by Toyota Motor Corporation.

1. Introduction

Our company has been producing power train system ECUs for over twenty years. Initially, they were for emission gas control, but recently developed ECUs have incorporated advanced functions, such as fuel injection, ignition timing, transmission, and electronic throttle control.

Furthermore, as mentioned in the Abstract, lower cost and a reduction in development period are also expected of them.

To meet expectations such as these, our company's Motoronics Headquarters, aiming to develop a revolutionary product, launched the SRM 2000 (Super Rapid Module 2000) Project in November 1997, performing concurrent development work with related departments (Quality Control, Manufacturing Engineering, Manufacturing, and others) starting from the production planning stage. As a result, we developed a power train ECU for the AZ system engine, which came off the line in May 2000.

This report will describe design-related actions that were taken to materialize the concept of the project activities (Table 1).

Table 1 Concept, manner, and aim of SRM2000

SRM2000 Concept: Speed / Slim / Inspection Detecting capability Improvement

Measure \ Aim	Quality (Q)	Cost (C)	Supply (D)
Complete conversion to surface-mounted parts	○	○	○
Reducing number of parts	○	○	○
Improvement of software development techniques	○	○	○
Special software for inspections (ICT elimination)	○	○	
Inspection of actual vehicle modes	○		

2. Complete conversion to surface-mounted parts

Aiming for a slim product form that supports higher densities and high-speed production, the company converted all electronic parts to surface-mounted types (reflow parts) and eliminated radiators (Fig. 1).

As a result, as shown in Fig. 2, it became possible to simplify the manufacturing process and mount parts simply by using a very-high-speed mounter.

To reduce the amount of power consumed by the ECU internal power supply, which created a bottleneck, a switching system (conventionally a series system) was adopted for the first time for the internal power supply as a power train ECU destined for the Toyota Motor Corporation.

Here is a list of the power supplies required by the ECU:

① 3V power supply: For 32-bit flash microcomputer
② 5V power supply: For system LSI circuit, 32-bit flash microcomputer, and output predriver
③ 5V precision power supply: For sensor, analog signal processing circuit, knock processing circuit, and system LSI circuit
④ 8V power supply: For 32-bit flash microcomputer writing

Even if the currently developed product used a conventional series system, the total power consumed by the power supply unit would be 3.8 watts; thus, as shown in Fig. 5, the power supply transistors, as lead-included components, would need a radiator in order to dissipate heat.

To solve this problem, the possibility of product materialization using a switching system was examined from the perspective of required voltage accuracy. Thus, it was determined that adoptability was possible for ①

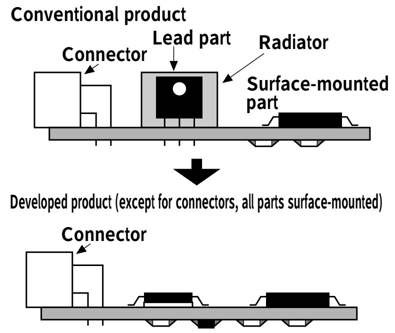

Fig.1 Product configuration

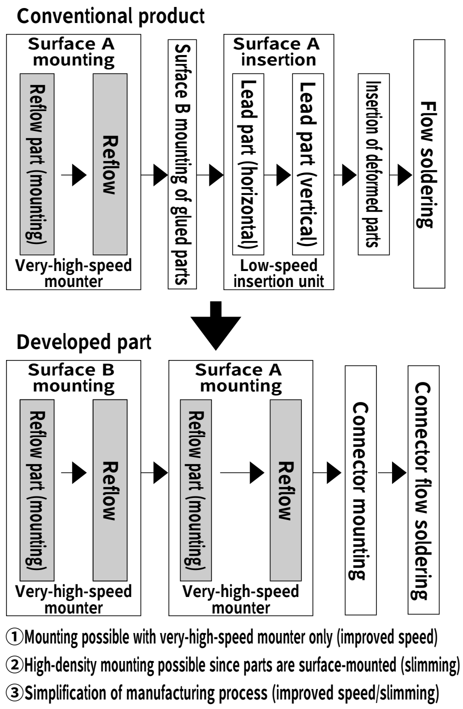

Fig.2 Manufacturing process

and ②. As a result, the total power consumption for ① and ② was 0.55 watt.

But because the power consumption was 0.25 watt for ③, which required high voltage precision; and the power consumption was 0.1 watt or less for ④; the conventional series system was adopted for use.

As a result, the total power consumption was 0.9 watts, enabling the product to be developed as a surface-mounted part.

To supply power for ①, ②, ③, and ④, a custom power supply IC was newly developed, making it possible to control all power supplies with a single IC.

Furthermore, for the radiator-equipped lead IC shown in Fig. 5, a SOP (surface-mounted) package with rear-surface radiator was adopted to actively radiate heat to the circuit board (Fig. 3).

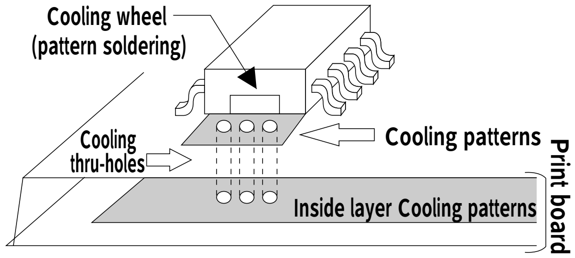

Fig.3 SOP (surface mounting) package with rear cooling wheel

3. Measures for reducing number of parts

During the development of this ECU, the development of ICs by functional block (Fig. 4) was examined and the following custom ICs were developed.

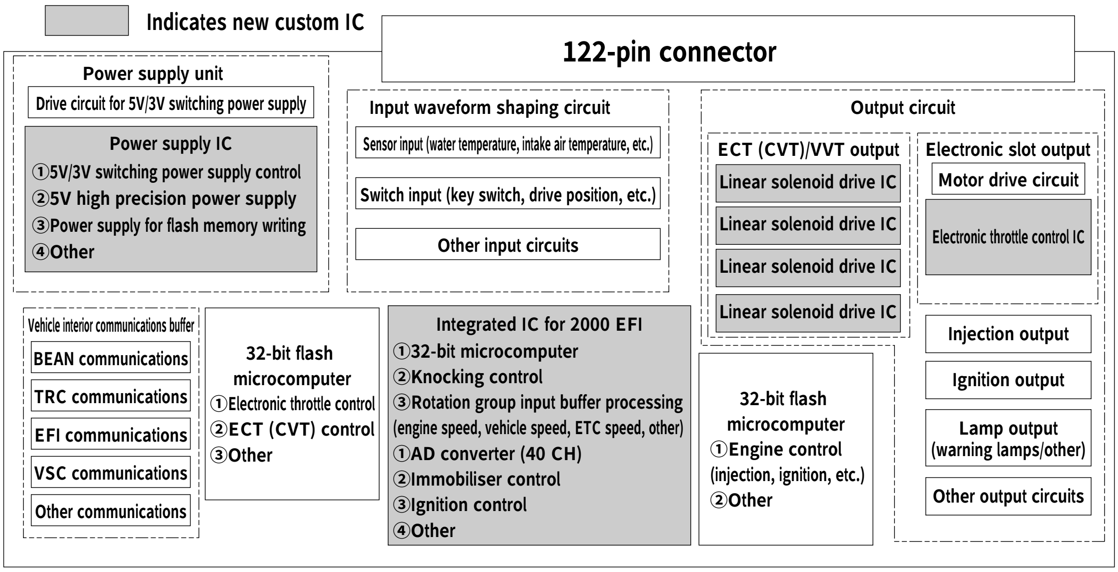

Fig.4 Functional block

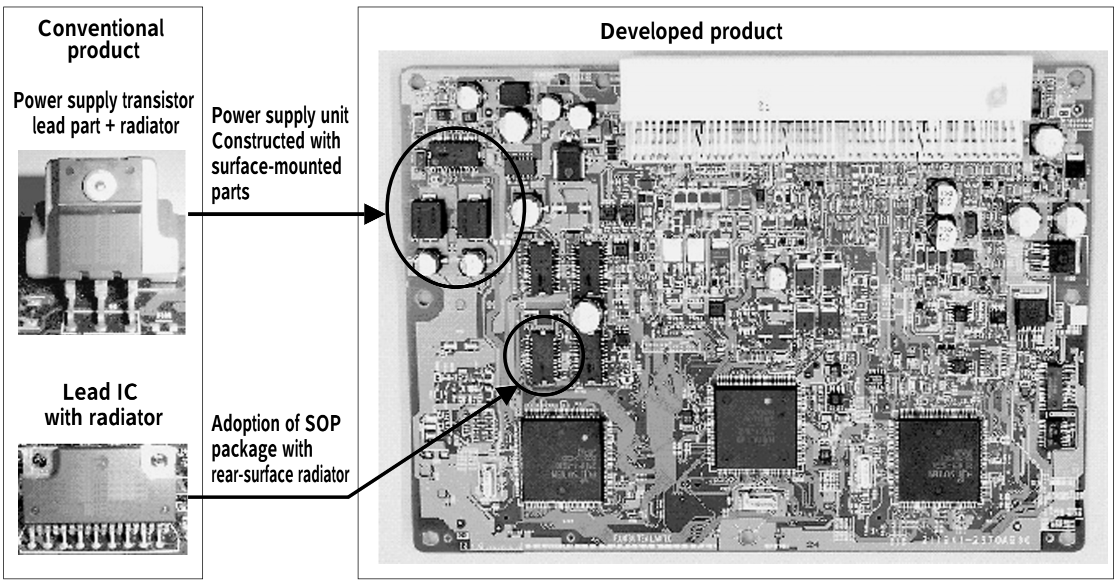

Fig.5 Product configuration of development product

① 2000 EFI system LSI circuit
② Electronic throttle control IC
③ Linear solenoid drive IC
④ Power supply IC

As a result, thinking of the number of parts in terms of the function of the developed product, we were able to reduce the number of parts from the original 1200 to 850. Fig. 5 shows the appearance of the newly developed product.

4. New inspection

4.1 Adoption of special software for inspections

With an advanced ECU such as this, high-density mounting inevitably becomes a necessity. Conventionally, an ICT (in-circuit tester, which checks by application of measuring pin to print board) was used to check the constants of components. In this case, however, a test terminal was needed for each component on the print board, so it was an obstacle to high-density mounting. And since it is necessary to prepare a fixture for an ICT of several hundred pins (and for the currently developed product, at least six hundred pins) for each model and to perform a setup change for each flow, this has become a major factor that complicates the manufacturing process and makes joint use with a temperature (temperature characteristics) inspection more difficult.

But since a microcomputer with built-in flash memory has now been adopted, the rewrite function will be utilized effectively, special software for inspections will be developed, and a boundary scan function will exist for the 2000 EFI system LSI circuit. Thus, it is possible to set up Hi (5V) and Lo (0V) output and input arbitrarily for microcomputer and system LSI circuit terminals.

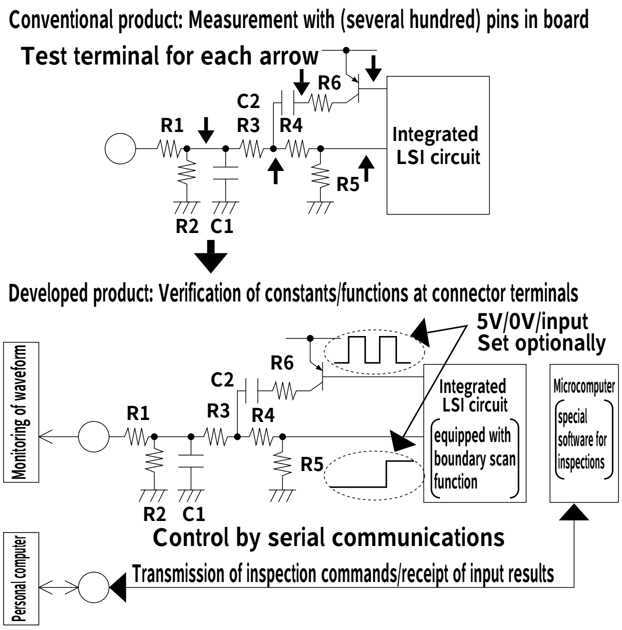

Fig.6 Inspection method

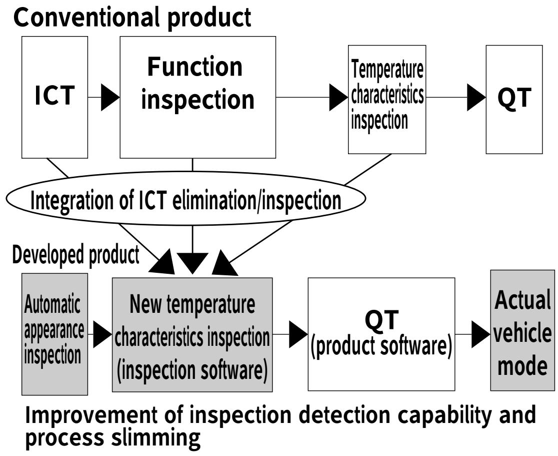

Fig.7 Inspection process

In this way, a microcomputer and system LSI circuit will monitor the connector terminals in the case of output settings, and will send the input results to a personal computer or other measuring instrument in the case of input settings. This makes it possible to simultaneously inspect the functions and component constants for each circuit block (Fig. 6). As a result, the conventional ICT inspection can be eliminated and this joint inspection can be conducted under temperature-insufficient conditions. Thus, improvement was made in detection capability and integration with temperature (temperature characteristics) inspections.

Furthermore, as shown in Fig. 7, an automatic appearance inspection and actual vehicle mode inspection were newly introduced in an effort to improve detection capability.

4.2 Introduction of actual vehicle mode inspection

With the aim of improving the detection capability of ECU shipment inspections, an actual-vehicle simulator (CRAMAS [*2]) was newly introduced with this product, and an inspection was added for actual vehicle mode.

During this actual vehicle mode inspection, travel patterns that have been recorded by the actual-vehicle simulator (CRAMAS) are utilized to operate an ECU. The ECU's output signals are continuously monitored in order to compare the expected values to real time (Fig. 8).

Furthermore, even in cases in which a phenomenon occurs only under certain travel conditions, adding to the travel patterns makes it possible to raise the level of inspection.

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*2 CRAMAS (ComputeR-Aided Multi-Analysis System)
Simulation system (developed by our company) that utilizes vehicle models to efficiently verify ECU operations and debug software under evaluation conditions that are similar to those of an actual vehicle.

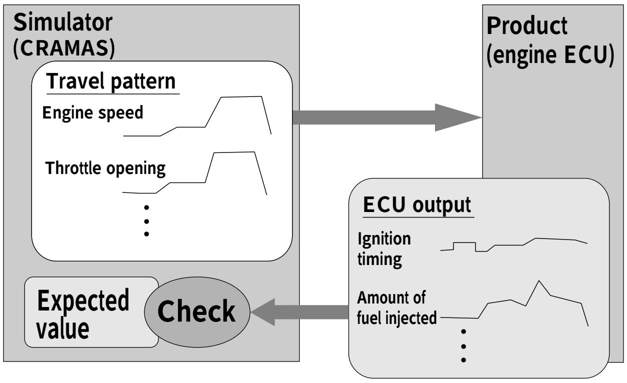

Fig.8 Actual car mode inspection

5. Improvement of software development techniques

As a result of improvements in fuel economy, tightening of emission standards, and implementation of other environmental measures in recent years, the demand for software for power train control ECUs has grown in scale and become more complicated. To meet such demand during the development of this product, we did not limit ourselves to simply standardizing software components; rather, we took the actions described below to improve reusability and ensure quality in order to effectively utilize the asset value of the software.

5.1 Software structure

With this product, we further reviewed software structure, an issue that we have engaged in for many years. To improve the reusability of software and adapt flexibly to system changes, we introduced hierarchical structure software (Fig. 9), the company's first such software for power train control ECUs; and developed software for parts (modularization).

5.1.1 Makeup of hierarchical structure software

1) Platform layer

① ECU hardware layer (ECU layer /CPU layer)
Processes ECU circuits and microcomputer (CPU) internal circuits.

② Application platform layer (APF layer)
Absorbs sensor and actuator characteristics, and combines the application unit and ECU hardware layer.

2) Application layer

Portion of software that is in charge of system control.

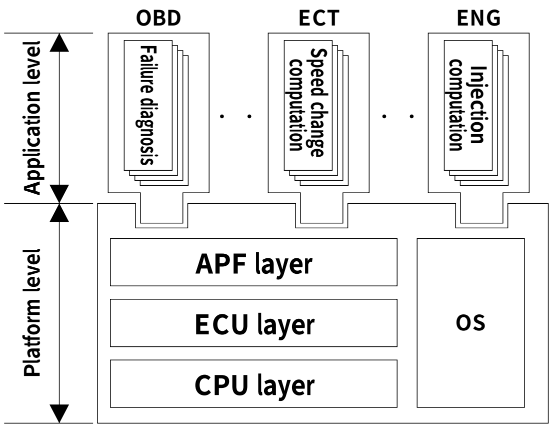

Fig.9 Software composition in hierarchical structure

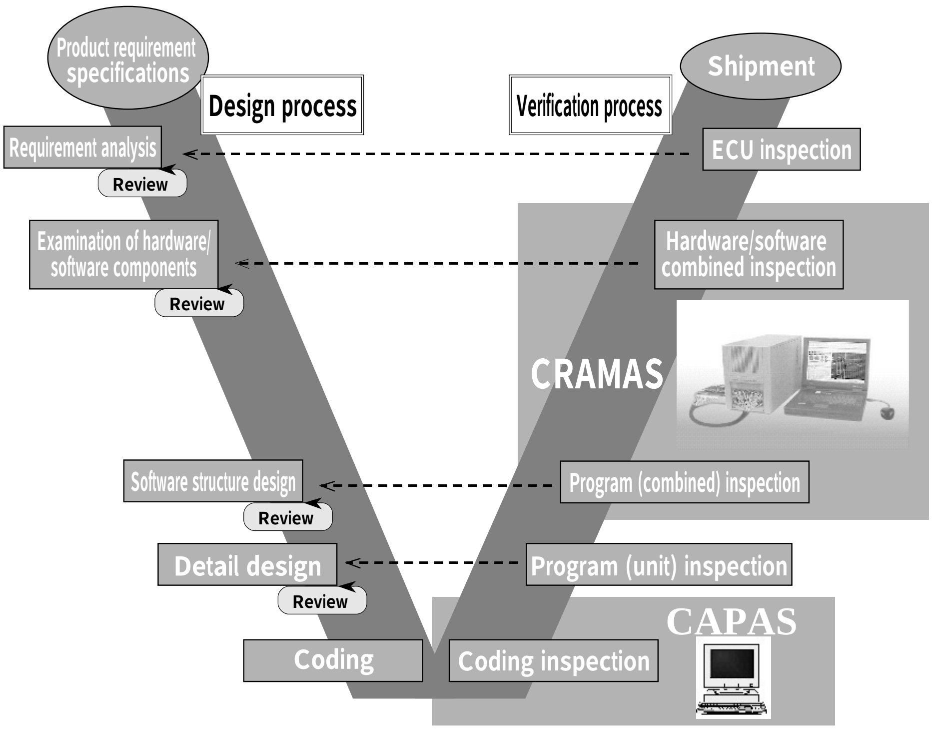

Fig.10 Software development process

5.1.2 Features of hierarchical structure software

In the past, when modifying the ECU circuit configuration, CPU internal circuits, and other hardware, it was also necessary to modify multiple related software components. By adopting this software configuration, however, it has become possible to adapt flexibly by replacing software components of the platform layer, without having to modify the application or redesign.

Furthermore, emphasizing reduced memory and high-speed response for automobile control and introducing a real-time OS that complies with ITRON specifications has made it possible to achieve efficient application software processing.

5.2 Improvement of development process

To further improve software reliability while expanding the number of objects of software control, improvements to the conventional software development process were added (Fig. 10).

5.2.1 Features of improved development process

1) Design process

Conducting a design review at each stage of design makes it possible to conclude work at each stage and minimize needed corrections, which in turn reduces the development period.

2) Verification process

Connecting the verification subject and design process helps to provide quality control for the design process as well. And when a problem arises, the nature of the work upstream helps to clarify the source of the problem, which in turn helps to prevent recurrence.

These improvements can be incorporated into the software development process, reducing the development period, and can serve as design standards for products developed after the current product.

5.3 Use of tools

For a long time, tools have been used to improve the efficiency of software development. During the development of this product, too, as shown in Fig. 10, new tools were introduced into each process of the software development process in an effort to achieve greater efficiency.

① Strengthening of design review function (CAPAS [*3])

To ensure program quality, techniques that utilize tools, rather than humans, to perform automatic checks have been generally adopted, and software, too, is available on the market.

Our company makes use of its independently developed CAPAS system to meet a variety of in-house needs.

During the development of this product, the quality of software in components was verified through the development of software components; however, it is important to verify the compatibility of components when mounting such components to the ECU.

Here, in addition to the original function of the CAPAS system, we strengthened the review function for portions related to the compatibility of components. Thus, it has become possible to detect problems during the early stages of the verification process.

② Actual-vehicle simulator (CRAMAS)

The recently developed CVT control was the first such system of the Toyota Motor Corporation, so ECU debugging required verification not only at the software component level but required checks of overall vehicle operations. Moreover, a tool that could replace an actual vehicle was indispensable.

CRAMAS was developed as an actual-vehicle simulator that could meet these needs, but although engine and transmission models were initially mounted, they were simplified. To produce operation that more closely approximated an actual vehicle, it was necessary to develop a precision model.

Thus, based on the CVT control specifications, a model of vehicle conditions required for ECU debugging was developed and incorporated into the actual-vehicle simulator (CRAMAS) (Fig. 11).

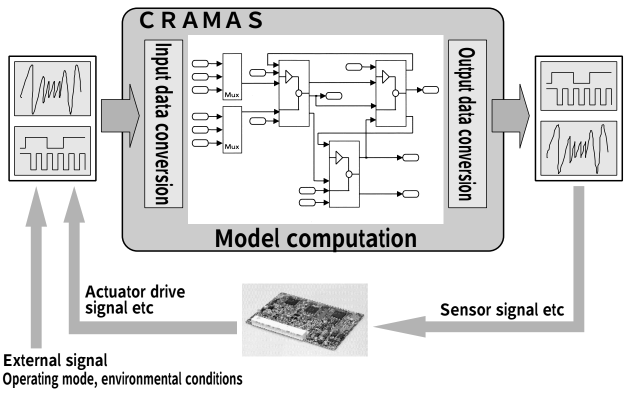

Fig.11 Actual car simulator (CRAMAS)

During the creation of the model, MATLAB/SIMULINK was utilized to create a model block diagram. As development proceeded, the CVT equipment advanced to successively higher levels as did the corresponding model block. As a result, an effective evaluation environment that more closely approximated an actual vehicle was achieved.

*3 CAPAS (Computer-Aided Program Analysis System)
A computer-aided software design and program analysis support system.

6. Positive results of development

Through this development, we have been able to materialize both a higher-performing ECU and slimmer product form.

As a result, we have achieved greater-than-ever quality, drastic simplification of the manufacturing process, and reduced cost.

Table 2 Comparison to the conventional type in development

	Conventional product (1997 model)	Developed product
Number of parts	400 items	850 items (conventional technology: 1200 items)
Processing cost (index)	100	75
Number of manufacturing processes	21	11
Line length	80m	45m
Flow tact time	30 sec	20 sec
Cost (function ratio)	100	75

Table 2 shows the effect of the currently developed product, which incorporates D4 control (fuel cylinder internal injection), CVT (continuously variable transmission), and electronic throttle control, comparing it to a conventional product (1997 model).

7. Future development plan

① During the development of the next model, create an ECU that is easier to make and strive for an improved degree of completeness.
Number of parts: 300 or less
Compactness: 235 × 170 mm 160 × 170 mm

② Utilize the actual-vehicle simulator for other controls as well, and further improve the efficiency of ECU debugging.

8. Conclusion

Through the aforementioned activities, we have been able to raise the productivity of the manufacturing line and improve our software design techniques. And in May of this year, we were able to start production of an ECU whose functions are more advanced than any in the past.

In closing, we wish to express our deep thanks to the Toyota Motor Corporation and SRM 2000 personnel who provided such outstanding support during the development of this product.

Profiles of Writers

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