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Digital validation by effective use of simulation

Validation numérique par utilisation efficace de la simulation

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Foreword

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This document was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 4, *Industrial data*.

Any feedback or questions on this document should be directed to the user's national standard body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Precision and high-performance electrical products can be defined as products that integrate mechanical, electrical/electronic, and software technologies. These digitally integrated products are expected to simultaneously achieve high functionality and low cost. In order to meet these needs, computer technology, which enables designing of highly functional products in a limited period of time, is necessary. Effective measures to realise such design can include active use of computer simulations from the functional design stage upstream of a design process, evaluating aspects of the feasibility of the expected function, and narrowing the appropriate design solutions at an early stage.

This document examines the business requirements for using simulation in the functional design process and identifies the key technical capabilities needed to satisfy those requirements. Based on a comparison with the capabilities of current technologies validated through research and experimental examples, this document identifies a number of digital validation technologies which need to be developed in order to meet future business needs, and the associated standardization requirements.

Digital validation by effective use of simulation

1 Scope

This document examines the standardization requirements for the necessary digital validation technology for improving design efficiency by effectively utilizing simulation data at the functional design stage of digitally integrated products.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions

3.1.1
digitally integrated product
precision and high-performance product that integrates mechanical, electrical/electronic, and software technologies

3.1.2
model-based development
MBD
mathematical and visual method of addressing problems associated with designing complex control-, signal-processing and communication systems

3.1.3
functional mock-up interface
FMI
standardized interface used in computer simulations to develop complex cyber-physical systems

Note 1 to entry: See FMI version in Reference [3].

3.1.4
functional mock-up unit
FMU
component that implements the *functional mock-up interface* (3.1.3)

3.1.5
co-simulation
two or more simulation functions interacting to simulate different aspects of a digitally integrated product

3.1.6
simulation time interval
Δt
simulation time step size in a dynamic simulation

3.1.7
supplier
manufacturer that supplies parts to *original equipment manufacturers* (3.1.8)

3.1.8
original equipment manufacturer
OEM
company that manufactures finished or semi-finished products to be sold by another manufacturer

3.1.9
machine-readable data
data in a format that can be automatically read and processed by a computer

Note 1 to entry: Machine-readable data shall be structured data.

3.1.10
human-readable data
encoding of data or information that can be naturally read by humans

Note 1 to entry: In computing, human-readable data is often encoded as ASCII or Unicode text, rather than as binary data.

3.1.11
reduced order model
ROM
mathematical model with reduced complexity for use in digital simulations

3.1.12
finite element analysis
method for solving problems of engineering and mathematical models

3.1.13
1D CAE
multi-domain systems simulation combined with controls

3.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply:

CAD computer aided design

CAE computer aided engineering

3.3 Trademarks

For the purposes of this document, the following trademarks are used. The reason that these trademarks have been used in this document is given in the footnotes.

Modelica®[1]: An object-oriented, declarative, multi-domain modelling language for component-oriented modelling of complex systems, e.g. systems containing mechanical, electrical, electronic, hydraulic, thermal, control, electric power or process-oriented subcomponents.

1) This trademark is provided for reasons of public interest or public safety. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC. Modelica® is a registered trademark of the Modelica Association.

MATLAB®[2]: A proprietary multi-paradigm programming language and numerical computing environment.

Simulink®[3]: A MATLAB-based graphical programming environment for modelling, simulating and analysing multi-domain dynamical systems.

SystemC™[4]: A type of hardware description language (HDL) intended for use in functional design of electronic circuit equipment.

ANSYS® Maxwell®[5]: A type of industry electromagnetic field simulation software for the design and analysis of electric motors, actuators, sensors, transformers and other electromagnetic and electromechanical devices.

ANSYS® RMxprt™[6]: A template-based design tool that designers of electrical machines and generators can use to enhance ANSYS Maxwell.

ANSYS® Twin Builder™[7]: An open solution that allows engineers to create simulation-based digital twins–digital representations of assets with real-world or virtual sensor inputs.

4 Business case for computer simulation in early design stage

Precision and high-performance electrical products, e.g. multifunctional copiers, printers, digital cameras, and automated teller machines (ATMs) can be recognized as examples of products that integrate mechanical, electrical/electronic, and software technologies. These digitally integrated products have to achieve high functionality, rapid development and low costs simultaneously, therefore, computer technology which enables designing of such highly functional products in a limited period of time is a key business demand. Effective measures to realise such designs can include actively utilizing computer simulations from the functional design stage upstream of a design process, evaluating the feasibility of the expected function, and narrowing the appropriate design solutions at an early stage [1,2].

These measures are common in a broad range of the manufacturing industry.

5 Major challenges in simulation

Figure 1 shows a typical design process of a digitally integrated product. The blue arrow in the figure indicates the software development process; the yellow and green arrows indicate the mechanical and electrical development processes, respectively. The arrow in the top section of the figure indicates the process where a part of the design work may be contracted to external collaborating companies.

2) This trademark is provided for reasons of public interest or public safety. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC. MATLAB® is a registered trademark of The MathWorks®, Inc.

3) This trademark is provided for reasons of public interest or public safety. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC. Simulink® is a registered trademark of The MathWorks®, Inc.

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5) ANSYS® Maxwell® is the of a product supplied by ANSYS. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

6) ANSYS® RMxprt™ is the trademark of a product supplied by ANSYS. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

7) ANSYS® Twin Builder™ is the trademark of a product supplied by ANSYS. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

The product specification is determined first, followed by the definition of the basic product system and architecture. Subsequently, the design process is classified into software, mechanical design, and electrical design workstreams. Further, functional design, detailed design, and performance design are conducted in that order in each workstream. Though the work is generally conducted independently in each workstream, information exchange is often carried out across the boundary of the workstreams and enterprises as necessary.

Various tests and trials are conducted, and the product functionality is confirmed during the performance evaluation stage. If problems are identified in this stage, information regarding the problems is fed back to the detailed design stage and design changes are executed to resolve the problems. In cases with serious problems, it can be necessary to return to the functional design stage and restart the work, which can result in large losses in cost and time. Prototyping and testing are conducted once performance evaluation is successfully completed and production is initiated after manufacturing preparation.

The EN/NAS 9300 series and sub referenced ISO 10303 series can be useful for manipulating design feedback.

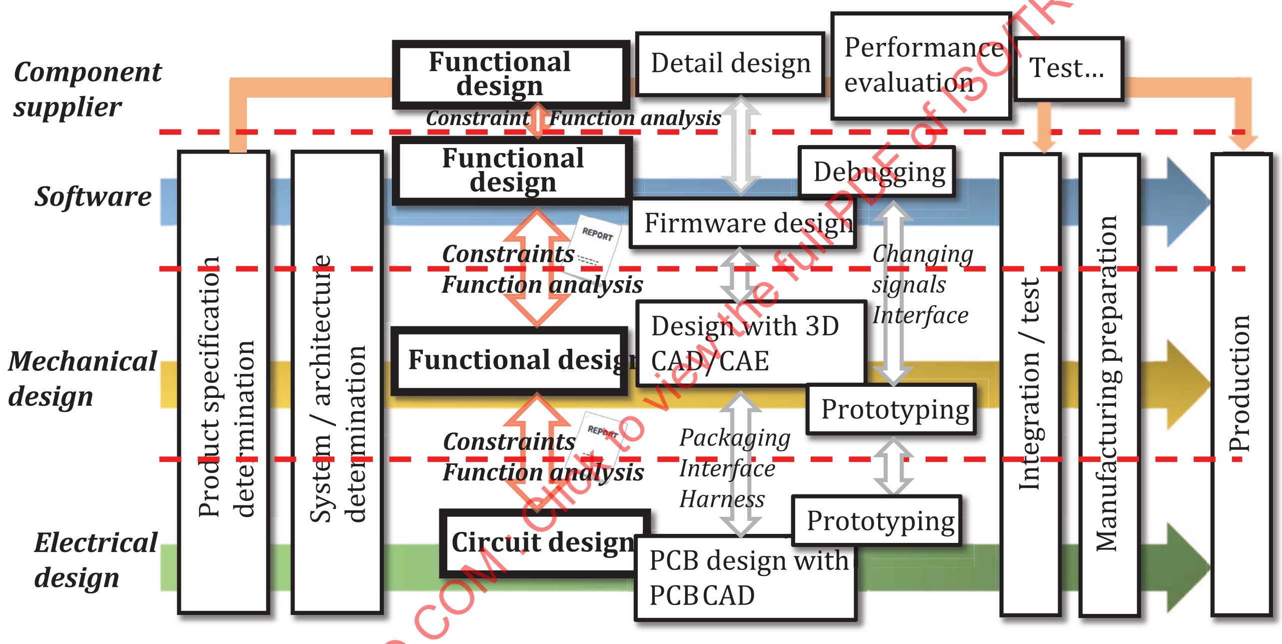


Figure 1 — Typical design process of the digitally integrated product

To achieve high functionality and low cost simultaneously, it is important to thoroughly conduct parallel computer simulations at the functional design stage upstream of the design process, to verify the design and reduce functional uncertainty as much as possible, and to reduce the possibility of cases where problems are detected downstream of the design process which would require rework of the product design.

Most geometric information related to the product is not determined at the initial functional design stage. Since many existing computer simulation or computer aided engineering (CAE) technologies are based on the shape information of the product, they are difficult to use in the verification work in such an early stage of the design. Some advanced companies have coped with these types of problems in their CAE software by developing their own simulation tools, but often their own design knowledge is embedded in proprietary software. This precludes independence from a specific toolset and constrains long-term maintenance and development.

Decisions in the upstream design are generally transmitted in the form of documents to the downstream processes. Therefore, the mechanism to reflect functional design results in the detailed design often depends on the interpretation of an individual designer, so neither uncertainty nor ambiguity can be removed. Currently, information exchange between different workstreams and enterprises is usually carried out through documents, and similar problems are unavoidable.

Based on these issues, the following requirements have been identified for digital validation technologies ensuring the effective application of simulations at the functional design stage.

a) Simulations without geometric information

   Simulations that do not require geometric information of the product are required to support functional design. These 1D CAE technologies, which are widely used in automobile and aircraft production, are considered a prime candidate for this type of simulation.

b) Co-simulation of different technical domains

   Functional verification of digitally integrated products requires technology that can evaluate phenomena in different technological domains, e.g. mechanical, electrical/electronic, and software, simultaneously and in parallel, i.e. technologies that can handle multiple simulations in different technical domains while considering interaction between them.

c) Simulations connected to 3D CAD/CAE

   There are 3D CAD models that have been developed based on functional design and detailed functional analyses have been conducted using 3D CAE. Currently, designers manually convert functional design results into 3D models. According to analysis results of 3D CAE, rework of functional design may be required. At present, the work which reflects the result of this 3D CAE back to the functional design is also carried out manually.

d) Simulations for collaborative design with multiple companies

   Many digitally integrated products are developed by the collaborative work of multiple workstreams within companies. Recently, the number of joint product developments by multiple companies is increasing. It is necessary to have a mechanism for sharing not only the relevant model data used in the simulation but also various technical information on the model beyond the boundary of the workstreams and enterprises.

This document describes the various components of digital validation technology that extend existing 1D CAE capabilities to satisfy these four requirements.

6 Digital validation technology

6.1 State of the art

Effective measures for increased performance, realisation of required complexity and reduced cost are common requirements in all manufacturing industries, and various solutions have been implemented to satisfy the requirements. Model-based development (MBD) has shown some success in the fields of automobile and aircraft production. MBD describes product function and design requirements as numerical models (often as ordinary differential equations) and conducts functional analysis/verification by solving the resulting numerical models. Functional analysis is possible even with incomplete geometric information of the product if differential equations are defined using this method; therefore, this method is suitable for use in the upstream design process. The use of MBD in the functional design process is often referred to as 1D CAE. Modelica and MATLAB/Simulink, which are examples of 1D CAE tools, have already been developed and applied in automobile design and aircraft design.

Multiple functionally common components are used for representing mechanical or electrical products. For example, many mechanical products use coupling, power transmission, power control, fluid transmission, and lubrication elements. Numerical models that correspond to two or more of these functional elements are packaged together and supplied as a library in the 1D CAE tool environment. A designer can select functional elements from a library and model product functions by connecting elements on a screen with a graphical editor, in order to simulate its behaviour. Common approaches include creating more complex elements by combining basic functional elements or distributing them as libraries by packaging these elements.

The use of 1D CAE is believed to be effective in the functional design support of digitally integrated products, if the following three digital validation technology functions can be provided.

a) In mechanical, electrical/electronic, and software domains, 1D CAE technologies suited for each domain are already widespread. Thus, it is important to create an interface function for activating multiple 1D CAE tools in parallel to achieve coupled simulations for different technical domains. It is believed that a functional mock-up interface/unit (FMI/FMU) is effective to achieve this type of interface.

b) The 1D CAE models obtained from the functional design results are refined into a 3D CAD model and used in high-accuracy functional analysis with 3D CAE. The functional design may need to be reworked based on the 3D CAE analysis results, and therefore, the ability to update the 1D CAE model based on the 3D CAD/CAE results is also important. An interface for this type of model conversion between 1D CAE and 3D CAD/CAE is necessary.

c) An interface which enables exchange of 1D CAE models and accompanying technical information between different workstreams and companies is required. Information exchange between different workstreams and companies are repeated as the design progresses, and the information is continuously revised along this process. A function that can suitably record this type of process and consistently manage the technical information accompanying the models is also required.

The next subclauses explore the state of the art in these technologies, using existing tools, and use examples to illustrate the new capabilities that are required.

6.2 1D CAE modelling of digitally integrated products

6.2.1 Introduction to example

1D CAE technology enables evaluation of design ideas at a stage where geometric information of the product is not yet determined. This satisfies the first requirement of the use of simulations in the functional design process of digitally integrated products. The effectiveness of 1D CAE in the functional design process can be demonstrated by an example of modelling and analysis of the behaviours of belt conveyor and heat roll mechanisms that simulate the paper conveyor mechanism and image fixing unit of a plain paper copying machine (copier), which is a typical digitally integrated product. The former is referred to as "mechanism analysis", the latter, as "thermal system analysis". These examples show that two completely different physical phenomena can be modelled using the same 1D CAE technology.

1D CAE is not yet supported by the ISO 10303 series. Such support would require a thorough integration with existing ISO 10303 parts to make it part of the comprehensive product lifecycle model of STEP. In order to support exchange, sharing and archival of 1D CAE data and their validation, the integrated resources of the ISO 10303 series need to be extended. This needs to be carried out in a consistent manner by following the current methodology and by extending existing and/or developing new documents. ISO 10303-209, ISO 10303-210, ISO 10303-235, ISO 10303-242 and ISO 10303-243[8)] include the new capabilities to offer them in an integrated manner to the industrial user.

6.2.2 Belt conveyor mechanism

Figure 2 shows the mechanism that conveys media such as paper using a belt. This mechanism is comprised of a belt transfer mechanism, a motor driving mechanism that applies a driving force to the belt, and a mechanism for controlling the motor by detecting the position of the medium by a light-blocking sensor. The belt conveyor mechanism can be viewed as a mechanical system; the motor driving mechanism, an electric system; and the motor control system, a software system. In the functional design of this belt conveyor mechanism, it is necessary to determine the sensor position to satisfy the

8) Under preparation. Stage at the time of publication: ISO/DIS 10303-243:2021.

specifications of the motor control mechanism (see Figure 3). A simulation model was developed with the following control conditions:

a) When the power is turned on, the drive motor rotates at a speed of M0.

b) The drive motor speed switches from M0 to M1 when the medium is conveyed on the belt from its initial position and passes the light-blocking sensor S1.

c) The drive motor speed switches from M1 to M2 when the medium is further conveyed and passes sensor S2.

d) The drive motor speed switches from M2 to M0 when the medium is further conveyed and passes sensor S3.

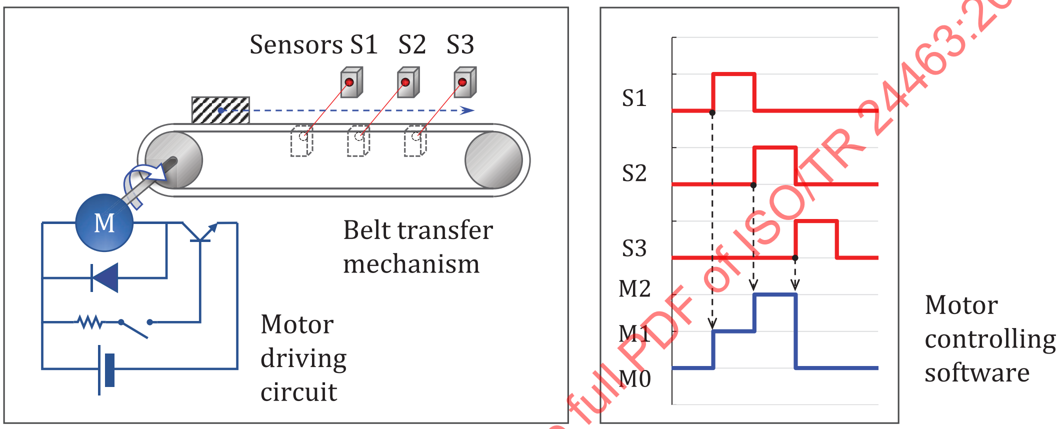


Figure 2 — Specification of a belt conveyor mechanism

Figure 3 shows the analysis model of the belt conveyor system created using OpenModelica. This model was designed by combining components provided in the Modelica Standard Library (MSL). For example, the belt conveyor mechanism was designed by combining the “Mass” and “SpringDumper” components. The motor drive mechanism was similarly realised by combining other components provided by the MSL. The motor control system comprises the light-blocking sensor and feedback control unit; however, components that correspond to these are not included in the MSL. Therefore, a model with equivalent functions needs to be created by combining simple components provided by the MSL. Figure 4 shows the analysis results obtained by using this model. The graph in Figure 4 shows the changes in the rotation speed and position of the objects on the belt. It also shows the changes in the torques of the drive and driven rollers. The roller and sensor positions can be determined to satisfy the specifications of the motor control system by referencing these results.

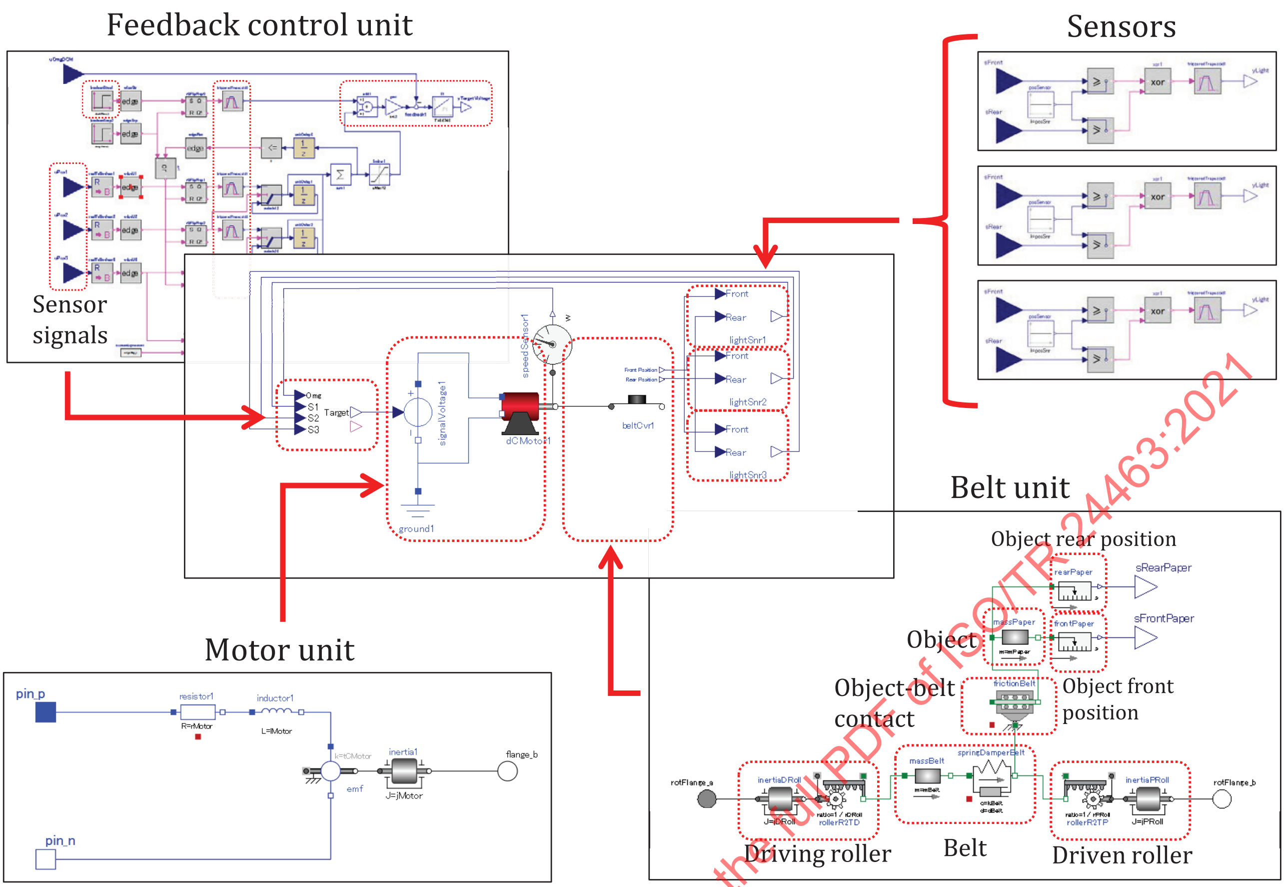


Figure 3 — Belt conveyor analysis model

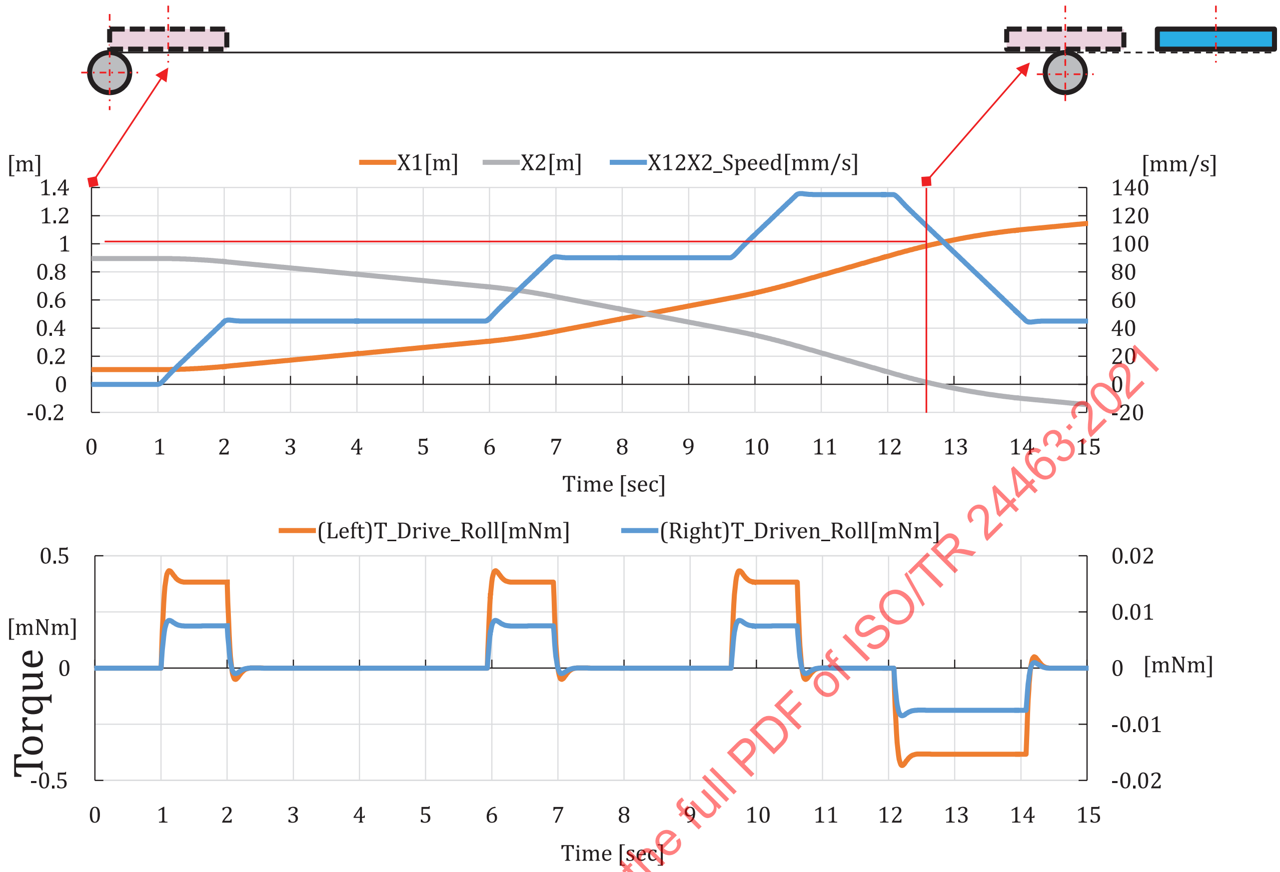
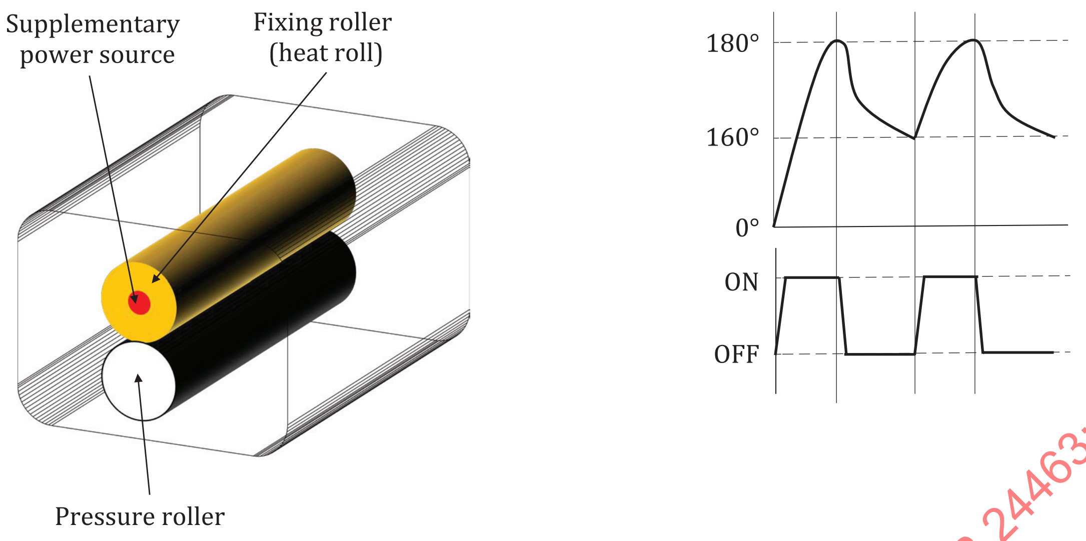


Figure 4 — Belt conveyor analysis results

6.2.3 Heat roll mechanism

The image fixing unit of a copier melts the toner by applying heat and pressure so that the toner is fixed onto the paper surface (Figure 5). An electric heater is included inside the image fixing roller, which transfers heat to the paper through this roller when heated. The temperature is controlled with a thermistor and electric circuit to maintain constant temperature on the fixing roller surface. Figure 6 shows a functional block of the image fixing unit. The model comprises a heat roller, pressure roller, paper, thermistor circuit, temperature controller, and a heat exhaust fan for cooling the housing. Heat is generated by the heat roller and transmitted to the heat roller surface, paper nip (section in contact with the roller), and the pressure roller. The heat and fixing rollers rotate to move the paper, and therefore, rotation and heat transfer must be modelled simultaneously. As in Figure 6, each roller is divided into four parts; the effect of the roller rotation was evaluated by changing the combination of these sections in contact over time. Figure 7 shows the 1D CAE model of the image fixing unit achieved by combining components provided by the MSL.



Heat roll structure **Heat roll temperature control**

Figure 5 — Specification of heat roll

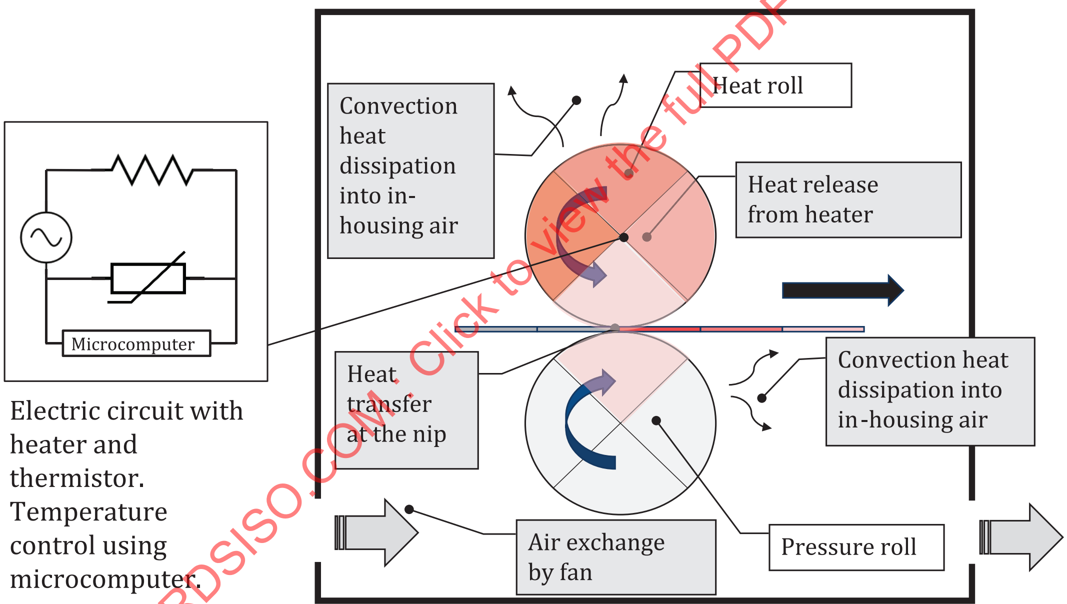


Figure 6 — Function block of heat roll

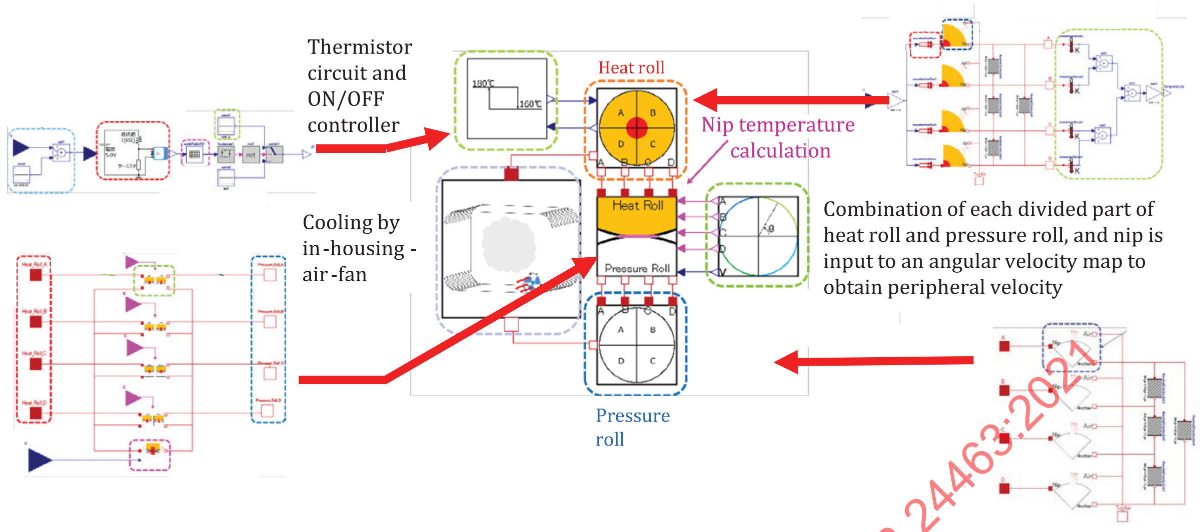


Figure 7 — Heat roll analysis model

Figure 8 shows the analysis results of the heat roller. Power is switched on for the copier, and after the heat roller temperature reaches 160 °C, media conveyance is repeated from the start to the end of the copying operation. The heater power is automatically turned off when the heat roller temperature reaches 180 °C.

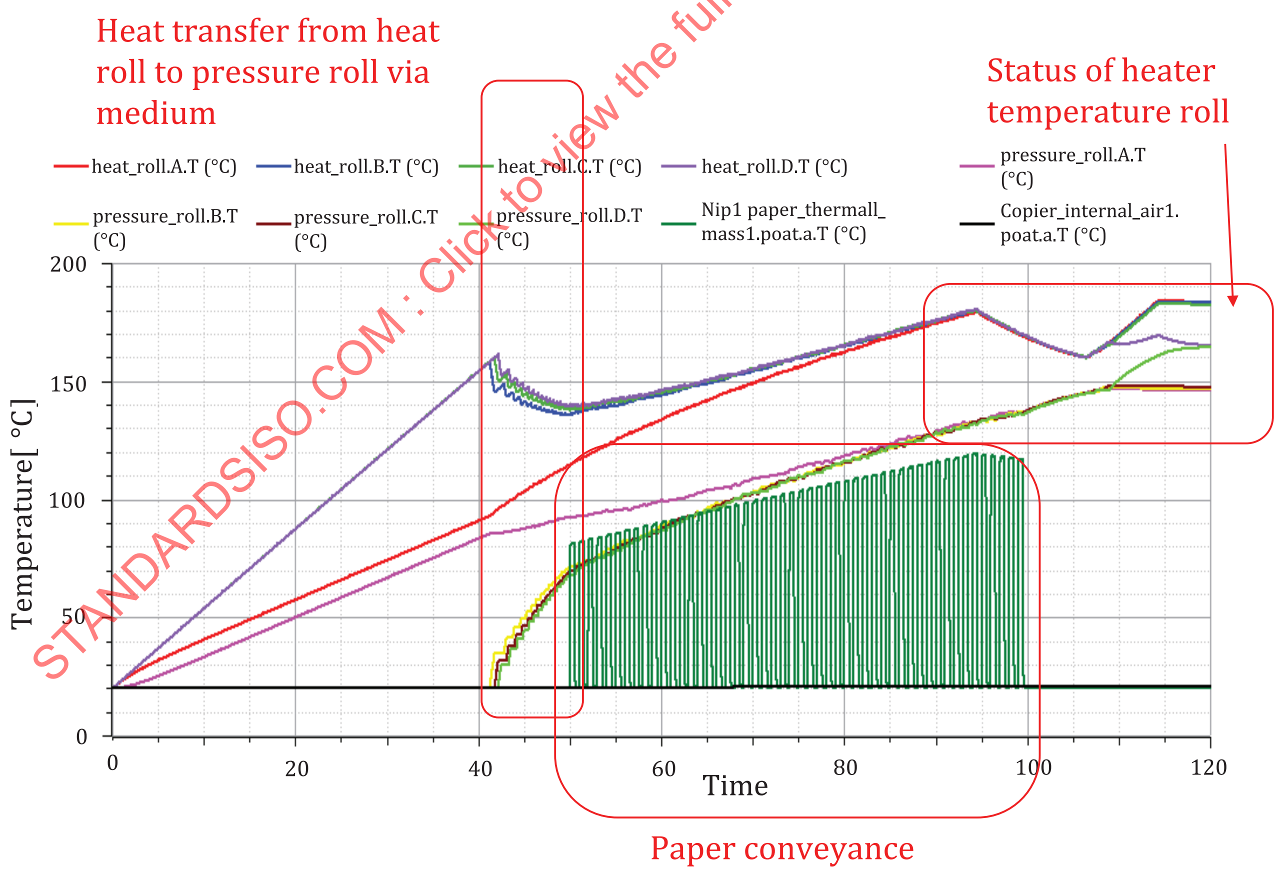


Figure 8 — Analysis result of the heat roller

6.3 Interface between simulations in different technical domains

6.3.1 Introduction to example

A common practice of the development of electrical products centred on analogue control was to first develop a mechanical system, and then to begin the development of the electric/electronic system, control system, and necessary software after confirming the function of the mechanical system. In the development of digitally integrated products, the design of electric/electronic system and software design must proceed at an early stage of product design to advance the development of time-consuming digital circuits. Thus, it has now become common to perform the simultaneous design of a mechanical system, electric/electronic system, and software system in parallel during the product design process.

The design of the mechanical system, electric/electronic system, and software usually use the optimal tools for their respective work, e.g. 1D CAE used in the design of mechanical system uses tools such as Modelica and its derivative tools, and the electric/control design often uses tools such as MATLAB/ Simulink. C or C++ are often used for software development, and SystemC is often used in electric/ electronic design. It is important to share design variables and simulation results between various software tools to advance design work while ensuring mutual cooperation. Therefore, a common interface that can facilitate the exchange of information between simulation models in different technical domains is required.

6.3.2 FMI/FMU-based co-simulations

The FMI/FMU [3] has been tested as a standard to connect 1D CAE models and software components. The expected effect was not obtained in some cases due to some restrictions and issues with FMI/ FMU. An example 1D CAE model for the digitally controlled electrical product has been created with reference to a copier. Computational experiments have been used to clarify the expected problems and mitigations when handling 1D CAE models in different technical domains.

Figure 9 shows a block diagram of the example digitally integrated product. This system comprises a belt conveyor system (unit A), a media sorting system (unit B), and an image processing system (unit C). Media such as paper are conveyed with a belt in unit A and ultimately sorted into two trays using unit B. When media conveyed by the belt pass the image reading sensors GS1 and GS2 in unit C, each sensor reads the two image codes recorded on the media and conducts pattern matching with a pre-defined pattern using image processing. After pattern matching, a signal corresponding to this result is transmitted to unit B, and medium sorting is carried out using a solenoid. Here, the media is sent to “bottom 1” tray if the images at two places on the media coincide with the pre-defined pattern, and the media is sent to “bottom 2” tray otherwise.

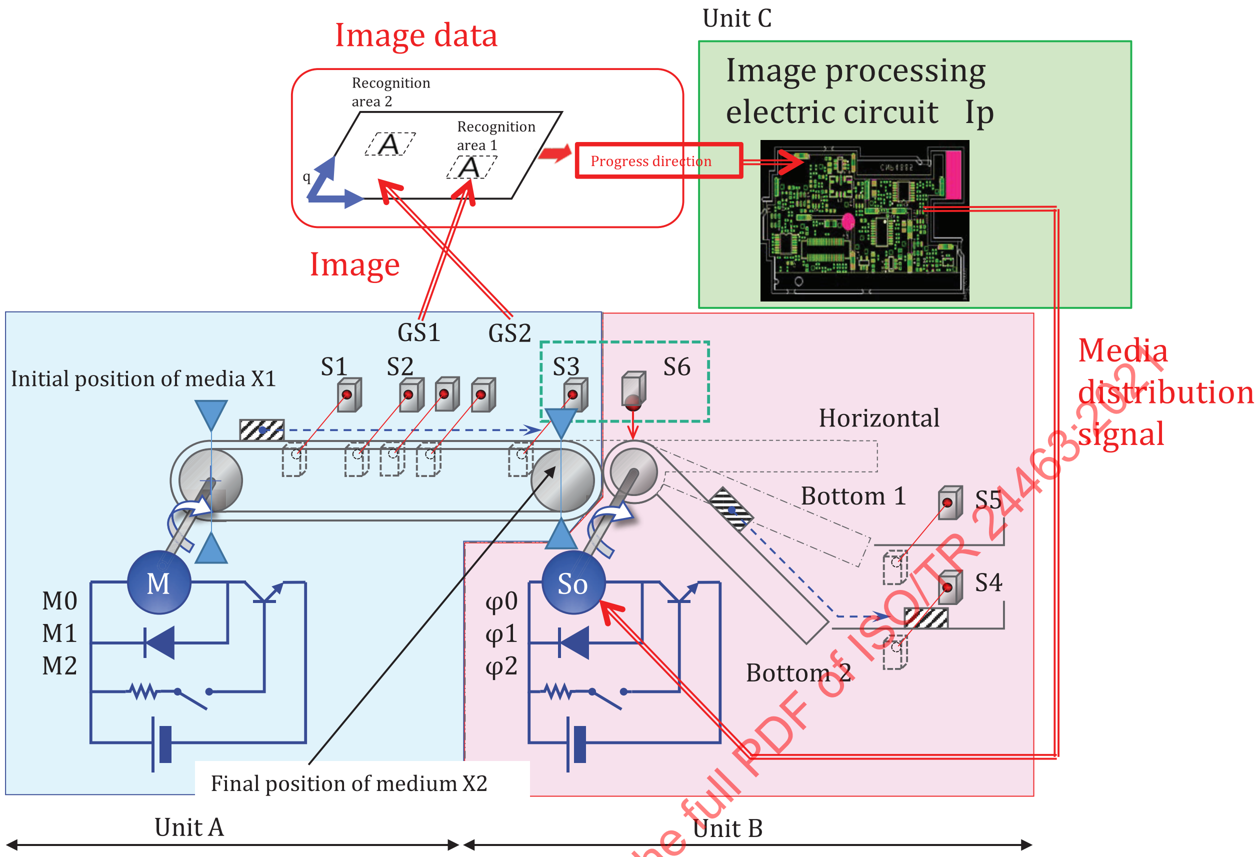


Figure 9 — Specification of a sample digitally integrated product

A 1D CAE model was created for each unit, and the models were executed in parallel; the coupled analysis of the behaviour of the entire mechanism was attempted. Figure 10 shows the developed coupled analysis model. The mechanical system models of units A and B were developed using Modelica. Unit C was written with SystemC, and the model that controls the entire system was written with MATLAB/Simulink. The Modelica and SystemC models were then converted into FMU using FMI, and the resulting units were combined with the 1D CAE model of the control system written in MATLAB/Simulink to achieve a co-simulation of the three units. At present, there is no general-purpose data conversion application which can convert a SystemC model into FMU; therefore, this was performed manually using methods that were researched and developed in Reference [4].

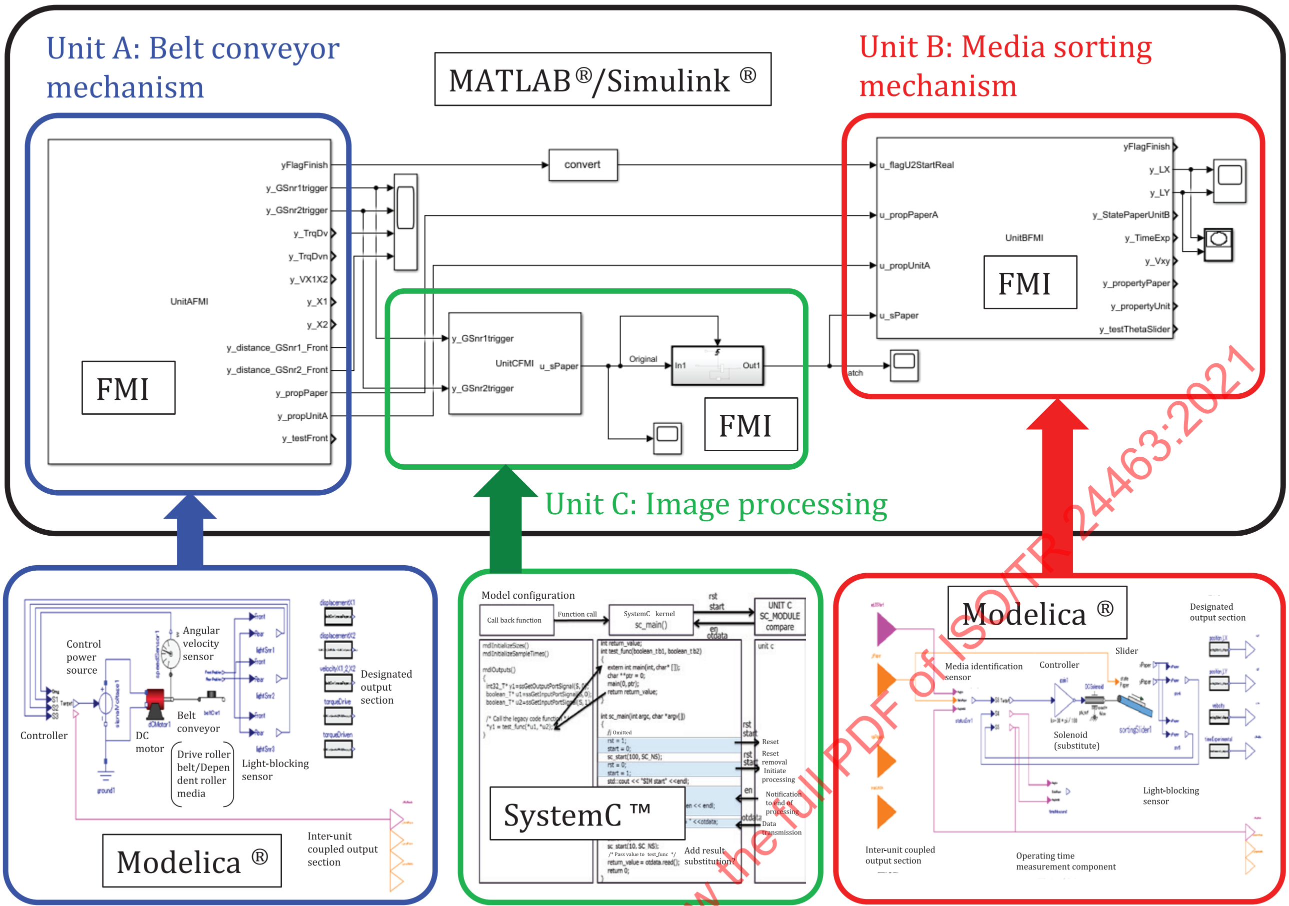


Figure 10 — Co-simulation model of the sample digitally integrated product

Digitally controlled electrical products achieve their functions by exchanging various signals between units. There is a causal relationship in the signals, and often, a given signal input acts as a trigger for initiating the operation of that unit. Figure 11 shows the exchange of parameters between units A, B, and C. The signal input from unit A acts as the trigger for unit C, and the operation of unit B is switched according to the signal from unit C. Therefore, the management of signals that control the unit operation is considered important in the co-simulations of digitally integrated products. The results of this experiment confirm that the FMU of the Modelica and SystemC models were appropriately incorporated into the control system model written using MATLAB/Simulink. As shown in this example, the FMI can be used to achieve co-simulations between models written in different modelling languages while exchanging parameters.

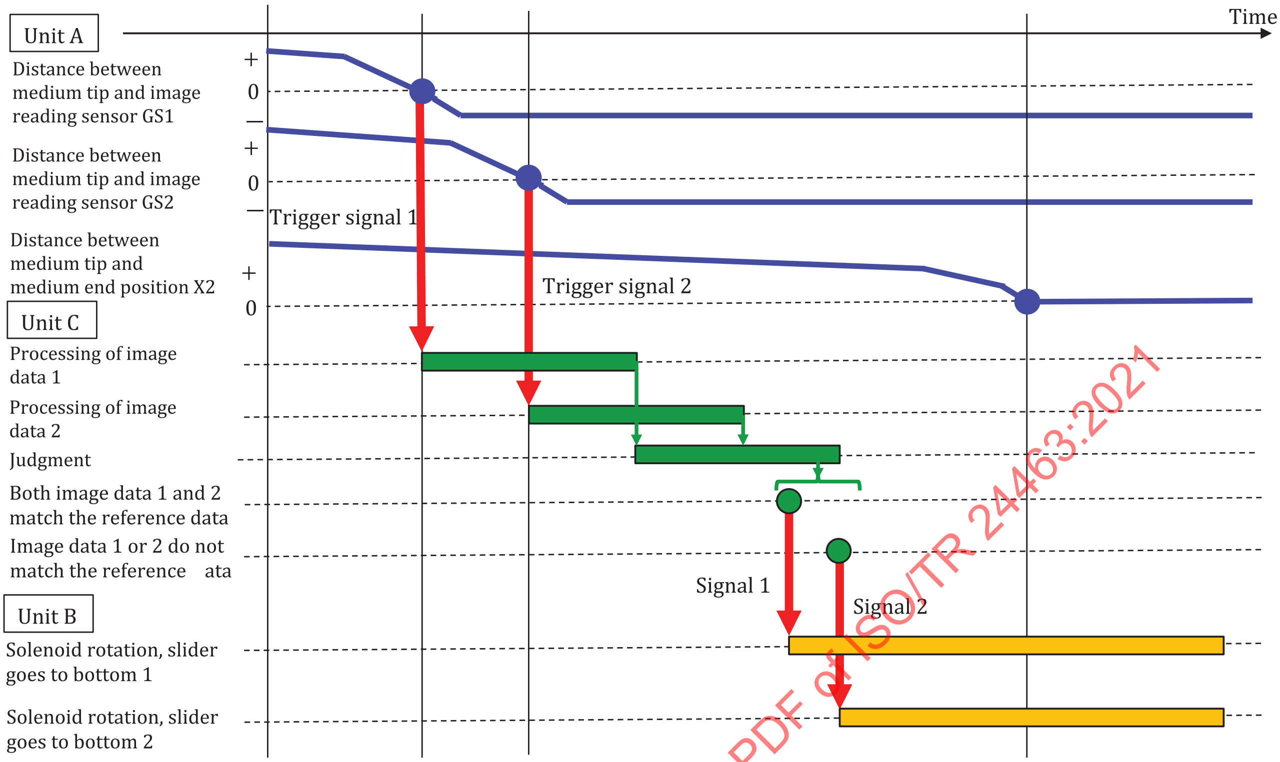


Figure 11 — Parameter exchange in the sample digitally integrated product

6.3.3 Control of simulation time

The control of the simulation time interval, Δt, emerged as an issue when using the developed model to conduct computational experiments. The behaviour and state of the unit at every unit time are required in the analysis of digitally controlled electrical products. This unit time is referred to as the simulation time interval, Δt. To carry out an accurate simulation, it is necessary to set the simulation time interval to an appropriate value for each simulation model. As shown in Figure 12, the operation of the mechanical unit is managed at an interval of 1 s, while image processing is performed by an electric circuit that operates at the chip clock time or at a nanosecond interval. Simulation time can become massive when conducting co-simulations between such models whose simulation time intervals, Δt, vary considerably. For example, the electric/electronic system unit would need to be analysed for 10^9 cycles for each cycle in a mechanical system unit if the simulation time interval, Δt, were set as 1 s.

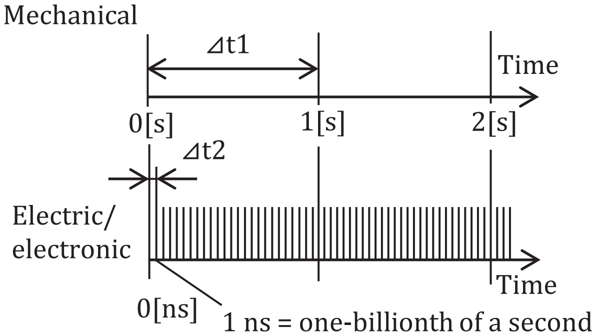


Figure 12 — Control of simulation time, Δt

The issue with controlling simulation time interval, Δt, can be handled using a coordinated function.[4] The co-simulation FMU includes a simulation solver, and it can independently conduct simulations from the start to the end of the transmission; therefore, the simulation time interval, Δt, can be changed for each co-simulation FMU. A common time interval was set up in the entire system, and the optimal time interval in each simulation was set for each FMU. By coordinating the timing of the data exchange between each FMU and the synchronization of the simulation solvers in each FMU, an efficient co-simulation was achieved while maintaining computational accuracy. The system developed here sets the simulation time interval, Δt, in the FMU of SystemC model as 1 ns. The coordinating time interval for the entire system and the simulation time interval, Δt, of the mechanical and electric system units were both set to 1 s. Co-simulations of the different models were conducted using these setups and favourable results were achieved.

6.4 Interface between 1D CAE and 3D CAD/CAE

6.4.1 Introduction to example

In current mechanical design, designers manually create 3D CAD models based on the functional design result and conduct detailed performance analysis using the obtained models and 3D CAE software. Redesign of the basic product function may be necessary depending on the results of the 3D CAE analysis; however, redesign at this stage can cause delays in development and large increases in cost. In order to avoid this kind of rework, it is important to carry out the analysis by 1D CAE and the analysis by 3D CAE concurrently as much as possible, i.e. to ensure that 1D CAE and 3D CAD/CAE representations are in a form that can be coupled (Figure 13).

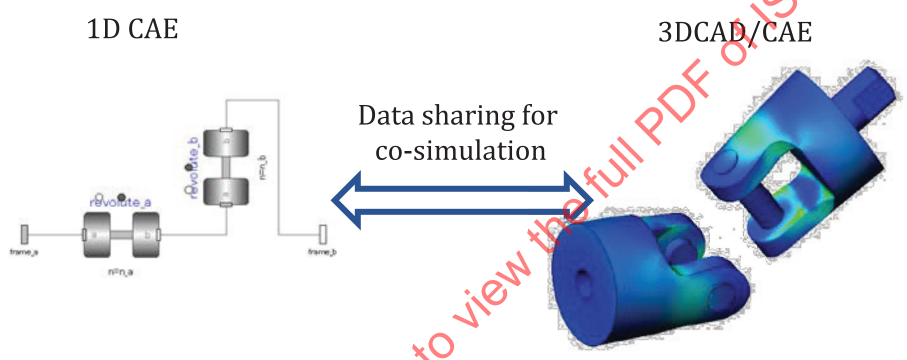


Figure 13 — Co-simulation of 1D CAE and 3D CAE

The two connections shown in Figure 14 are believed to be necessary to couple 1D CAE and 3D CAD/CAE by doing the following:

— Develop a 3D CAD model based on design parameters obtained from 1D CAE and run 3D CAE analysis.

— Modify the 1D CAE model based on the results of 3D CAE analysis.

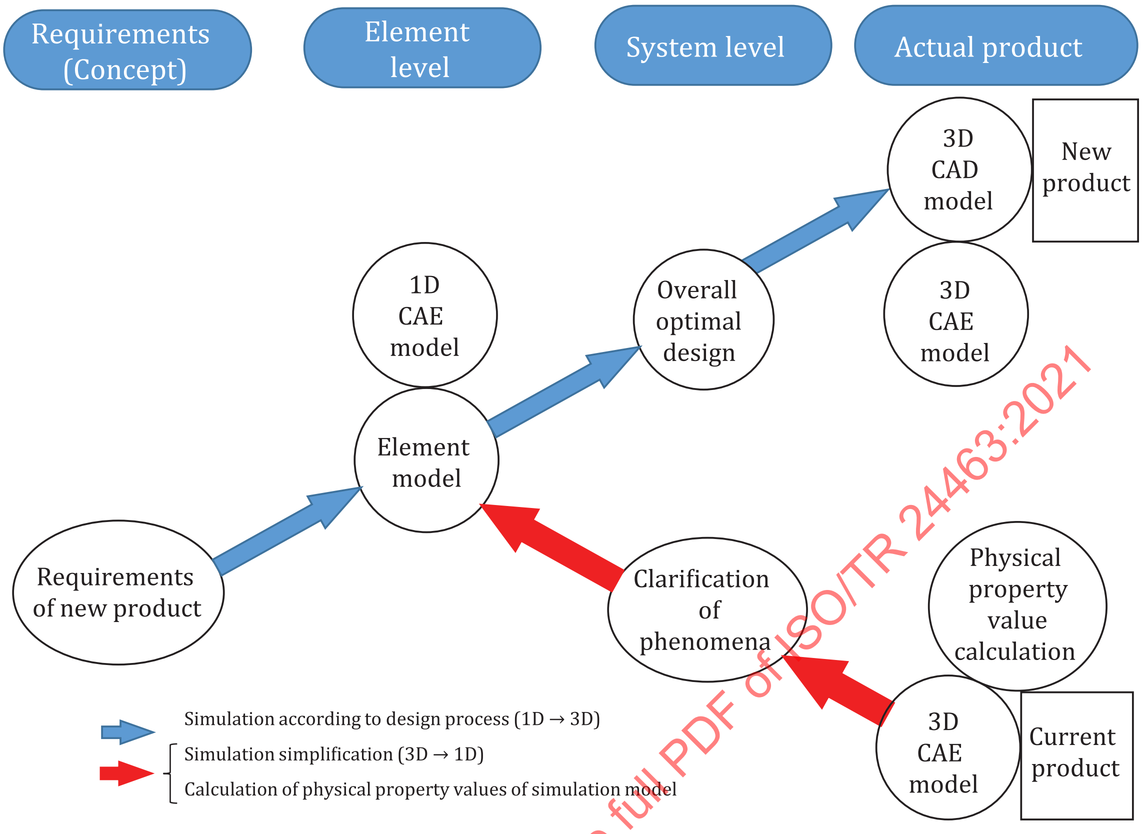


Figure 14 — Coupled information between 1D CAE and 3D CAD/CAE[5]

6.4.2 Realisation of 3D CAD models based on 1D CAE results

A mechanism that adds 3D shape information automatically to a 1D CAE model is required to construct a 3D CAD model based on the analysis results obtained from 1D CAE. It is difficult to achieve this type of mechanism, and currently, designers manually create 3D CAD models that inherit functional design results while referencing the analysis results of 1D CAE.

In the case of a design where the detailed design is driven explicitly by the functional design, for example, only selecting and arranging parts satisfying the design parameters determined in the functional design, or where the part shape is automatically determined when the parameters are given, the 3D CAD model can be automatically or semi-automatically generated based on the result of the 1D CAE, and the 3D CAE analysis work can be started immediately.

As an example of the former, an automatic design method for the copier using the component library shown in Figure 15 can be defined. The media (e.g. paper) conveyor pathway and operation are determined during the functional design of the copier. A 2D CAD software is used to create a conveyor pathway model, and these data are incorporated into a 1D CAE software. The media conveyor operation is then analysed using a 1D CAE simulation and the placement of primary mechanical units (e.g. conveyor belts, fixing unit) is determined. 3D CAD models of the primary mechanical units are registered in the library in advance as standard parts, and therefore, a 3D CAD model of the main part of the product can be completed after determining the placement and orientation of each unit by calling the corresponding models from the library and placing them. After that, the fixing method of the parts can be decided, and further, the detailed design of the product can be finalised by arranging the cover part and harness so as not to mutually interfere.

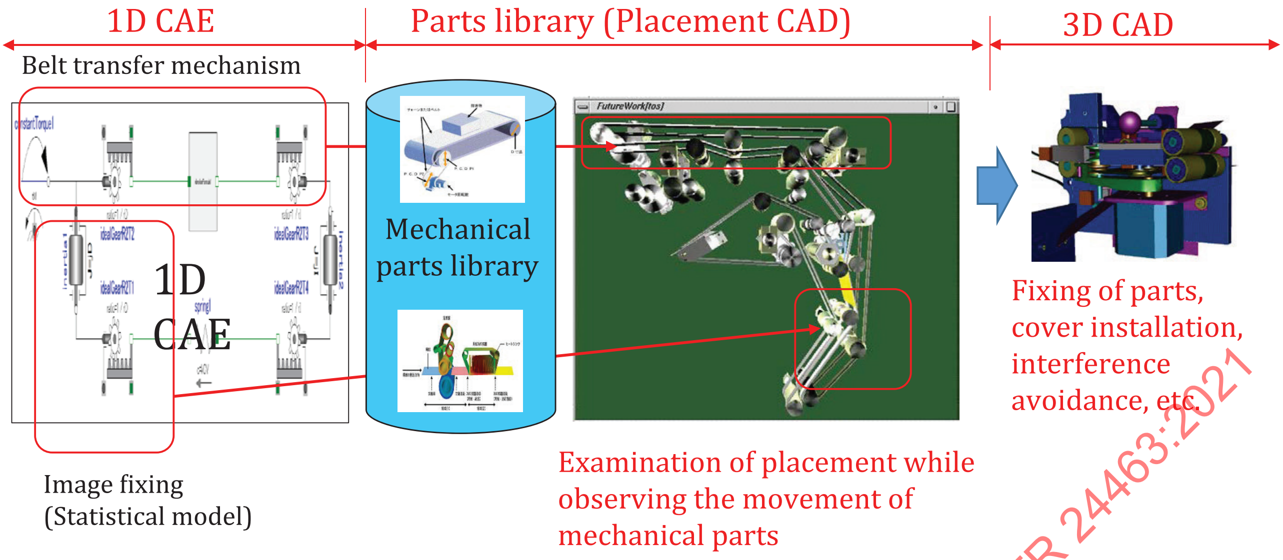


Figure 15 — Automatic generation of 3D CAD models using part library

A template-based motor/generator design tool is introduced as an example of the latter, where the 3D shape of the product is directly created based on design parameters obtained from 1D CAE. Here, a template is a type of parametric CAD model where a 3D CAD model can be created by following a determined procedure and inputting parameter values from a computer screen. A motor/generator design tool developed using ANSYS RMxprt is shown in Figure 16 as an example of this technology.[6] Basic parameters such as “Operation Type,” “Load Type,” “Rated Output Power,” “Rated Voltage,” “Rated Speed,” and “Operating Temperature”, and analytical motor theory and equivalent magnetic circuit methods are used to create a 1D CAE model of the motor/generator. A 3D CAD model of the initial shape of the motor/generator is created after conducting several hundred rounds of what-if analyses, determining parameter values, and inputting them into a template. A detailed electromagnetic field analysis is conducted using this model and ANSYS Maxwell. The shape of the motor/generator is further refined based on these results.

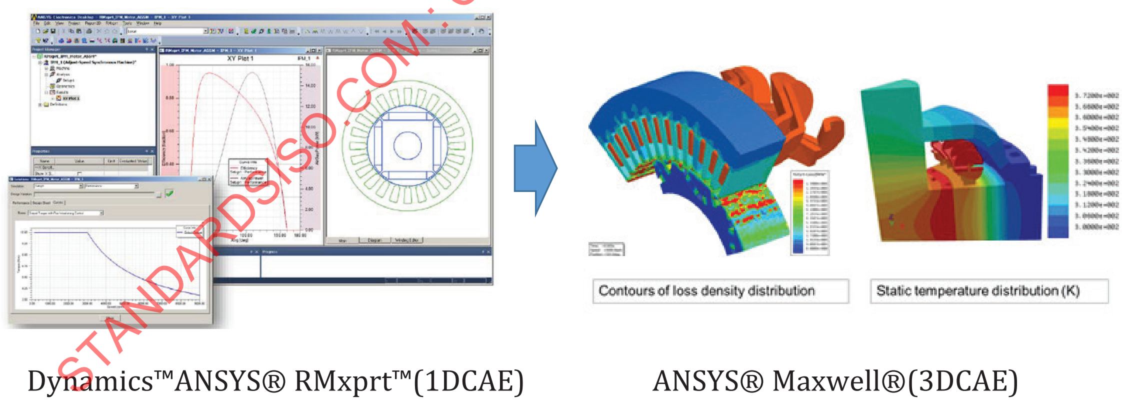


Figure 16 — Template-based motor/generator design tool

6.4.3 Modification of 1D CAE model based on 3D CAE results

In the development of digitally integrated products, work often starts with the improvement of existing products. In such cases, the behaviour of the existing product is analysed, its characteristics are understood, and properties of the product to be improved are selected. In the case of existing products, 3D CAD models or analysis models for 3D CAE often already exist. Analysis based on 3D CAE usually requires a large amount of time due to the level of detail in the model, and therefore, it is difficult to understand the characteristics of a product using these models as they are. Thus, attempts have been made to introduce efficiency in the improvement design process by creating a 1D CAE model from 3D CAD/CAE models and by using these to repeat performance analyses. The model conversion in which a 1D CAE simulation model is created from a 3D CAE simulation model is referred to as "reverse 1D CAE".[5] Reverse 1D CAE uses a reduced order model (ROM) technology, which reduces the degrees of freedom in a computational model and renders it easier to handle.

The effects of ROM technology are explained via an example of a heating ventilation and air conditioning (HVAC) design in an aircraft, as shown in Figure 17.[7] In the unsteady analysis of the heat flow for HVAC design, the temperature and flow velocity of the air conditioning outlet are specified. The flow velocity, temperature, and predicted mean vote (PMV) distributions in the aircraft are simulated using finite element analysis. This analysis requires handling highly nonlinear phenomena such as airflow separation, sunlight, humidity, radiation, and natural convection, and therefore, a large-scale mesh is required for achieving high-accuracy simulation. Therefore, even a 20-core computer required 48 h to conduct simulations based on the 3D CAE model shown in Figure 17. Use of 3D CAE for investigating such design proposals is not realistic.

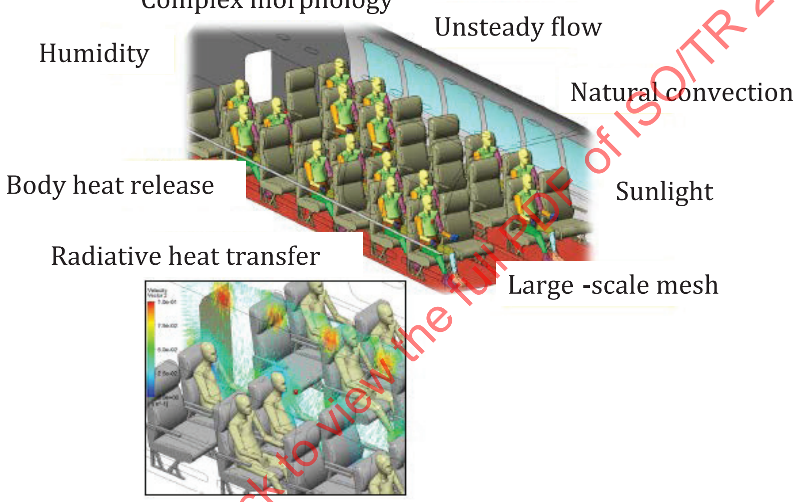


Figure 17 — HVAC design inside aircraft

ROM processing can be conducted with machine learning. A simulation model for 1D CAE can be created using a dataset that combines 3D CAE models and analysis results if software such as ANSYS Twin Builder is used.[8] Learning was conducted in this example using six types of datasets that changed the input conditions and output ranges. The results of the unsteady analysis of heat flow in the aircraft obtained using the 1D CAE model showed a strong match with the analysis results from 3D CAE software. These can be said to be sufficiently reliable results. The simulation completes within a few seconds when a 1D CAE model is used, and therefore various design proposals can be investigated.

There has been ongoing research on methods that evaluate the reliability of 1D CAE models created from 3D CAE models using the law of conservation of energy.[9] Numerous nonmachine-learning-based methods that convert 3D CAE simulation models into 1D CAE simulation methods while maintaining the characteristics of the former have been proposed. The known examples include the “response surface method,” which replaces the relationship between the 3D CAE model (input) and simulation results (output) with an approximate or empirical equation, and the “mass property method,” which replaces the characteristics of the 3D CAD model with characteristic values such as mass, rigidity, volume, and surface area [10].

6.5 Interface between original equipment manufacturer (OEM) and supplier

6.5.1 Introduction to example

Various documents related to 1D CAE simulations are drafted during the design process of digitally integrated products including product specifications, work reports, used material tables (e.g. physical property values), experimental reports, simulation results, and change notifications. The 1D CAE model is usually managed using a product data management (PDM) system. Other documents are managed with methods that are different from those for the models. There is no standard method, and independent methods are often employed in each company. The 1D CAE model changes multiple times during the product development process. The associated documents need to be manually updated with each model change, leading to potential inconsistency in the information for analysis engineers and designers. New documents related to the 1D CAE model need to be sent from the supplier to the OEM each time a design is changed when a product is developed in collaboration with multiple companies (Figure 18). Coordinating a product lifecycle management (PLM) or document management system between different companies is difficult from an information security perspective, and currently, accurate and secure sharing and managing of 1D CAE models and documents between multiple companies is a major source of potential errors.

Several methods have been proposed for sharing and managing documents where the analysis model and associated technical information are recorded. For example, ISO 10303-243 (MoSSEC) [19] and SmartSE [11] initiatives are well known in the aerospace and automobile production industries, respectively. In these methods, the product development process is specific to the target product (aircrafts and automobiles), and the technical information exchanged between companies is limited to specific contents. Across the entire range of digitally integrated products, there is a great variation of product development processes and exchanged information. Therefore, it is difficult to constrain the managed information, and thus, there is a demand for methods that are more flexible than existing technology.

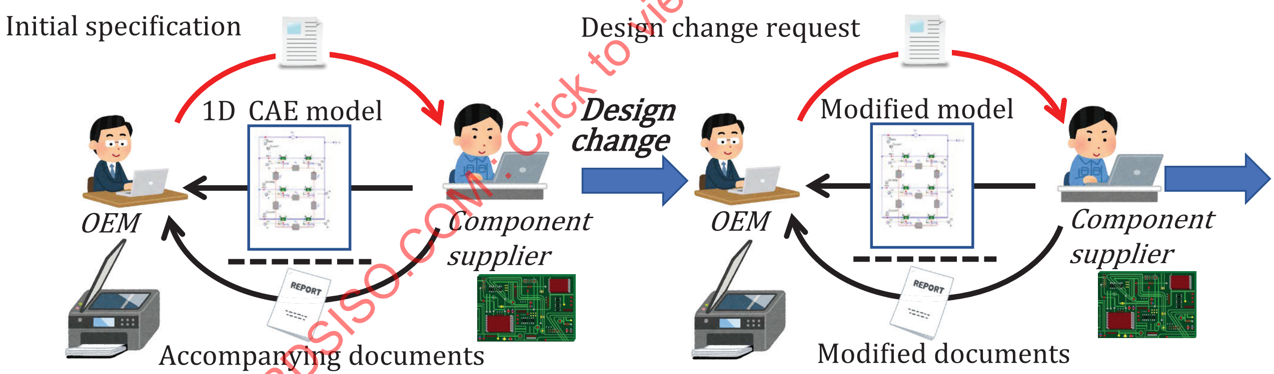


Figure 18 — Typical model exchange process in the joint development with OEM and supplier

6.5.2 Multi-enterprise modelling

Here, appropriate management methods for the 1D CAE model and documents are examined for the collaborative development of digitally integrated products such as the copier shown in Figure 19, and Figure 20 shows a collaborative development process of this product. It is assumed in this scenario that the OEM is in charge of overall product management and mechanical design, supplier A is in charge of electrical design, and supplier B is in charge of software design, respectively. In the functional design of this product, it is necessary to progress mechanical design, electrical design, and software design in each company, while the information of the media conveyor pathways and the media conveying method are shared by three companies.

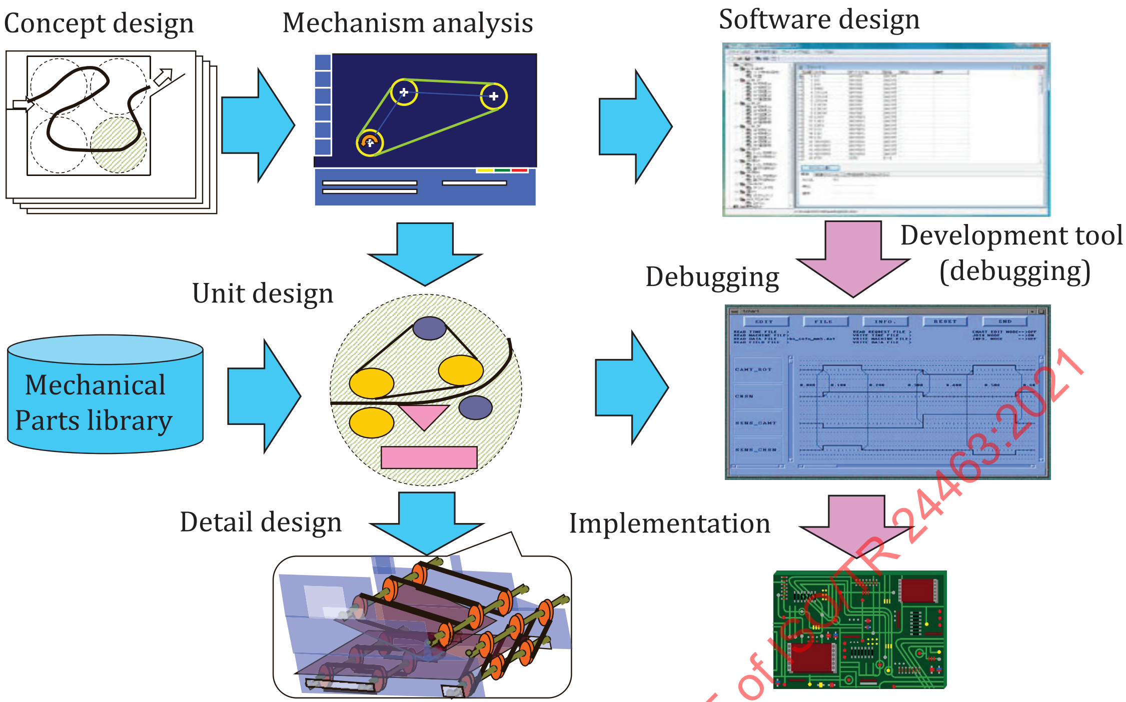


Figure 19 — Development process of digitally integrated products

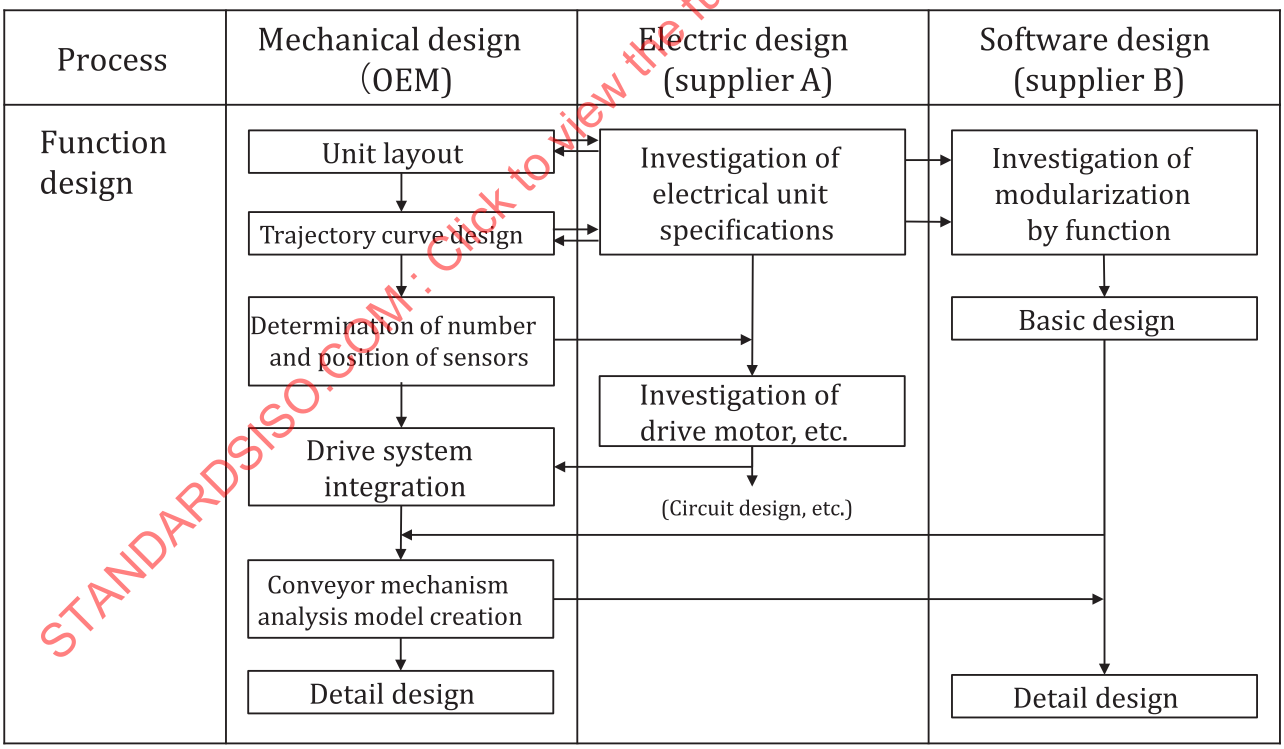


Figure 20 — Development process of digitally integrated products

The conveyor pathway and movement of the conveyed media in the mechanical design are expressed with a CAD model and 1D CAE model, respectively. Meanwhile, the physical property values, points of caution related to the model use, and other work information are recorded in a document. In the electrical design, the 1D CAE model that expressed the movement of media is incorporated into the analysis software of the electric system, the drive torque is calculated, and a drive circuit is determined.