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GENERAL-PURPOSE M&S (MODELING & SIMULATION) SYSTEM UNDER THE USER EXPERIENCE OF SME USERS

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Abstract. *In this paper, we propose a general-purpose modeling and simulation (M&S) system that lets small and medium-sized enterprise (SME) users simulate product characteristics easily. The main structure of the platform and the cooperative workflow process between each pair of application modules are proposed. The challenges for implementing a general-purpose M&S system for SMEs are discussed. Moreover, integration with a kind of workflow and easily FEM/CFD analysis method is presented.*
Keywords: Small and medium-sized enterprise (SME), User experience, Finite element method (FEM), Computational fluid dynamics (CFD), Workflow

1. **Introduction.** In Korea, small and medium-sized enterprises (SMEs) are defined as those that have fewer than 300 staff, and assets less than $US 4.7 million. Data supplied by the government of Korea, show more than 3 million small and medium-sized enterprises in Korea. Individually, these numerous SMEs earn little money and attract few people, and each has a small share of the huge market. They have neither famous brands nor distinctive design.

Nonetheless, because of their large numbers and diversity of specializations, SMEs constitute a significant part of the Korean manufacturing industry. They strongly contribute to accelerating the growth of the GDP, provide employment and help to optimize economic structure. Many SMEs lack the ability to perform research and development of product design and simulation. To upgrade the competitiveness of SMEs, a state-of-the-art IT technique is required.

Most existing SMEs primarily focus on improving product quality; they also create demand for expanded IT capacity, because hundreds of simulations may be required to predict product responses over the full range of expected real world operation. To meet these requirements, an M&S system is a critical component of an effective IT environment for simulation [1,2].

Despite the importance of computer simulation in engineering product design, SME often has difficulty using the software (SW), because it has a difficult user interface, and lacks an adaptation model and automatic method. The programs are too complex for novices and casual users such as industry workers to learn and use for their purposes.

Also, the licenses of existing M&S software allow users to run it only on specified allowed computers. The pre-processing and post-processing programs are fully hard-coded and tightly coupled with a corresponding commercial simulation tool; an example is the coupling of Abaqus with Abaqus CAE. Users must independently manage and learn many simulation processes.

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Engineering is a field that provides solutions for many other fields. Engineers use their knowledge of fields such as science, mathematics, logic, and economics, and then combine this knowledge with appropriate experience or tacit knowledge to find suitable solutions to a problem. Computers and software are increasingly important in this process. If the software and techniques used in engineering are costly, then the solutions that they produce are also costly. The use of open-source SW is an efficient approach to obtaining cheap solutions for low-budget fields; such SW is also easy to update and free to distribute [3]. We use quality function deployment (QFD) analysis to identify the user requirements and technical requirements of SMEs. To design the M&S system architecture for easy and accurate simulations under the user experience of SME users, some requirements must be met [4]. First, to get the maximum level of automation, the solution must support automatic geometry healing and automatic surface contact. Second, a workflow approach based on based orchestration can reduce the time that users must spend to managing simulation details such as meshing, healing, contacting, and establishing boundary conditions over different simulation problems.

Workflow technology and process support lies at the center of modern information systems architectures [5]. Workflow can be defined as a representation of the operational aspect of a work procedure: (i) the structure of tasks and the application and humans that perform them; (ii) the order of task invocation; (iii) task synchronization and the information flow to support the tasks.

Recently, by combining technologies such as workflow, a new simulation system has been proposed. Our proposed system is a new integrated M&S system mode that utilizes workflow, a healing CAD model and automatic contact detection to provide easy and accurate simulation services according to the SME customer's demand.

The proposed approach brings easy and accurate simulation to the system for SME users. The workflow services facilitate cooperation among user and among M&S simulation services. The proposed approach allows users to conduct simulations of the workflow, to heal the CAD model and to detect contact automatically. The users can choose the appropriate service to solve his problem. The user can also simulate problems easily and accurately. The rest of this paper is organized as follows. Section 2 explains SME user's requirements analysis for developing M&S system. Section 3 explains the proposed service. Section 4 explains HEMOS, which is an application prototype of the proposed M&S system. Section 5 presents a usability study of the proposed system. Section 6 concludes with some remarks.

2. SMEs Requirements Analysis for Developing M&S System.

The proposed M&S simulation system is intended to bridge the gap between system-requirement engineering and software design. We interviewed and observed 450 SME users, and found that some of them do not have an M&S system. Furthermore, some SMEs who have been running an original manufacturing business (such as OEM), and who want to enhance their business and obtain core technologies, do not have sufficient knowledge in developing and using M&S system that is suitable to develop the core technologies model.

The purpose of this chapter is to identify the user requirements and technical requirements. These requirements are part of the quality function deployment (QFD) analysis, as applied to manufacturing SMEs. The research method begins by collecting user requirements, then using QFD to analyze them. This QFD yields an interaction matrix (Table 1) which is the core of the QFD method. QFD is performed by connecting the product's attributes (project objectives) with its technical parameters. The relationship is then evaluated for each cell of the matrix, and the relationships are classified as strong, weak or absent.

Calculation of the matrix interaction stage detects technical characteristics that have a score > 100; these are tabulated separately (Table 2).

Table 1. QFD matrix about requirements

Objectives	**Engineering Characteristics (Technical Parameter)**															
	Healing CAD Model	Ribbon/Dynamic Menus Interface	Modal Frequencies Analysis	Thermal Analysis	Static Stress Analysis	Workflow Based Interface	Fatigue Analysis	Particle Analysis	Explicit Dynamics	Incompressible Flow	Heat Transfer	Compressible Flow	Multiphase Flow	Non-Linear Contact Analysis	Mesh Generation	Automatic Contact Detection
M&S SW for easy use	98	88	24	25	32	99	3	1	1	45	1	1	11	23	65	99
M&S SW for solving mechanical structural analysis	99	78	86	88	99	98	2	12	12	56	23	5	5	98	98	97
M&S SW for solving mechanical fluid analysis	78	85	43	89	78	99	1	4	5	87	87	8	2	45	98	87
Scores	**275**	**251**	**153**	**202**	**209**	**296**	**6**	**17**	**18**	**188**	**111**	**14**	**18**	**166**	**261**	**283**
Percent	**11.14**	**10.17**	**6.2**	**8.18**	**8.47**	**11.54**	**0.23**	**0.66**	**0.7**	**7.33**	**4.33**	**0.55**	**0.7**	**6.47**	**10.17**	**11.03**

Table 2. SMEs requirements analysis for developing M&S system

Engineering Characteristics (Technical Parameters)	Sum Scores	Priority (%)
Workflow Based Interface	296	11.54
Healing CAD Model	275	11.14
Automatic Contact Detection	283	11.03
Mesh Generation	261	10.17
Ribbon/Dynamic Menus Interface	251	10.17
Static Stress Analysis	209	8.47
Thermal Analysis	202	8.18
Incompressible Flow	188	7.33
Non-Linear Contact Analysis	166	6.47
Modal Frequencies Analysis	153	6.2
Heat Transfer	111	4.33

Our proposed system is a new integrated M&S system to provide easy and accurate simulation service according to the SME customers' requirements.

3. Proposed General-Purpose M&S System for SMEs.

The proposed M&S system (Figure 1) can be divided into four layers.

3.1. Workflow model layer.

This layer analyzes the business requirements of the user, and then defines the appropriate workflow process. Therefore, the users can call different service modules to respond to different problem requirements. Then we define and generate the workflow process (Figure 2) according to the SME user's experiences.

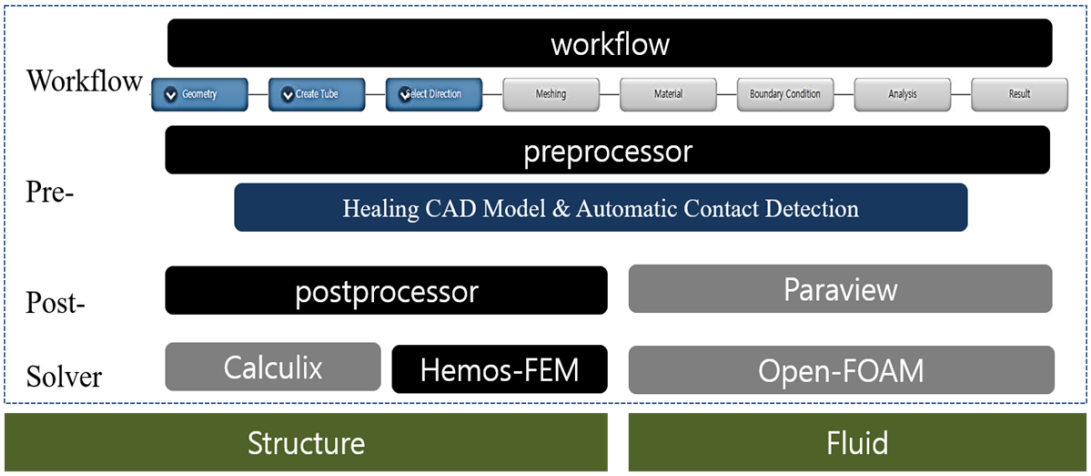

FIGURE 1. Proposed system architecture

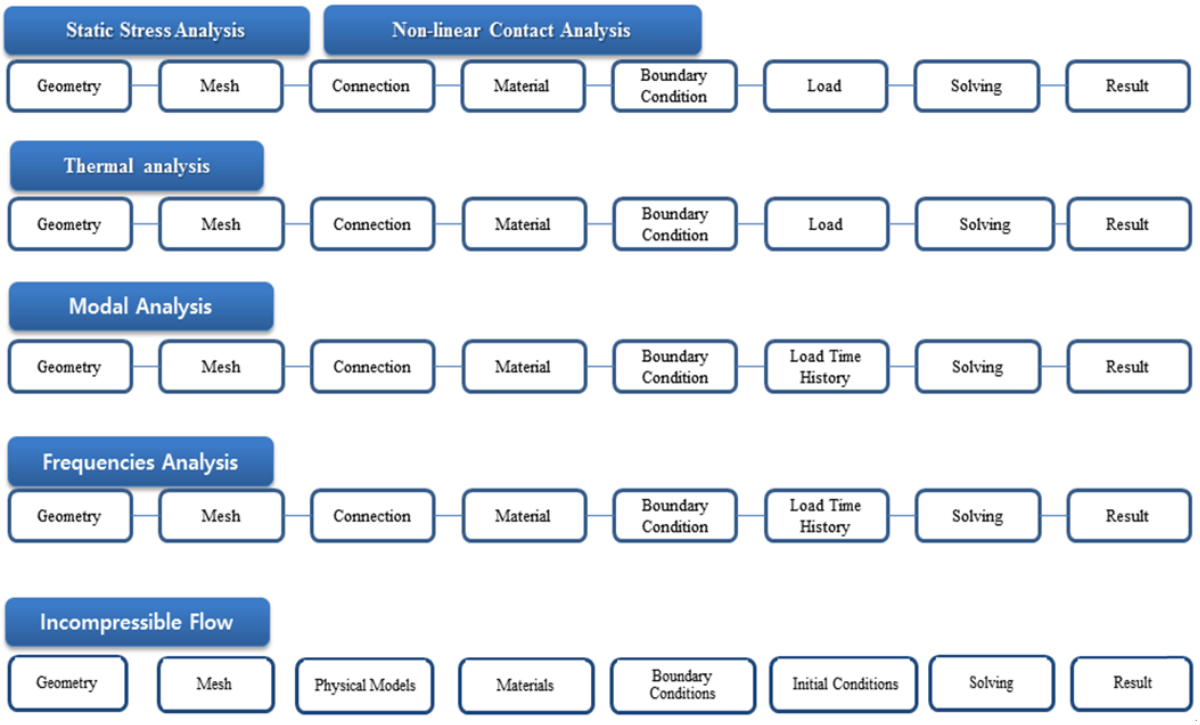

FIGURE 2. Defined and generated workflow list for M&S system

3.2. **Pre layer.** This layer must design and realize the function of easy and accurate simulation. CAD processing is modeling of 3D surfaces and solids. The most widely used open-source CAD system uses OpenCASCADE [6] technology. The mesh generation step represents an engineering digital product by using algorithms from the MeshGems [7] library to generate hexagonal, tetragonal, and hybrid meshes from model standard STEP, IGES and CAD data.

The finite element method (FEM) of computational fluid dynamics (CFD) has become the most used approach to simulating mechanical behaviour. To accelerate those analysis loops, a healing CAD model is necessary [10]. The automatic healing step simplifies the CAD model geometry by finding regions (flipped normal, duplicated faces, duplicated points, folds on surface, self-intersections) and eliminating details (holes, gaps, t-joints, sliver) and faces.

Stress analysis on an assembly requires that the used carefully ensure that the interactions between parts are represented accurately. In simulation, this is referred to as contact;

it is critical for accurate results. Contact is also one of the most frequently misunderstood areas of analysis. To accelerate and correct this analysis loop [11], an automatic method to detect contacts is necessary. The automatic contact detection method consists of performing parallel-based decomposition, grouping elements, extracting parameters, and calculating surface regions.

3.3. **Solver layer.** The FEM analysis engine consults standard STEP, IGES and CAD data to analyze engineering digital product service by using Calculix [8] to apply thermal, contact, and linear analysis algorithms.

The Hemos FEM engine is based on a multi-frontal method. We have developed multi-front solution based modeling & simulation software that can use a supercomputer to perform the thermal/structural analysis that is required for product design. We applied this engine to industrial technology support to reducing product design cost and to improving product quality.

The fluid analysis engine consults standard STEP, IGES and CAD data to analyze engineering digital product service by using OpenFOAM [9] solver to run incompressible flow algorithms.

3.4. **Post layer.** The post layers manage post-processing of 3D elements (CAD, mesh, analysis result). These layers generate views of the shared FEM, CFD digital product model and generate adaptive views that consider the OS context and user preferences.

4. **HEMOS: An Application Prototype of the Proposed System.** The workflow is illustrated using an example of analysis of contact during tube insertion and removal, and uses the HEMOS workflow (Figure 3). This research performs the whole process from using CAD software to prepare the assembly model to visualizing the result.

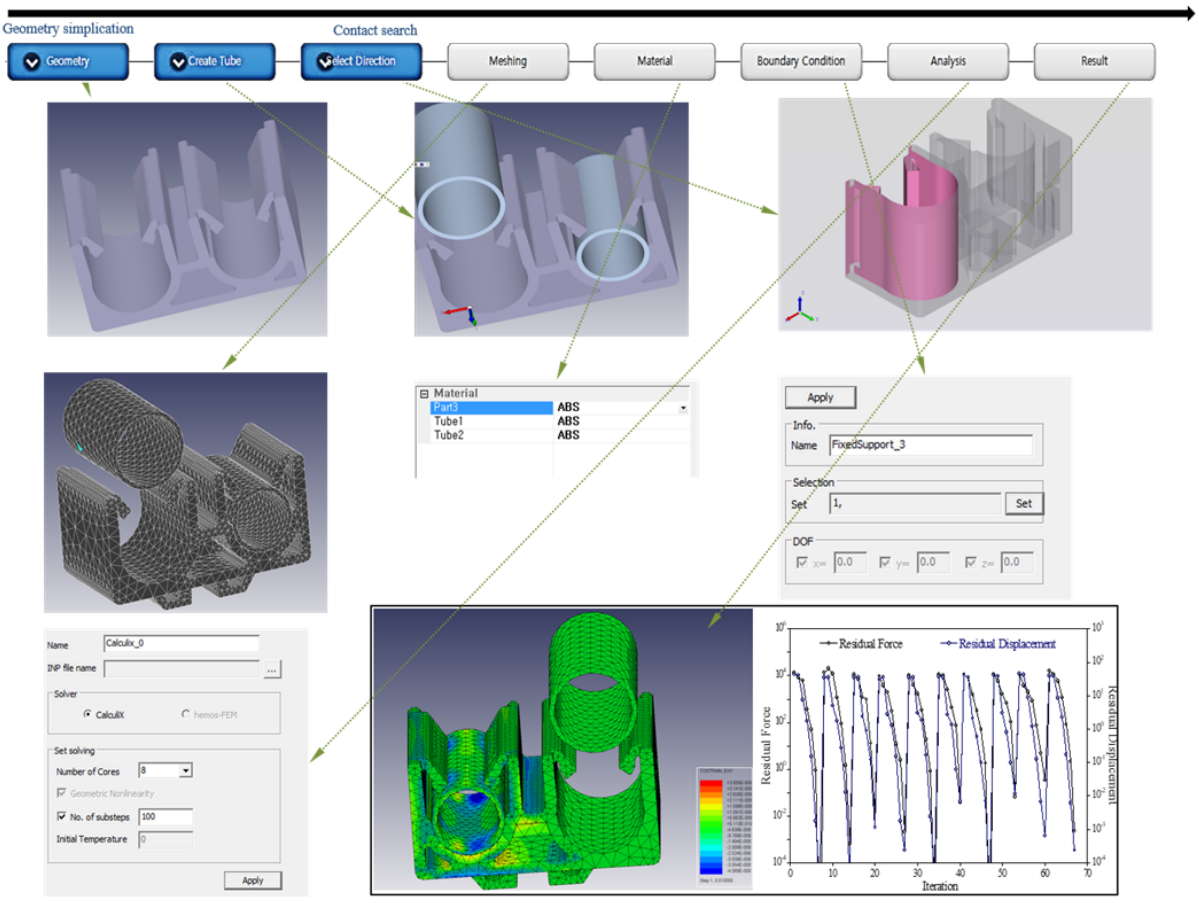

FIGURE 3. Implementation of HEMOS

Our system supports standard CAD formats such as STEP or IGES. The part that is to be analyzed is exported to a supported file type, and then uploaded to the system. The user can review the design model by using 3D mode.

Our system runs a healing CAD model to simplify the geometry of the model, then automatically decomposes it to a solid model and searches for contact surfaces. The user sets material characteristics for physical simulation.

The FEM/CFD calculations require a subdivision of the part into separate elements. This happens during the mesh generation process. One of the automated meshing procedures is used to quickly and efficiently generate a mesh for the model. Then the user sets the simulation's boundary condition parameters.

Our system updates the user about the progress of the simulation. For transient simulations, the user can access intermediate results while the simulation is running. Once the simulation has finished, 3D visualizations can be used to analyze the results.

5. **Usability Study.** To investigate the usefulness and quality of the proposed system, we performed a quantitative usability study, which ensures that participants can complete the intended tasks effectively; the proposed approach was then compared with a well-known commercial SW named Abaqus [12]. Thirteen SME users were asked to perform certain tasks and then to complete questionnaires to measure the easy-of-use of the SW, and the accuracy of the result.

The SME users were given a short introduction, and then performed several tasks (Table 3). Then the users answered several questions (Table 4). All responses were scored on a five-point scale, and each question included a field in which the user could add comments. The analysis suggests that the proposed M&S system provides an interface that is easier and more intuitive than the Abaqus interface (Figure 4). Most of the participants also stated that the workflow, adaptation of the CAD model, and contact search gave more effective and accurate FEM/CFD analysis in various user experiences.

Table 3. Tasks for usability study

No.	
1	Execute linear static analysis
2	Execute non-linear contact analysis
3	Execute thermal analysis

Table 4. Questionnaires for usability study

Easy-of-Use	
1	Automatic contact detection
2	Simulation given problems using workflow
3	Healing CAD model
Accuracy	
1	Displacement result
2	Principal stress result
3	Stress result

The proposed approach was easier to use than other approaches such as contact search, workflow based problem oriented interface. Finally, the usability study indicated that the trend of displacement, principal stress and stress of the proposed system were similar to those of Abaqus.

To investigate the usefulness and quality of the proposed approach, it was compared with Abaqus that uses an element model (Table 5). The proposed system and Abaqus had similar accuracy (Table 6).

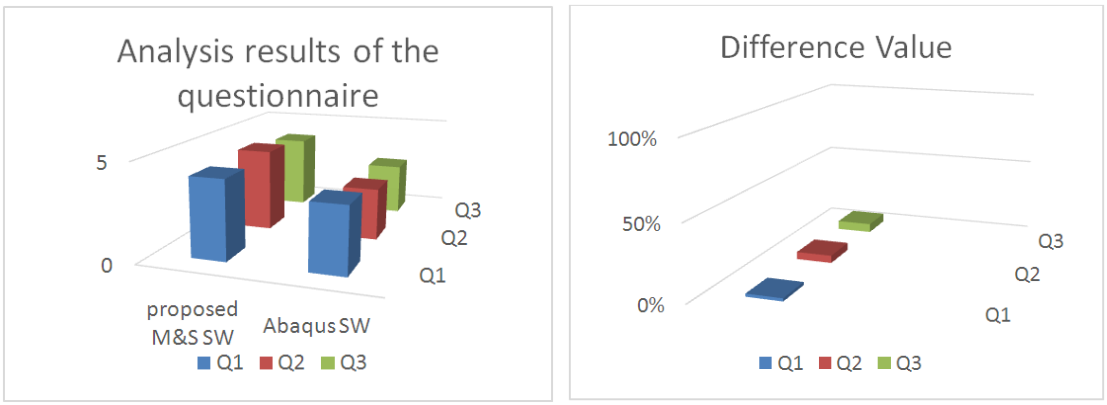

FIGURE 4. Analysis results of the questionnaire

TABLE 5. Validation model

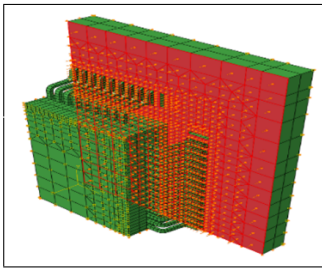	Elements	Tetrahedral: 4121 Hexahedral: 3456 Wedge: 665
	Loads	Temperature Heat Flux Gravity Concentrated Load

TABLE 6. Relative error (%)

Steady-State Heat Transfer		Transient Heat Transfer	
Temperature	Displacement	Temperature	Displacement
0	0.96	0.6	2.12

6. **Conclusions.** This paper presents a general-purpose M&S system that SMEs can use for easy and accurate FEM/CFD simulation. Our proposed system is a new integrated M&S model that uses the workflow, a healing CAD model and automatic contact detection to provide easy and accurate simulation according to the SME customer's demand. For future work, we are improving the M&S system, making it capable of analyzing a variety of product engineering designs, and able to use a cloud platform to share simulations among SME users.

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