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Design in Face-shovel Hydraulic Excavator Based on Question-answer Drive

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Abstract: For the process modeling of complex product, a methodology of an iterative question driven simulation process is introduced. In which, the design process model is capable to describe problem statements, model specifications, simulation models and problem answers as separate objects. This enables a granularity level of information that allows traceability on an object-to-object level between the attributes in the requirements specification and the estimated product properties. This also offers a traceability and reuse of partial result created during the verification of a specific requirements attribute as well as a possibility to study the effects that changes in the requirements specification have on product properties. A methodology for an iterative question driven simulation process using this design process model has been illustrated in a modeling and simulation scenario of a working unit in a large hydraulic excavators from Taiyuan Heavy Industry Co.,Ltd. Based on an iterative question-answer driven process, the best design plan of hinge points is chosen from 5120 different attachment hinge points' designs and the traceability from the establishment of the requirement specification to the draft process of the decision basis is realized. It showed that the question-answer driven method is a valid method, could meet the design requirement.

Key words: Question-answer driven, optimization design, behavior model, requirement specification

INTRODUCTION

Process modeling is the primary problem in the research and application of the product development process. And the process model is a formalization description of the inherent discipline in the product development process which can reflect the essence of the product design and development process. Design process of complex products, is actually an iterative process of seeking the answers to the product requirement. In the iteration process, according to the product function and the user requirement, it decomposes requirements specification and establishes behavior models and simulation models, further refines the requirements specification and finally gets the design which meets task needs. Thus, in the whole product design process, it is crucial to detail requirements specifications and realize the traceability of the demand.

Malmqvist (2001) used the chromosome product model raised by Andreasen (1992) as the foundation, discussed a model that requirements drive products and process, put forward that the information granularity level of demand management system is the important parameter to determine the system has traceability or not. This kind of the information granularity level can be either the object granularity or the document granularity and it points out that three types of traceability can be supported in the requirement management system, document-to-document, object-to-document and object-to-object.

Almefelt *et al*. (2003) researched the requirement management system in the automobile industry application. It found that the requirements traceability is more complex and uncertain than the requirements management. In order to ensure the traceability of information, Sutinen *et al* (2000) put forward three methods:

- Traceability tables
- traceability lists
- Automated traceability links

This article takes the simulation optimization of a large face-shovel hydraulic excavator working device as an example, it completes the optimal selection of the 5120 different work device hinge points design programs by the question-answer drive iteration method and realizes the complex products traceability which from the establishment of the requirement specification to the draft process of the decision basis. So the information granularity level can meet the traceability for object-to-object or at least object-to-document level.

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DESIGN PROCESS MODEL

In order to improve the traceability and the verifiability of the requirement, this paper established a design process model as shown in Fig. 1 which associated the model of the gateways management system (Kim, 2012) with the general design process model put forward in literature (Almefelt *et al.*, 2003). The information flow in Fig. 1 shows, the product concept can be further improved according to the requirements specification in a design phase and then it gets the decision at gate G-3. This process will be completed in the product concept design phase. And it should be investigated in the activity "Investigate problem" in Fig. 2; the decision basis from the activity is used for the next gate in the design process.

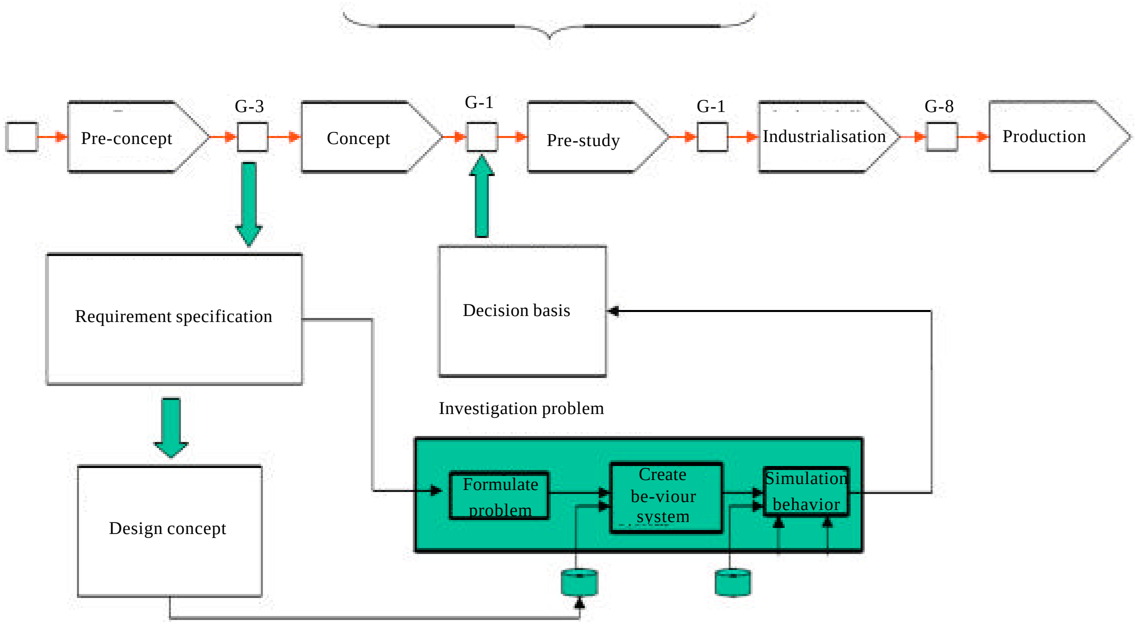

Fig. 1: Design process model of complex product

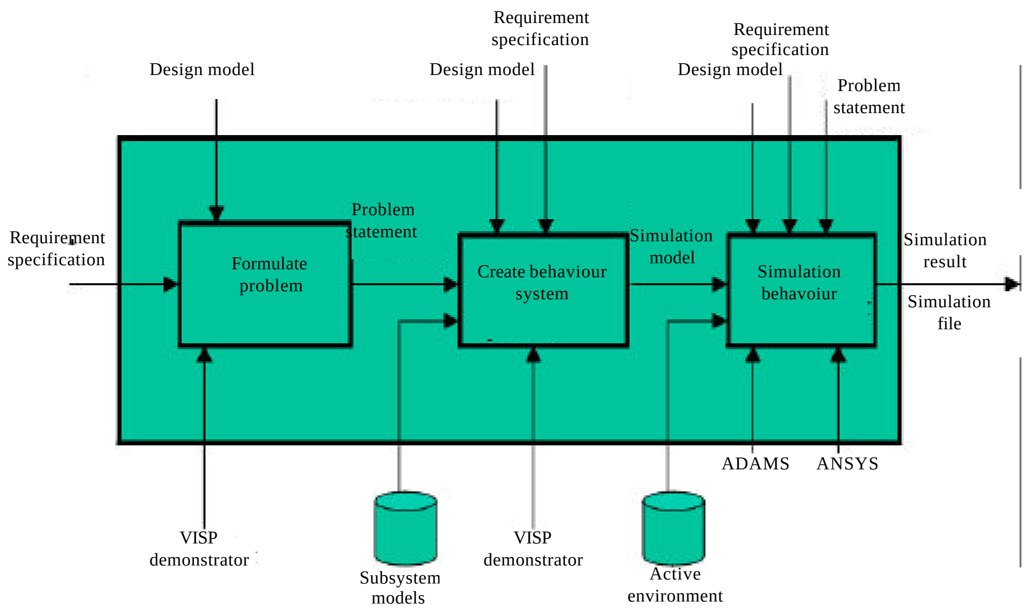

Fig. 2: Activity "Investigate problem"

Verification of requirements specification: The activity "Investigate problem" (Fig. 2) is the key to the verification of requirements specification. "Formulate problem" mainly focuses on exploring the properties of the design concept, it takes the requirement specification as input.

The more precisely is this activity described, means the designer can define the problem more accurately, e.g., a web-based interface support technology is formulated as a question, this information is then stored as an instance of the "problem" object. The "Create behavior system", First of all, we should try to solve the problem in the activity "Formulate problem" based on the given conditions. After that we need to make an model specification in that we illustrate what kind of information to get from the simulation, e.g., which kind of properties should we need, dynamic or static? Then the system model must be configured, based on the pre-made subsystem models stored in the modeling database. In the "Simulate behavior", added the interrelationship constraint, it can work well for simulation and analysis of performance under all kinds of conditions. Thus, the simulation model can be imported into the selected analysis tool, such as ADAMS, ANSYS, where the additional conditions are defined.

EXAMPLE

The presented design process model can be used in a modeling and simulation optimization design of hydraulic excavator work device. It focuses on how to apply the iterative method in question-answer driven process to realize the optimization design of the work device hinge points within the verification cycle process of requirements specification. The excavator working range, namely the envelope of the excavating track, refers to the limit range that the bucket tooth top of hydraulic excavator can achieve in any normal work position (Frimpong and Hu, 2004). It can intuitively reflect the working range and special working size of the work device, such as the maximum digging radius, the maximum digging depth, the maximum digging height which is an important indicator of the performance in the evaluation of the wok device (Frimpong *et al*., 2008). And the performance of the work device in working conditions of lifting, digging and horizontal pushing, including whether or not the bucket posture is the best, whether the mechanism dead point exists, can be used to verify the reasonableness of the excavator working range. So the static maximum working range and the performance in lifting, digging, horizontal pushing conditions of the work device were taken as requirements attributes, as shown in Fig. 3, it completed a series of activities from the requirements specification to the decision basis and realized the optimization design of the work device hinge points (Hall and McAree, 2005; Lin *et al*., 2010; Kagoshima *et al*., 2007).

Formulate problem: "Formulate problem", the first step in the verification of requirements specification, includes the following: The problem object description, application scenarios, requirement attributes, simulation model and problem answer. The information is stored as the problem

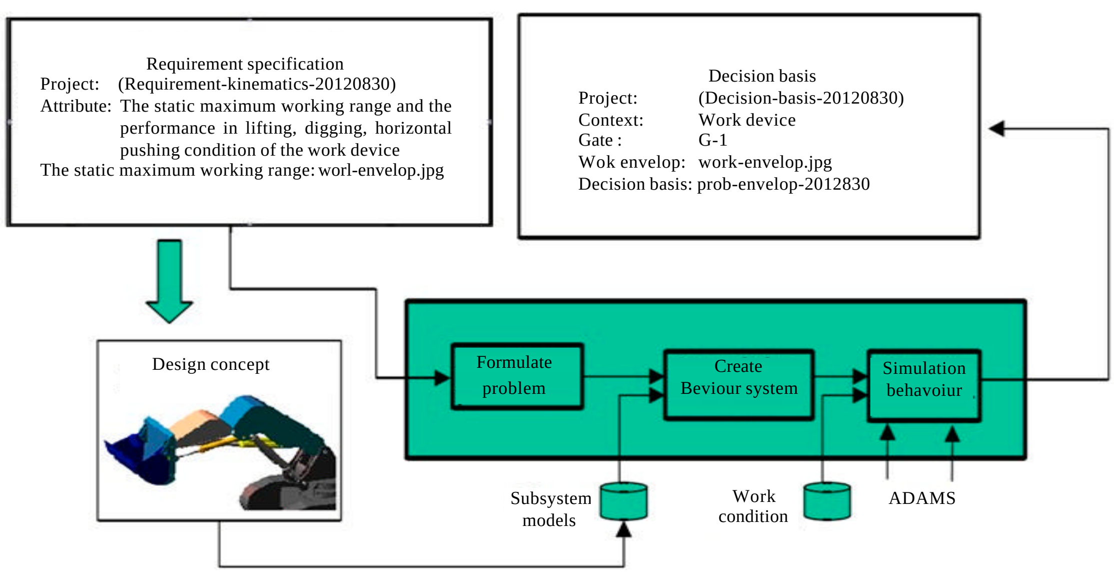

Fig. 3: Requirement verification cycle of the work device

Name	Prob-envelop-2012830
Context	The work device of hydraulic excavator
Description	How much is the static maximum working range of the work device? How much about the performance of lifting, digging and horizontal pushing condition?
Applies to	Req-kinematic-2012830
Attribute	Work-envelop-2012830
Simulation model	Simulation-envelop-2012830
Problem answer	Answer-envelop-2012830

Fig. 4: Problem object

Name	Work-envelop-2012830
Context	The work device of hydraulic excavator
Description	The static maximum range and the performance in lifting digging, horizontal pushing conditions of the work device
Value	Maximum digging radius (>15.35 m), maximum digging height (>17.85 m), maximum digging depth (<-3.42 m), both cylinder maximum arm of force (>2.6 m), boom cylinder minimum arm of force (>1.24 m), arm of force (>1.54 m)
Image	Work-envelop-2012830
Problem answer	Simulation-envelop-2012830
Problem answer	Answer-envelop-2012830

Fig. 5: Requirement attribute object

object, as shown in Fig. 4. Among them, the requirement attributes is also been stored as the opposite object, as shown in Fig. 5.

Create behavior system: Based on the problem object description, it is to define the model specification and establish the simulation model. As a typical multibody system, the hydraulic excavator working device consists of the rotating platform, the bucket, the arm, the boom and the corresponding cylinders. Therefore, we chose ADAMS to establish the rigid body kinematics simulation model of the work device, as shown in Fig. 6. Firstly, it sets X and Y coordinates of 9 hinge points for the design variable and investigate the values range of each design variable in DOE method and make sure there is no interference with the attachment at all virtual experiments. By using the Monte Carlo method, it is to determine value interval of the design variables and carry on the values of 18 design variables with the permutation and combination, eventually

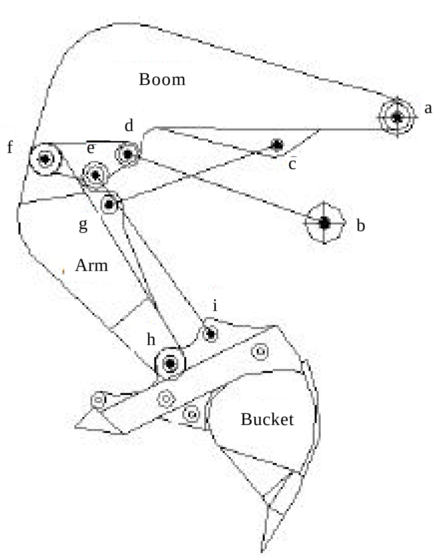

Fig. 6: Work device components and key hinge points

Name	Model-specificetion-2012830
Context	The work device of hydraulic excavator
Description	Calculate the static maximum working range of the work device
Problem	Problem-envelop-2012830
Target application	Application ADAMS
Submodel	Bucket, arm, boom, bucket cylinder, arm cylinder, boom cylinder

Fig. 7: Model specification object

Name	Simulation-specificetion-2012830
Context	The work device of hydraulic excavator
Description Problem	Calculate the static maximum working range of the work device, verify the perform of the work device in lifting, digging and horizontal pushing codition
Model specification	Model-specification-2012830
Simulation file	WE-calculation-20120830

Fig. 8: Simulation model object

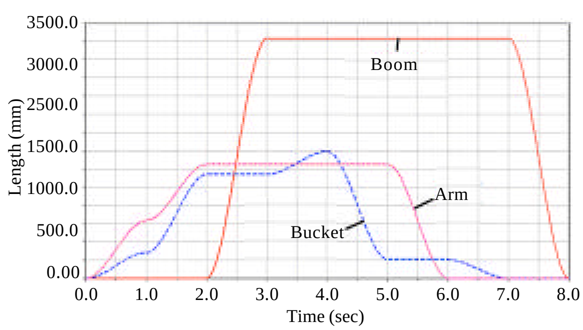

Fig. 9: Driving function of three hydraulic cylinders

generate 5120 work device hinge point programs. The defined model specification object and the simulation model object in the activity "Create behavior system" is shown in Fig. 7 and 8.

Simulate behavior: By imposing restrictions on the work device simulation model, the restrictions of 9 hinge points of the device are set to the revolute pair, the restrictions between the boom cylinder, the arm cylinder, the bucket cylinder and the corresponding piston rod are set to the cylindrical pair, it achieves the maximum working range and the simulation of lifting, digging and horizontal pushing by controlling the working stroke of the three cylinders.

Simulation analysis for the maximum working range of the work device: It can receive 5,120 groups of the excavating track envelope diagram of the work device by imposing the kinematic pairs and drive functions (as shown in Fig. 9) on the three cylinders. Based on the requirement attribute of the problem object Problem_envelop_20120830, the best idea working range (as shown in Figure 10) is obtained, by analyzing the priority principle of 4 performance indexes (the boom cylinder maximum arm of force, the boom cylinder minimum arm of force, the arm cylinder maximum arm of force, the arm cylinder minimum arm of force) of the work device digging force.

Performance simulation analysis of the work device in the digging condition: When arm digging, it requires the bucket to keep or be close to the optimal relief angle (the angle between the outline of the bucket bottom and the bucket tip trace should be 5°) within the whole digging area and the bucket-arm parallelogram mechanism should have no dead point position. To this end, the boom cylinder stroke is divided into 12 sections, the simulation verification for the optimization model of the work device

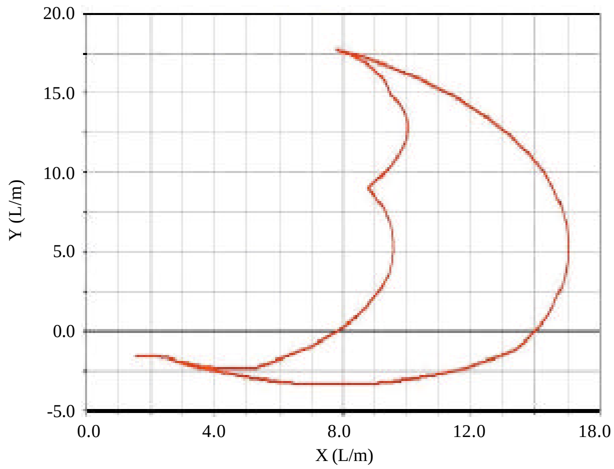

Fig. 10: Excavating envelope diagram of the simulation model

Name	Decision-basis-2012830
Description	Decision basis for optimization design of the work device
General attributes	
Maximum digging radius	15.392 (m)
Maximum digging depth	6.427 (m)
Maximum digging height	17.921 (m)
Boom cylinder maximum arm of force	2.601(m)
Boom cylinder minimum arm of force	1.306(m)
Arm cylinder maximum arm of force	1.561(m)
Change of bucket angle in lifting	0-33°
Bucket relief angle in digging	5°
Maximum distance in horizontal pushing without changing in bucket relief angle	5.51(m)
Decision basis	Problem-envelop-2012830

Fig. 11: Decision basis object

Table 1: Bucket angle change within boom lifting process unit: m

Arm cylinder length within boom lifing	Bucket initial angle	Bucket ending angle	Change of bucket angle
5.03	70.00°	89.63°	19.63°
4.83	67.70°	89.63°	21.93°
4.43	66.90°	89.09°	22.19°
4.03	65.11°	88.26°	23.15°
3.83	55.54°	88.73°	33.2°
3.43	43.66°	89.99°	46.33°
3.23	29.23°	78.03°	48.8°

proceeds respectively in each section. Results show that it can keep or be close to the optimal relief angle in the arm digging area and the bucket-arm parallelogram mechanism has no dead point.

Performance simulation analysis of the work device in horizontal push-and-press condition: It requires the bucket to keep the relief angle essentially unchanged within the whole digging area and the working device should have no dead point. To this end, on horizon plane for halting, the simulation verification for the optimization model of the work device proceeds. The bucket tip moves respectively to the plane of 1, 1.7, 2, 3.4 m above the horizon, the process of the horizontal push-and-press digging can be achieved individually. And the maximum distance of the horizontal push-and-press digging is 5.51 m.

The above analysis shows that, the optimal hinge points design program of the work device meets the performance requirement of the work device under the typical working conditions such as arm digging, boom lifting and horizontal pushing. The answer to the raised question in the simulation results and the object description of formulate problem should be stored in a diagram form, as shown in Fig. 11.

CONCLUSION

This proposed design method is mainly used for the conceptual design of complex products. By importing formulate problem, behavior model, simulation model and decision basis in the design process model, it realizes the object-object information granularity level between product attributes and requirement specification attributes through taking question-answer driven iteration verification solution for product requirement specification. The example shows that the method is practicable and the performance of the designed excavator work device meets the design requirement.

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REFERENCES

Almefelt, L., F. Andersson, P. Nilsson and J. Malmqvist, 2003. Exploring requirements management in the automotive industry. Proceedings of the 14th International Conference on Engineering Design, Stockholm, August 19-21, 2003, Sweden, pp: 63-64.

Andreasen, M.M., 1992. Designing on a designer's workbench (DWB). Proceedings of the 9th WDK Workshop, March 1992, Rigi, Switzerland,.

Frimpong, S. and Y. Hu, 2004. Parametric simulation of shovel-oil sands interactions during excavation. Int. J. Surf. Min. Reclamat. Environ., 18: 205-219.

Frimpong, S., Y. Hu and H. Inyang, 2008. Dynamic modeling of hydraulic shovel excavators for geomaterials. Int. J. Geomech., 8: 1532-3641.

Hall, A.S. and P.R. McAree, 2005. Robust bucket position tracking for a large hydraulic excavator. Mech. Mach. Theory, 40: 1-16.

Kagoshima, M., M. Komiyama, T. Nanjo and A. Tsutsui, 2007. Development of new hybrid excavator. Kobelco Technol. Rev., 27: 39-42.

Kim, S.Y., 2012. A development of the virtual design system for the attachments of a hydraulic excavator. SAE Int. J. Commer. Vehm, 5: 327-332.

Lin, T., Q. Wang, B. Hu and W. Gong, 2010. Development of hybrid powered hydraulic construction machinery. Autom. Construct., 19: 11-19.

Malmqvist, J., 2001. Implementing requirements management: A task for specialized software tools or PDM systems. Syst. Eng., 4: 49-57.

Sutinen, K., L. Almefelt and J. Malmqvist, 2000. Implementation of requirements traceability in systems engineering tools. Proceedings of the Product Models 2000, November 7-8, 2000, Linkoping, Sweden, pp: 313-328.