Steps in Conceptualizing a System for System Dynamics Model-Building: A Case Study of an Oil Refinery of a Petroleum Corporation

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Abstract

The effort of this paper is to document how system conceptualization takes place in an oil refinery. The product of this work is a conceptual model elicited from high-level managers and ten representatives of divisions of the refinery. The steps mentioned in this paper could let model builder elicit knowledge from policy makers' mental models and let policy makers modify the conceptual model.

The research described in this paper is part of a project which includes three stages: conceptualization, formalization, and building a microworld. This paper focuses on the first stage. For a detailed description of the second and third stages, please see Young and Hwang (1999).

Introduction

Because Taiwan government has decided to open the domestic petroleum market and the average refining costs of the oil refinery is higher than the average refining costs of the competitors, it is important for the managers of the refinery to understand the consequences and interactions of their policies. However, there is considerable evidence which shows that managers are not good at intuiting the dynamic behavior that will be produced by the interaction of their policies (Sterman, Repenning, and Kofman 1997, Paich and Sterman 1993, Sterman 1989).

A project that regards the application of system dynamics to develop a microworld to support the examination, evaluation and reformulation of the policies in the refinery was carried out (Hu and Hwang 1999). The project includes three stages of conceptualization, formalization, and building a microworld. Due to page limitation, this paper focuses on the stage of conceptualization. As for the stages of formalization and building a microworld that are also presented in this conference (Young and

Hwang 1999).

Steps of system conceptualization

In the conceptual stage, the archival data of the important refinery objectives, the policies to fulfil the objectives, and the main effects and side effects of the policies were first reviewed. Then, two meetings with high-level managers of the refinery and three meetings with the ten representatives of divisions were taken place. The section chiefs of the refinery were also interviewed. In the meetings and interviews, questionnaires were utilized to collect the data with regard to objectives, the policies to fulfil the objectives, and results of policies. Causal loop diagrams were utilized to develop conceptual models based on the results from archives, interviews, returned questionnaires, and meetings. The process of conceptual stage will be explained as follow:

Step 1. Gaining executive support

In order to gain executive support for the overall project, the origin, purpose, anticipating contribution, and steps of this project had been written and was sent to participants. About two hours were spent on introducing the project to high-level managers, and receiving their feedback later. Table 1 presents a questionnaire that was used in this meeting. However, some participants had opinions as follows: “This questionnaire expresses individual opinions instead of the division’s viewpoint.”, “Completing the questionnaire wastes time and gives only individual opinions instead of the organization’s view.” Hence, the director of the refinery said that “In fact, it is obvious about the objectives of our refinery, for instance, reducing headcount, reducing cost, and reducing the industrial disaster. I suggest that the Personnel Division be in charge of this project. Representatives from each main division, who are familiar with jobs of division, compose as a project team to continue the project. I hope the objectives of our refinery gather opinions from each division. Otherwise this project couldn’t reach the consensus. I hope we could do our best.” This is why the participants didn’t fill this questionnaire out. After this meeting, ten representatives from different divisions in the refinery were selected to form a project team to continue the project.

Step 2. Eliciting objectives of the client organization

About two hours were spent with the project team on a discussion of the short and long term objectives of the refinery. Table 2 presents a questionnaire that was designed to elicit participants’ knowledge concerning objectives. Participants didn’t fill this questionnaire out due to some opinions as follows: “It’s hard to set objectives and policies due to lack of information.”, “ Members of project team not only don’t

understand enough about policies of our refinery but also lack of data at hand, so it's hard to set objectives." and "The opinions of project team are just for reference or publishing?" During the meeting, however, decreasing cost, achieving the refining amount of crude oil, reducing the headcount, lowering the total disaster index and raising the productivity seemed to be the main objectives of the refinery.

Table 1. Questions for eliciting participants' knowledge about objectives, current situations, and policies of the refinery

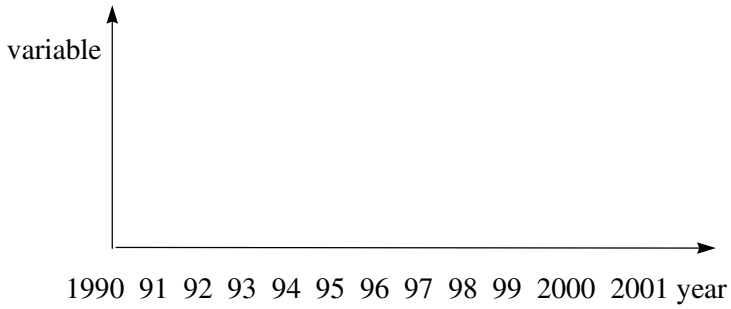
1. Please write down the objectives of your refinery:
2. Please write down the current situations with regard to objectives:
4. Please write down the policies in order to achieve objectives:
5. Please estimate the time from carrying out related policies to achieve the objectives:
6. Please describe graphically the relationship between the variable and time from 1990 to 2001: 

Table 2. Questionnaire for the objectives of the refinery and its divisions' sub-objectives at different time frames

objectives of the refinery					
Sub-objectives schedule	divisions' objective	divisions' objective	divisions' objective	divisions' objective	divisions' objective
Short term 0- 2 years					
Middle term 2-4 years					
Long term Above four years					

Step 3. Eliciting relationships among objectives, current situations and policies

In order to establish the causal and feedback relationships among objectives, current situations and policies, a questionnaire was designed according to the five objectives from the first meeting of project team. The questionnaire consists of five pages. Each page contains five questions. Table 3 gives an example of part of the questionnaire (reducing cost part). The questionnaire was given to each member of the project team before this meeting. About two hours were spent on a discussion of questions in the questionnaire.

Table 3. An example, reducing cost part, of part of the questionnaire

1. What policies did the refinery have in order to reduce cost?												
2. How much time does it take to carry out the cost reduction policies?												
3. What intended results could occur when carrying out the cost reduction policies?												
4. What unintended results could occur when carrying out the cost reduction policies?												
5. Please provide annual cost from 1991 to 1998 and estimate annual cost in the next four years.												
year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
annual cost												

Five responses consisted 21 pages were received due to one of the five responses just having one page. Only one respondent provided the answer to question 5 which was; please provide annual total disaster index from 1991 and estimate annual total disaster index in the next four years, in lowering the total disaster index part. This was because participants had some opinions about question 5. For example, “A big oil refinery had divided into three sub-oil refinery on 1 October 1996, but the fiscal account divided into three sub-oil refinery until 1 July 1997. So the data before 1 July 1997 belongs to three sub-oil refineries.”, “How could we filter the data before 1 July 1997?” and “We didn’t want to filter it not because we couldn’t do it but because lots of databases has been lost.”

There were 21 pages with the answer to question 1 (e.g.: What policies did the refinery have in order to reduce cost?). Policies to fulfil the objectives of the refinery based on the answers were organized in table 4.

Eleven of twenty-one pages about question 3 (e.g.: What are the results of carrying out the policies of reducing cost?) were filled, the rests were blank. Nineteen

of twenty-one pages about question 4 (e.g.: What unintended results could occur when carrying out the cost reduction policies?) were filled, the rests were blank. Intended and unintended results caused by the policies of the refinery were organized by causal loop diagram.

Table 4. Objectives and policies of the refinery

Objectives	Policies to fulfil the objectives
achieving the refining amount of crude oil	eliminating the bottlenecks, enhancing maintenance, and increasing the utilities rate of equipment
reducing headcount	preferential retire policy, no recruitment, and training specialty
lowering the total disaster index	industrial safety, hygiene, fire drill, check pipelines, check erosion resistance, check oil tanks, and replace old equipment
reducing cost	improve refining operation, reducing refining cost by decreasing the expenses of fuel and steam, controlling the budget of employing workers, saving cost of maintenance, reducing inventory, reducing cost of purchase and engineering
raising productivity	technique training, work counseling, access achievements

Some policies making for achieving objectives caused intended results could improve current condition and achieve objectives. For example: (1) Enhancement of maintenance, checkup of pipeline, checkup of erosion resistance, checkup of oil tanks, and replacement for old equipment will contribute to the achievement of the refining amount of crude oil and lowering the total disaster index. (2) Preferential retire policy and no recruitment will reduce the headcount, the expenditures of personnel salaries will then diminish so it would be beneficial to fulfill the objective of decreasing cost.

Some policies making for achieving an objective caused unintended results would obstruct another objective. For example: (1) Checkup of pipeline, checkup of erosion resistance, and checkup of oil tanks are good for lowering the total disaster index, however, the expenditures of maintenance would increase. (2) Replacement for old equipment is advantageous to reduce the total disaster index, however, the cost of purchasing and engineering would increase. Both (1) and (2) are not good for reducing cost. (3) Reducing the expenditures of maintenance in order to reduce cost could diminish the times of maintenance. (4) Reducing the cost of procuring and engineering in order to reduce cost might decrease the quality of equipment. Both (3) and (4) caused promoting the total disaster index.

Step 4. Submitting a preliminary conceptual model

For the sack of understanding the factor related to policy, archives were reviewed and three section chiefs of divisions were interviewed. Figure 1 shows a preliminary conceptual model that was designed on the basis of available archives and knowledge eliciting from participants by discussions, interviews, and retrieved questionnaires.

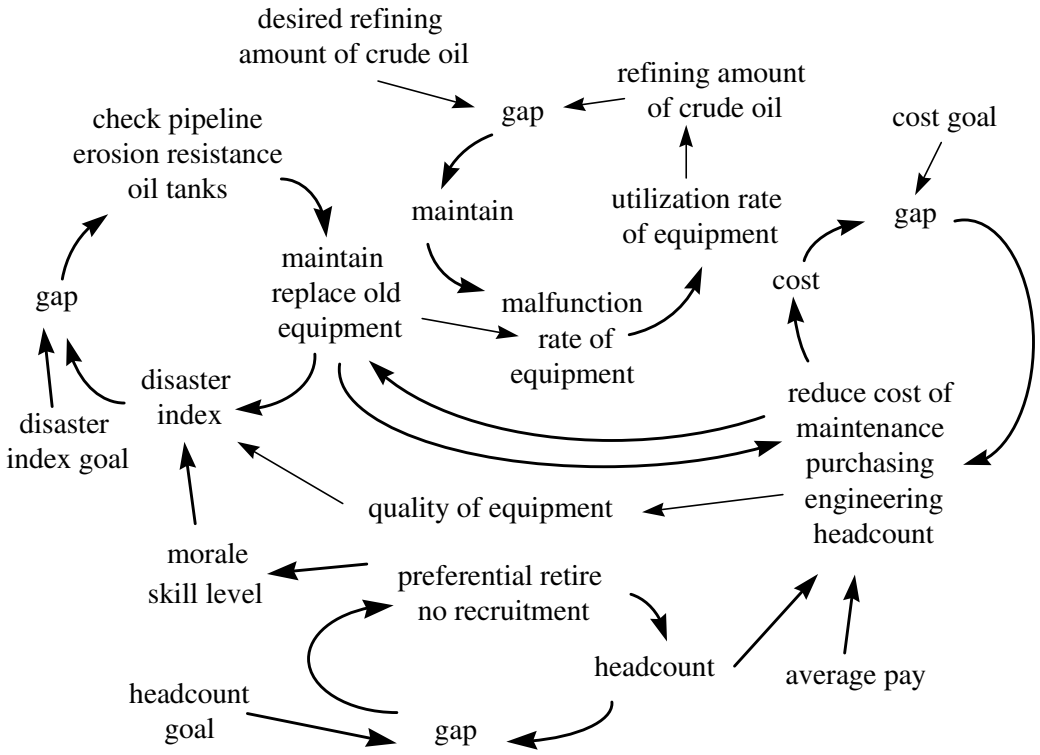


Figure 1. Preliminary conceptual model

Step 5. Modifing the preliminary conceptual model

In order to modify the preliminary conceptual model, two questionnaires were designed and sent to the project team before meeting. The loops of balancing process with delay (Senge 1990) were used in the first questionnaire to help map the relationships among objectives, policies, and results of the policies. The second questionnaire is about the level of unintended results could happen during carrying out the policies. About two hours were spent on a discussion of questions in the questionnaires.

It was stated in discussion that the total disaster index only indicated the loss from staffs suffering from disabling injury due to industrial disaster. The total disaster index couldn't completely show the losing conditions of industrial disaster in the refinery. For including the disaster loss that the refinery paid for machinery equipment and the loss from people who didn't belong to the refinery, the authors suggested that the total disaster index be replaced by disaster loss during the discussion with the project team.

The first questionnaire consisted of five pages and four responses were received.

One of the four was full of answer, the rests were incomplete. Eight responses of the second questionnaire were received. The results from eight responses can be seen in table 5.

Table 5. Frequencies and accumulation % of answers for questions (N = 8)

	Question 1	accumulation %	Question 2	accumulation %	Question 3	accumulation %	Question 4	accumulation %
very impossible	0	.00%	0	.00%	0	.00%	0	.00%
impossible	1	12.50%	1	12.50%	4	50.00%	0	.00%
unsure	3	50.00%	4	62.50%	0	50.00%	1	12.50%
possible	3	87.50%	3	100.00%	2	75.00%	3	50.00%
extreme possible	1	100.00%	0	100.00%	2	100.00%	4	100.00%
	Question 5	accumulation %	Question 6	accumulation %	Question 7	accumulation %	Question 8	accumulation %
very impossible	0	.00%	0	.00%	0	.00%	0	.00%
impossible	0	.00%	2	25.00%	2	25.00%	0	.00%
unsure	0	.00%	0	25.00%	1	37.50%	0	.00%
possible	6	75.00%	5	87.50%	2	62.50%	5	62.50%
extreme possible	2	100.00%	1	100.00%	3	100.00%	3	100.00%
	Question 9	accumulation %	Question 10	accumulation %	Question 11	accumulation %	Question 12	accumulation %
very impossible	0	.00%	0	.00%	0	.00%	0	.00%
impossible	0	.00%	0	.00%	0	.00%	0	.00%
unsure	2	25.00%	3	37.50%	1	12.50%	5	62.50%
possible	6	100.00%	5	100.00%	4	62.50%	3	100.00%
extreme possible	0	100.00%	0	100.00%	3	100.00%	0	100.00%
	Question 13	accumulation %	Question 14	accumulation %				
very impossible	0	.00%	0	.00%				
impossible	0	.00%	0	.00%				
unsure	3	37.50%	0	.00%				
possible	5	100.00%	5	62.50%				
extreme possible	0	100.00%	3	100.00%				

The answers of question 1, 2, 3, and 12 were more diverse than others as can be seen in table 5. The contents of the four questions were as follows: “question 1: The policies of preferential retire, no recruitment, and training for specialty will cause increasing the total disaster index.”, “question 2: The policies of preferential retire, no recruitment, and training for specialty will cause reducing morale.”, “question 3: The policies of preferential retire, no recruitment, and training for specialty will cause

reducing the average skilled level." and "question 12: When the cost of procurement and engineering reduced will cause rising the total disaster index." Although there was no consistence on question 1-3, but the authors doubted that the causal loop relationships explained in the preliminary conceptual model were not clear. Hence, the preliminary conceptual model was modified in order to show clearly the causal loop relationships between question 1-5. Although there was no consistence on question 12, but question 13 to 14 explained about question 12 got consistence. Question 13 to 14 are as follows: "question 13: When the cost of procurement and engineering reduced will cause lowering quality of equipment." and "question 14: When the the quality of equipment lowering will cause increasing the total disaster index." Hence, the authors doubted that the inconsistent answers of question 12 resulted from unclear meaning of question 12.

From the discussion and responses of questionnaires, causal loop relationships among objectives, present situation and policies were elicited from project team to modify the preliminary conceptual model. Figure 2 presents the modified conceptual model.

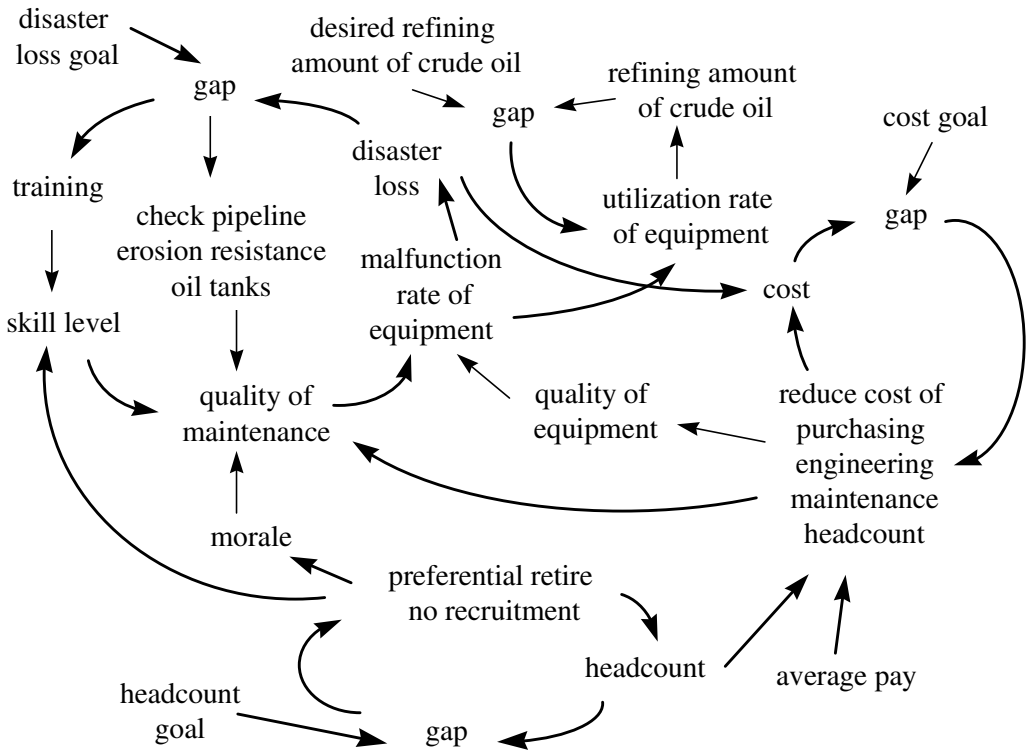


Figure 2. Modified conceptual model

Step 6. Completing conceptual model

In order to understand the validity of the modified model, a questionnaire was designed and sent to the high-level managers before meeting. About two hours were spent on a discussion of questions in the questionnaire. The questionnaire consists of

two parts. One part of the questionnaire is about the level of unintended results could happen during carrying out the policies. The loops of balancing process with delay were used in the other part of the questionnaire to help map the relationships among objectives, policies, and results of the policies.

In this meeting, participants have some opinions to objectives. For example, headquarters have a very important objective named profit and ask our refinery to achieve it. Of course those objectives in questionnaire are related to profit, however, it's impossible to achieve the objective of profit through those objectives in questionnaire. So, is the objective of profit given by headquarters really important? The authors found that participants from different levels or divisions held different viewpoint. Hence, The objectives of the refinery from five objectives of project team as follows: decreasing cost, achieving refining amount of crude oil, reducing headcount, lowering the total disaster index and raising productivity to two objectives of the high-level managers as follows: reducing costs and increasing profits, and four sub-objectives as follows: achieving refining amount of crude oil, reducing headcount, lowering the total disaster index and raising productivity.

Seventeen responses of this questionnaire were received. The results from seventeen responses can be seen in table 6. The answers of question 4, 9, and 12 were more diverse than others as can be seen in table 6. The contents of the three questions were as follows: "question 4: Although reducing cost is harder and harder than ever, we'll do our best in order to let the cost no higher than competitors. However, some policies might cause industrial disaster due to reducing cost.", "question 9: Preferential retire and no recruitment might cause industrial disaster." and "question 12: Preferential retire and no recruitment might cause morale decreasing." Although there was no consistence on question 4 , but question 5 to 8 that explained about question 4 got consistence. Question 5 to 8 are as follows: "question 5: Although reducing cost is harder and harder than ever, we'll do our best in order to let the cost no higher than competitors. However, some policies might cause reducing quality of repair and maintenance.", "question 6: When the quality of repair and maintenance of your refinery reduced will cause industrial disaster in the future.", "question 7: Although reducing cost is harder and harder than ever, we'll do our best in order to let the cost no higher than competitors. However, some policies might cause reducing quality of machinery equipment." and "question 8: When the quality of machinery equipment of your refinery reduced will cause industrial disaster in the future." Hence, the authors doubted that the inconsistent answers of question 4 resulted from unclear meaning of question 4. As for question 9, there was no consistence on it, but question 10 to 11 that explained about question 9 got consistence. Question 10 to 11 are as follows: "question 10: Preferential retire and no recruitment will cause reducing

average level of technique.", "question 11: When the average level of technique reduced will cause industrial disaster." Hence, the authors doubted that the inconsistent answers of question 9 resulted from unclear meaning of question 9. Because the extremely inconsistent answers of question 12, the authors removed these variables and causal loops related question 12 in the modified conceptual model.

Table 6. Frequencies and accumulation % of answers for questions (N = 17)

	Question 1	accumulation %	Question 2	accumulation %	Question 3	accumulation %	Question 4	accumulation %
blank	0	.00%	0	.00%	0	.00%	0	.00%
very impossible	0	.00%	0	.00%	0	.00%	0	.00%
impossible	0	.00%	0	.00%	0	.00%	3	17.65%
unsure	0	.00%	0	.00%	2	11.76%	5	47.06%
possible	8	47.06%	11	64.71%	11	76.47%	9	100.00%
extreme possible	9	100.00%	6	100.00%	4	100.00%	0	100.00%
	Question 5	accumulation %	Question 6	accumulation %	Question 7	accumulation %	Question 8	accumulation %
blank	0	.00%	0	.00%	0	.00%	1	5.88%
very impossible	0	.00%	0	.00%	1	5.88%	0	5.88%
impossible	2	11.76%	0	.00%	1	11.76%	0	5.88%
unsure	2	23.53%	3	17.65%	2	23.53%	5	35.29%
possible	13	100.00%	9	70.59%	13	100.00%	8	82.35%
extreme possible	0	100.00%	5	100.00%	0	100.00%	3	100.00%
	Question 9	accumulation %	Question 10	accumulation %	Question 11	accumulation %	Question 12	accumulation %
blank	1	5.88%	0	.00%	1	5.88%	0	.00%
very impossible	1	11.76%	0	.00%	0	5.88%	1	5.88%
impossible	2	23.53%	1	5.88%	0	5.88%	3	23.53%
unsure	5	52.94%	3	23.53%	1	11.76%	7	64.71%
possible	8	100.00%	11	88.24%	11	76.47%	4	88.24%
extreme possible	0	100.00%	2	100.00%	4	100.00%	2	100.00%
	Question 13	accumulation %	Question 14	accumulation %	Question 15	accumulation %		
blank	0	.00%	0	.00%	1	5.88%		
very impossible	0	.00%	2	11.76%	1	11.76%		
impossible	0	.00%	0	11.76%	1	17.65%		
unsure	1	5.88%	3	29.41%	1	23.53%		
possible	11	70.59%	9	82.35%	11	88.24%		
extreme possible	5	100.00%	3	100.00%	2	100.00%		

The causal loop relationships among objectives, current situation and policies

were elicited from discussion during this meeting and retrieved copies of questionnaire to correct the modified conceptual model. Figure 3 shows the final conceptual model.

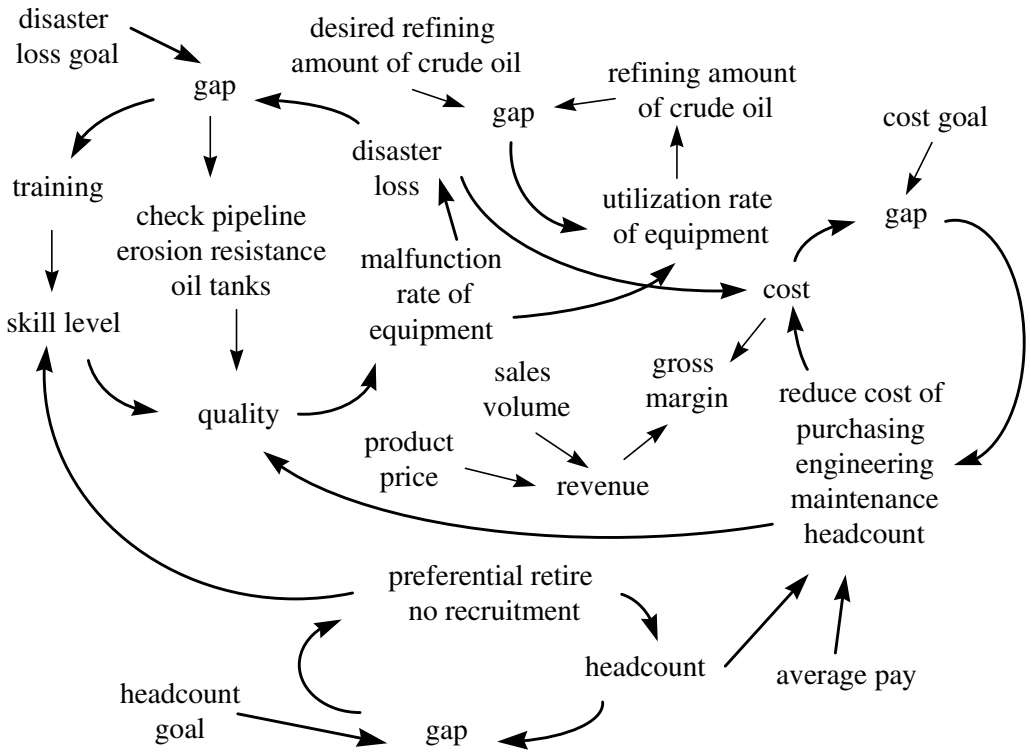


Figure 3. Final conceptual model

Discussion

Lowering the total disaster index is one of objectives of the refinery, however, the total disaster index only indicates the loss from staffs suffering from disabling injury due to industrial disaster. The total disaster index couldn't completely show the losing conditions of industrial disaster in the refinery. For including the disaster loss that the refinery pays for machinery equipment and the loss from people who didn't belong to the refinery, the authors suggested that the total disaster index be replaced by disaster loss.

Participants from different levels or divisions hold different viewpoints. The project team which consists of ten representatives of divisions in the refinery thinks that the objectives of the refinery are decreasing cost, achieving the refining amount of crude oil, reducing headcount, lowering the total disaster index and raising productivity. But, the high-level managers think that increasing profits is the most important objective of the refinery. Andersen and Richardson (1997) state that "The most important aspect of any conference is ensuring that the right people are in the room for the modeling conferenc."

Summary

Six steps in the stage of system conceptualization were developed. In the beginning of each step, different questionnaires were designed and handed to participants. In step 1, the goals and process of the project were introduced to the high-level managers of the refinery to gain executive support for the overall project. Then, a project team including ten representatives of divisions of the refinery was organized. In step 2, the project team was invited to discuss about the objectives of the refinery. In step 3, the project team discussed about relationships among objectives, current situations and policies. In step 4, a preliminary model about the objectives, policies, and results of the policies was designed on the basis of available archives and knowledge eliciting from participants by discussions, interviews, and retrieved questionnaires. In step 5, the preliminary conceptual model was commented on by the project team and consequently modified by the authors. In step 6, the modified model was commented on by the high-level managers and the project team. Then, a final conceptual model was designed on the basis of the results from the above steps.

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References

Andersen, D. F. and G. P. Richardson. (1997). Scripts for group model building. *System Dynamics Review*13: (2) 107-129.

Hu, Gary and Lihlian Hwang. (1999). *The Interaction of Decisions Under Multiple Objectives and Its Time Delay Effects: A Case Study of Kaohsiung Oil Refinery of China Petroleum Corporation*. The National Science Council. NSC 87-CPC-H-110-003. Taipei, Taiwan.

Paich, Mark and J.D. Sterman.(1993). Boom, bust, and failures to learn in experimental markets. *Management Science* 39: (12) 1439-1458.

Senge, P. M. (1990). *The Fifth Discipline: The Art and Practice of the Learning Organization*. New York: Doubleday Press.

Sterman, J.D., (1989). Modeling managerial behavior: misperceptions of feedback in a dynamic decision making experiment. *Management Science* 35: (3) 321-339.

Sterman, J.D., Nelson P. Repenning, and Fred Kofman. (1997). Unanticipated side effects of successful quality programs: exploring a paradox of organizational improvement. *Management Science* 43: (4) 503-521.

Young, Showing H. and Lihlian Hwang. (1999). A microworld customized for an oil refinery of a petroleum corporation. *Proceedings of the 1999 International System Dynamics Conference*. New Zealand.