An experimental study

On the construction of electricity power stations in China

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Abstract

The history of electric industry in China can be generalized as cycles of electricity shortage and surplus. It's widely believed that lack of accurate future electricity demand is the main cause to this problematic phenomenon. However, there are still very few people who believe long-time power station construction so that the investors ignore the stations under construction is the main effect, rather than the information about electricity demand. In this paper, an experiment is carried out to test whether these thoughts are right or not. Factorial designs with 2 treatments, information about stations under construction and information about future electricity demand, are used to test which of these two factors is the main effect. Statistics indicated that awareness of how many stations are under construction will greatly improve the performance of subjects, while information about the future electricity demand, although assumed accurate, has no significant effect on the performance of the subjects.

Key words: *experiment; electricity industry; electricity cycles; System Dynamics*

1 Introduction

In the past 50 years, the electric industry in China has witnessed cycles of electricity shortage and surplus (drcnet.com.cn 2005), which is waste of energy, resources and money. Moreover, the whole nation is suffering from this kind of oscillations, especially in times of electricity shortage, which brought a lot of inconvenience to the whole society, and impeded the overall economic development at the same time.

Currently, there exist mainly two ways of thinking about this problem. Some people think it's due to lack of precise information about the future electricity demand (Finance.sina.com.cn 2005). Others find this problem closely related with the oscillations in other industries such as commodities and real estate (Sterman 2000; Ford 2001). Based on these two ways of thinking, the author will carry out an experiment to test which thinking is more reasonable.

It's true that inaccurate information about future electricity demand can be misleading for investors. However, even if precise information about future electricity demand is available, it takes time to construct a power station, more than 10 years for nuclear power stations (nonewnukes.ukrivers.net 2006). Fossil fired power stations take the shortest time to construct, which is 4 years on average (Cohen 1990). As a result, when there is a boom in the electricity demand, electricity production will lag behind demand for at least 4 years. During these days of electricity shortage, investors tend to exaggerate the gap between electricity demand and supply and build much more new power stations than needed. Even if they do not exaggerate the gap, they tend to ignore the stations that have been under construction and always try to fill the gap between existing electricity production and desired electricity demand. A few years later, when all the electricity power stations begin to produce electricity, the electricity demand is not as high as expected, thus much lower than the electricity production. In order to minimize their operational cost, they have to shut down some of the power stations; some investors even have to claim bankruptcy. This actually is a form of electricity surplus, which is a big waste.

What's the cause to this phenomenon? The hypothesis held by the author is that the investors ignore the stations under construction; they ignore the long delays between the construction of power stations and the production of electricity by these power stations.

In the past few years, a lot of study has been done in this field. Most researchers focus on the forecast of future electricity demand. They believe the problem can be solved if investors are given accurate forecast of future demand. Therefore, they are dedicated to improving the accuracy of electricity demand forecast in the future. Mathematics Methods, such as Statistics, Econometrics, Time Series Methods and so on so forth (Gellings 1991) are utilized in order to achieve good forecast. On the other hand, some researchers focus on how to accelerate the construction speed and efficiency of electricity power stations. Engineering, Management theories are in the majority in this field (Yu.Zhenquan 1998). In this paper, System Dynamics will be used to model the construction of power stations, based on which an experiment of factorial design will be carried out. The focus of the experiment will be the effect of information about the stations under construction and information about future electricity demand. The goal of the experiment is to test which information is the main effect.

This paper is organized in this way: In the second section, the underlying model of constructing power stations will be explained to the reader. After that comes section 3, the experimental design, in which the process of experiment will be thoroughly discussed. The author will disclose the results of the experiment in section 4 and interpret the results in section 5 with some discussions. Conclusions will be given in section 6.

2 The model

Figure 1 is the causal loop diagram of the underlying model.

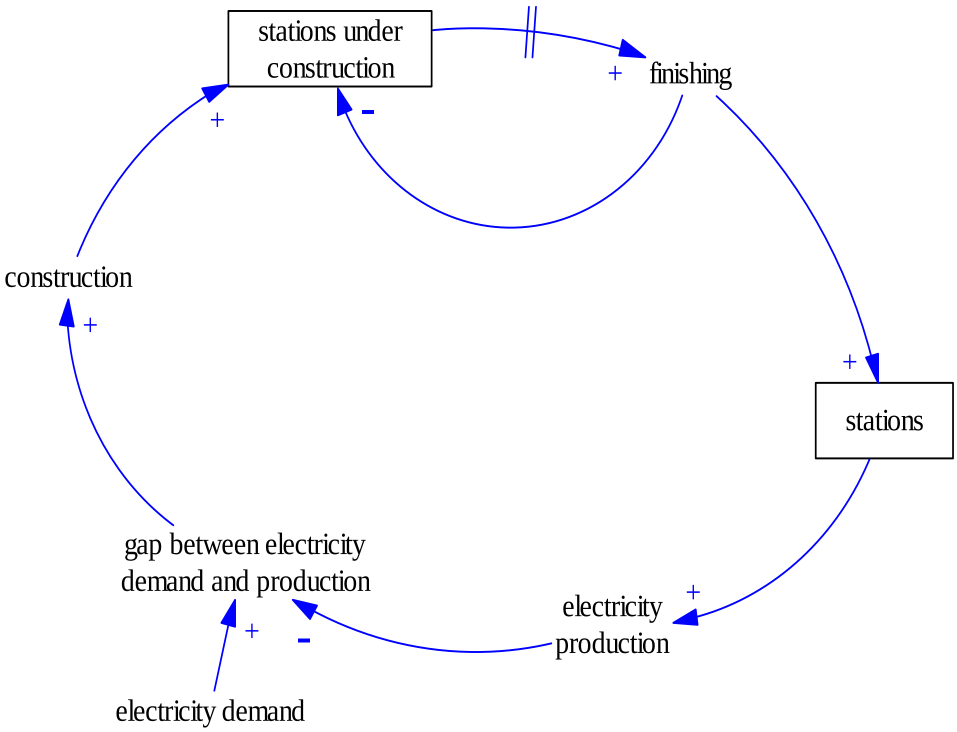

Figure 1 Causal Loop Diagram

Construction adds to the stock of stations under constructions, while finishing subtracts from stations under construction because those stations have been finished. The more stations under construction, the more stations will be finished after a certain delay, which add to the stock of stations. The more stations which produce electricity power, the bigger the electricity production. The bigger the electricity production, the smaller the gap between electricity demand and production, given the electricity demand which is totally exogenous. The smaller the gap, the less number of new stations needed to build.

After the causal loop diagram, let's go to the stock and flow diagram in figure 2.

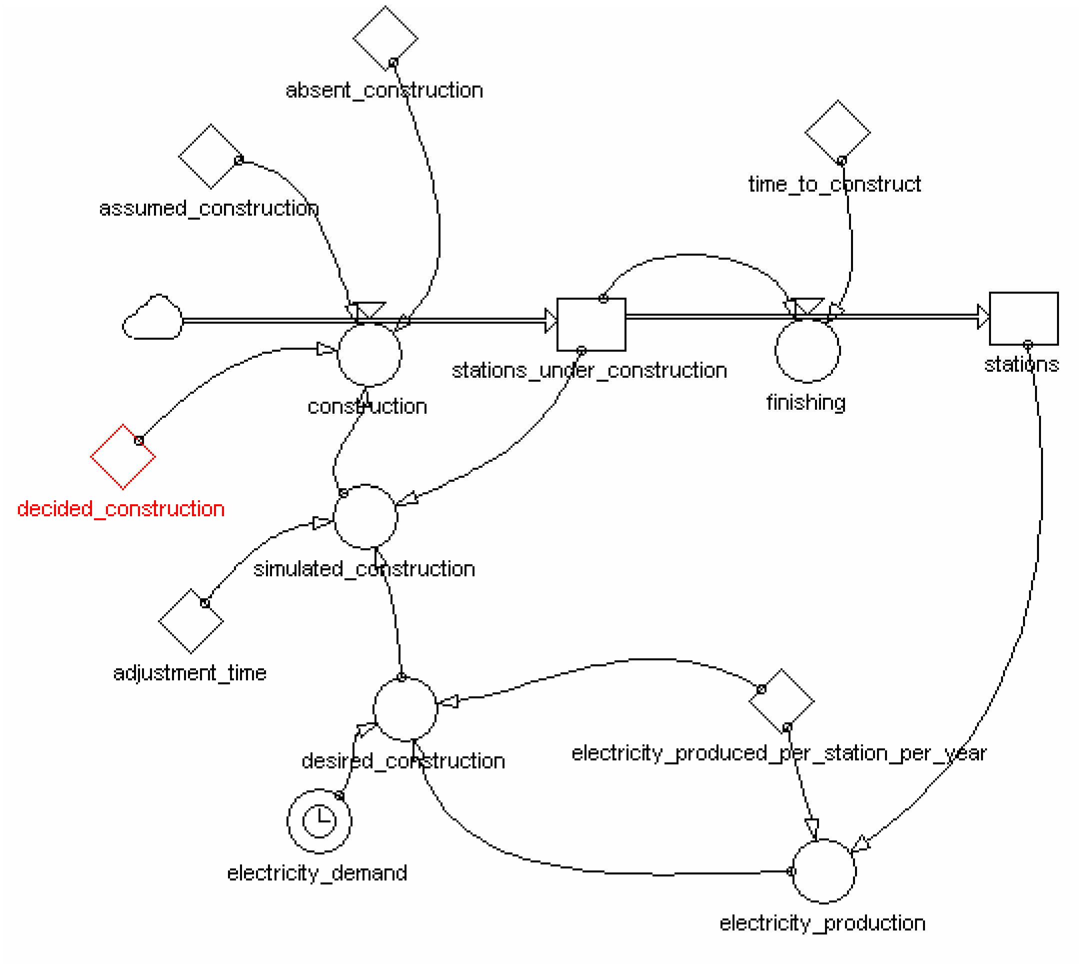

Figure 2　Stock and Flow Diagram

The variable 'decided_construction' labeled as red is the decision made by the participants.

The equations for the model are in the appendix.

2.1 The interface

A simple interface with the above-mentioned underlying model was used in order to carry out the experiment, see Figure 3.

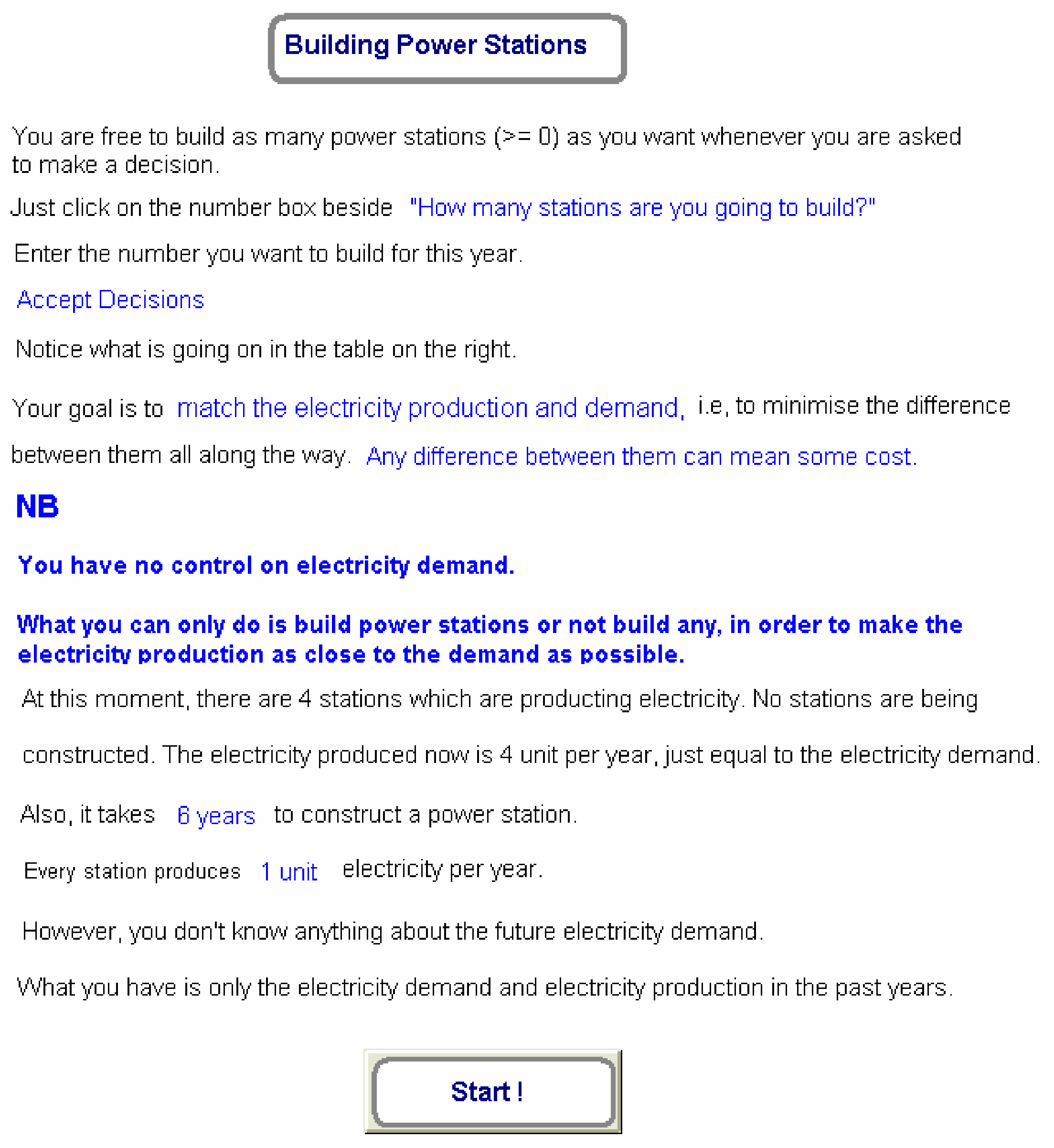

Figure 3 Instructions on the Interface

After the subjects press start, Figure 4 will be shown to them.

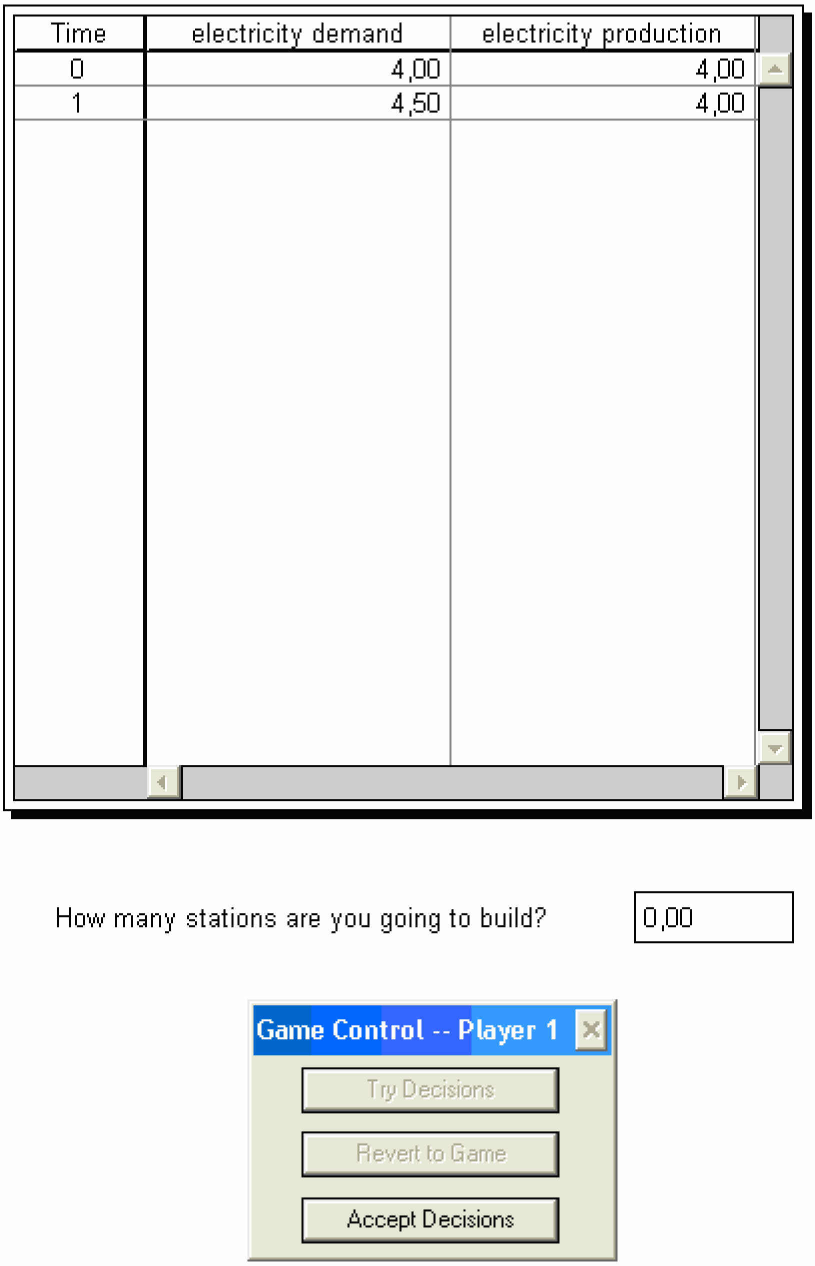

Figure 4 Interactive Outcome Feedback

The subjects just need to click on the number box and enter the number of power stations they want to build for the next year, in order to make electricity production as close to electricity demand as possible. Then 'Accept decisions', the result of the second year will come out. The subjects are supposed to do this year after year until the 20th year when the experiment is over.

There are two treatments involved in the experiment:

Treatment 1: Information about stations under construction

Treatment 2: Information about future electricity demand

Both treatments have two levels: with and without

Since this is a 2*2 factorial design, 4 different interfaces will be given to subjects, the only difference between each other is the level of treatments.

For the group with the first level of treatment 1, the information about stations under construction will be given on the interface. Figure 5 is an example of the information at the beginning of the experiment.

Figure 5 Stock in Transit Feedback

For the group with the first level of treatment 2, a graph depicting the electricity demand in the following 20 years will be given, as shown in figure 6.

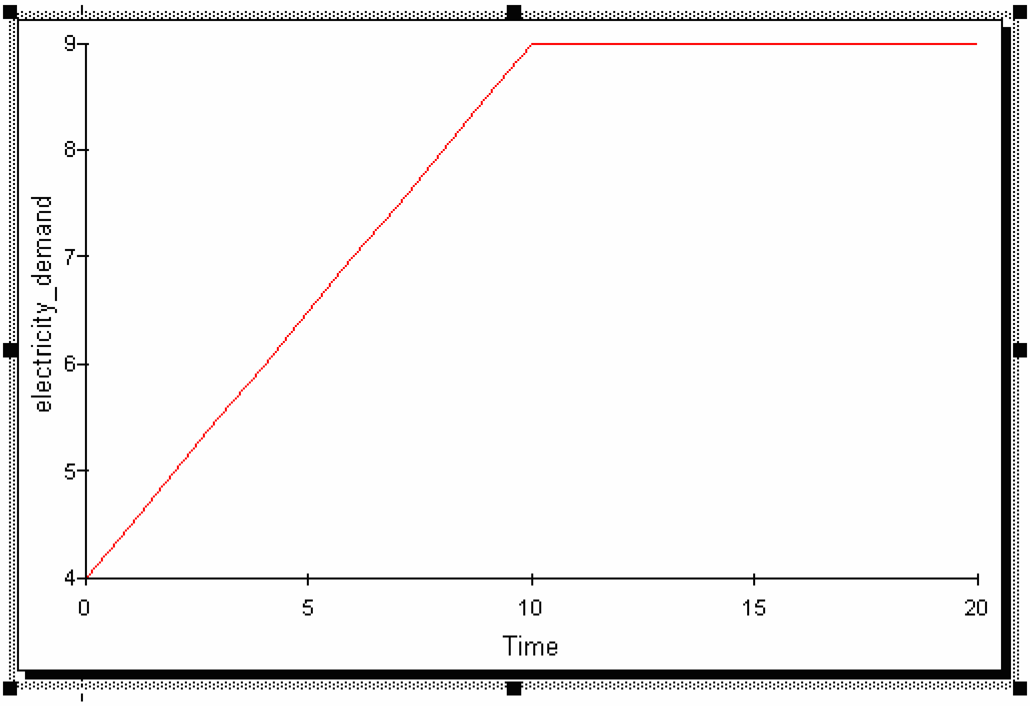

Figure 6 Future Electricity Demand

For the group with the first level of both treatments, both information will be given on the interface.

The criterion which the subjects should try to minimize is the gap between electricity demand and electricity production, i.e, to make the gap as small as possible.

2.2 The difference between the model and reality

As can be seen in the early parts of Section 2, the experiment simplifies reality in many ways, as follows:

1) The depreciation of stations is ignored for sake of simplicity. The subjects are asked to make decisions on how many new stations to build this year. They are supposed to focus on the gap between electricity demand and current electricity production. It will add complexity to them if they have to consider at the same time how many stations are worn out this year.

2) They can not close down the stations in order to reduce the number of stations which are generating extra electricity. In reality, managers or investors can close the stations when supply is over demand (Here I mean permanently closing. Closing a station and reopening again is still regarded as electricity surplus.). However, it can be reckless to permanently close a station, just because electricity production is more than demanded. Therefore, closing a station is not involved in the experiment. Moreover, whether to close or not does not affect the hypotheses of the experiment at all. In consideration of this, closing stations is removed from the model.

3) There's pipeline delay used in the model, which is not realistic. Why just a first-order delay is used in the model is that whether to use pipeline delay or just a first-order delay has no significant effect on the experiment, although pipeline delay can make the construction of power stations more comprehensible and more realistic.

4) The initial state of this experiment is unrealistic as well such as initial stations, initial stations under construction. The initial values are very simple numbers so that it's very easy for the subjects to calculate.

5) In this experiment, the author simply assumes the electricity demand increases linearly in the first 10 years and then keeps constant. For the time being, the modeling of electricity demand is not the focus because it's a very complex variable, which involves price, demand elasticity, industrial structure, technical factors and so on so forth.

3 Experimental design

In this section, we will first discuss about the task of the experiment. After that, the benchmark of the experiment will be explained. Then come the hypotheses as well as some information about the procedures and subjects of this experiment.

3.1 The task

All the participants were told explicitly what to do in the experiment, to build new power stations every year.

They were also given explicitly the goal of the experiment, which is to minimize the difference between electricity demand and electricity production. Therefore, they knew what they would practically do in the experiment is to build new power stations or not in order to make the electricity production as close to electricity demand as possible.

The subjects were not given the model structure. However, they were told that electricity demand was exogenous on which they had no control. They were also told the initial number of stations, stations under construction, and the electricity produced per station per year. As shown in Figure 7.

You have no control on electricity demand.

What you can only do is build power stations or not build any, in order to make the electricity production as close to the demand as possible.

At this moment, there are 4 stations which are producting electricity. No stations are being constructed. The electricity produced now is 4 unit per year, just equal to the electricity demand.

Also, it takes 6 years to construct a power station.

Every station produces 1 unit electricity per year.

Figure 7 Information about the model

Moreover, a thorough outcome feedback were given to all the participants, as shown in the following table (Figure 8).

Time	electricity demand	electricity production
0	4,00	4,00
1	4,50	4,00
2	5,00	4,00
3	5,50	4,17
4	6,00	4,81
5	6,50	5,34
6	7,00	5,78
7	7,50	6,15
8	8,00	6,46
9	8,50	6,72
10	9,00	7,51
11	9,00	8,18
12	9,00	8,73
13	9,00	9,19
14	9,00	9,58
15	9,00	9,90
16	9,00	10,16
17	9,00	10,39
18	9,00	10,57
19	9,00	10,73
20	9,00	10,86

Figure 8 An example of the outcome feedback at the end of an experiment

Here table was used instead of graph to give feedback due to two reasons:

1) Graph tend to bring some measurement error, while table can show precisely the difference between electricity demand and production
2) A lot of subjects of this experiment have no knowledge about graphs at all, while almost every one can read tables.

In brief, the experiment provides limited information about the model in the sense that the participants don't know the underlying model at all, in terms of stocks and flows. However they are given full description of the outcome feedback.

Factorial design

The subjects were divided into 4 groups, as shown in table 1.

Table 1 Grouping of subjects

Group	Level	
	Treatment 1	Treatment 2
1	without	without
2	with	without
3	without	with
4	with	with

All the subjects were asked to make decisions on how many power stations to build every year, based on all the information given in the interface.

3.2 The benchmark

Since the goal of the experiment is to minimize is the difference between electricity demand and electricity produced and make the difference as close to 0 as possible, the ideal benchmark should be the curve of electricity demand, as shown in figure 9, where the benchmark exactly overlaps the curve of electricity demand.

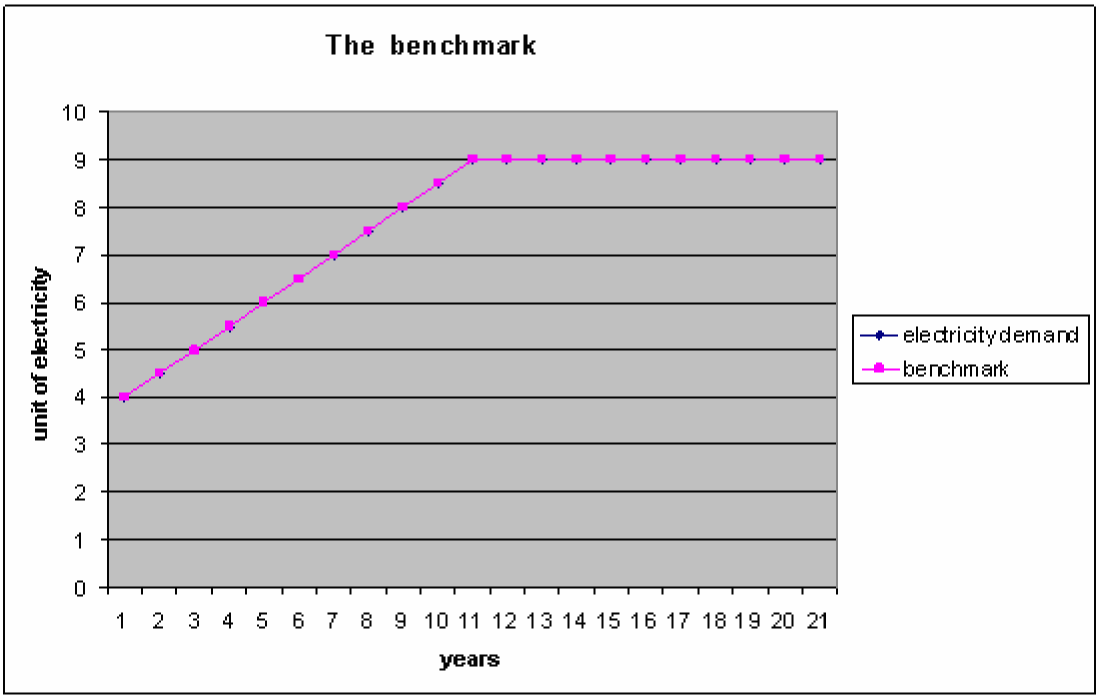

Figure 9 The Benchmark

3.3 Hypotheses

There are two hypotheses in this experiment; one is that ignorance of information about stations under construction causes unwise decision-making about power station construction, the other is that lack of information of future electricity demand causes unwise construction of power stations.

For these two hypotheses, there are two null hypotheses correspondingly.

Assume the first null hypothesis is H_0

H_0: information about stations under construction has no significant effect on improving the performance of participants

An alternative hypothesis is H_1

H_1: information about stations under construction can significantly improve the performance of participants

Assume the second null hypothesis is H_0'

H_0': information about future electricity demand has no significant effect on improving the performance of participants

An alternative hypothesis is H_1'

H1': information about future electricity demand can significantly improve the performance of participants

3.4 Other design issues

This is a completely randomized design, without learning effect in the experiment as well.

First 20 people's names were written down and labeled 1, 2… 20. Then Group 1, 2, 3 and 4 were written on another sheet of paper. After that, the author just randomly wrote 5 numbers from 1 to 20, respectively under group 1, 2, 3 and 4, without repetition of course. The subjects carried out the experiment separately. Only between group design was used in order to avoid learning effect. The participants were from a variety of backgrounds, except System Dynamics.

4 Results

It's discovered in the experiment that group 1 (without either information) did the worst, while group 4 (with both information did the best). Group 3 (with information about future electricity demand) did better than group 1, but not as well as group 2 (with information about stations under construction). Group 2 did almost as well as group 4.

The results are shown as follows:

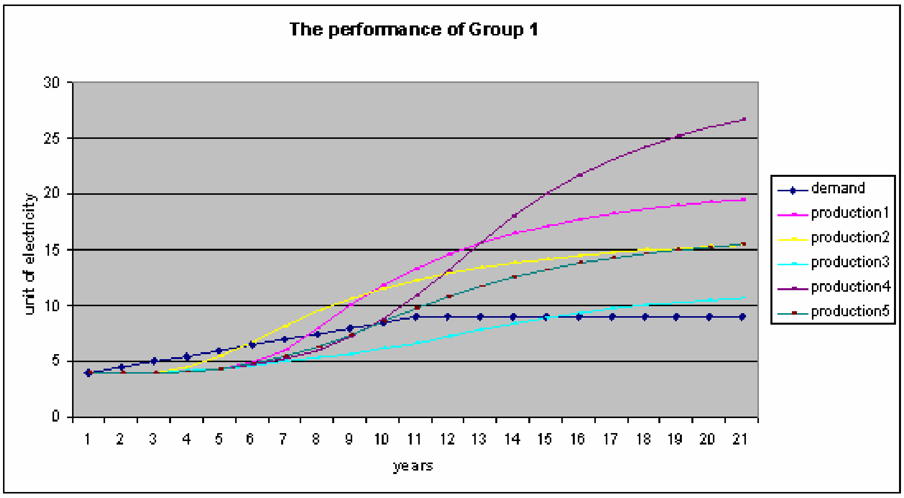

Figure 10

Where, production 1, 2, 3, 4, 5 is the electricity production achieved respectively by subject 1, 2, 3, 4, 5 in Group 1, the same applies to the graphs for the other groups shown below as Figure 11, Figure 12 and Figure 13.

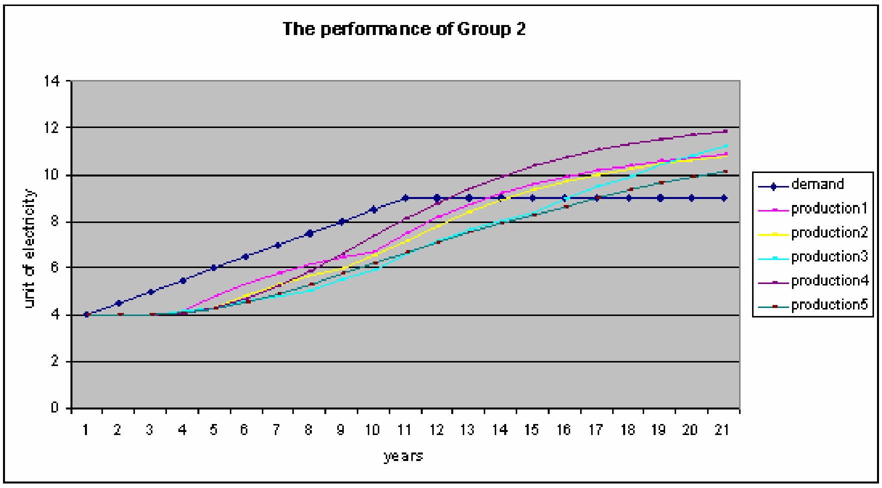

Figure 11

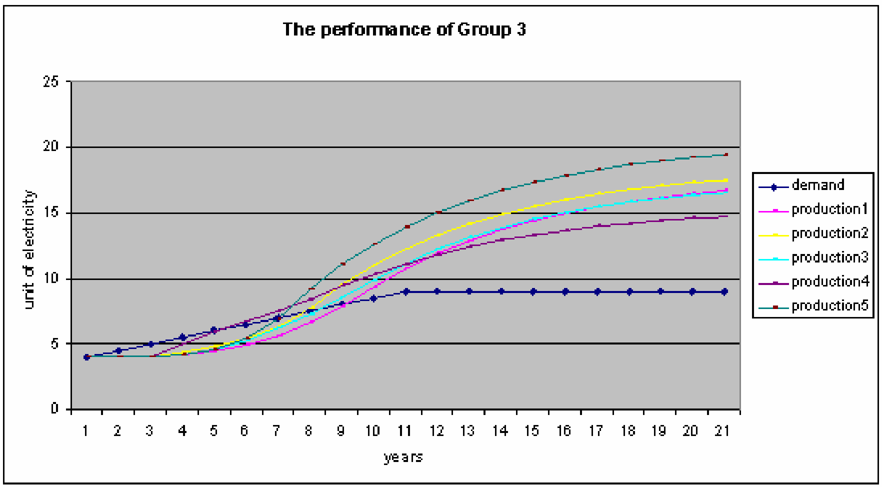

Figure 12

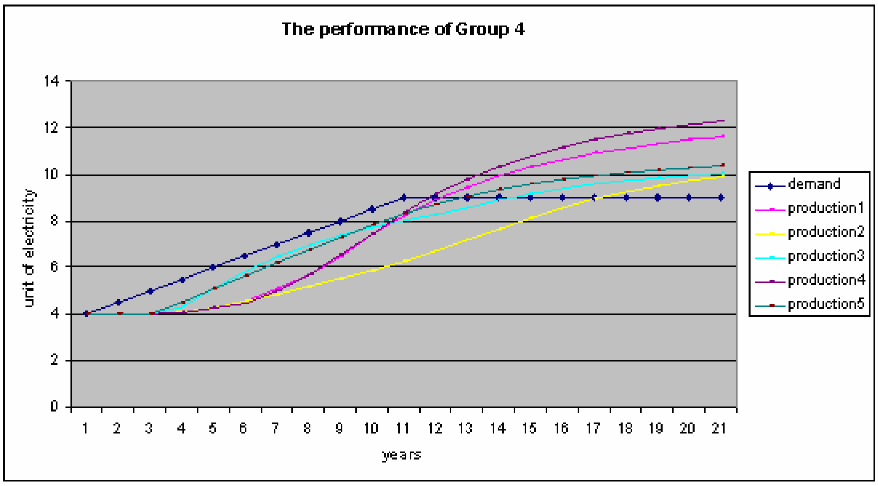

Figure 13

Data processing

For every subject, the sum of difference between electricity demand and supply in every year is calculated as the numeric performance. During the years when electricity production is lower than the demand, absolute value is taken to calculate the sum of difference. For example, when the demand is 5 and the production is 4.5, the difference in this year is the absolute value for (-0.5), which is 0.5. Table 2 shows the numeric results of the experiment

Table 2 Numeric performance of subjects

Difference between electricity demand and production		Treatment 1	
		With	without
Treatment 2	with	29.69	69.27
		28.04	81.88
		13.61	69.51
		34.49	54.94
		15.71	106.78
	without	23.03	103.56
		25.72	69.68
		30.18	27.74
		30.16	136.17
		26.23	57.25

ANOVA was applied to do the analysis (Significance level is 0.05).

Since this is an experiment with two factors and one dependent variable, Univariate analysis is supposed to be used here. However, a test of homogeneity of variance is necessary before going any further. Table 3 shows the result of Levene's Test

Table 3 **Levene's Test of Equality of Error Variances(a)**

Dependent Variable: difference between electricity demand and supply

F	df1	df2	Sig.
6.304	3	16	.005

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a Design: Intercept+Treatment1+Treatment2+Treatment1 * Treatment2

According to table 3, Levene's test is significant so there's no need to go any further to do univariate analysis.

Modified procedures are needed in order to test the hypotheses. We can compare group 1 and group 2, as well as group 1 and group 3, separately. Here group 1 is treated as control group. Group 2 and group 3 are treated as experiment group, which are given treatment 1 and treatment 2 separately. Oneway ANOVA was used with Brown-Forsythe statistics, which assumes significant variance.

For Treatment 1, the result is shown in table 4.

Table 4 **ANOVA**

difference between electricity demand and supply

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6712.245	1	6712.245	7.566	.025
Within Groups	7097.113	8	887.139		
Total	13809.357	9			

For Treatment 2, the result is shown in table 5.

Table 5 **ANOVA**

difference between electricity demand and supply

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	14.448	1	14.448	.013	.910
Within Groups	8570.830	8	1071.354		
Total	8585.278	9			

From table 4, it's not difficult to find that null hypothesis H_0 can be rejected, which means the information about stations under construction is significant.

According to table 5, null hypothesis H_0' can not be rejected, which means that the information about future demand has no effect.

5 Discussion

The results indicate that information about stations under construction is significant. Stations under construction can be recognized as supply line in the commodity market. Normally, people tend to ignore the supply line (Sterman 2000), which is a main cause of oscillations in the supply chain, as well as a main cause to business cycles. In reality of electric industry, it means that the policy makers, investors as well as the government officials should bear in mind how many stations have already been under construction. In the mean while, effort should be made to improve the information system of power stations all over the country. Regulations are needed as well in order to have a good control and plan over constructions. No power stations can be built without permission. Moreover, the number of power stations which are really constructed should be exactly the same as that which are reported to the information system. Honesty is also very important in order to achieve a perfect information system of power stations.

Different from earlier literature, which mainly focuses on accurate forecasting of future electricity demand, this paper puts an emphasis clearly on the importance of stations under construction. Of course precise forecasting about future demand is very important too. However, driven by the profitable goal of matching the electricity production and demand all the time, the policy makers tend to ignore the information about future demand even if it’s accurate. This also indicates that policy makers need to take into consideration the long delays in real life and stop being aggressive. It will help a lot if they are far-sighted rather than just concerned with short-term benefit.

6 Conclusions

The experimental design based on a System Dynamics model in this paper found that information about stations under construction is the main cause to the cycles in the electric industry. However, in reality, people tend to ignore the stocks in transit when making decisions.

There is still a lot to do with this problem in the future. In fact, I’ve already made this paper a point of departure for my master thesis. What still needs to be done as an extension in my master thesis can be as follows:

- Improvement on the some unrealistic stuff in this experiment, as mentioned before.
- Extending the boundary of the system studied to include environmental and economic issues: modeling the influence of constructing power stations (pollution, energy consumption, energy efficiency and so on); modeling the future electricity demand thoroughly (taking in consideration of price, demand elasticity, industrial structure, energy structure and technical improvement and so on so forth)
- Changing the goal of experiment, i.e. the goal can be the comprehensive outcome of environmental effect, economic development and so on.
- Changing treatments of the experiment, for example, the future electricity demand itself can be a treatment. National regulations, backgrounds of subjects, information about outcome feedback can also be the treatments.

7 Reference

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Appendix

The equation for simulated_construction is

simulated_construction=
MAX((desired_construction-stations_under_construction)/adjustment_time,0) (1)

Where desired_construction is the gap between electricity demand and production. The stock stations_under_construction is the power stations which are still under construction. The time constant adjustment_time is 1 year. Max function is used here because the subjects can only build new power stations but not tear down power stations which are under construction.

The equation for construction is

construction =
SELECTDECISION(INDEX(1),decided_construction,assumed_construction,simulated_construction,absent_construction) (2)

Where index (1) means the first player (this is due to the interface using powersim constructor; there is only one player in this simulator), decided_construction is the decision the subjects need to make every year, assumed_construction is the decision the current player assumes other players will make, which has no effect here on this model at all since there is only one player in the simulation. In the model, assumed_construction equals to 0. The variable absent_construction takes effect when some players are absent from the game, which is 0 as well and it has no effect on this model for the same reason. Anyway, here Equation 2 will function in such a way that construction equals to decided_construction which is decided by the subjects.

The equation for desired_construction is

desired_construction=
(electricity_demand-electricity_production)/electricity_produced_per_station_per_year (3)

Where electricity_produced_per_station_per_year is 1 unit/year. There is no need to specify what the unit specifically is for the sake of simplicity.

The equation for electricity_demand is

electricity_demand = 4+RAMP(0.5,0)-RAMP(0.5,10) (4)

The equation for electricity_production is

electricity_production = stations*electricity_produced_per_station_per_year (5)

The equation for stations_under_construction is

stations_under_construction(t+dt)
= stations_under_construction(t)+dt*construction-dt*finishing (6)

Where finishing is the flow of stations which have been finished. Initially, stations_under_construction=0.

The equation for finishing is

finishing = stations_under_construction/time_to_construct (7)

Where the time constant time_to_construct is 6 years, for explanation please refer to section 1.

The equation for stations is
Stations (t+dt) = stations (t)+dt*finishing (8)
Initially stations=4