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Research on the Effects of Urbanization on Steel Demand: An Empirical Study in China

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Abstract

Forecasting of steel demand is very important for our economy. In order to find out the connection between modernization and steel demand, we chose urbanization rate as a bridge. The study constructed an immigration model to indicate the urbanization process, then an system dynamics model was established to forecast the steel demand based on steel needs per capita. The result showed that the peak of steel demand in China would be around 100 million tone, along with 72% urbanization rate.

***Keywords**: Urbanization; Steel Demand; System Dynamics; Forecasting*

1. Introduction

The forecasting of steel demand had been taken seriously in recent years. As for China, steel industry has always been the mainstay of heavy industry. It is generally believed that the peak of steel demand in China hasn't arrived yet, since the urbanization is still on process [1]. China's urbanization rate in 2012 was 52.57%, which meant that there was still nearly half of the population working in agricultural area. And throughout the world, the peak of steel demand all comes after a higher level of urbanization.

Scholars, both domestic and foreign, had carried out some valuable research in forecasting of steel consumption peak. The most commonly used method was statistical methods. For example, Li Kai , Guo Lijie and Gao Xinrui used growth curve modeling to predict the peak of steel consumption and the time point when the peak would arrive, based on foreign steel industry historical data and trends [2-4]. Paul Crompton applied Bayesian vector auto regression method to predict the peak interval [5]. Another commonly used method was neural networks. For instance, Liu Lanjuan gave the possible developing trend of steel demand with recursive neural network [6]. And besides the two ways mentioned above, Xiang Yin, Yan Jian-ming and Guo Hua based their research on 'bottom-up' analysis [7-9]. According to the regular pattern of steel demand in construction, appliance, automotive, shipbuilding and other industries, a summarized law of steel needs had been submitted.

However, all the methods above had high requirement about historical data to do timing analysis and prediction. The fact is that there is insufficient statistical data over the years to reflect its variation. In China, the steel production and consumption have been obviously impacted by policies. Currently, speeding up the urbanization process is the policy's encouraging direction. In this study, the relationship between the level of urbanization and amount of steel consumption was the starting point. The study took advantage of the feature of the system dynamics which was that it didn't require large

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amount of historical data. Reasonable relationship between the variables and a small amount of data would be enough to do the prediction. So the study build an "Urbanization - Steel consumption "model, and brought in scenario analysis to achieve the steel consumption forecasting target.

The level of urbanization was shown through the proportion of urban population published by National Bureau of Statistics.

Table 1, showed the levels of urbanization in some nations when they reached their steel consumption peak:

Table 1. Level of Urbanization and Steel Consumption Peak in Developed Nations

	Peak year	Peak amount (10000t)	Urbanization rate
Former Soviet	1988	16304	65.3%
Belgium	1970	Between 2700-2800	94.35%
USA	1973	13680.4	73.5%
France	1974	2702.3	>70%
Britain	1970	2831.6	>70%
Germany	1974	5323	70%以上
Japan	1973	11932.2	70%

*data source: <Steel Statistics> (1949-1979), Metallurgical Press, 1980, 11.

In the 1970s, along with the completion of the industrialization, most developed countries ushered their steel consumption peaks. The values of peaks varied among different countries: peaks of France, Britain and Belgium have emerged at around 2.7 million tons; while Germany at about 500 million tons. Japan and the U.S. reached their peak in the same year, which was one hundred million tons; former Soviet’s highest level appeared a little later. And before the peak arrived, there was slight fluctuation. Then it reached 1.6 billion tons in 1988, the peak, which was followed by a gradual decline. Sweden is not included in the table, but its top consumption was only 5.97 million tons; while developing countries such as India, Argentina remain a sustained rising trend in their consumption curve [10].

The analysis above showed that a country's steel consumption peak and its specific number had no direct relations. However, the top value of consumption and production were highly correspondent with urbanization rate. Generally speaking, main reasons could be summarized as the following:

First, industrialization was an inevitable choice for the modernization of developing countries. It can be seen from the economy evolution rule that the industrial structure had all experienced a process from the textile industry leading to heavy industry leading, and then upgraded to the technical-intensive industry [11]. The level of urbanization was an important measurement for the level of industrialization. And it was promoted by industrialization. Urbanization’s growth was accompanied by industrialization, while the rising of urbanization could also encourage and promote the industrialization.

Second, the steel industry was not only a typical heavy industry itself, but also the basis for other industrial enterprises. At the same time, steel industry was the indispensable raw material provider for urban infrastructure. Therefore, both the country's industrialization and urbanization process were inseparable from the development of the steel industry. So, not until the industrialization was finished would the steel industry start to shrink.

Third, after the developed countries had completed their industrialization, the levels of urbanization have also reached a higher level accordingly. Because at this time, national infrastructure had been basically completed, and thusly, rigid demand for steel has been gradually reduced. According to market adjustment mechanism, steel production would be maintained at a relatively stable level.

In contrary, in China, urbanization still stayed in the lower level. The urbanization rate in China in 2012 was equivalent to the Britain in 1900, the United States in 1920 and Japan in 1960.

Obviously, there is still a lot of space in China's urbanization. On the one hand, China's urbanization rate increased by 1 percentage point each, which means about 13 million rural people into cities and towns, due to the need to improve their respective homes and public facilities, so the development of urbanization in China, will boost demand for steel [12]. On the other hand, the developed countries such as Japan [13], steel structured construction accounted for over 50% of all construction, while the ratio in China was less than 5%. So there would be huge potential to improve.

2. Methods

2.1. Introduction of Leslie Matrix

Leslie was a traditional method for population forecasting. Its basic concept was like this: supposing that the longevity of human life was l years, and divided it into s time periods with the same length of T=l/s. Correspondingly, the female population was also classified into s class. $Y_k(t),(k=1,2,..,s)$ represented the number of population in k-th age group in period t. Vector $\xi(t)=(Y_1(t),Y_2(t),\dots,Y_s(t))^T$ was the age structural vector in time period t.

Moreover: $X_k(t)\geq 0$ was the number of female population in k-th group in t-th time period and $b_k \geq 0\,(k=1,2,\dots,s)$ indicated the average fertility rate of women in k-th group; Vector $0<m_k\leq 1\,(k=1,2,\dots,s-1)$ stood for the proportion who can surviving from k-th to (k + 1)-th group.

It can be seen,

$$\begin{aligned} &Y(t+1)=\sum_{k=1}^{s} b_k X_k(t)+\sum_{k=1}^{s} Y_k(t), \\ &Y_k(t+1)=m_{k-1}Y_{k-1}(t),\quad k=2,3,\dots,s. \end{aligned} \tag{1}$$

Then the matrix with the form of

$$L=\begin{pmatrix} b_1X_1 & b_2X_2 & b_3X_3 & \dots & b_{s-1}X_{s-1} & b_sX_s \\ m_1 & 0 & 0 & \cdots & 0 & 0 \\ 0 & m_2 & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & m_{s-1} & 0 \end{pmatrix} \tag{2}$$

was called Leslie matrix.

(1) can be expressed as

$$\xi(t+1)=L\xi(t) \tag{3}$$

2.2. Improved Leslie Matrix

The classic Leslie was designed for general situation. In this particular situation, the model should be rewritten. The model used in this study based on the following assumptions:

First, the system boundary is our permanent residents, including two subsystems: the urban and rural populations. There are migrants between the two subsystems and the entire system won’t exchange material with the environment, which means that the impact of the annual migration abroad doesn’t count.

Second, within the research time period, there won’t be any accident like war or large-scale natural disasters which may lead to dramatic changes in the population.

Third, according to the statistical data, the age range was set from 0 to 90 years old: newborn infants aged 0, and 90 years old, including 90 and the crowd above.

Fourth, the population transfer is unidirectional, which means only rural population to urban areas, no reverse transfer exists.

Under this assumption, the present study was conducted for the following aspects to improve:

1) Discretion of the age: dividing the age interval into groups;

2) In a considerable period of time, the fertility policy remains unchanged. Assuming that women's reproductive age are g1 ~ g2, and those who are out of this age zone have a zero fertility rate. Which means b1, ..., bg1-1, b g2 + 1, ..., bn = 0. According to the National Bureau of Statistics caliber, taking g1= 15, g2= 49.

3) Different from traditional model, we assume that the number of people in time period t+1 (i.e., the last age group) is composed of two parts: those female who were originally in this group and had survived over the time period t and female population from one s-1. Namely:

$$X_s(t+1)=(1-d_{s-1})*X_{s-1}(t)+(1-d_s)*X_s(t) \tag{4}$$

Making $0 \le w_k \le 1\,(k=1,2,\ldots,s)$ the proportion of women in k-th age group, the vector recurrence formula for Y(t) in time t is：

$$Y(t)=\frac{S*X(t-1)}{W}+B*X(t-1) \tag{5}$$

Wherein

$$S=\begin{pmatrix} 0 & & \cdots & \cdots & & 0 \\ 1-d_1 & & & & & \\ 0 & 1-d_2 & & & & \\ \vdots & & \vdots & 0 & \vdots & \vdots \\ & & & 1-d_{s-2} & & \\ 0 & \cdots & & 0 & 1-d_{s-1} & 1-d_s \end{pmatrix} B=\begin{pmatrix} 0 & \cdots & b_{g1} & \cdots & b_{g2} & 0 & \cdots & 0 \\ 0 & \cdots & 0 & \cdots & 0 & & \cdots & 0 \\ \cdots & & \cdots & & \cdots & & & \cdots \\ 0 & \cdots & 0 & \cdots & 0 & & \cdots & 0 \end{pmatrix} \tag{6}$$

According to the recurrence formula of Y(t), the population can be forecasted based on the following variables: initial female age group demographics vector X(0), sub-age female mortality rate dk, female reproductive matrix Bk and proportion of female in the population.

In this study, the total population can not meet the forecast demand. Then we focus on the population structure.

We set Yu(t) and Yr(t) to stand for urban and rural population, there is

$$Y(t)=Y_u(t)+Y_r(t) \tag{7}$$

Based on assumption 4, $M_k(t),(0 \le M_k(t) \le Y_r(t-1))$ is the vector for population in k-th age group transferring from rural to urban area in t-th time stage. The rural and urban population considering immigration can be expressed as follows:

$$Y_u(t) = \frac{S_u X_u(t-1)}{W_u} + B_u X_u(t-1) + M_u(t) + e(t) \tag{8}$$

$$Y_r(t) = \frac{S_r X_r(t-1)}{W_r} + B_r X_r(t-1) - M_u(t) + e(t) \tag{9}$$

Where e(t) refers to a random disturbance term of population in each age group in t-th time stage, with expectations mean 0.

2.3. System Dynamics

System Dynamics (SD) is a classic systematic method, which was originally proposed by Professor Jay. W. Forrester, from the Massachusetts Institute of Technology (MIT) in 1956. The topic was elaborated upon in the book "Industrial Dynamics" in 1961. SD was initially used in industrial business management, which is the reason SD is also known as "Industrial Dynamics". After the introduction of "industrial dynamics," Professor Forrester published two further books in the following years: "Principles of Systems" (1968) and "Urban Dynamics" (1969). These three works built the theoretical foundation of SD.

In the early 1970s, the famous Club of Rome's used Professor Forrester's world model (WORLD II) to address the resource crisis brought about by global population growth. The group published "Limits to Growth" in 1972 [14] and "Toward Global Equilibrium" in 1973 [15]. These works led to a more complete model, “WORLD III”. Another opportunity for SD to flourish came about in 1972, when Professor Forrester undertook the task of modeling American society. The study lasted 11 years, and no fewer than 4,000 equations were established to solve the presence of a number of long-term problems in the U.S. economy. In October, 1983, Professor Forrester gave a speech at an international conference. He discussed the long-wave, a recession and innovation, all of which greatly promoted the rapid progress of his system dynamics theory and its empirical application.

Since then, the SD method has “stepped down from the altar” and has become widely used in numerous areas. Project management researchers use SD to analyze the non-linear system, since SD provides a top-down, strategic level method to describe the progress of a project, estimate the project time and forecast the cost risks [16,17]. Researchers studying energy and environment [18,19], management [20,21] and logistics [22,23] have all devoted their own efforts to the application of SD in their respective fields.

The basic mechanism employed to understand any problem in SD is closely based on the mutual dependence between the system behavior and the internal relationship. In addition, the solving process is mainly built upon the process of establishing and manipulating a mathematical model. The causality in the system is called the “structure” of the SD. The main elements constituting the SD model structure include the following items: "Flow" "Level" "Rate" and "Auxiliary".

Each variable in the model has very real physical significance. A very important feature of any SD model is that it has feedback control. Feedback control refers to the process of sending the output back to the input, in order to compare and to define the deviations, which, in fact, is to guide the present and future states with the past state. Two different types of feedback exist in the control system, namely negative feedback and positive feedback. If the returned signal produces an inhibitory effect on input, it is treated as negative feedback, which can be used to stabilize the system. If the returned information enhances the input, it is called positive feedback, which can then be designed to strengthen the input signal.

An SD model is described by DYNAMO language, which is an acronym for “Dynamic Model”. The only independent, continuous variation in DYNAMO language is time (t); every other variable can be expressed as a function of constant or t. The DYNAMO model is constituted by a group of algebraic equations, each of which pictures how a certain part of the system runs simply and clearly. In standard DYNAMO language, variables are indicated by a string with from one to five letters, while some variable names are pre-ordained "TIME", for instance).

A system dynamics model is described by six basic equation types, which are, respectively:

L: Level variable equation. It is critical to select a set of variables as LEVEL. They are the quantitative indicators within the system. Accumulation is the basic characteristic of LEVEL, and the L equation is designed to describe the process. The value of LEVEL at the current time point t numerically equals the value at time point t-1 plus the changes during DT.

The L equation is expressed in the following form:

$$L \quad F_{l,t+1} = F_{l,t} + DT * \Delta R_{l,t}$$

In which refers to the value of level variable l at time t + 1; is the value of variable l at time t. DT is the time increment, and represents the changing rate of l in DT.

R: Rate variable equation. To describe the changes over time, RATE is used in DYNAMO language. Identifying the factors that affect the RATE variable, we can control the rule of system dynamic. R equations were created to define the RATE resulting in changes of LEVEL variables.

The R equation is expressed in the following form:

$$R \quad R_{l,t} = f_{l,t}$$

$R_{l,t}$ means the changing rate of l during t period, under the rules of .

A: Auxiliary variable equation. In addition to the LEVEL, RATE and constants, there are variables for decision support called AUXILIARY.

The general expression of the A equation is:

$$A \quad A_t = f_{a,t}$$

It is the value of the auxiliary variable in time t, is the changing rules.

N: Initial value equation

$$N \quad N_{t0} = Int$$

N_{t0} as the initial value at time t0 with the value of Int, which is usually expressed as a constant, vector or matrix (the latter two need to achieve through a table function).

T: Assignment to Y in table function

T equation is a table function equation, indicating the corresponding assignment of ordinate Y. The form depends on the circumstances.

C: Constant assignment equation

2.4. Leslie-SD Modeling

The Leslie-SD modeling are as follows:

Step 1. Construction of rural and urban female age group vector in t time period: Xu(t),Xr(t);

Step 2. Construction of Leslie matrix for rural and urban population in t time stage:

$$Leslie_u = S_u X_u(t-1) + B_u X_u(t-1) \tag{10}$$

$$Leslie_r = S_r X_r(t-1) + B_r X_r(t-1) \tag{11}$$

Step 3. Forecasting the population in t+1 time stage, see for 8 and 9;

Step 4. Forecasting steel demand by Leslie-SD matrix:

Step 4.1. LEVEL formula

$$\begin{aligned} L\quad & Y_u(t+1)=Y_u(t)+DT*\Delta Y_u(t) \\ & Y_r(t+1)=Y_r(t)+DT*\Delta Y_r(t) \\ & HS(t+1)=HS(t)+DT*\Delta HS(t) \end{aligned} \tag{12}$$

Step 4.2. RATE formula

$$\begin{aligned} R\quad & \Delta Y_u(t)=B_u X_u(t)+M_u(t)+e(t) \\ & \Delta Y_r(t)=B_u X_r(t)-M_u(t)+e(t) \\ & \Delta HS(t)=Delay1(\Delta Y_u*HS/A*Are/p) \end{aligned} \tag{13}$$

Step 4.3. AUXILIARY formula

$$\begin{aligned} \mathrm{A}\quad & UrR(t)=Y_u(t)/sum(Y_u(t),Y_r(t)) \\ & =\left[\frac{S_u X_u(t-1)}{W_u}+B_u X_u(t-1)+M_u(t)\right]/ \\ & \left[\begin{array}{l} \frac{S_u X_u(t-1)}{W_u}+\frac{S_r X_r(t-1)}{W_r}+B_u X_u(t-1) \\ +B_r X_r(t-1)+M_u(t)+M_r(t) \end{array}\right] \\ & ArcS(t)={}^{HS(t)}\!\big/_{HoR} \\ & StD(t)={}^{ArcS(t)}\!\big/_{ArcR} \\ & StP(t)=\alpha*StD(t) \end{aligned} \tag{14}$$

Step 4.4. Initialize the variables

$$\begin{aligned} N\quad & X_u=2.724715 \\ & X_r=3.613385 \end{aligned} \tag{15}$$

The relationship of steel demand and population can be described as:

$$\begin{aligned} StP(t) & =\alpha*{}^{ArcS(t)}\!\big/_{ArcR} \\ & =\alpha*{}^{HS(t)}\!\big/_{HoR*ArcR} \\ & =\alpha*{}^{Delay\,1(\Delta Y_u*HS/A*Are/p)}\!\big/_{HoR*ArcR} \\ & =\begin{cases} \alpha*\dfrac{Delay\,1[(B_u X_u(t)+M_1(t))*HS/A*Are/p]}{HoR*ArcR}, \\ UrR(t)\le UR; \\ \alpha*\dfrac{Delay\,1[(B_u X_u(t)+M_2(t))*HS/A*Are/p]}{HoR*ArcR}, \\ UrR(t)>UR. \end{cases} \end{aligned} \tag{16}$$

3. Variables and Data

Before 2004, China's crude steel production was slightly lower than the demand, the demand for yield ratio remained at around 1.1; from the beginning of 2005, crude steel production exceeded demand, the demand for yield ratio dropped to around 0.9. According to current trends, this study assumes that in 2030, demand for crude steel output ratio is maintained at the current level. With StP for crude steel production, StD for crude steel demand, the above relationship can be expressed by the formula:

$$StP=StD/\alpha, \alpha = 0.9$$

According to data released by the Planning Institute of Metallurgy, 2005, China's construction steel accounted for 54.7% of total demand of steel, and housing construction steel took up for 35% of the total urban construction steel; according to data released by the Ministry of Housing, China's urban per capita housing area in 2000 was 20.4m2, 26m2 in 2005, and 31m2 in 2013; different types of construction have different amount of steel consumption, according to the amount of all types of residential construction steel building design classes offered in an average of about 40kg/m2.

"Scenario" was firstly appeared in 1967 in the book coauthored by Herman Kahn and Wiener —"THE YEAR 2000" (Herman Kahn and Anthony Wiener 1967). Unlike the previous trend extrapolation method, scenario analysis added some qualitative analysis which meant to join the personal experience into analysis process. Thusly, the deviation between quantitative analysis results and actual data could be eliminated effectively.

4. Results and Analysis

4.1. Prediction under Different Scenarios

This study focused on the relationship between the process of urbanization and the demand for steel. Natural growth rate of the urban population could be seen as fixed in a certain time period while the immigration rate would be effected significantly by the policy and other external factors. So the immigration rate was set to be the scenario variable.

There were four different scenarios in this study according to the real population mobility rate:

Scenario ONE: the immigration rate was set the same as the current level, which means there were 2% of rural population move into the urban area each year. At this level, China's urbanization rate would achieve the target- 70% in year 2037, and steel demand would hit its peak in 2043 valued 1.033 billion tons. After that the steel demand showed a slow decline.

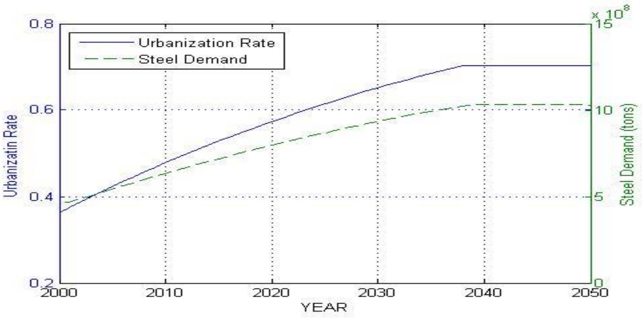

Figure 7. Scenario ONE (Urbanization Rate & Steel Demand with 0.02 Immigration Rate)

Scenario TWO: the immigration rate was set the same as the highest value in history, which was 0.026. In this level, the urbanization rate would reach 70% in 2029, and the steel demand also meet the highest level in 2043, which would be about 1.0315 million tons.

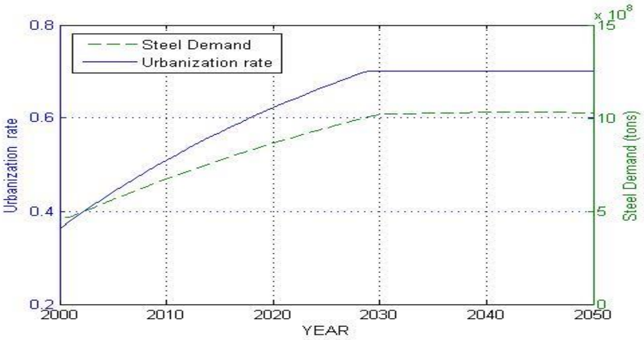

Figure 8. Scenario TWO (Urbanization Rate & Steel Demand with 0.026 Immigration Rate)

Scenario THREE: the immigration rate was set the same as the lowest level in history, namely 0.01. Under this circumstance, till 2050, the urbanization rate and steel demand would still be growing without meeting the established goals.

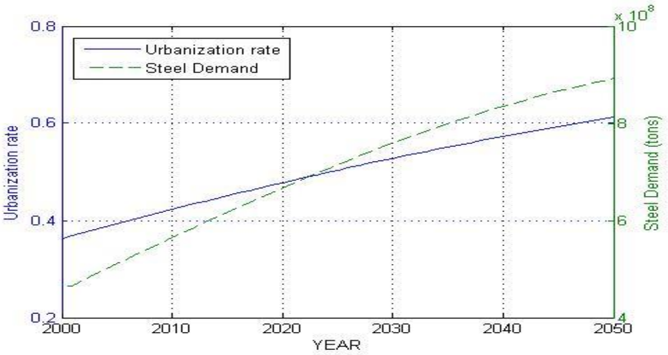

Figure 9. Scenario THREE (Urbanization Rate & Steel Demand with 0.01 Immigration Rate)

Scenario FOUR: In accordance with the agreed targets which indicated that the urbanization rate would achieve 70% in 2050. Correspondingly, the conversion rate was approximately 0.0151. In 2050, the urbanization rate would be 69.94%, and steel demand 1.0198 million tons. And both curves were still growing.

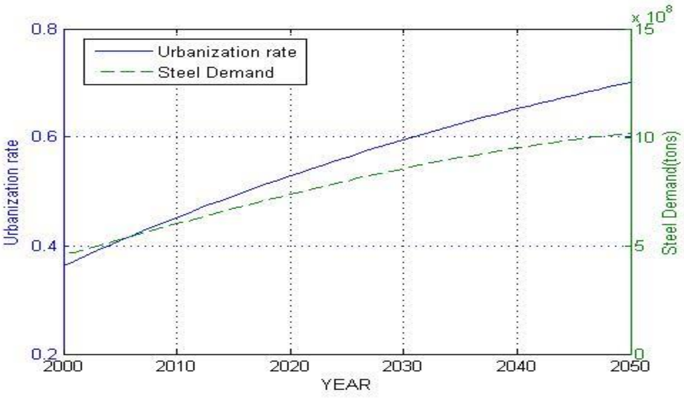

Figure 10. Scenario FOUR (Urbanization Rate & Steel Demand with 0.0151 Immigration Rate)

4.2. Discussions

It can be seen from the simulation results in 4.1 that:

(1) Under the conditions of the existing policy, China's steel demand will reach its peak, which would be about 1.033 billion tons, in 2043. This number is at the same level with Japan and United States when their peak arrived. The urbanization would be 70.3213% at that time point which is also the same with the developed countries.

(2) If the policy encouraged the process of urbanization, which means that the migration rate would remain at a high level, then the peak of China's steel demand will still appear around 1.03 billion tons or so, while the urbanization rate of approximately 72.0546%.

(3) If some kind of suppression appeared and the urbanization rate was kept at a relatively low level, then by 2050, the peak demand for steel has not appeared yet. The level of urbanization is about 61% at that time.

5. Conclusion

To draw a conclusion, China's steel demand peaks will appear in the level of one billion tons, accompanied by a 70% -75% of urbanization level, which is similar to the development of United States, Japan and other developed countries. With encouraging policy, this state will occur around 2030; and with current existing policy, the peak achieved in 2040s.

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