Quantitative Risk Evaluation of Strategy Planning For Oil and Gas Development

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I. Background and Aims

Strategic Planning is comprehensive, forward-looking and is a guiding principle to action for healthy development of a country, an enterprise, or an organization. For an oil and gas company, the strategic planning is regarded as the guiding principle for its future development. A good strategic planning enables oil and gas field to follow its own natural rule, and enables the enterprise to achieve efficient and sustainable development. But the phenomenon is contradictory that we use deterministic parameters to formulate oil and gas development strategic planning while there are so many uncertainties in this process, such as reserves, costs, and price. Therefore, it urgently needs to establish an effective evaluating method which can help to improve the guidance function of strategic planning.

Risk analysis was initially introduced to evaluating oil and gas industry in 1960s which focused mainly on research of drilling projects, and then extended to the areas of exploration and development projects as well as environment protection projects in 1990s. In recent years, it focuses on comprehensive evaluation of the oil and gas industry chain. But it is different between general studies and strategic planning. And there are four main differences:

(1)Unlike the general risk analysis mostly having only one field, strategic planning usually involves a large number of fields and it must be determined firstly whether all the fields will be developed and which specific one should be developed later. Meanwhile those fields are in different stage: proved developed, proved undeveloped, and unproved. Each type has its own characteristic and need specific solution.

(2)The starting time of a project is considered totally differently. The general risk analysis just focuses on the production of each year, no matter in which year the project will begin. While in strategic planning time will act an essential function.

(3)Maximum economic benefit and reasonable production profile are equally important to strategic planning, but for general risk analysis, economic benefit is the only target and less production risk is mentioned. In China, production is also important and is no less than economic benefit.

(4)The result of quantitative risk evaluation of strategic planning will present the production profile and economic profit probability distribution; furthermore, it would show the effecting extent of variable parameters. Moreover, those parameters have their own distributions, with different floating rates unlike sensitive evaluation in general risk analysis the parameters changing at two fixed values ±10%.

Because of those specificities, a new method has been established to evaluate the risk and solved the peculiarity in a better way which can improve strategic planning scientific, controllability and ability to resist risks.

II. Classification of Risks

The oil and gas company systematically sums up the development history, precisely evaluates the present status, scientifically predicts the future, and formulates development direction and goals. The strategy planning is a comprehensive output. There are many fields in an oil and gas region and those fields are in different stage: proved developed reservoirs, proved undeveloped reservoirs, and unproved reservoirs. From the exploration and exploitation stage, the risks are analyzed in detail as follows.

A. **Risks in exploration Stage**

The task of exploration activity is to find out enough reserves served for development needs. The practical experiences show that uncertainties in reserves scale are often the greatest risk in strategic planning implementing. Because of the regional resource conditions and the influence of human activity, exploration results have great uncertainty, which display in the following two aspects, namely the reliable resources and exploration speed.

(1) Risk of reliable resources refers to the uncertainty in reserves scale that could be found out in exploration stage. The more scientific the resource sequence, total oil and gas resources quantity(Fig1), hypothetical resources, potential resources, remaining forecasting reserves and controlled reserves is, and the reasonable the awaited drilling echelon is, the easier resources transformation process is to control, and the more confirmatory reserves scale could be found out, and the less risk is. And different with risks in unproved reserves, the proved reserves' risks come from reservoirs' acreage, thickness, porosity, oil and gas saturation and the volume coefficient.

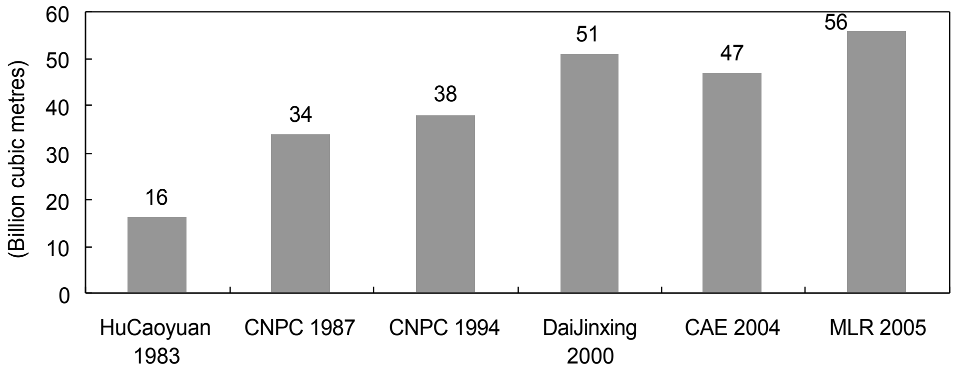

Fig1 Chinese resources evaluation results in history

(2) Exploration speed risk refers to uncertainty of annual proved reserves scale to be found out. Limited by harsh geographical environment, increasingly complex exploration targets, exploration technology, investments and some other reasons, annual submitted reserves is limited. In a short time, the action to get higher degree by trying to drill more exploratory pits takes great risk. There is a reasonable range for annual proved reserves and the more reserves we want, the more time we need.

B. **Risks in Development Stage**

After submitting proved reserves, productivity evaluation and delineation, it goes into productivity construction and production stages. Oil and gas field development pursuits for reasonable production scale, longer plateau period and higher ultimate recovery. Whether the target can be achieved depend on avoiding risks from productivity construction and production.

(1)Productivity construction contains well drilling and surface construction. Risks of productivity construction exist objectively because of harsh geographical environment, the uncertainty of reserves, drilling cost vibration, level of drilling and completion technology and the team quality.

(2) Production implementation risks can be divided mainly into objective aspects and subjective aspects. From the objective point, the geology we realized initially maybe deviate from the reality underground because of the complexity of geological conditions. From the subjective point, artificial measures without considering the objective law also increase the uncertainty.

C. **The Constrained Risks**

Mainly includes the economic profit, transportation capacity, downstream demand and policy constraints. One side, some factors increase the uncertainty to economically develop, especially in marginal reserves, such as price vibration, investment and cost control, etc. On the other side, constraints from market demand, midstream transmission, laws and regulations, intensify the uncertainty of development indirectly. The development of American unconventional gas is a represented example reflected the energy laws and regulations uncertainty. According to Conocophillips calculation, 30% profits derive from the policy support in the unconventional gas development at early stage.

III. Risk Evaluation Methods

Monte Carlo method is introduced in order to quantify the risk of oil and gas development strategy planning. The general process usually includes four steps: defining evaluation objectives, alternating simulation function, describing quantitative parameters and case study.

A. Evaluation Objectives

The first important step is articulation of strategic objectives. This can be challenging when there are multiple, inconsistent objectives. Here are the leading objectives identified by oil and gas producing company: net present value of cash flow, stable production, short-term cash flow, ultimate earning, HSE and flexibility. Primarily, the operator pursues maximization of NPV of cash flow, calculated using the corporate discount rate. But in China, oil and gas enterprises are mainly state-owned enterprises, and the attributes of state-owned decides it is very important to ensure the long-term and stable supply of resources while pursuing the economic profit, which can be named the need to shoulder more social responsibility. Therefore, stable production is equally important with economic profit. From a dialectical point of view, either profits without stable production supply capacity or production without profits can't represent the planning target. Thus regard the economic profit and production as the evaluation objectives.

B. Production Simulation Model

The risk simulation is to setup the relationship between quantized risk target and impact parameters by logical or mathematical expression.

(1) production simulation without constraints

There are more than ten methods to predict oil and gas production and the most commonly used method is production component which divides the evaluating region into many small evaluating units referring to their development stages, such as proved developed, proved undeveloped and unproved reservoirs. Then the whole region's production can be got by summing up all units' production.

$$\sum_{i=1}^{m+n+q} q_{i,t} = \sum_{i=1}^{m} PD_{i,t} + \sum_{i=m+1}^{m+n} PUD_{i,t} + \sum_{i=m+n+1}^{m+n+q} UD_{i,t} \qquad (1)$$

q : evaluating unit production rate, PD : proved developed reservoirs' production rate, PUD : proved undeveloped reservoirs' production rate, UD : production of unproved reservoirs that would be founded out during the planning period, m 、 n 、 q : number of reservoirs in different stage, t : time, i : subscript.

A reservoir is the minimum evaluating unit of production component method. It usually goes through three stages, increasing production stage, stabilized production stage and decline period (Fig2). Without regard of constraints, the production profile is described by equation 2.

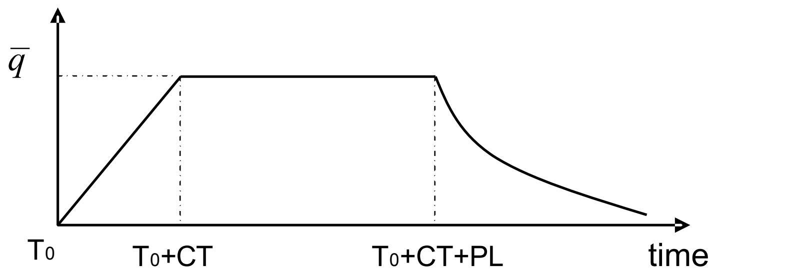

Fig2 Schematic diagram of reservoir development stage division

$$q_t = \begin{cases} (t - T_0) \bar{q} / C_T, & if\ T_0 \le t < T_0 + C_T \\ \bar{q}, & if\ T_0 + C_T \le t < T_0 + C_T + PL \\ q_{t-1} \times D_R, & if\ T_0 + C_T + PL \le t < T_f \\ 0, & if\ t \ge T_f\ \text{or}\ t < T_0 \end{cases} \quad (2)$$

t: time, T_0 : commissioning date, C_T : productivity construction period, PL : years of stabilized production, T_f : the whole life cycle, D_R : decline rate. Besides, $\bar{q}$: production scale during plateau period (Equ3):

$$\bar{q} = R_e \times R_{PR} \times P_R \quad (3)$$

R_e: reserve scale, R_{PR} reserve producing degree which refers to the degree reserves can be put in developed , P_R recovery rate.

（2）production simulation within constraints

Actually, oil and gas reservoirs have to face so many constraints and both evaluating units' and the whole region's production profile needs to be adjusted.

Constraints that should be taken into account in evaluating unit are as follows:

- Internal constraints derived from evaluating unit itself. So many factors should be considered, such as whether investment is enough, whether workload is supportive enough (mainly refers to the drilling well number), whether purification plants can meet the processing requirement and so on. Considering the constraints, production rate should be adjusted; it should be the minimum between ideal production rate and constrained production rate (Equ4).
- External constraints derived from the evaluating region. After considering constraints, production rate should be adjusted one more time, which should perform with region's production rate adjustment simultaneously.

$$q'_{i,t} = \min(q_{i,t}, q_{i\,constrained}) \quad (4)$$

Constraints in the whole evaluating region are:

- Market demand constraint, taking smaller value by comparing total reservoirs' production rate and market demand.
- Transmission capacity constraint, taking smaller value by comparing total reservoirs' production rate and transmission capacity.
- Policy and regulation constraint, taking smaller value by comparing total reservoirs' production rate and constraint production rate.

Among three constraint scenarios, when total reservoirs' production rate is less than constraint production rate, production rate of evaluating unit and the whole region are no need to be adjusted; when total reservoirs' production rate is more than constraint production rate, production limitation should be performed to part of the reservoirs. And the determination of limitation sequence and scale should refer to the following factors comprehensively:

- Difficulties in recovering production scale.
- The minimum production scale requirement. Usually we won't shut all the wells simultaneously.
- Development economic profit. Production limitation begins with the non-profit or low-profit reservoirs.
- Influences to ultimate recovery by production system adjustment

After taking all the constraints into account, production adjustment should be carried out as follows:

$$\sum_{i=1}^{x+y} q'_{i,t} = \begin{cases} \sum_{i=1}^{x+y} q'_{i,t}, \quad upper, \; if \; \sum_{i=1}^{x+y} q'_{i,t} < Q_{constraint} \\ \sum_{i=1}^{x} q'_{i,t} + \sum_{i=x+1}^{x+y} q'_{i,t} / c_{i,t}, \quad upper, \; if \; \sum_{i=1}^{x+y} q'_{i,t} > Q_{constraint} \end{cases} \quad (5)$$

x : number of reservoir with no production adjustment, y : number of reservoir with production adjustment, $c_{i,t}$: adjusting coefficient of production rate.

After considering reservoirs' constraints, then actual production rate should be adjusted one more time.

$$q'''_{i,t} = \begin{cases} q''_{i,t} & if, \; i < x \\ q''_{i,t} / c_{i,t} & , \; if \; i > x \end{cases} \quad (6)$$

Based on production rate adjustment, the actual production rate in a given year is calculated. By the end of this year, the recovery is calculated, which helps to select simulation function for the next year (equ2). At this process we realize constraints from one time nodal to another (Fig3).

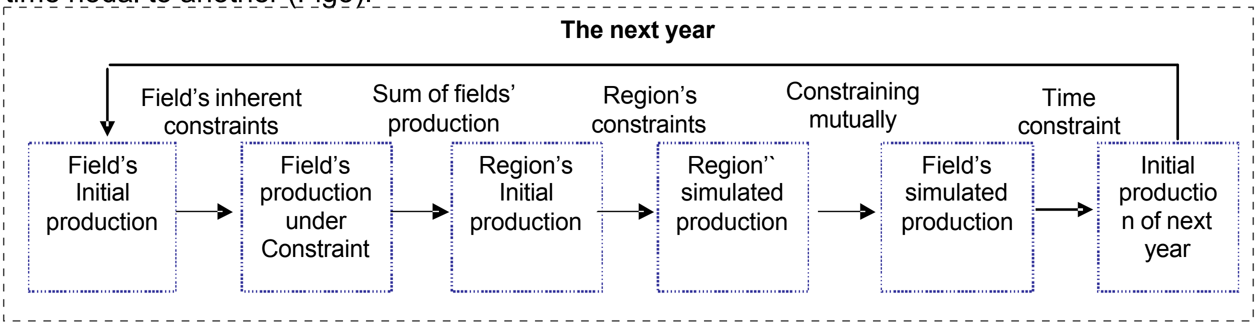

Fig3 Production simulation process considering constraints

C. Economic Profit Simulation Model

Cash inflow and outflow method is introduced to evaluate economic profit. Due to different stage where reservoir stands and different parameters for cash flow calculation, corresponding calculating function should be selected. It can be divided into two types.

① Method for developed reservoirs' cash flow calculation. For there is no productivity investment, we incite production cost (sum of depreciation and operating cost) to cash flow calculation; occurred productivity construction investment is reflected by depreciation. The method for calculating the annual cash flow is as follows:

$$Bf_t = \left\{ q[Rco \times (Prc \times rice) - Cpu](1 - Rct)(1 + Rdc)^{t-1} \right\}_t \quad (7)$$

Bft : annual discounted cash flow, q : production rate, Rco : commodity rate, Prc : price, Cpu : production cost, Rct : general tax , Rdc : discount rate, t : time.

② Method for undeveloped reservoirs' cash flow calculation. As the reservoirs need a lot of investment to be developed, productivity investment with operating cost should be taken into consideration when calculate cash flow. The method is as follows:

$$Bf_t = \left\{ q[Rco \times Price - Cop] - Rct - Invest \, (1 + Rdc)^{t-1} \right\}_t \quad (8)$$

Cop : operating cost, $Invest$: productivity investment.

During economic profit evaluation, the probability of annual discounted cash flow beyond zero of the whole appraisal area should be calculated, which means the total income is less than the total expenditure and represents high risky.

Besides, accumulative cash flow of new developed reservoirs during total life cycle can be calculated. The probability of cash flow beyond zero represents how risky the new investment is.

D. Quantitative Parameters Description

Based on analysis above, quantitative risk analysis of production rate and economic profit involves parameters as follows: reserve scale, reserve producing degree, productivity construction period, production rate, years of stabilized production, decline rate, ultimate recovery, price, cost, etc. The probability distribution functions of those parameters can be defined through two methods which based on abundant statistic and standard functions selected by characteristic of each parameter, such as uniform distribution, triangular distribution and normal distribution and so on.

Development stage should also be considered to determine parameter distributions. As in different development stages, the same parameter in different evaluation units would be described diversely. For unproved reservoirs, it usually takes surrounding fields' parameters as reference according to geological characteristics. Proved undeveloped reservoirs' parameter distributions are mainly based on geological characteristics through statistical analysis and discrete function. Developed reservoirs' parameter distributions tend to use decision tree method, because of detailed dynamic information and better understanding.

E. Quantitative Parameters Sensitivity Evaluation

Different distribution means different risk. We simulate the quantitative parameters sensitivity with the same probability step of one parameter, for example with accumulative probability by 0%、20%、40% … respectively.

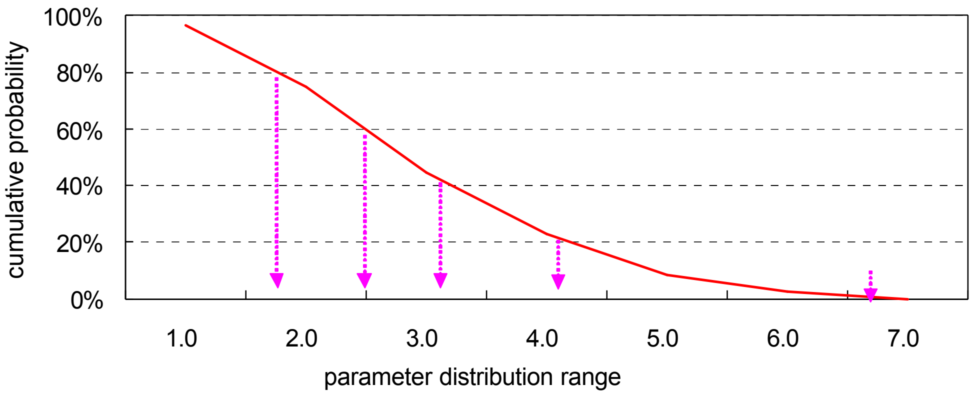

Fig4 Quantitative parameters sensitivity evaluation based on the same probability step

IV. Case study

A. Background

Taking a structural belt for example, it has entered into fast growth phase, with a production from 0.8 million cubic meters in 2000 to 18 million cubic meters in 2010. The major developed fields are in production plateau, and undeveloped reserves concentrated in a few large potential fields certified by the pilot test. However, the burial depth of those fields is more than 5000 meters, resulting in slow productivity construction. So a strategic planning was made to speed up the whole development. And at the mean time, quantitative risk assessment and corresponded countermeasures would be launched.

B. Subdivision of Evaluating Units

Before simulation, it is very important to effectively divide or merge evaluating blocks according to their characteristics. Developed reservoirs in this structural belt distributed concentratedly. But they have different geologic characteristic. Some reservoirs are low permeability and the others are high pressure, deep zone and high permeability. As the differences in geologic characteristic and development laws, they need to be stimulated separately. Proved undeveloped fields usually have similar geologic characteristic and development law, so they could be merged as one unit. Besides, the structural belt have some exploration potential, with some reserves being in control or forecasting status, some resources being in potential traps waited for drilling.

C. Comprehensive Risk Evaluation

Based on analysis above, the production profile and cash flow are simulated 1000 runs. From the simulation results, we see that it has the largest risk to achieve the production target. In details, there is no more than 5% probability achieving the production target of 30 million cubic meters in 2015(fig 5 and fig6). But the probability of annual net present value larger than zero surpasses 80% throughout planning period because of high individual well producing rate, which means low economic risk (fig7).

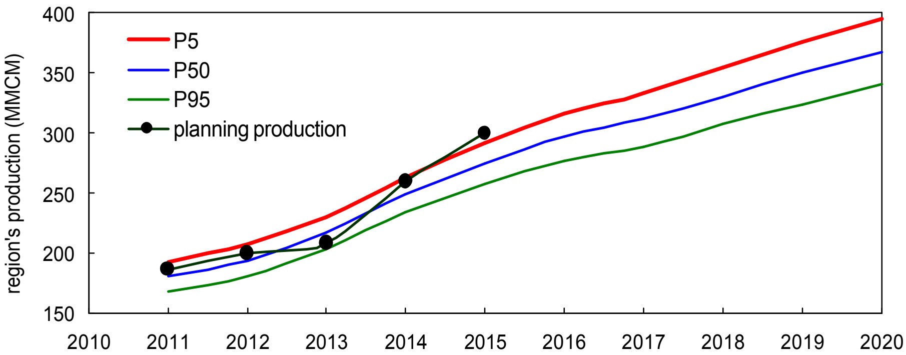

Fig5 Tectonic belt's production trend under different probability scenarios

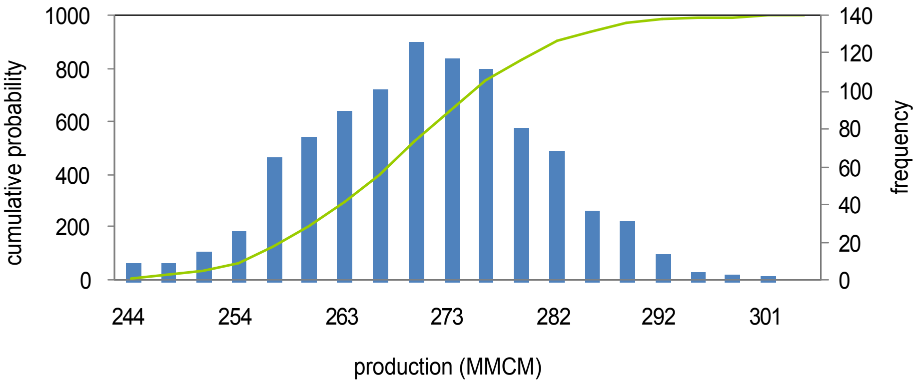

Fig6 Tectonic belt's 2015 production distribution based on MC simulation with 1000 runs

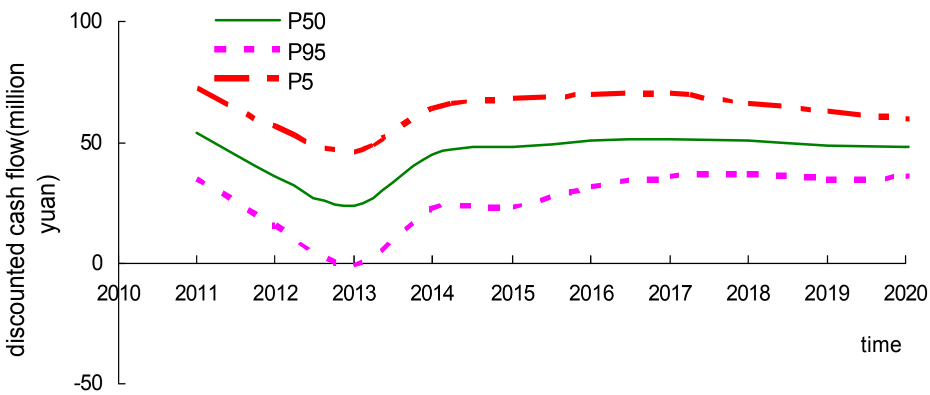

Fig7 Tectonic belt's discounted cash flows trend under different probability scenarios

D. Risk Factors Analysis

From year 2011 to 2015, the risk factors affecting production are mainly from reserves, producing degree and recovery rate, while the degree of reserve recovery at the end of production plateau, decline rate and recovery factor have less influence.

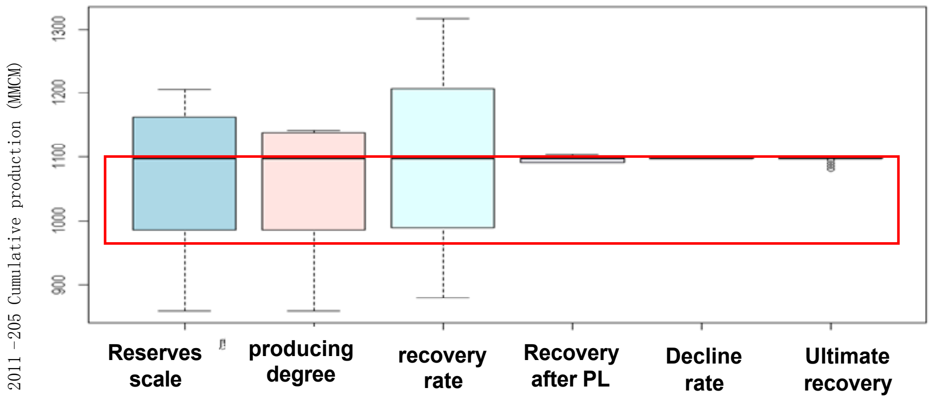

Fig8 results of the sensitivity analysis of 2011-2015 cumulative production

E. Countermeasures Against Risks

In order to achieving the production target of 30 million in 2015 (no less than 50% probability) and guaranteeing the production targets of year 2011 to 2014, the cumulative production should reach 1240 million cubic meters during year 2011 to 2015. Two ways could be used either by finding newly incremental reserves by 220 million cubic meters from year 2011 to 2012 considering drilling cycle (table 1) or by increasing recovery rate by 10% (Fig9). But there is no help to meet the production target by increasing the producing degree or degree of reserve recovery.

Table 1 relationship between production rate and **incremental reserve**

Year 2011-2012 newly incremental reserve	Production rate in 2015， P50
110 million	28.5 million
220 million	30 million

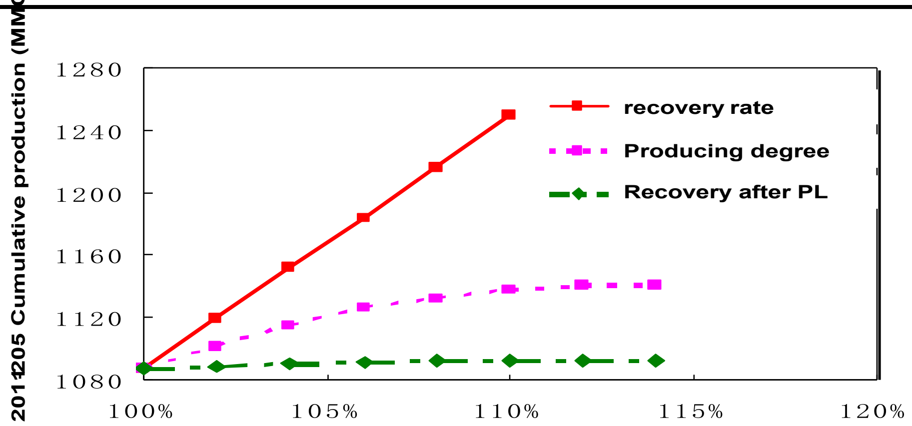

Fig9 relationship between cumulative production and parameters' relative increments

V. Conclusion

Considering the specificities of strategy planning, this research tries to convert the complex 'physical problem' to 'quantitative mathematical problem' by choosing suitable production and economic functions, which solves the problem of mutual influence relation among different reservoirs and different time codes. From the case study, we realize that this model not only draws the development future of the evaluated region, but also shows main risks that influence the assessed results, which help decision-makers to take proper measures to avoid risk occurrence. It is a leap-forward from qualitative analysis to quantitative analysis, which improve the quality of oil and gas development strategic planning and strengthens its leading function.

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