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PARTICLE SWARM OPTIMIZATION FOR MANAGING AS INJECTION ALLOCATION

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Abstract

In oil and gas industry, the size of hydrocarbon reserves and type of the reservoir is crucial to the design methods and lifting the hydrocarbons for further processes. PT. XYZ uses the gas lift injection design to lift the oil content from the reservoir. In some conditions, the production choke valve shall be opened moreto increase the hydrocarbon production rates. However, it causes the reservoir instability, decreasing the reservoir pressure, and reducing the oil production drastically.Therefore, optimization of allocating gas lift injection rate on each of the production is needed to produce maximum oil and to improve the sustainability of oil and gas production on PT.XYZ. This paper proposes optimization technique for managing gas injection allocation using Particle Swarm Optimization (PSO). The procedure optimization can be explained as below; first step uses prosper modeling software to generate the model of production wells. Second, it obtains the curve of the gas lift injection rate against the oil production. Third, each well production model is validated by reference data from the well test result. The best PSO simulationwith limited gas injections which is 17 MMscfdresults of the gas lift injection allocation for each production wells are 0.98, 2.66, 1.39, 0.98, 3.19, 1.61, 1.78, 2.03, 1.40, and 0.98 MMscfd.With these gas injection allocations, the oil production increases to 4908.7 Barrels of oil per day (BPD). Maximum company profit after optimization reaching USD$ 578,004 compare with before optimization. The other optimization using Genetic Algorithm (GA) is also used for comparison.

Keywords: Optimization, Prosper Modeling, PSO, GA.

INTRODUCTION

Company PT. XYZ is one of exploration and exploitation of oil and gas production, expanding its area in East Java region. At the beginning of the production development, simultaneously operations had setup to produce oil and gas as well as to continue the drilling activities for new wells. The produced gas from the reservoir injected back into the new wells using gas-lift method to gain oil content. The opening and closing the gas valve injection is utilized the mechanical process at certain process conditions.

The Initial oil production was approximately 1,000 Barrel per-day (BPD). Fairly consistent of drilling program provides addition new wells and increasing the oil production into 2,000 BPD. To reach the production target and customer requirements, the gas well was produced faster than it should be by more opening the production choke valves. It’s resulting in higher gas production rates for certain period but after that period the reservoir pressure decreasing and cause the reduction of oil produced.

To solve the optimization problem associated with the allocation of gas injection flow rates in multi wells, it's requires well production models approaches which in this paper will be defined using prosper software. In fact, the amount of gas is need to be injected into the wells is very limited since its use the produced gas from the reservoir.

Gas lift performance curve (GLPC) was developed to determine the optimum gas injection rates for each wells and to calculate the total gas required to produce the maximum oil production. The availability of gas injection is one limitation of the field beside the water treatments capacity. The result from GLPC is needed to approach with exponential function to get the mathematics formula.

The next step is implementing the optimization of gas-lift using PSO method. The result is also solved by genetic algorithms (GA) method from solver function add-in for comparison. The results will be incorporated into the objective function for company’s profit. It is expected that the comparison of these results would generated the best solution to solve the problems of gas-lift optimization at PT. XYZ.

PSO is easy to implement compare to other GA technique and has been successfully applied in many areas such as function optimization. The attractive of PSO is that there are few parameters to adjust. One formulation, with slight variations, works well in a wide variety of applications. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.The PSO used to find approximate solutions for difficult numeric maximization and minimization problem such as gas lift allocations optimization for this studies.

WORK METHOD

The study of gas-lift optimization in this problem consisted of three stages.The first stage is preliminary studies then continue with second stages which is GLPC modeling and the third parts is optimization of the GLPC model that are obtained to increase the oil productions.

GLPC model is developed from collective field data and mainly use to provide the transfer function from the field data into mathematics formulation which is fit to exponential function. The results of GLPC modeling as necessary will be validated against actual field conditions through a comparison mechanism using the well production test data.

Preliminary study is requires to determine the objective function, constraint functions and the analysis of production optimization possibilities. The Optimization method used is PSO method and compare with GA from adds-in solver function. These two methods are used to solve nonlinear optimization problems using the principles of evolution found in nature for finding an optimal solution. The type of these optimization methods uses artificial neural network is defined as a non-deterministic method, which can produce solutions that are slightly different on each time the experiment is done.

PRELIMINARY STUDIES

At the preliminary study stage, it starts with conducted initial research on production data owned by PT. XYZ and explored declining issue in oil production rates. Furthermore, it determines the literature study of the relevant theories and concepts related the solving problems.The theories and concepts that are used in this study includes the actual data at process conditions, reservoir data, GLPC modeling, gas-lift optimizations, generating economical objective, constraints in the field of production, calculation of production profit, PSO and GA. By determining the allocation amount of the required gas-lift injection on each of the production wells, the company can increase the oil production rates and maximize the profit [1].

The PSO and GA optimization methods are to solve nonlinear optimization problems using the principles of evolution which found in nature for finding an optimal solution. Optimization method used artificial neural network is a non-deterministic method, which can produce a solution that is slightly different on each time the experiment is done.

The solution of optimization using GA is represented as a chromosome. The initial population is generated at randomly to obtain the initial solution. Reproduction/selections, crossovers and mutations are the common operations that use in GA to get the solutions. After a few generations, these generated chromosomes will have converges to a certain value. This value is the best solution that generated using GA method [3].

The application used PSO method for solving optimization problem focuses in the computational heuristic particle velocity settings and probabilistic. Each initial randomly particle is assumed to have two characteristics for position and velocity. These particles move in a space to pass the best position is the value of the objective function.Each of the particles conveys information for particle best position to another. It also adjusts its position and speed based on the information is receiving from the best position information.

Field Data Collection

Based on literature studies, field data collection is conducted to get the collective data production owned by PT. XYZ. These data is used in this study as primary data obtained from the exploration and drilling data such as the pressure, volume, temperature, completion, well tests, wellheads pressure, oil production rates, and gas injection rates. Table 1 is listed the production data before optimization.

Table 1 Production data before optimization

WELL	OIL_COND	WATER	FORM_GAS	GL_GAS	TOTAL_GAS
UPB1	39	5,554	300	2,115	2,415
UPB2	644	4,232	1,521	1,659	3,180
UPB3	566	3,885	1,211	2,239	3,450
UPBGAS	23	-	9,302	-	9,302
UPB4	13	3,523	115	1,573	1,688
UPB5	1,194	3,113	935	1,567	2,502
UPB6	666	1,242	121	1,709	1,830
UPB7	479	4,037	477	2,045	2,522
UPB8	432	2,924	122	1,561	1,683
UPB9	247	1,975	69	1,539	1,608
UPB10	270	1,055	2,591	1,019	3,610

GAS LIFT PERFORMANCE CURVE MODELING

GLPC modeling is needed to develop for each production wells as shown in Figure 1. It is based on actual data which shall be used its mathematical function to solve the optimization problem. The GLPC mainly shows the correlation function between the gas injection rates and the oil production rates. Prosper software is used to develop the GLPC modeling [2].

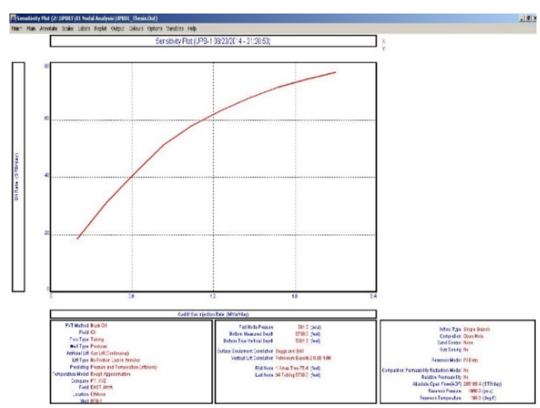

Figure 1. Sample of GLPC modeling results

The GLPC modeling results shall be approached with an exponential function or a higher order polynomial function. Early research has conducted by Robert N. Hatton and Ken Potter [4] states that exponential function can be used to fit the data and from the statistical measures and resultant shape of the curve assessed show better match compare to curve fitting with polynomial function. The following seems to best fit generalized gas-lift curves by exponential equation:

$$f(x) = a_3 + \left(\frac{a_2}{(a_0/a_2)} - 1\right) * e^{-a_1 x} - e^{-a_0 x} \quad (1)$$

where:

- x is the independent variable (gas-lift injection rates).
- a_0, a_1, a_2, a_3, and a_4 are independent coefficients.

GLPC model for each wells are approached with exponential regression based on Equation (1). This method is use to find the value of each independent coefficients a_0, a_1, a_2, and a_3. The discrete gas-lift optimization data points from GLPC are fitted to create a continuous function with the independent variable in gas injection flow.Solution of optimal gas injection rates to aim highest production flow are calculated by PSO method and compared by GA method. The results of well production modeling in exponential function can be viewed as figure 2.

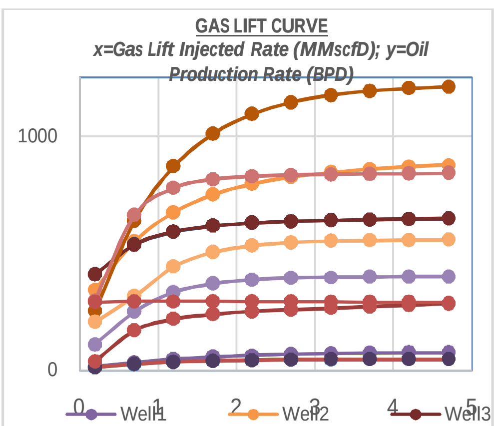

Figure 2. Gas lift curve fitting to exponential function

MODEL VALIDATION

Well production modelis validated by comparing the simulation results with the well test results to check the correlations. Validation is to determine the extension of accuracy and precision of the models based on the actual measurement. The validation shows a significant correlation results with average value 0.9394 for all oil, water and gas productions as shown in figure 3.

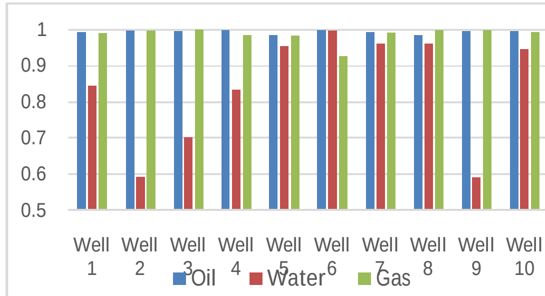

Figure 3 Correlation results between well test and production well modeling

Objective Function and Constraint Functions

Objective function for maximizing company's profit using managing the gas lift allocation is defined as Equation (2),

MaximizationProfit :

$$\left(POIL * \sum_{i=1}^{i=10} f(x_i) - PGAS * \sum_{i=1}^{i=10} x_i - OilProductionCost - PWTR * \sum_{i=1}^{i=10} f(y_i) \right) \quad (2)$$

where:

- POIL = current oil price
- $f(x_i)$ = Sum of oil productions
- PGAS = Current gas price
- PWTR= Current produced water treatment cost
- $f(y_i)$ = Sum of produced water

The produced water rates figure can be determined from the well test result as a constant function. Field well tests indicate the correlation of produced water function as magnitude of oil produced rates. Constant function value is based on each well test data (water-cut rates) are defined as follows,

$y_1 = 0.99 * x_1/(1 - 0.99)$ $y_2 = 0.85 * x_2/(1 - 0.85)$

$y_3 = 0.86 * x_3/(1 - 0.86)$ $y_4 = 0.99 * x_4/(1 - 0.99)$

$y_5 = 0.7 * x_5/(1 - 0.7)$ $y_6 = 0.65 * x_6/(1 - 0.65)$

$y_7 = 0.88 * x_7/(1 - 0.88)$ $y_8 = 0.86 * x_8/(1 - 0.86)$

$y_9 = 0.88 * x_9/(1 - 0.88)$ $y_{10} = 0.78 * x_{10}/(1 - 0.78)$

There are two limitations that is use as constraint function in this optimization problem.The first constraint is the limited gas injection source which is using the production gas from reservoir.

Gas lift injection rates =
$\sum_{i}^{n} x_i - \leq \textit{Total available gas injection}$ (3)

$x_i \geq 0$ gas injection rates non negative

x_i is independent variable or causes variables used to determine the relationship between observed phenomena which in this study is the magnitude of gas injection rate on oil production rates.

$$\textit{Maximum gas lift injection rates} = \sum_{i=1}^{i=10} x_i - \leq 17\ mmscfd \quad (4)$$

The second constraint is the produce water treatment facilities limitation. At current field design, producing water from hydrocarbon separation will be injected back into the reservoir through three water injection pumps; each pump has a limited design volume as 213 M3 per hour is equivalent to 32,153 BPD.

$$\textbf{Produced water rates} = \sum_{i=1}^{i=n} y_i - \textit{Total produced water capacity} \quad (5)$$

y is the dependent variable related to the condition from the observable phenomenon. The dependent variable is the large amount produced water.

$$\textit{Maximum produced water rates} = \sum_{i=1}^{i=10} yi - \leq\ 32153\ BPD \quad (6)$$

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PARTICLE SWARM OPTIMIZATION

PSO as well as other techniques of Swarm Intelligence has been defined to perform a search in the space of solutions to optimize results in problems mono and multi-objective. The basic idea is that each particle that has been generated randomly and is searching for the optimum value. Each particle is moving and has its own velocity. Those particles in the swarm works together as they exchange information about what they've discovered (particle best value) in their current places. Each particle knows the fitness of those in neighborhood and uses the position of the one with best fitness (global best value). This global best value is simply used to adjust the particle's velocity [5].

The PSO formulation that used in this research is as below with *x(i)* as the gas lift injection rates for respective production wells:

*set maximum and minimum velocity
v_{min}=-(max(x_{max})-min(x_{min}))/(N*2);
v_{max}=(max(x_{max})-min(x_{min}))/(N*2);

*set the particles random value
swarm(i,j) = rand( )*(x_{max}(j)-x_{min}(j))/2;

*set coeffisien *GLPC* as the problems
a4(1)=77.2445172;*a3*(1)=4.42302241;*a2*(1)=14.714841;a1(1)=0.8204564;
a4(2)=225.36768;*a3*(2)=9.1729957;*a2*(2)=1.0541622;a1(2)=-0.01591551;
a4(3)=320.219613;*a3*(3)=2.58763;*a2*(3)=1.6859163;a1(3)=-0.014272276;
a4(4)=5.5426553;*a3*(4)=-0.8725935;a2(4)=0.9005563;*a1*(4)=0.01744292;
a4(5)=33.63406;*a3*(5)=0.0333677;*a2*(5)=1.0175688;a1(5)=-2.86643E-05;
a4(6)=-16.756789;a3(6)=1.5201493;a2(6)=2.326276;a1(6)=-0.00420778;
a4(7)=399.965492;a3(7)=67.73755;a2(7)=11.298452;a1(7)=1.624844884;
a4(8)=557.486145;a3(8)=153.55153;a2(8)=7.04800554;a1(8)=1.5179472;
a4(9)=-67.615986;a3(9)=4.9937388;a2(9)=2.1562375;a1(9)=-0.0364925;
a4(10)=288.01014;a3(10)=372.94235;a2(10)=0.764273;a1(10)=0.807188;

*PSO & Velocity formulation
f(j,i)=a4(i)+((a_3(i)/(a_1(i)/a_2(i))-1))*(exp(-a_2(i)*x(j,i))-exp(-a_1(i)*x(j,i)));
v=*v*+*randnum1*.*((gaux*Pbest-x)+randnum2.*(gaux*Gbest-x));

Calculate the problem to get maximum objective function as determine in equation 2, check the value function and it should be within the constraint then get the initial Pbest and Gbest.

*update particles value
```
x = x+v;
for j = 1:N,
    for k = 1:dim,
        if x(j,k) <xmin(k)
            x(j,k) = xmin(k);
        elseif x(j,k) >xmax(k)
            x(j,k) = xmax(k);
```

With the update velocity, recalculate the objective function and check the value with the constraint. Update the Pbest and Gbest with the best solution provides].

GENETIC ALGORTHM

Genetic algorithms method is a method that generate solutions for optimization problems using techniques that inspired by natural evolution, such as inheritance, mutation, selection, and crossover. The GA optimization method that used in this reserach is using a combination of the following steps:

1. Initialization initial random members
2. Encoding value to binary
3. Solution initial population
4. Creating new solutions through mutation
5. Combining solutions through crossbreeding
6. Selecting a solution by the method of "Survival of the Fittest"

The first step in implementing GA is by randomly generated many individual solutions to form an initial population. The population size depends on the nature of the problem, but typically contains several hundreds or thousands of possible solutions.
Encoding method which is done by using the calculation of the amount of each member of the bits which are then correlated into the minimum and maximum values of the value of the gas injection rate at each production well. For example, a random value from a member of the population:1 0 1 0 1 1 1 1
The number of decimal value of all 8 bits are:
20 * 1 + 21 * 1 + 22 * 1 + 23 * 1 + 24 * 1 + 25 * 0 + 26 * 1 + 27 * 0 = 87
The minimum value of the members of the population is 0, while the maximum value is 255. The minimum value limit gas injection rate is equal to 0 while the maximum value is equal to 5, so that when the value of 87 correlated into the gas injection rate is equal to 1.7055. These values were later incorporated into the gas lift curve function to produce the amount of oil production obtained by the well.

The problem that used in this method also the same problem that used in the PSO method which is the formulation of GLPC that has been explained earlier in PSO section. The fitness function is defined over the genetic representation and measures the quality of the represented solution. The best initial solutions where defined as the fitness function and used for generating the next population.The initial solutions may be "seeded" from initial population solutions in areas where optimal solutions are likely to be found. The best value will be keep as the initial best solution.

The next step is to generate a second generation population of solutions from those selected through a combination of genetic operators: crossover (also called recombination), and mutation. These processes ultimately result in the next generation population of chromosomes that is different from the initial generation. Generally the average fitness will have increased by this procedure for the population, since only the best organisms from the first generation are selected for breeding, along with a small proportion of less fit solutions. These less fit solutions ensure genetic diversity within the genetic pool of the parents and therefore ensure the genetic diversity of the next subsequent generation.
The iterations stop until meet the maximum iterations number and or has achieved the maximum solutions. In this research, the maximum solution value is unknown therefore the iterations will stop when the maximum iterations number has reached.

RESULT AND DISCUSSION

The problems faced in the gas-lift injection optimization are to determination the gas injection allocation at each production wells for obtaining maximum oil. The solving PSO optimization formulations are programmed by Matlab. Few experiments have been done to investigate the PSO effectiveness related to combination of initial populations and the number of iterations. The initial assumption uses the total gas productions from the reservoir for gas lift injection which is 33.52 MMscfd.

The experiment results are shown in Figures 4-6. The number of iterations is 500, 1000, and 2000, respectively. Theabscissa is the number of iterations and the ordinate is the expectation of many oil can be produced. Figures a, b, c, and d use an initial population of 5000, 2500, 2000, and 1000, respectively.

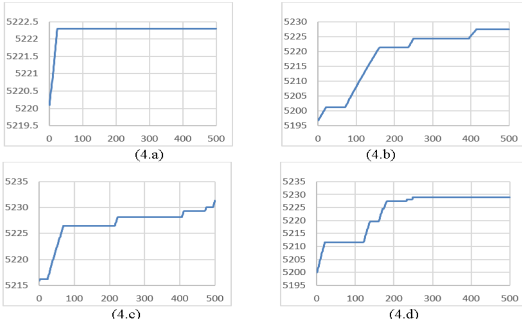

Figure 4. The results of the gas injection optimization using PSO method with a maximum 500 iterations

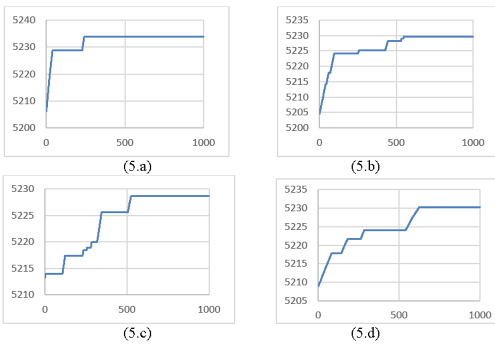

Figure 5. The results of the gas injection optimization using PSO method with a maximum 1000 iterations

It is observed that the increments number of maximum iterations does not have significant impact to the optimum solutions. The obtained optimization solution is required the maximum iterations number around 440.It is also confirmed that the initial population around 2000 can provide the maximum benefits. These compositions is used subsequently in optimization problem causes it is potentially easier to get the best solution.

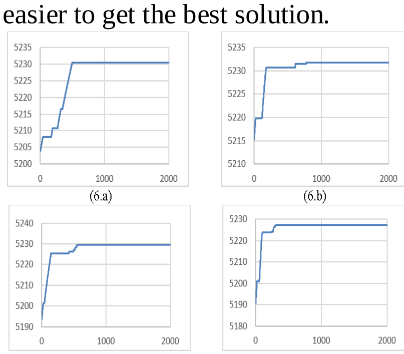

Figure 6. The results of the gas injection optimization using PSO method with a maximum 2000 iterations

The optimization result obtained by GA is shown in Figure 7 for comparison. It is observed that PSO is little superior than GA method. It means that PSO can obtain the best optimal solution. The PSO is satisfied for managing allocations of gas injection flow rate to increase oil production in XZY plant.

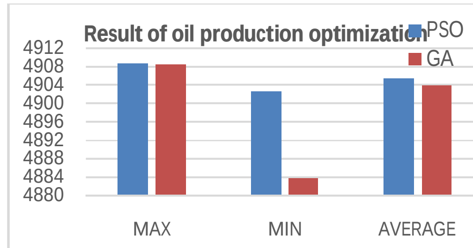

Figure 7 Optimization results between PSO and GA methods with constraints 17MMscfd gas lift injections and 32,150 BPD produced water.

Assumptions of the oil price released by the ministry of energy and mineral resources is USD $ 102.76 per Barrel is used to calculate the company's profit. While the assumptions of the production and processing crude oil cost is USD $ 15.89 per Barrel. It is known that lifting cost is taken from the annually average operating expenditures. Calculating the water treatments cost is based on the equipment rental cost. It is not combined as lifting cost assumed around USD$ 0.8 per Barrel. The increasing in oil production will inevitably also increase the production cost. The figure 8 shows the result of profit calculation.

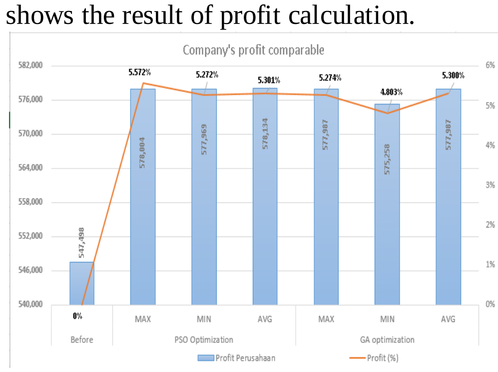

Figure 8. Profit calculation results.

It is observed that the simulation results of the allocation of gas injection on each of the production wells are 0.98, 2.66, 1.39, 0.98, 3.19, 1.61, 1.78, 2.03, 1.40, and 0.98 using gas injection limitations for 17 Million standard cubic feet per day (MMscfd) gain maximum product.The oil production increases to 4908.7 Barrels of oil per day (BPD). Maximum company profit after optimization reaching D$ 578,004 compare with before optimization.

CONCLUSIONS AND FURTHER RESEARCH

The PSO method can be used for determined the optimal gas lift allocation problem at PT. XYZ and increased oil production.The PSO is little superior than GA method to determine the optimum gas lift injection rates allocations in order to maximize the total oil production rates and company's profit.

By performing 200 experiments; PSO method provides maximum oil production 4,908.7 BPD or 7% increments. The minimum value oil production rateis equal to 4,902.2 BPD or 5% increments. The average oil production rateis 4,904.47 BPD or 6% increments.

The simulation results of the allocation of gas injection on each of the production wells are 0.98, 2.66, 1.39, 0.98, 3.19, 1.61, 1.78, 2.03, 1.40, and 0.98 using gas injection limitations for 17 Million standard cubic feet per day (MMscfd) gain maximum product.The oil production increases to 4908.7 Barrels of oil per day (BPD). Maximum company profit after optimization reaching USD$ 578,004 compare with before optimization. It is also observed that PSO method is little superior than GA method.

Since the PSO method provides faster calculation compare to GA, PSO can be done for real time implementation of optimization problem for near future research. It is also possible to consider the more integrated production wells for determining the optimum gas lift injection rates allocations in order to maximize the total oil production rates and company's profit.

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