The Quahog Oil Production Simulator: A Case Study of the Rapid Development of a Management Flight Simulator for Training

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ABSTRACT

The People Express Management Flight Simulator (Sterman 1992) developed a new area of research in the use of interfaces to enhance the learning value of system dynamics simulation models. Participants impressed with the learning power of the People Express learning laboratories frequently ask how they can have such a simulator customized for their own company or industry. This case study describes the rapid creation of a simple, yet highly dynamic and descriptive model (with a graphical interface) of a national oil company, and the experimental introduction of that model into an already established new employee training program in that organization.

The Problem

In 1990 we conducted a series of one-week intensive training programs in systems thinking for a national oil company. Many of the participants were impressed with the People Express management flight simulator used on the fourth day of our workshop. The difficulty in balancing the human-resource based service capacity with the aircraft-based physical capacity was of particular interest to a team sent by the manager of human resources. After seeing the causal loop diagram of the People Express simulator, several of them requested that a simulator be created to represent their company. This flight simulator would be used as a training tool during the company's week-long employee orientation program. It was proposed that the user would be able to assume the role of the president and owners and make decisions that affect the entire company. In this way the oil company managers hoped to provide their employees with a general overview to allow them to see their job as part of the entire corporate system.

This project was seen as an experiment in using management flight simulators for rapid training and culture change. The hypotheses were that: 1) the use of a management flight simulator would improve the learning process and increase the enjoyment of the training programs, 2) employees would respond better to a simulator of their own industry rather than a simulation model of an airline company, 3) the simulator would increase the trainees' understanding and identification with company goals and the total quality management program, and 4) the use of a simulator would improve the employees' understanding of the whole company, which would increase communication laterally and vertically, thereby facilitating participation in and development of a more decentralized strategy process (de Geus 1988).

Given the extremely tight time schedule and budget of the client it was not clear that it would be possible to achieve a sufficiently interesting but simple representation. The opportunity to participate in the orientation program would require that the simulator be completed within a month. Over the last two days of our five-day systems thinking workshop, participants worked on separate group projects. The class had representatives from most divisions of the company, so causal loop diagrams were created that effectively covered the company's key areas. At the end of the workshop we were able to combine the conceptual architecture of three of the projects as the preliminary outline for the simulator. We divided up into two teams. One team created the model while the other team produced the graphics and reports that would be used to increase the usability of the management flight simulator. A simple prototype STELLA™ (Richmond 1987) model was then designed with the assistance of one of the managers who attended the systems thinking workshop. This model was not completely calibrated, but all major sectors were represented and the behavior it produced was sufficient for a prototype. Next the model was connected to a MicroWorld Creator™ (Diehl 1990) interface and presented to the management team. This prototype gained a budget authorization for an additional three person-weeks of work to be done in the U.S. to refine the model and write a 20-page workshop manual. It was then delivered and tested in the next orientation workshop.

The simulator is currently introduced on the third day of the company's orientation program for all new employees. The participants play the combined role of the president and owners of the company, allocating the investment in new wells, gas lift, secondary recovery, maintenance, new hires, and training. The manager of human resources has since reported that, "The flight simulator gives the trainees the chance to be in charge of oil production and see how the whole system works. It's a great interactive experience, and the most highly rated segment of the program."

Overview of Employee Briefing

The new employees are presented with the history of their own company and its strategies. In order to preserve company confidentiality, this paper presents a disguised version of the interface rather than the actual simulator used by the oil company. Although the training simulator does not contain any classified information and has been distributed outside of the company, in order to avoid any possible misunderstandings, we have changed the data and strategic issue as protection for the company. In this paper, we will describe a hypothetical national petroleum company called Quahog Oil Company. Figure 1 presents the overview of the three main sectors of the model.

Quahog Petroleum, a large national oil company with stable production for the past decade has decided to expand production by 50% over the next five years. By simultaneously implementing a comprehensive total quality program they hope to achieve this expansion with a modest 15% increase in their labor force. Such an ambitious new strategy would require unprecedented change in the corporate culture and a reallocation of their capital investment program.

The performance of the simulated company is effected by the decisions made by the new employees while using the simulator. The decisions reflect the policies to be implemented in the company. Each year, the user makes six decisions which fall into two categories: production decisions and human resource decisions. The decisions are to determine the level of activity in the following areas: 1) **drilling of new wells**, 2) **gas lift**, 3) **secondary recovery**, 4) **maintenance**, 5) **new hires**, and 6) **training**.

The volume of oil produced each day depends on many factors: the number of wells, the production capacity of the reserves, how well the machines are working, etc. It also depends on human resource factors—if the company does not have enough skilled employees, it will not be able to achieve the highest productivity out of the wells.

Much of the world's petroleum deposits lie in natural rock at depths from 150 to 7,600 meters below the surface of the ground. The petroleum deposits, or reservoirs, are prevented from migrating upward by intervening layers of dense rock. As a general rule, the deeper deposits have higher internal pressures and contain greater quantities of gas and oil.

Oil wells have an economic life of roughly 30 years. Over time, the production rate of a well (measured in barrels of oil per day, BD) declines and eventually drops off. A new well can produce anywhere from 200 BD to over several thousand. For this simulation, the average production of a new well is 500 barrels per day.

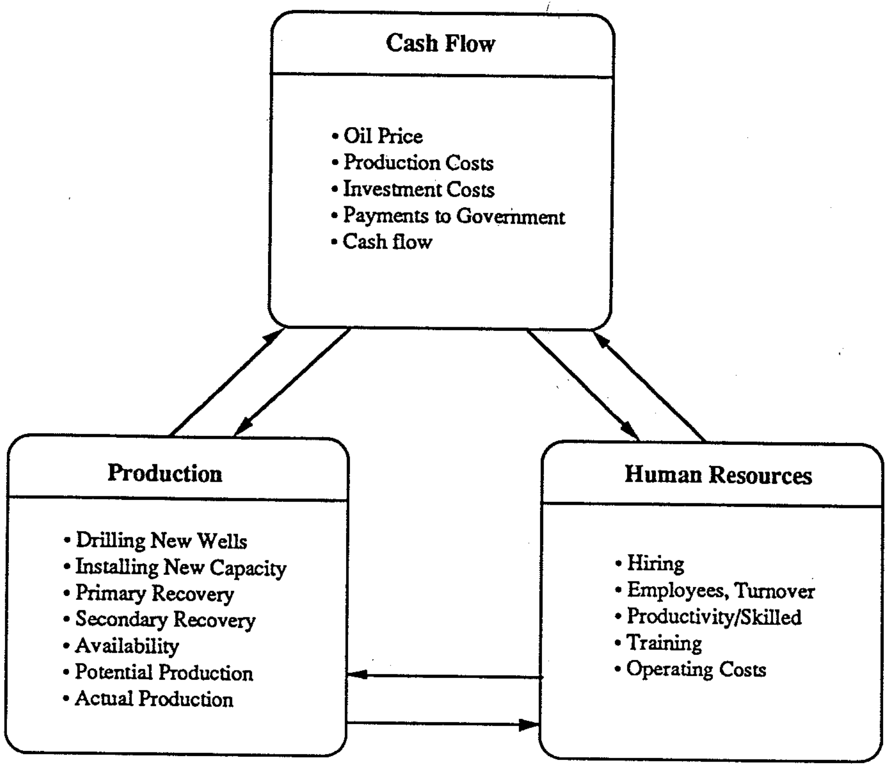

Figure 1. Overview of the Quahog Oil Production Simulator

Drilling New Wells. The primary method of extracting the gas and oil from a reservoir is to drill a series of wells into the formation. As a result of internal natural pressure, the oil will begin to flow from the well. With time, however, this rate of flow declines as oil is removed and the pressure in the reservoir falls. Figure 2 shows the production which results from a typical well in the region. The average production begins at 500 Bbl./day and declines at a rate of roughly 10% each year.

Oil may be produced as long as enough reservoir pressure remains to cause the oil to flow into the well. Since a decline in reservoir pressure invariably accompanies oil production, a point is reached at which commercial quantities of oil or gas no longer flow into the well. In many crude oil fields less than one-third of the oil originally present can be produced using only the reservoir pressure.

The user of the simulator must decide how many new wells to drill each year. Each year a number of wells are lost, in order to maintain current production, new reserves must be tapped. In addition, new wells can be added in order to increase overall production. Developing a new well costs $US 1.5 million.

Gas Lift. When a large part of the crude oil cannot be recovered simply by allowing the original reservoir pressure to furnish the driving energy, another method for supplying extra energy must be found. Usually, an injected fluid such as water or gas replaces the produced oil and maintains the reservoir pressure. Such artificial lifting methods help boost the production capacity of a well. A method very common at Quahog, called **Gas Lift**, uses the buoyancy of a bubble of gas injected into the casing of the well to push the oil to the surface. As oil and gas is produced from the well, the gas is separated and then compressed to be reused in the gas lift process. Gas lift increases the overall rate of production of a well.

The user must decide how many thousands of barrels per day (MBD) to add to current gas lift capacity. Each year 7% of the capacity wears out and needs to be replaced. Each additional unit of capacity, (one MBD of oil production), costs $US 5.0 Million.

Although gas lift creates a temporary increase in oil production, the production rate of the well will still begin to decrease over time. Once the well reaches the age of 10-15 years, **secondary recovery** techniques are used to once again boost production. The type of secondary recovery in the simulator is water injection. Water, after treatment to remove certain impurities, is injected through some of the wells. In moving through the formation, it pushes oil toward the remaining production wells. The wells to be used for water injection are usually spaced evenly among producing wells so that the oil has the shortest possible paths to follow.

Utilizing gas lift and secondary recovery technologies boost the overall production capacity of a well. Although water injection greatly increases the recovery of oil from a particular reservoir, it leaves one-fourth to one-third of the oil behind.

The user of the simulation must decide how many thousands of barrels per day (MBD) to add to current secondary recovery capacity. Each year 5% of the capacity wears out and needs to be replaced. Each additional unit of capacity, (one MBD of oil production), costs $US 7.5 Million.

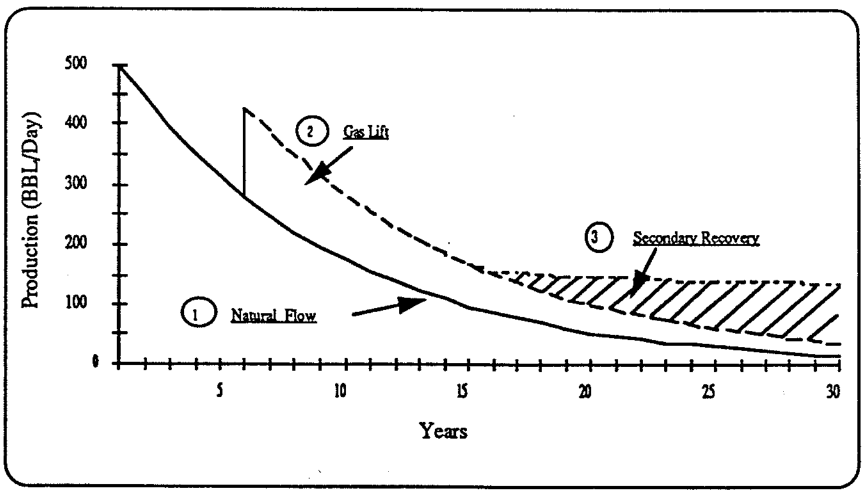

Figure 2. Production Flow from Investment in Secondary Recovery Capacity

Quahog has a substantial amount of money invested in capital equipment in the production sector. This investment includes the oil wells, production facilities, pipelines and marine terminals necessary to recover oil and move it to the end user. Just as it is important to invest in new production capacity to replace the equipment which wears out, it is equally important to invest resources in routine **maintenance** to insure that that the current capacity works at its peak efficiency. The availability of equipment depends directly on how much money is invested in maintenance. Figure 3 shows the availability of a typical new piece of capital equipment. In this example, availability refers to the percentage of time which the equipment is operating in a typical year. An availability measure of 100% indicates that the equipment is operating 365 days out of every year. Over time the availability of equipment will decline by roughly 5% each year. With maintenance the availability of equipment can be increased to over 90 percent.

The model user must decide how to invest in maintenance of machinery. This is measured in $US per year per MBD of production capacity. Investing money in maintenance increases the number of productive hours (or "up time") for machinery. The more hours each machine can work in a day (meaning the less time spent on breakdowns and repairs) the more oil can be produced.

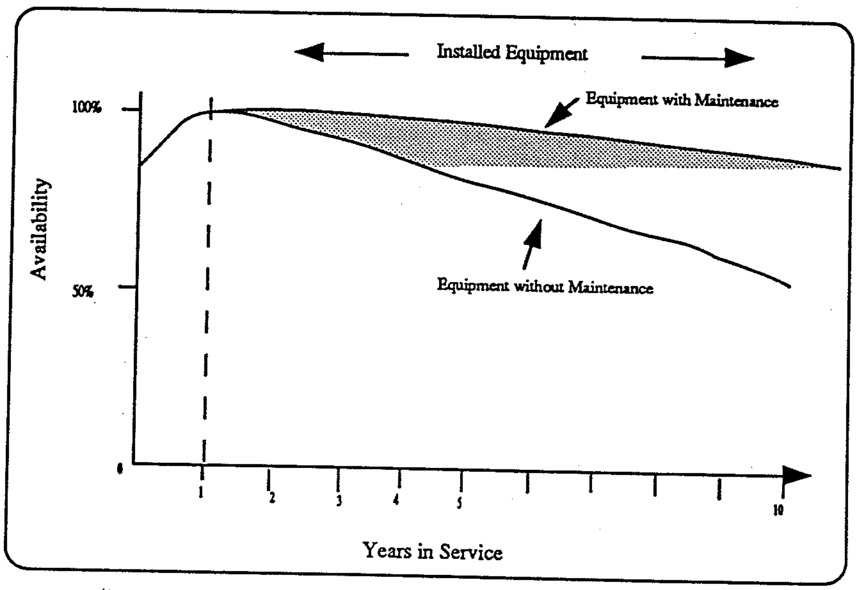

Figure 3. Equipment Maintenance

The typical **new hire** in the oil production simulator is a motivated employee with no previous industry training. Quahog estimates that the learning curve for a new hire is two years—that is, it takes approximately two years for a "rookie" to reach the skill level of an experienced worker (Figure 4). By investing in training programs, however, it is possible to shorten the learning process and boost the productivity of new workers from an average of 50% to 75% by the end of the first year.

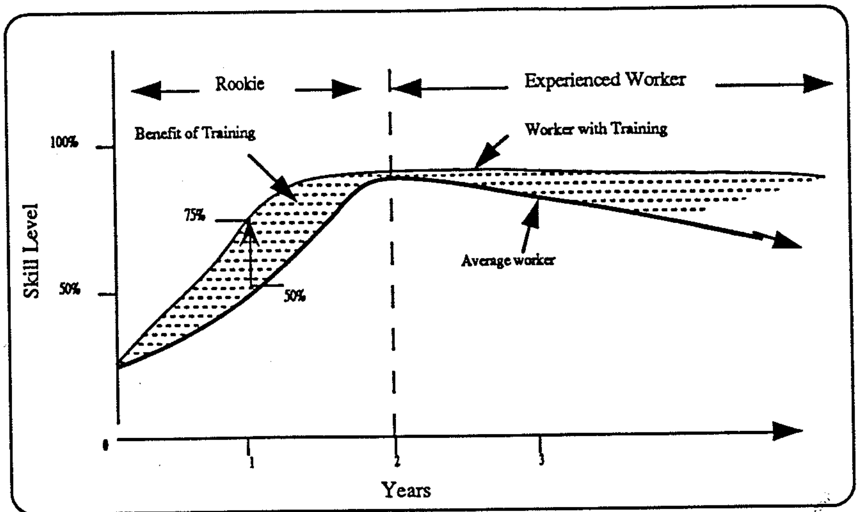

Figure 4. Skill Level of a Quahog Employee

However, the oil industry is continually changing. New innovations in equipment and procedures make it necessary to continue training throughout an employee's tenure with the company. Without continued training, the productivity of an experienced worker will decline, since he or she will not be up-to-date on the new technologies.

The user must decide how many employees to hire (or fire). The number of people who are leaving the firm must be taken into account. For example, to expand the staff by 300 people when there was a 200-person turnover, 500 people must be hired.

In the simulation, a decision must be made about the amount of money to invest in **training** per employee. A more skilled workforce will be more productive and lead to more overall production capacity. However, the skill level of a worker cannot grow forever. After workers have reached a desired level, continued investment in training programs will not be very effective. That is, workers will not be 200% more productive simply by investing all available funds in training programs.

Using the Simulator

After reading the complete briefing materials (the previous section presented an abbreviated version of the briefing), each participant begins to experiment with the simulator. During the first experimental run, participants are instructed to make no investments at all in order to discover what happens in the most extreme form of a liquidation strategy. The initial value of each decision is zero.

One interesting real world interpretation of this first experimental run that is on the minds of the participants at this time in the workshop is the continual intense social debate within this country about how much of the oil industry revenues should be diverted to the government versus how much should be reinvested in the industry. This first run suggests that the government or stockholders chose to keep 100% of the free cash flow. In this case the oil production and consequent revenues decline at approximately 10% a year. The cumulative tax revenue for the owners is $US 32 billion and the cash flow in the final year is $US .026 billion.

During the second experimental run, participants are instructed to maintain current capacity. New wells are drilled to replace ones that expire. Everything that breaks is maintained and anyone that leaves is replaced. The cumulative tax revenue for the owners for this run is $US 73 billion and the cash flow in the final year is $US 6.7 billion.

In subsequent runs, participants are encouraged to try their own strategies and increase production capacity by 50% over the next five years. In well managed scenarios they can usually achieve cumulative taxes to the government of over $100 billion dollars with a final cash flow of $7 billion.

One of the significant lessons learned by the new employees is that investments that seem costly in the short-term have a substantial favorable long-term impact on cash flow and profitability. This insight is important in a county for which there is tremendous social pressure to spend money on urgent needs. Finding the best balance between financing the short-term social needs and financing the highly profitable longer-term opportunities in the oil industry represents a difficult political and social as well as economic challenge. One unexpected value of the training simulator may be that it facilitates such discussions in a more constructive manner.

Conclusion

In conclusion, we suggest that this implementation experiment has contributed to knowledge about the use of management flight simulators in corporate settings. This case study has demonstrated that a simple model with complex dynamics can be developed in a short amount of time. The graphical interface which enables the user to manipulate the model without an in-depth understanding of the underlying STELLA equations was an essential factor in getting the simulator approved for use in an orientation program with the highly specific goal of introducing oil industry issues not systems thinking issues or software. The simulator's focus on the oil industry and company specific history was also greatly helpful in gaining approval and student acceptance in this training forum where the People Express case seemed less appropriate despite the fact that its feedback structure and general lessons are similar.

The manager of human resources and others who commissioned the work were willing to accept the validity of the simple model because of their participation in the creation of the causal loop diagrams and simulation model used to create the final interface.

One year after the simulator was created it has been and continues to be successfully used in the established corporate training program. It has been suggested by anecdotal evidence and self-reports from employees, that the first two of the four hypotheses may be true, i.e., 1) the use of a management flight simulator would improve the learning process and increase the enjoyment of the training programs and 2) employees would respond better to a simulator of their own industry rather than a simulation model of an airline company. According to the manager of human resources, the oil production simulation learning lab is frequently the highest rated part of the orientation program on the employees evaluations.

The management flight simulator needs further testing of its effectiveness as a learning tool. A longer development lead time would allow for a pretest of employee's knowledge of the company and industry and a posttest after the use of the simulation. The employees should be required to make their policies explicit prior to making decisions in the simulator. Decisions made while using the simulator should be captured to track the employees changing strategies and any inconsistencies in their policy design. This case illustrates the differing pressures from academic and research goals and the pressures of a consulting orientation. Further applications and research based on this case study should include an awareness of how customer demand and research initiatives need to be balanced in order to provide research results which can lead to new designs for learning.

Interviews with the employees once they have been established in their jobs (perhaps six months after the training program) can be used to gather retrospective data about employees perceptions of the value of the simulator to their future positions in the company. The simulator experience should provide some understanding of the systems perspective which should be reflected in employee understanding of their work environment in relation to the entire organization.

In retrospect the value of this project to the academic community would have been greatly enhanced if we had given more consideration and resources to the research design before the project began. An assessment of the organizational culture would be particularly important in understanding the impact of the simulator as a learning intervention. We hope to make arrangements with the oil company to assess the simulator and learning experience, as well as the cultural implications, since it is still used consistently in the new employee orientation program.

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