THE JUICE CAPACITY GAME: AN EXCEL BASED SIMULATION

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ABSTRACT

The operations management discipline has long incorporated experiential exercises into their curriculum. However, many of these exercises require direct hands-on interactions during face-to-face instruction. The most popular of these exercises include variations on the Forester's beer game simulation (focused on supply chain communication), the Deming's bead activity (focused on quality control), and the Goldratt's matchstick experiment (focused on system variability and bottlenecks). Many attempts have been made to create computer simulations of these activities, but their ability to deliver a similar learning experience to the original in class activity has limited both their development and usage. COVID 19 in early 2020 had a drastic impact to face-to-face course delivery and the ability of faculty to deliver a similar experience in online and hybrid modalities This renewed motivation encouraged the development of the Juice Capacity Game (JCG) based on Goldratt's matchstick experiment. Using Excel VBA as the development platform, I created JCG to help students better understand capacity related operations management concepts and demonstrate the impact of dependent events, statistical fluctuations, and constraints on capacity in a flow process.

INTRODUCTION

Experiential exercises have long been used by the operations management discipline to introduce and motivate students in their introductory operations management (OM) course (Ammar & Wright, 1998). One exercise that has received a lot of attention can be traced back to an experiment conducted during a boy-scout hike in the classic book *The Goal* (Goldratt & Cox, 1992). Variations on this experiment have been introduced in the simulation game literature as the Goldratt game, the matchstick game, or the dice game (A. C. Johnson & Drougas, 2002). The purpose of the these games centers on helping participants understand the effects of statistical fluctuations on dependent events in flow processes, see Figure 1. Event dependency is created by sequential operations in a flow process, where a unit of output must be processed at one operation before it can move to the next operation. To create statistical fluctuation the production output at each operation is determined by dice rolls. In the traditional hands-on simulation, the output units have been represented by matchsticks, pennies, bolts, and poker chips (Tommelein, Riley, & Howell, 1998).

FIGURE 1
Flow Process

These games are traditionally played as hands-on experiential activities in a traditional face-to-face classroom. The rules are relatively simple, with each operation's output dependent on a combination of the input inventory available and its production capacity (i.e., dice rolls). The participant responsible for operation 1 rolls the designated number of dice to determine how much raw material will be processed and moved into inventory for the next operation. The participant responsible for operation 2 then rolls their dice to determine how much they can process. If the dice roll exceeds the number in inventory all units in inventory will be processed and delivered to operation 3's inventory. If however, the dice roll is less than the number in inventory, only the number on the dice roll will be moved to the next operation's inventory, with the balance remaining in that processes inventory. This process continues through the entire flow line until the last operation delivers finished units to the customer and the next period begins (A. Johnson, 2002).

Several simulated versions have been developed allowing their use in remote learning environment (Gupta & Boyd, 2011; A. C. Johnson & Drougas, 2002; Lambrecht, Creemers, Boute, & Leus, 2012). Unfortunately, these games fail to deliver a context and visual experience to motivate student learning. The Juice Capacity Game (JCG) was developed to provide a relevant context and simple visual interface to encourage participants to easily experiment with different configurations.

THE JCG LEARNING OBJECTIVES

The initial implementation of the JCG was for an introductory undergraduate operations management course taken by all business majors. Therefore, the learning objectives described below do not take full advantage of all the capabilities being developed in the simulation. After participation in the JCG simulation, undergraduate operations management participants should be able to:

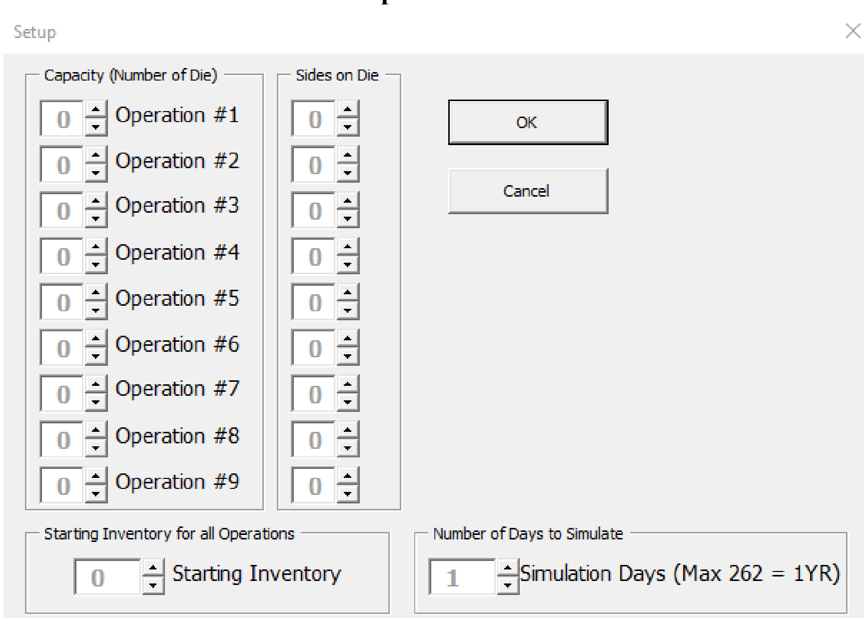
1. Describe the key characteristics of flow process layouts
2. Differentiate expected capacity from maximum capacity
3. Calculate utilization and efficiency of operations and processes
4. Identify the effects of production rate variability (i.e., statistical variations)
5. Identify the effects of complexity on throughput
6. Identify the constraints/bottlenecks in a process and their effect on throughput
7. Show understanding and apply the Theory of Constraints to flow processes

THE JCG DESIGN

The JCG is configured as illustrated in Figure 1. In context, the game is centered on a juice bottling flow process that requires a number of dependent operations from raw material input to bottled juice output. The number of operations is a setup variable and can vary from 1 to 9. The current version of the JCG has unlimited inventory buffers at all operations, however, a more advanced version is being considered, for graduate courses, that may allow adjustment of buffer size. Capacity of each operation is determined by the number and type of simulated die.

Each operation has a unlimited storage for inventory, with operation 1 being supplied by an unlimited amount of raw material inventory (e.g., because operation 1 has unlimited access to raw materials it will never run out and therefore we can consider it a just in time process i.e., there is no cost for associated with raw material inventory). The process also assumes that all product produced is shipped to a customer. Each operation's capacity, the amount that each operation can produce, is determined by the roll of a simulated die. Capacity can be increased by either increasing the number of die in a roll or by increasing the number of sides on a die (where each side has a unique number from 1 to the number of sides). Variability is also increased by increasing the number of die or the number of sides on a die. A simulated period is one day, one shift, on JCG bottling line. The simulation is currently configured to run for a maximum of one year, or 262 simulated days (i.e. periods). If desired, the line can be seeded with a starting inventory at each operation. Figure 2 illustrates the JCG simulation setup parameters.

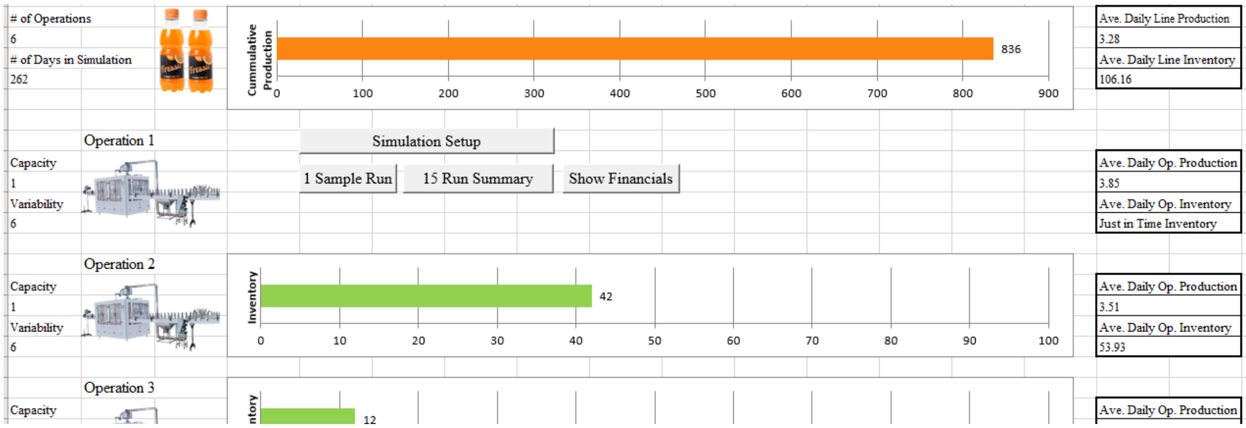
FIGURE 2
Setup Parameters



In addition to flow process setup, a rudimentary cost and revenue model has been developed. The goal with this addition is to enhance the participant's learning by allowing them to compare line configurations on a cost basis rather than solely on throughput differences. Because line configurations can be compared with financial metrics, the context of the JCG becomes more realistic. This rudimentary feature is being developed to allow even greater experimentation for more advanced participants. The current implementation of the JCG sets the revenue from a bottle of juice at $5, fixed costs on a per die basis at $50 per side (e.g., 6 sided die = $300) allocated at 33% per year, a production cost of $0.10 per unit, WIP cost of $0.07 per day, and raw material cost of $0.50 per unit.

The JCG has options to perform a single sample run (with visualizations) and a 15 run summary (without visualization). The former allows the participant to see (visualize) the production and WIP levels for the entire line, see figure 3.

FIGURE 3
Single Sample Run Visualization



Depending on the setup, there can be significant variability between individual runs, therefore, a 15 run summary can rapidly be created without the visualization, see figure 4.

FIGURE 4
15 Run Throughput Summary

RESULTS (15 Runs)		
Simulation No.	Throughput	Ave. Inventory
1	3.218	53.656
2	3.156	76.954
3	3.160	65.538
4	3.061	96.454
5	3.076	67.454
6	3.275	53.859
7	3.156	81.874
8	3.149	73.031
9	3.137	59.496
10	3.004	44.622
11	3.248	57.477
12	3.137	64.481
13	3.130	97.802
14	3.031	79.252
15	3.233	88.244
Average	**3.145**	**70.680**

Unlike the traditional hands-on version of the game, it is extremely easy to add financial elements as highlighted previously. Thus, the ability for the participant to calculate the financial impact of different configurations has been added. Figure 5 shows the fixed costs, variable costs, revenues generated, and profits for each of the 15 simulation runs. Also included are the costs associated with the one sample run, so that participants can identify which operation may be the most costly, see figure 6.

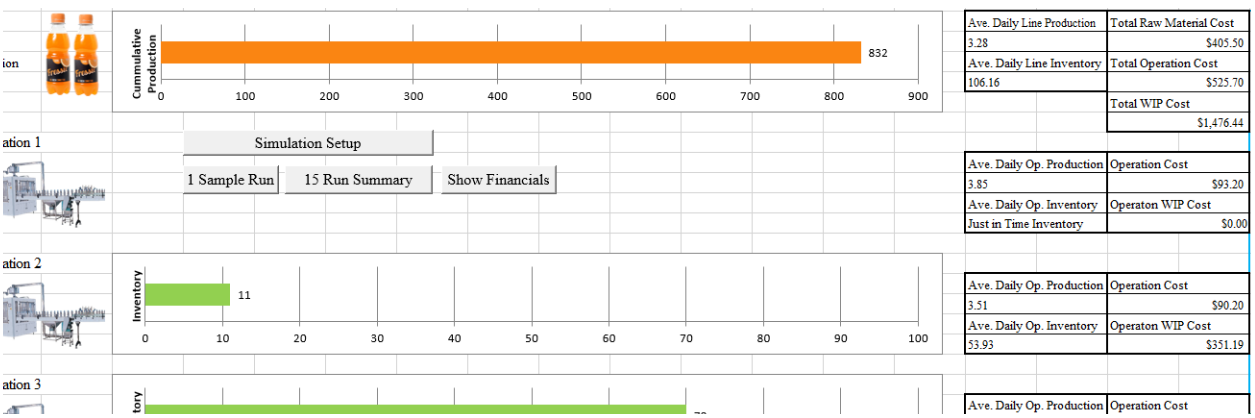
THE JCG ASSIGNMENT

Using the JCG, data are collected for a variety of flow line configurations, see table 1. The capacity for each operation determined by the roll of 1, 2, or 3 common 6 sided die as indicated in the configuration. From this configuration the participants can

FIGURE 5
The Financial Summary

PROFITABILITY RESULTS (15 Runs)				
Simulation No.	Allocated Fixed	Variable Costs	Revenues	Profit
1	$ 594.00	$ 1,562.76	$ 4,215.00	$2,058.24
2	$ 594.00	$ 1,990.04	$ 4,135.00	$1,550.96
3	$ 594.00	$ 1,780.67	$ 4,140.00	$1,765.33
4	$ 594.00	$ 2,347.67	$ 4,010.00	$1,068.33
5	$ 594.00	$ 1,815.81	$ 4,030.00	$1,620.19
6	$ 594.00	$ 1,566.47	$ 4,290.00	$2,129.53
7	$ 594.00	$ 2,080.27	$ 4,135.00	$1,460.73
8	$ 594.00	$ 1,918.08	$ 4,125.00	$1,612.92
9	$ 594.00	$ 1,669.86	$ 4,110.00	$1,846.14
10	$ 594.00	$ 1,397.07	$ 3,935.00	$1,943.93
11	$ 594.00	$ 1,632.83	$ 4,255.00	$2,028.17
12	$ 594.00	$ 1,761.28	$ 4,110.00	$1,754.72
13	$ 594.00	$ 2,372.38	$ 4,100.00	$1,133.62
14	$ 594.00	$ 2,032.18	$ 3,970.00	$1,343.82
15	$ 594.00	$ 2,197.10	$ 4,235.00	$1,443.90
Average	**$ 594.00**	**$ 1,874.96**	**$ 4,119.67**	**$ 1,650.70**

FIGURE 6
Single Sample Run Costs



identify the maximum output and expected output for each line. Note that the maximum output for a line with a bottleneck (i.e., Line 2) is constrained to the maximum output of the bottleneck operation. Therefore, Line 2's maximum output is constrained to the maximum output of operation 1, table 3.

TABLE 1
JCG Line Configurations

Process Step	Line 1 Capacity	Line 2 Capacity	Line 3 Capacity	Line 4 Capacity	Line 5 Capacity	Line 6 Capacity	Line 7 Capacity
Operation 1	1	1	2	2	2	1	3
Operation 2	1	2	2	2	2	1	3
Operation 3	1	2	2	2	2	1	3
Operation 4	1	2	1	2	2	1	3
Operation 5	1	2	2	2	2	1	3
Operation 6	1	2	2	1	2	1	3
Operation 7						1	
Operation 8						1	
Operation 9						1	

The simulation is run for 1 year (262 work days) with 0 units of initial inventory, generating the sample results in table 2.

TABLE 2
JCG Sample Results

Line	Operation with highest ave. daily inventory	Operation with highest ave. daily inventory	Ave. 15 run line throughput (actual output/day)	Ave. 15 run line Inventory	Ave. 15 run line fixed costs	Ave. 15 run line variable costs	Ave, 15 run line revenues	Ave. 15 run line profits
1	2	39.49	3.157	74.401	$ 594.00	$ 1,924.71	$ 413,567.00	$ 1,616.96
2	2	3.7	3.458	18.306	$ 1,089.00	$ 1,067.44	$ 4,530.00	$ 2,373.56
3	4	429.42	3.504	488.67	$ 1,089.00	$ 9,695.41	$ 4,589.67	$ (6,194.75)
4	6	389.74	3.558	490.308	$ 1,089.00	$ 9,751.44	$ 4,660.33	$ (6,180.11)
5	2	30.76	6.487	113.201	$ 1,188.00	$ 3,235.00	$ 8,497.67	$ 4,074.47
6	2	26.5	3.031	98.558	$ 891.00	$ 2,435.36	$ 3,970.33	$ 643.97
7	2	40.36	9.928	150.047	$ 1,782.00	$ 4,521.46	$ 13,006.33	$ 6,702.87

With these data the participants can calculate the line utilization, line efficiency, and the profit per bottle, see table 3.

TABLE 3
JCG Configuration Comparison Metrics

	Maximum output	Expected output	Utilization	Efficiency	Calculate the profit per bottle
Line 1	6	3.5	53%	90%	$ 1.95
Line 2	6	3.5	58%	99%	$ 2.62
Line 3	6	3.5	58%	100%	$ (6.75)
Line 4	6	3.5	59%	102%	$ (6.63)
Line 5	12	7	54%	93%	$ 2.40
Line 6	6	3.5	51%	87%	$ 0.81
Line 7	18	10.5	55%	95%	$ 2.58

Given all the data above and an introduction to the Theory of Constraints, participates can simply be asked to make recommendations. However, for an undergraduate course, a more guided discussion and analysis may be needed. Asking the participants to consider the reason for difference between the maximum capacity and expected capacity can bring up the concept of how variability decreases capacity. If all processes have variability then a reduction in variability will increase output. Comparing line 1 with line 6 it is clear that adding three operations, thus increasing the complexity of the line, decreased the utilization and efficiency of the process slightly 2-3% but impacted profitability by 2.4 times.

Comparing lines 2, 3, and 4, all having the same maximum and expected output, illustrates the impact of a bottleneck resource. If the bottleneck is the first operation in the line, utilization and efficiency may be lowered but there is substantially less inventory, reflected by a higher profitability. In fact, because of the large cost of inventory, both lines 3 and 4 result in negative profits, even with high efficiency and utilization. This demonstrates the idea that just activating a resource to keep it busy is not always productive.

Finally, lines 1, 5, and 7, shows the effect of the coefficient of variation (CV). Observing that line 1's CV is 48.8, line 5's CV is 34.5, and line 7's CV is 28.17, it is evident that efficiency and utilization increase with a decline in CV.

DISCUSSION

The JCG is a useful exercise to focus learning on the impact of variability and dependency on throughput, inventory, and profitability. The addition of visually instructive graphics and simple financial elements added a degree of tangibility for remote learners. Although throughput was still a focus of the activity, throughput became more meaningful when it was assigned a financial value. Participants could visually see the bottleneck and the financial impacts of this constraint. They could see that increased variability and inventory reduced throughput. They could observe the effect of moving the bottleneck to control line flow and that higher efficiency is not always better.

Others have suggested game extensions that include limited buffer sizes (Lambrecht et al., 2012), less-than-perfect yields (A. C. Johnson & Drougas, 2002), and changing underlying distribution assumptions (Tommelein et al., 1998). As the game is developed some of these additional feature may be incorporated in the design. The current version of the game was designed for an undergraduate OM course, but the core game can easily be extended to other configurations along with more sophisticated financial analysis for a graduate level course.

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