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Daily Play at A Golf Course: Using Spreadsheet Simulation to Identify System Constraints

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We present a spreadsheet-based simulation model of daily play at a golf course and how it can be used in teaching. The model represents the variability and interactions that impact pace of play on a golf course as measured by throughput (rounds played) and cycle time (round length). The model predicts that most of the waiting time will occur on par 3 tee boxes. Alleviating this bottleneck by allowing the following group on par 3 holes to tee off while the group ahead is walking to the green, was shown to improve throughput by 13% without increasing cycle time. The model was developed using MS-Excel and @RISK, a Monte Carlo simulation package.

1. Introduction

Daily golf course play is a stochastic system where random events (golfer ability, lost balls, weather, and poor shots) and interactions (waiting for the group ahead) heavily impact the pace of play. Although complex, daily golf course operations are very similar to other complex systems such as:

- A manufacturing plant where parts are moving from production process to process
- A distribution network where transportation devices (trucks, boats, planes, ...) move from location to location
- An emergency room at a hospital where patients wait for treatment

In all of these systems, variability and interactions impact performance. Nevertheless, these and other complex systems have been analyzed with modeling. Therefore, a golf course system should be a candidate for modeling. Through use of a model, system improvement opportunities can be identified. In Goldratt's The Goal (1984), theory of constraints (TOC) for system improvement is presented. TOC is applicable to any system, including daily play at a golf course.

Incorporating golf as a teaching tool has many benefits. Most undergraduate students are unfamiliar with manufacturing systems, supply chains, or healthcare service systems. However, many students are familiar with golf. Golf is a recreational activity that many students find more enjoyable to think about than such mundane activities as manufacturing. Also, business students may view golf as a game where business decisions are made, and they may be interested in learning the details of the game for that reason. Even if they do not play, the rules are simple to explain: Use a club and hit the ball into a hole! Finally, sporting activities have been used recently as a medium for teaching OR/MS. Chu (2003) demonstrated how the Poisson process is reflected in the occurrence of soccer goals, where he also cited another sports-related Poisson process, the scoring spree of ice-hockey legend, Wayne Gretzky (Schmuland 2001).

As with any modeling effort, customers and their current method for solving the problem should be identified. A model that represents daily play at a golf course is beneficial for both designers and course managers. For both designers and managers, qualitative measures and experience are the primary tools. Although we should be careful of being too critical of judgment and experience, we should emphasize the importance of math (or logical) models in decision-making. Little empirical knowledge exists that provides the quantitative impact on throughput. For example, how much do the following impact throughput: fairway width, length of course, elevation changes, bunkers, green size...? Certainly, designers know that the above impact pace of play. However, quantifying the impact is much more difficult. One study has shown that the number of bunkers and the hilliness of the course did not influence revenues (Schmanske 1999). Course managers also have questions regarding throughput. How much do the following impact throughput: tee-time intervals, shotgun starts,[1] group size (2, 3, 4, 5 ...), carts vs. walking ...? Increasing throughput and controlling, or at least forecasting, cycle time are two of the most important factors in revenue management (Kimes 2000).

This paper has three objectives. The first is to offer an OR/MS teaching tool illustrating a novel application area. The second is to demonstrate how the model can be used to identify and alleviate system constraints to improve throughput, cycle time and work-in-process (WIP). Finally, the third objective is to illustrate the abilities of spreadsheets in analyzing queuing systems.

Our golf course simulation model is attractive for teaching purposes for several reasons. Identification of queues on a golf course is a nice example to propose to students. Our data collection process, although not extensive, gave students a dose of reality that is difficult to present in a textbook. Finally, the model is developed using MS-Excel and makes heavy use of powerful functions such as RAND(), IF(), and OFFSET(). These types of functions turn MS-Excel from a data presenting aid into a system analysis tool. The included model is large enough to require up-front design choices to be made about whether the model is to be used only once or as a decision support system for multiple projects.

We have used the concepts presented in this paper on several levels. In our Operations Management class, two concepts were applied: queue understanding and data collection. For teaching queues, we did not go into detail of the model. Rather, through the use of pictures/schematics, we discussed where and why golfers wait on a golf course. Additionally, we discussed how queuing affects profitability (which may not always be negatively). The data collection process was a very successful group project. Groups of 3 or 4 students were assigned a data type to collect. The students had to prepare data collections sheets, gain permission from a golf course manager (through a signed consent form), collect data (about 30–50 data points per student that took about 1 to 3 days of effort), and present their results to the class.

In our Management Science class, we teach spreadsheet-based simulation using the text, Simulation Modeling Using @RISK by Winston (2001), which has excellent examples. This golf spreadsheet model is used primarily to demonstrate that model design is critical for larger spreadsheet models. Until now, we have not given assignments based on using the model. Finally, the Arts and Science School hosts a Lecture Series in which the entire university and the local community are invited. We presented the golf model in the Series, and it was positively received.

2. Modelling Methodology

2.1. Simulation Modeling

The most used method for modeling systems with variability and interactions is discrete-event simulation (DES). DES is a venerable and well-defined methodology of operations research and many excellent explanatory texts exist (Hauge and Paige 2001, Law and Kelton 2000, Pritsker 1995, Winston 2001). The methodology is particularly useful in evaluating interdependencies among random effects that may cause a serious degradation in performance even though the average performance characteristics of the system appear to be acceptable (Shapiro 2001). Additionally, simulation models are intuitive, which is an important reason for their longtime and continuing application to complex systems.

Our literature review found one published article where discrete-event simulation was applied to modeling golf course play (Kimes and Schruben 2002). In this model, waiting occurred only on the first tee. Our model is more general, allowing for waiting at every hole and at locations other than just the tee box for each hole.

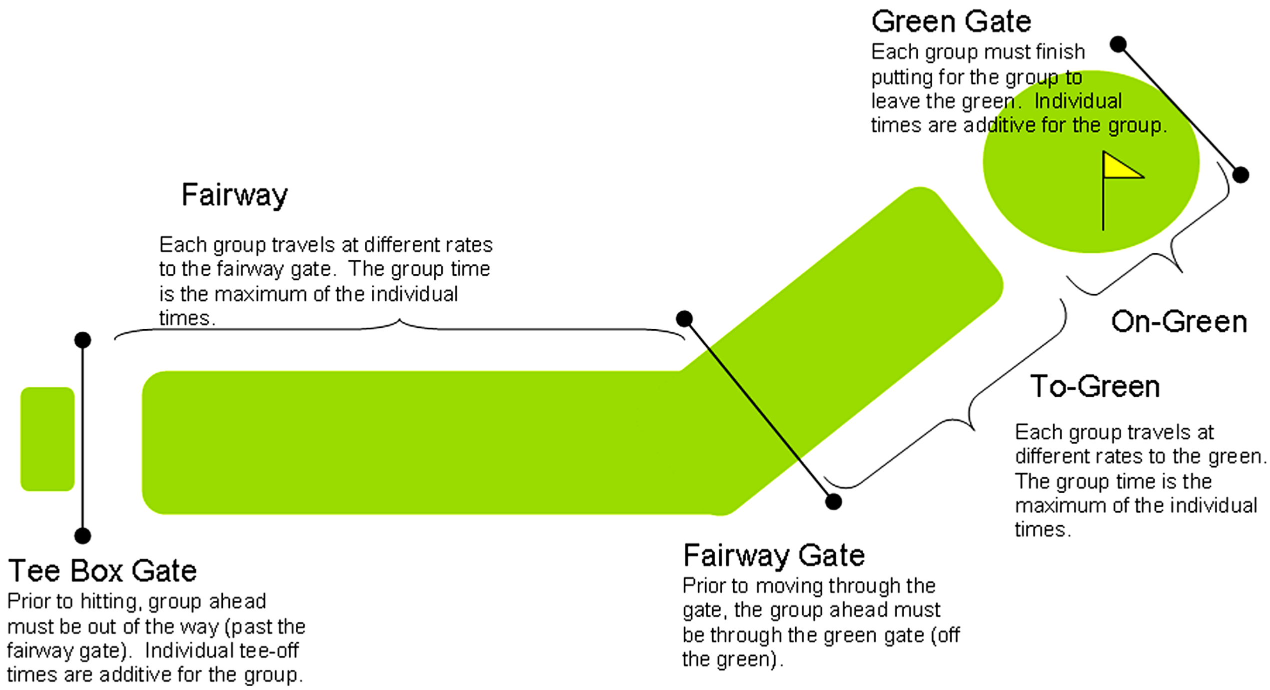
2.2. System Description

Defining and describing the system often requires the modeler working with a domain expert. Failure to adequately represent the system is often due to not working with someone knowledgeable in the field to be modeled. (Instructors should remind their students that a project's success often depends upon other factors than how skillful the modeler.)

A golf group consists of individual golfers, usually ranging from 1 to 4. Once set, the number of golfers in a group does not change. On each hole, the group begins on the tee box and then the golfers hit one at a time. The group moves towards the green once all golfers in the group have hit from the tee box. Some golfers move to the green more quickly than others depending on many factors. The United States Golf Association (Rule 10) dictates that the farthest golfer from the green is first to hit http://www.

[1] A shotgun start is a policy for managing how golfers begin their round of golf. Traditionally, golfers begin on the first hole and proceed to completion on the 18th hole. Course managers sequence the golfers by assigning a tee time, which is the planned time to begin the first hole. In a shotgun start, the golfers begin at the same time; however, rather than starting on the first hole, groups of golfers are assigned to various holes. Each group listens for a signal (a shotgun blast) to begin the round. The advantage of shotgun starts is the course is completely utilized at the beginning of the day. A disadvantage is the course plays at its slowest due to the heavy utilization.

Figure 1 Gates for a Par 4 Hole



usga.org/rules/index.html (2004); however, that rule is often overlooked in recreational play. Ready-golf is more often followed. Ready-golf is simply to hit when ready (provided it is safe and prudent to do so). Having reached the green, each golfer finishes by putting (one at a time) his/her ball into the hole. Once all golfers in the group have finished putting, the group proceeds to the next hole.

The group's pace is dictated not only by its own processing time, but also by the group ahead and the type of hole (par 3, 4, or 5). A group must wait for the group ahead to be out of the way. For example on a par 4 (or 5), a group cannot begin to hit from the tee box until its predecessor is sufficiently out of range to prevent injury by hitting someone. Because of the short distance of a par 3, a group cannot hit from the tee box until its predecessor is off the green. On par 4 or par 5 holes, a safe distance is between 225 and 300 yards. We define the point that allows the group behind to safely hit as a gate and refer to waiting for the group ahead to be out of the way as gate management. In simulation modeling, gate management refers to carefully controlling the flow of work items. Gate management has been used to model Kanban systems and drum-buffer-rope scheduling (Hauge and Paige 2001). Moving through gates is managed by the golfers. Their decisions are influenced by their ability and the hole design. On par 3's, the golfers traditionally wait for the group ahead to leave the green. For par 4 and par 5 holes, the gate is probably at around 300 yards. However, on some holes, the design requires hitting a shorter club off the tee. In these cases the fairway gate could be considerably closer to the tee.

An interesting aspect of our modeling approach that needs to be emphasized is that modeling of individual stroke play is not needed.[2] All time-based events (hitting a ball, hitting preparation, travel time to a ball, searching for a ball, group communication, etc.) were incorporated into the time to move to (and through) gates. These times are random; therefore different values occur. Large times represent poor play, searching for a ball, inherently slow golfers, etc. Shorter times represent well played shots and direct travel to the ball. Three types of gates were identified on a golf course: tee box (teeing-off), fairway, and green (putting). Each is explained in Figure 1.

2.3. Modeling Technique

A single replication of the model represented one day of play (approximately 12 hours) at a golf course. The model was implemented using MS-Excel and @RISK, an MS-Excel add-in. Although not a standalone discrete-event simulation software package, MS-Excel has an assortment of functions that make

[2] Math modeling requires representing a real system with logic and/or math. Often, seemingly very difficult systems can be adequately described with a relatively simple model, provided the modeler can use his/her imagination. Our initial approach (and maybe yours as well) to modeling this system was to model golfers moving from coordinate to coordinate based on where the golfer's ball was hit, his mode of transportation (walking or sharing a cart), and hole design. For our purposes, this type of model was quickly seen as too complex. We brainstormed to simplify our model.

Table 1 Processing Times (Seconds) for a Par 4

Group	Golfer	Time to tee-off	Time through gate	Time to green	Time to putt
1	1	60	110	70	70
	2	30	90	60	30
	3	20	100	200 (max)	10
	4	40	140 (max)	40	70
	Group	**150**	**140**	**200**	**180**
2	5	40	100 (max)	40	30
	6	40	60	60	40
	7	60	70	70	50
	8	20	80	80 (max)	40
	Group	**160**	**100**	**80**	**160**

Table 2 Event Times for a Par 4

Group	Tee-time	Off tee-box	Through gate	To green	Off green
1	0	150	290	490	670
2	360	520	670	750	910

it possible to model a gate-management system. The add-in, @RISK, provides a concise method for modeling different scenarios and collecting statistics from multiple replications.[3]

To illustrate the gate management modeling logic, consider the first hole at the beginning of the day. Tables 1 and 2 illustrate the progress of the first two groups. Group 1 tees off at time zero, and group 2's tee time is six minutes (360 seconds) later. Table 1 shows the processing times (not event times) for each group. Since hitting from the tee box is a serial process (golfers hit one-at-a-time), times are additive, and group 1 takes 150 seconds. Before group 2 can hit from the tee box, group 1 needs to be out of the way. We define a gate 300 yards from the tee box that group one must be through prior to group two hitting.

The golfers in group 1 move to the gate at different speeds, and the slowest golfer (golfer 4 in this example) is out of the way in 140 seconds (after leaving the tee box). Note that these 140 seconds encompass everything that golfer 4 does (hitting, moving, searching, preparing, ...) to reach the gate. From this gate, golfers in group 1 proceed to the green. Golfer 3 takes the longest (200 seconds). Once on the green, putting time is additive; therefore, the total putting time is 180 seconds, and the group's total time to complete the hole is 670 seconds.

Similar logic applies for group 2, except its pace is dictated not only by its tee time and processing time, but also by group 1's pace. Table 2 shows the event times. Group 2's tee time is six minutes (360 seconds) after group 1. Since group 1 is through the gate at 290 seconds, group 2 does not need to wait for group 1 and begins to hit exactly at its tee time. However, group 2 is not as fortunate on the fairway. Group 2 takes 160 seconds to hit from the tee box and 100 seconds to reach the gate; therefore it is ready go through the gate at 620 seconds. However, it cannot get through the gate until 670 seconds because group 1 is still on the green. Therefore, group 2 waits on the fairway for 50 seconds. This delay does not prevent group 3 (not modeled) from hitting at its scheduled tee-time of 720 seconds; however, this can change as the day progresses. As often happens with queuing systems, once behind, it is very difficult to get back on schedule.[4] For par 3 and par 5 holes, similar logic is needed, except par 3s have no fairway gate, and par 5s can have two fairway gates.

2.4. Assumptions

The spreadsheet model has the capability of modeling various group sizes from one to four golfers; however, for this analysis, all groups consisted of four golfers. Also, no play-through logic[5] was allowed; therefore, the same group order was maintained throughout the round. Another assumption was that the gates are hole-specific, not golfer-specific. This was a significant assumption that is fundamental for model development using a spreadsheet. To illustrate, assume a par 4 hole has a fairway gate that is 280 yards from the tee box. This gate prevents a group from hitting from the tee box until the group ahead reaches this gate. Since the gate is hole specific (vs. golfer specific), all golfers must wait for the group ahead to reach the 280 yard gate even if none of the golfers in the group have the capability of hitting a ball 280 yards.[6] Another assumption was disregarding any specific golfer designations such as the transportation mode (carts vs. walking), or ability (good vs. bad, straight vs. erratic, long vs. short). Finally, course traits such as water, bunkers, rough height, and elevation changes are not modeled.

2.5. Data

2.5.1. Time Data. For representing to-gate times, data were collected by a class of Operations Management students as a data analysis exercise. Four different types of data (500+ values) were collected from

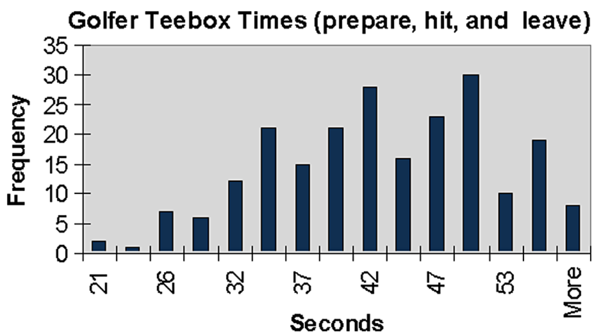
[3] @RISK offers many features for simulation systems. Our primary use of @RISK was to collect data and simulate replications. The enclosed model does not have @RISK functionality, which allows the readers without @RISK software to still use the model. For an excellent text on @RISK, see Winston (2001).

[4] A counter-intuitive feature often seen in queuing systems. See the story of Herbie in The Goal (Goldratt 1984).

[5] Often, a fast group is allowed to move through (pass) the group ahead. This is playing through. Our model does not allow this.

[6] This was a crucial design choice. It allowed using a spreadsheet versus a more complex discrete-event simulation software package such as Arena or Simul8.

Figure 2 A Histogram of a Golfer's Tee Box Time

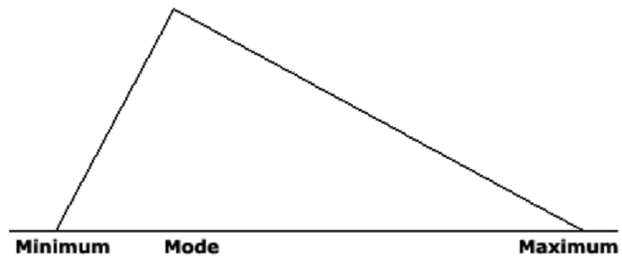


five different local courses. Data collection was a great exercise for the students. It forced them to understand the system, take some responsibility (asking course managers for permission and to sign a consent form), and reminded them that data requires time and effort.

One type of data collected was the time it took for a group of golfers to prepare, hit, and leave the tee box. Figure 2 shows the histogram of times (in seconds).[7] We used triangular distributions[8] (see Figure 3 for an example) to model all random quantities in the model. All of the fitted triangular distributions passed a chi-squared goodness of fit at a 5% significance level. Table 3 shows the estimated parameters (minimum, mode, and maximum) for each random quantity. Note that the tee box and putting values are times (minutes), and the other values are rates (yards/minute). The rates allow transit times to be determined on any hole on any course by dividing the hole-specific distance by the randomly generated rate.

2.5.2. Input Data. A good decision support system (DSS) separates input data from modeling logic; thus, developing a tool that can be applied to many different systems. Our model-driven DSS separates course data from the modeling logic. Therefore, if a new course is to be analyzed, only the input data needs to be modified. (The spreadsheet that we included clearly separates input information from the

Figure 3 A Triangular Probability Density Function



remaining part of the model logic by designating one of the worksheets as an input worksheet.) The modeling logic takes into account which hole is a par 3, 4, or 5 and represents the gate management system accordingly. The input data structure used is shown in Table 4. The first hole is a par 5. The first fairway gate is 250 yards from the tee box. The next fairway gate is 200 yards from the first fairway gate. The green is 50 yards from the second fairway gate, and the second hole's tee box is 50 yards from the first green. The second hole is a par 4; therefore, it does not have a second fairway gate. The third hole is a par 3; therefore, it does not have any fairway gates.

2.6. Validation[9]

Validation, determining that the model accurately represents the real system, relied primarily on experience and expert judgment. Avid, if not talented golfers, the authors have a wealth of experience of how long a round can be played without waiting as a single or in a group. Results of a no-waiting analysis accurately depicted the authors' experiences and well established expectations. Similarly, the modeling of a busy course accurately reflected upwards of 5 hours for a weekend round of golf.

3. Identifying and Alleviating Constraints

Many factors can influence pace of play. One system-wide factor is the tee time interval, which is the duration that separates groups beginning their round on the first hole. A small tee time interval puts more golfers on the course (high WIP), and a large tee time interval puts fewer golfers on the course (low WIP). Using a 100-day simulation run, Figure 4 shows the average rounds played and the average round length as a function of the tee time intervals 6, 7, 8, 9, and 10 minutes. A tee time interval of 9 minutes or less increases the average number of rounds

[7] Although not the focus of the paper, it is worth noting that a data cleansing exercise was required after the students collected the data. One specific reason for the cleansing was a failure of the students to understand the data type. The students were only to collect processing times, not waiting times. For example, if a group of golfers reach a tee box and must wait for the group ahead, the waiting time was not to be collected. Only the processing times of preparing, hitting, and leaving the tee box were to be collected. The model addressed the queuing issues.

[8] The triangular PDF is a great function to illustrate non-symmetrical variability. Although better fits of the data were possible, we preferred simplicity to accuracy. For a spreadsheet-based reference on generating random values from a triangular distribution, see Ralph (2004) website: http://www.eng.cam.ac.uk/~dr241/chevening/option-ex.xls.

[9] Our validation is admittedly weak. Rather than exclude, we thought that this statement should be included to demonstrate an often used initial step in validation, the common-sense test: "Does the model's results seem reasonable?" From this point, instructors can explain a more formal method on how to proceed in validating the model.

Table 3 **Data Values**

Data type	Description	Min	Mode	Max
Tee box time (minutes)	The time for an individual golfer to address and hit the ball on the tee box. No waiting time included.	0.30	0.77	1.00
Tee box to gate (yards/minute)	After leaving the tee box, an individual golfer's rate while reaching an arbitrary (but identified) point/gate in the fairway.	40	70	160
Gate to green (yards/minute)	From an arbitrary (but identified) point/gate in the fairway, an individual golfer's rate while reaching the green.	40	90	200
Putting time (minutes)	The time for an individual golfer to complete putting and leave the green.	0.23	1.05	1.50

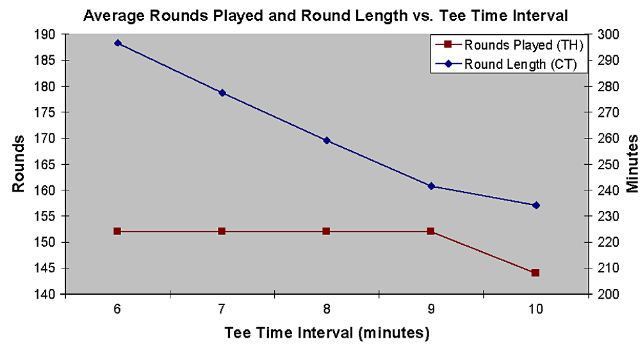
played versus a 10 minute tee time interval. However, no improvement is offered for a tee time interval of 9 minutes or less. The average round length continually drops as the tee time interval is increased.

A course manager has two objectives, increase revenue by increasing throughput (rounds played) and providing a round of golf in an acceptable time frame (usually between 240 and 270 minutes on a busy day). To accomplish these two objectives for this system, the manager should set the tee time interval to 9 minutes, which provides an average of 152 rounds per day and takes 250 minutes to complete a round.

Table 4 **Input Data**

Hole	Par	Distance	To gate 1	To gate 2	To green	To next hole
1	5	500	250	200	50	50
2	4	440	250	0	190	50
3	3	160	0	0	160	50
4	4	370	250	0	120	50
5	5	500	250	200	50	50
6	4	420	250	0	170	50
7	4	350	250	0	100	50
8	3	200	0	0	200	50
9	4	370	250	0	120	50
10	4	440	250	0	190	50
11	5	520	250	200	70	50
12	4	390	250	0	140	50
13	4	340	250	0	90	50
14	3	170	0	0	170	50
15	5	560	250	200	110	50
16	4	330	250	0	80	50
17	3	200	0	0	200	50
18	4	370	250	0	120	50

Figure 4 **Average Rounds Played and Round Length as a Function of Tee Time Interval**



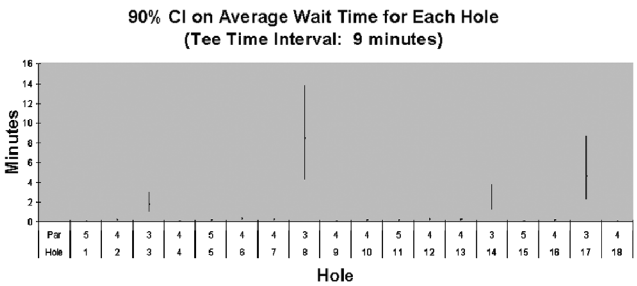
To improve the system, constraints must be identified. Figure 5[10] shows the 90% confidence interval for the average group waiting time for each hole (tee time interval is 9 minutes). The average group waiting time is the time that a group waits on the group ahead. Holes 3, 8, 14, and 17 show significant waiting times, with hole 8 averaging over 8 minutes for each group. Table 4 identifies that all of these holes are par 3's. Traditionally on par 3's, a group waits for the group ahead to completely finish the hole before beginning the hole. The primary reason is that on par 3's, it is possible (and expected) to reach the green in a single stroke. Using gate management strategy, the following group must wait for the preceding group to be completely out of the way before beginning; therefore, the following group waits for the preceding group to (1) tee off, (2) proceed to the green, and (3) putt before beginning the hole. On busy courses, the consequence of this is increased delays and reduced throughput.

One option for improvement is removing the par 3's (and converting them to par 4's).[11] However, we propose a different operating policy for par 3's. If the following group is ready and can complete teeing off before the preceding group reaches the green AND no group is on the green, it does. This policy allows the following group's to tee off in parallel with the preceding group moving to the green. This allows up to two groups to play the hole versus the traditional method of only one group on a par 3. Under the traditional policy, these activities are additive. With the proposed policy, only the maximum of these activities

[10] Figures 5 and 6 are of a type used to display daily stock values. However, we used this type of chart to display confidence intervals. To do this requires that the proper format is followed (High-Low-Close = UCL-LCL-Mean).

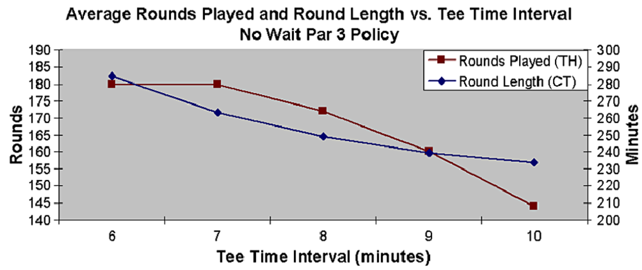
[11] Designing a course without any par 3 holes is certainly non-traditional (and probably not acceptable to the golfing public). Nevertheless, one advantage of modeling is allowing non-traditional ideas to be explored without causing too much controversy.

Figure 5 Average Waiting Time for Each Hole



Note. The par for each hole is shown on the horizontal axis.

Figure 7 Average Rounds Played and Round Length as a Function of Tee Time Interval Using a Par 3 No Wait Policy



impact round length. Figure 6 shows the hole-specific waiting times, which indicate a significant reduction of the average group waiting time for par 3's. Figure 7 shows the impact on the average rounds played and average round length. When compared to the base case, an 8 minute tee time interval provides the same round length and increases the rounds played from 152 to 175 rounds (13% improvement).

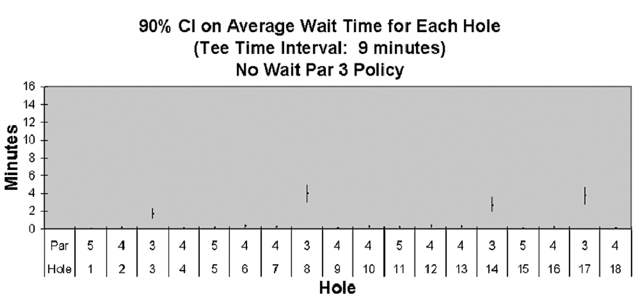
Implementation of this new par 3 policy has some limitations. First, the design of the hole must allow the preceding group to move safely to the hole while the following group hits from the tee. This design change is not trivial; however, some holes naturally provide this safe path. Second, the golfing public must be informed and trained to use this policy. Signs and course marshals can provide these. Also, this policy can be applied to any hole on the course, provided the design provides a safe path to the green.

4. Spreadsheet Implementation http://archive.ite.journal.informs.org/Vol4No2/TigerSalzer/Golf_DSS.xls

A slightly modified version from the one used for the above analysis is included (see attachment). The modifications are strictly to provide easier access. The simulation add-in, @RISK, is no longer embedded in the model. Consequently, only single days are modeled, and the modified model is not designed to provide simulation replications for analyses. However, the model is capable of producing unique individual (daily) results by simply pressing the "F9" function key. The "F9" key re-calculates the spreadsheet and updates all the RAND() functions within the spreadsheet, thus generating a unique daily run of the model. Additionally, to reduce the size of the model, only 36 groups (144 golfers if four golfers per group) are modeled.

Despite these changes, the model still possesses significant complexity and is capable of addressing other analyses not addressed in this paper. We encourage you to develop your own analyses (or class exercises) by using the spreadsheet to either change the input values or fundamentally modifying the modeling logic. Table 5 lists our suggestions for additional class exercises. Rather than provide a detail of every formula, Table 6 summarizes each of the worksheets in the MS-Excel-based model.

Figure 6 Average Waiting Time for Each Hole Using a Par 3 No Wait Policy



Note. The par for each hole is shown on the horizontal axis.

Table 5 Suggested Class Exercises by Modifying the Spreadsheet Model

Topic to investigate	Model changes
How does the system change due to variability reductions?—Do golfer time and rate variability significantly impact performance measures or bottleneck location?	On the INPUT worksheet, modify the triangular PDF parameter values.
How does the system change due to unique modes of transportation? One potential application of the Segway Human Transporter http://www.usga.org/ is as a golf cart. Would it improve the system (and improve profitability)?	On the INPUT worksheet, modify the triangular PDF parameter values.
How does newer equipment technology affect system performance—Equipment technology is creating longer shots. What does this do to the system?	On the INPUT worksheet, modify the hole gate distance values.
Are four golfers per group best?	On the INPUT worksheet, modify the cumulative distribution values for the group size.

Table 6 DSS Worksheet Description

Worksheet name	Description
Input	Provided no fundamental design changes are performed, this worksheet is where users change parameters. Three types of data can be changed: hole-specific parameters, operating policies, and gate timing data. Hole-specific parameters change the course characteristics, whether that is the par, yardage, gate distances, par-3 policy, and distance to the next hole. Operating policies impact how the course is managed. A tee-time interval is required. The number of golfers per group is dictated with a discrete probability distribution. Gate time data are the parameters for the times and rates. All PDF's are triangular.
Output	This worksheet provides the daily performance measures for 36 groups including the average time to play a round and the average waiting time per group. Hole specific waiting times are provided by location that the waiting occurred. Waiting occurs when a group cannot proceed due to the preceding group.
Graph	This worksheet graphically summarizes the Output worksheet in graphs 1 through 3. Graphs 4 and 5 shows how cycle times, throughput, and WIP change over time.
Golfer_Gate_Times	The largest worksheet. This worksheet provides the processing times for each individual golfer for each hole (and location). This worksheet is similar in logic to Table 1; however, it calculates the processing times (minutes) for 36 groups for each of the 18 holes. The worksheet makes heavy use of the IF(), RAND(), and VLOOKUP() functions.
Group_Finish_Times	This worksheet provides the completion times for each group for each hole (and location within the hole). This worksheet is similar in logic to Table 2; however, it is expanded to 36 groups for each hole. The worksheet makes heavy use of the IF(), OFFSET(), and MAX() functions.
Waiting	This worksheet determines whether a group was waiting for the preceding group by location. The worksheet makes heavy use of the IF(), and OFFSET() functions.
WIP	This worksheet determines the number of golfers on the course by time period (hourly increments).
CT&TH	This worksheet determines the average round length and rounds played by time period (hourly increments).

5. Conclusions, Model Limitations, and Future Research

The primary significance of this paper is to provide an interesting and unique application of OR/MS using a readily available analysis tool, MS-Excel. We have demonstrated that improvements in the revenue-generating ability of a golf course exist by improving operations management through modeling and TOC. In the past, little effort has been devoted to modeling a golf course system as a complex system impacted by variability and interaction. The model was developed using MS-Excel and @RISK, a Monte Carlo simulation package.

Many model limitations exist. Without modeling each individual stroke and the subsequent movement of the golfers to the golf ball's location, model reality is lessened. Consequently, future research is plentiful.

Obviously, implementation is another matter. Golf is a social system steeped in tradition and slow to change. However, demonstrable revenue-generating opportunities are not ignored in business, including golf.

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