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ARTICLE

Analyzing the Pace of Play in Golf: The Golf Course as a Factory

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The time it takes to play a round of golf at American golf courses is considered a major obstacle to the growth of the game, to increasing facility revenue and profitability, and to the enjoyment of the game for millions of golfers and would-be golfers. This paper examines the problem of slow play from the standpoint of the science of "factory physics" (2000), the principles behind the great improvement in manufacturing productivity, which modern economies have enjoyed (Hopp & Spearman, 2000). This study applied those principles by employing the use of computer simulations and statistical data analysis to reach an understanding of the problems that create slow play and to point to solutions to improve it.

Keywords: golf, pace of play, factory physics

This paper examines three sets of factors affecting slow play: Player-Specific Factors, Group-Interactive Factors, and Course Design/Management Factors, with the emphasis in this paper being the first two sets. Simulations of a wide variety of conditions have lead to many findings, some of which are the following:

General Findings

The pace of play problem is complex and the result of an interaction of many factors. There is no silver bullet to solve the problem. It will take a comprehensive approach to make any progress.

Player-Specific

- Individual Player Factors (like not moving directly and briskly to your own ball and not being ready to hit when it is your turn) may add as much as one hour to the time to play a round.

Group-Interactive

- The slowest groups determine the pace of play for all groups on the course behind them, setting up a weakest link dynamic. The amount of time groups following the slow group "wait to hit" increases as their pace increases, leading to frustration and bad habits.

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- Even if all groups are "fast" but experience some time/shot variability, even if the overall pace is quick, most groups will experience some waiting and will perceive that the pace is slow.
- Situations in which most golfers are "fast" but play a few individual holes slowly due to a lost ball or a three putt, the pace of play is not the average pace but closer to the sum of the slowest play of any group on each hole. As such, almost everyone may contribute to slow play.
- Waving up on par 3s can have a beneficial effect on course capacity and the distribution of total wait time, and in some cases, but not all, may improve overall time to play.

Course Design/Management

- Tee Time Intervals can have as much to do with slow play as individual and group behaviors.
- "Revenue management" and "time to play management" compete against each other rather than complement each other. Most courses rationally maximize revenue by putting too many groups on the course at one time, and as a result create rather than manage pace of play problems.
- Designers who create courses with long walks between holes or long walks to a landing zone may have added in some cases 30–40 minutes of extra time to play 18 holes.
- Course managers, not just individual golfers, have to learn to recognize what is causing the delays and how they contribute to them.

Background

Growth of the game was steady from its introduction in the late nineteenth century all through the twentieth century. In the past ten years little if any growth has been seen by operators of public and daily fee operators. By the end of the first decade of this century, more golf courses were lost to other forms of development than new ones opened. Although there are many reasons for this situation, one significant one is length of time it takes to play the game. Five and six hour rounds are not unheard of, forcing golfers to make a full day commitment to the sport each time they wish to play. A study by Frank Thomas (2005) found the time commitment to be the major barrier to people playing more golf. Many commentators have said similar things, and no one complains that a round of golf is too fast. This paper explores the problem of slow play, presents a review of significant, previous work done on the subject, details an analysis of the problem using simulation and other analysis techniques, and presents results and conclusions that likely will lead to improvements.

Pace of Play—The Problem Defined

For most golfers, the time to finish a round is the problem. For others the problem is the long waiting periods before strokes can be played even if the overall time is not bad. For golf course operators, slow play limits the number of rounds they can provide (and sell) in a day. Everyone has an idea of how to speed up play. Some people believe if everyone walked faster, the pace would be better. Some believe carts speed up play, others believe they slow things down. Some believe "conceding" short putts would speed up play. Others say that everyone should go to their own ball and be ready to hit when it is their turn to play. Others say practice swings should be eliminated. Even this author wrote an article humorously summarizing many of those ideas in a 1987 *Golf Digest* issue. Perhaps the best discussion of what individual golfers should do to speed up play can be found in Pat Mateer's work, *The Return of the Four Hour Round* (2010). Would any of these actually speed up play? And if so by how much? Some may be good for some situations but useless for others. What factors determine slow play? What factors determine total and distributed waiting time? How can total rounds played in a day be maximized? How can we find the answers to these questions? This study examined the issue of pace of play through a series of simulations and other models designed to determine what factors lead to slow play and what changes would lead to significant improvements in the time to play.

Previous Studies

Two significant and well-done academic studies and at least two practical analyses have been done on this subject. Kimes and Schruben (2002) studied golf course administration from a revenue management perspective. Using simulation, they examined the relationship between tee time intervals and the total number of groups a course could accommodate in a day. They found (as would be predicted by Factory Physics) that shortening tee time intervals is good up to a point (the capacity of the bottleneck hole) after which there is a rapid deterioration in pace of play.

Tiger and Salzer (2004) developed a simulation model of the daily play at a golf course primarily to use as a classroom simulation teaching aid. However their model was substantial enough to consider pace of play and course throughput concerns seriously. They concluded that the bottlenecks on many courses are the 3 pars and that a "wave up" strategy could improve throughput by over 10%. This study found similar results.

Yates (2011) using an approach developed by Dean Knuth, former Director of Handicapping for the USGA, called the USGA Pace Rating System (1993) evaluates golf courses to rate the pace at which golfers should play a course given its difficulty and other factors. Similar work has been expertly done by Southard (2010) advising course managers on how to rationally approach the pace of play problem and its revenue implications.

In summary, Kimes focused on the slow play issue from a tee time interval management perspective (how does management's tee interval decision affect pace?), Tiger from a player characteristic standpoint (how do player behaviors affect pace?), Yates from a course design point of view (how does the course affect pace?), and Southard from a comprehensive course management perspective (what are the things course managers can do to improve pace?) This study attempts to consider all perspectives.

The Golf Course as Factory: Applying Factory Physics to Golf

All factories consist of processes which when provided with the right resources, produce finished products. Processes are made up of individual operations generally done in a series. In our golf analogy, each hole is an operation and each foursome is a work-in-process product.

In factory physics, the time it takes one unit of product to go from raw input to finished product is called Throughput Time. In golf, the throughput time is the time it takes one group to play their full round. Cycle time is the time between successive outputs, or completed products, of a factory. In golf, that would be the time between successive groups finishing the 18th hole. Both measures can be defined for each hole as well as the whole course.

The Capacity of a factory is its maximum production per hour or per day. If a factory has several operations done in series, the lowest capacity operation limits the capacity of the *entire* factory. The lowest capacity operation is called the bottleneck. Capacity and Cycle Time are inversely related. A capacity of 10 per hour is equal to a cycle time of one every 6 minutes. The input rate should not be more than the capacity of the bottleneck. If it is, long waits build up in the factory. All of these have a direct application to the problem at hand.

The Models

Several models were developed, from simple spreadsheets to full computer simulations, to consider different aspects of the pace of play problem. The first model (Single Group/Single Shot) calculated the effect different ways one group goes about playing one shot has on pace of play. The second model (Single Hole Bottleneck Analysis) was a spreadsheet analysis of how, in general, certain holes become either bottlenecks or nonbottleneck holes. A third was developed to study overall playing time and waiting time for many groups playing on an 18-hole course (18 holes/Multiple Groups.) This computer simulation model was used two ways. First it was run assuming constant times to play shots and to move from shot to shot (Deterministic.) Second it was set up to include several more realistic and varied assumptions (Multiple Groups with Variability), specifically the natural variability in taking shots and moving to the next one. Lastly a model using Kimes' (2002) results was built to examine the pace of play consequences of course management's understandable desire to maximize revenue. All of these proved helpful in uncovering an understanding of the problem from different perspectives.

Single Group/Single Shot Model

The single group/single shot spreadsheet model simulated the individual strokes and movement of each player in a group of four to complete the play of a fairway stroke on a par 4 hole. The purpose of this model was to test the effect on playing time of different player movement strategies. Three movement-disciplines were tested with constant times to play. The first had all golfers move to the position of the shortest tee ball with all waiting until the first hits his second shot (30-second preshot routine and a 15-second ball striking routine.) Then everyone advances to the next shortest (15 seconds to walk.) They all wait until that player hits, and then they move. This continues until all have hit. The second discipline had everyone move to their own ball, but wait until the previous player hits before they begin their preshot planning. The third discipline has everyone move to their own ball and immediately begin their preshot planning.

In the first discipline, it takes 3 minutes and 45 seconds for the group to clear the landing area. In the second discipline, it takes the group 3 minutes to clear the area. In the third it takes only one and one half minutes. Clearly golfers' individual movement/preparation strategies can make a significant difference in the time it takes to clear a landing area. Assuming the savings could be realized, the difference between the first and third disciplines can save as much as one hour per round. Figure 1 is a depiction of the three approaches for the time to play a fairway shot on a par 4.

Single Hole Bottleneck Analysis Model

The bottleneck analysis model simulated the regular play of one par 3, par 4 and par 5 and the play of a par 3 with "wave up." The purpose of this model was to demonstrate how the different par types affect the overall capacity and waiting time of a course. The analysis assumed all groups were accomplished golfers with fixed times to play. For this example, those fixed times were: tee off in 3 minutes, take three minutes to walk to the next stroke (to the green on par 3s), 3 minutes to clear the second on par 4s and 5s and, on par 5s, clear the third shot. It also assumed a two-minute walk to the green from the fairway and on par 5s to walk to the third. It assumed all groups on all holes took 4 minutes to clear the green. Using these figures, it would take a group 10 minutes to play a par 3 (3 minutes to tee off, 3 minutes to walk to the green and 4 minutes to clear the green.) It would take a group 15 minutes to finish a par 4 and 20 minutes to play a par 5. Although the par 5 takes the longest, our experience tells us that par 3s tend to be bottleneck holes (where groups wait.)

Figure 2 confirms our experience. The numbers under the label "Time" are the times it takes each group to clear the next hitting zone or green, and to walk to the next shot. Looking at the first part of the chart—"Par 3 No Wave Up"—the first group clears the tee at time 3, walks to the green in three minutes (time 6), then putts out to finish the hole in 10 minutes. At that point group 2 can start to tee off. In this first case, it can be seen that each group takes 10 minutes to play the hole (throughput time) and that a group finishes every 10 minutes (cycle time.) The capacity of the hole is six groups per hour. The par 4 throughput time is 14 minutes for the first group to play. However the next group cannot begin play until after the first group hits its second shots and clears the hitting area.

In the paper by Tiger et al., this is called clearing the "gate." The second group cannot hit their second shots until the first group clears the green. The spreadsheet models show that using these time estimates, the second group and each subsequent group must wait one minute for the group ahead to clear the green before they can begin hitting their second shots. As such the second group and each group after it will take 15 minutes to play the hole (throughput time.) However the model

Single Group/ Single Shot

Player	0	45	60	75	90	105	120	135	150	165	180	195	210	225
Everyone Waits At First Player Before Moving														
1		**Play**	*Walk*	Wait	Wait	Wait	*Walk*	Wait	Wait	Wait	*Walk*	Wait	Wait	Wait
2		Wait	*Walk*	**Play**	**Play**	**Play**	*Walk*	Wait	Wait	Wait	*Walk*	Wait	Wait	Wait
3		Wait	*Walk*	Wait	Wait	Wait	*Walk*	**Play**	**Play**	**Play**	*Walk*	Wait	Wait	Wait
4		Wait	*Walk*	Wait	Wait	Wait	*Walk*	Wait	Wait	Wait	*Walk*	**Play**	**Play**	**Play**
Walk But Wait Before Pre-Shot Routine Starts														
1		**Play**	*Walk*	Wait	Wait	*Walk*	Wait	Wait	*Walk*	Wait	Wait			
2		*Walk*	**Play**	**Play**	**Play**	*Walk*	Wait	Wait	*Walk*	Wait	Wait			
3		*Walk*	Wait	Wait	Wait	**Play**	**Play**	**Play**	*Walk*	Wait	Wait			
4		*Walk*	*Walk*	Wait	Wait	*Walk*	Wait	Wait	**Play**	**Play**	**Play**			
Walk to Own Ball and Hit When Your Turn														
1		**Play**	*Walk*	*Walk*	*Walk*									
2		Walk/Pre	**Play**	*Walk*	*Walk*									
3		*Walk*	Pre Shot	**Play**	*Walk*									
4		*Walk*	Wait/Pre	Pre Shot	**Play**									

Time To Play Hole (Seconds)

Figure 1 — Three approaches for the time to play a fairway shot on a par 4.

Par 3

No Wave Up		**Group Number**							
		1	2	3	4	5	6	7	8
	Time								
Tee	3	3	13	23	33	43	53	63	73
Walk	3	6	16	26	36	46	56	66	76
Green	4	10	20	30	40	50	60	70	80
Thru-Put Time		*10*	*10*	*10*	*10*	*10*	*10*	*10*	*10*

With Wave Up									
		1	2	3	4	5	6	7	8
Tee	3	3	9	16	23	30	37	44	51
Walk	3	6	12	19	26	33	40	47	54
Wait		9	16	23	30	37	44	51	58
Green	4	13	20	27	34	41	48	55	62
Thru-Put Time		*13*	*14*	*14*	*14*	*14*	*14*	*14*	*14*
Cycle Time			*7*	*7*	*7*	*7*	*7*	*7*	*7*

Par 4 Hole

		1	2	3	4	5	6	7	8
Tee	3	3	12	21	30	39	48	57	66
Walk	3	6	15	24	33	42	51	60	69
Fairway Shot	3	9	18	27	36	45	54	63	72
Walk	2	11	20	29	38	47	56	65	74
Green	4	15	24	33	42	51	60	69	78
Thru-Put Time		*15*	*15*	*15*	*15*	*15*	*15*	*15*	*15*
Cycle Time			*9*	*9*	*9*	*9*	*9*	*9*	*9*

Par 5 Hole

		1	2	3	4	5	6	7	8
Tee	3	3	12	21	30	39	48	57	66
Walk	3	6	15	24	33	42	51	60	69
Fairway Shot	3	9	18	27	36	45	54	63	72
Walk	2	11	20	29	38	47	56	65	74
Fairway Shot	3	14	23	32	41	50	59	68	77
Walk	2	16	25	34	43	52	61	70	79
Green	4	20	29	38	47	56	65	74	83
Thru-Put Time		*20*	*20*	*20*	*20*	*20*	*20*	*20*	*20*
Cycle Time			*9*	*9*	*9*	*9*	*9*	*9*	*9*

Figure 2 — Times to complete each aspect of hole.

indicates that the time between groups starting and finishing the hole is 9 minutes (cycle time) yielding a capacity of 6.67 groups per hour. Interestingly, although the time to play the par 4 hole is larger, it has a higher capacity than the par 3. A similar analysis for par 5s shows that their capacity is the same as the par 4s, 6.67 per hour. Given that the capacity of the par 3s is lower than the capacity of the others, they are by definition the bottlenecks.

Unfortunately, most courses start with a par 4 or 5. Groups generally start as soon as the previous group clears the hitting zone (the first "gate.") As shown above, the capacity of par 4s and 5s is 6.67 per hour or one group every 9 minutes. In this model, new groups enter the course every 9 minutes, 6.67 per hour. Since the capacity of a par 3 is 6 per hour, a queue has to build up. The optimal tee time interval for pace of play is equal to the cycle time of the hole with the lowest cycle time, generally the par 3s, not the opening hole. Sending groups out at a rate faster than the capacity of the bottleneck creates delays and significantly slows the overall pace of play. Now consider the par 3 "Wave Up" case. The first group reaches the green at time 6. It then waits for the second group to tee off. They resume putting at time 9 and finish the hole at time 13. Although it took them longer to play the hole, each successive group finishes the hole with an interval of 7 minutes. With "wave up", par 3 capacity jumps from 6 groups to 8.57 per hour, a 46% increase. But the increase cannot be fully realized since the par 4s and 5s now become the bottlenecks. So by waving up, the capacity of the course goes from 6 to 6.67, a 10% increase.

This model can help pinpoint how the different parts of playing a hole can affect the hole's playing time and capacity. If the players walked faster to their fairway shots, say, by one minute faster, the first group would play the hole in 14 minutes instead of 15 minutes. The next group (and each following group), however, would still play it in 15 minutes since their faster walking pace would be met with a one minute wait while the previous group cleared the green. In this case, the extra minute saved at the front end of the hole does not result in any improvement. Walking faster is good if there is no "interference" from other groups.

This confirms the experience of many regular golfers who realize it is not "worth" speeding up play at the front of a hole. It is, as they say in the army, "hurry up and wait." As a result, many golfers just do not hurry up, leading to bad habits that carry over to other parts of play. On the other hand, speeding up or slowing down at the back end of the hole has significant effects. Speeding up (or slowing down) by one minute either in the walk to the green or clearing the green reduces (or adds) two minutes to the throughput time and one minute to the cycle time. One of the two minutes saved on throughput time is the one-minute of faster play and the other is the one-minute of waiting time in the fairway. The lesson here is that a minute saved can, in one place, improve nothing and, in another place, be worth more than a minute.

It is important to understand what parts of play have a significant effect on pace of play and capacity and which do not. One of the rules of factory physics is to design the process with the bottleneck near the beginning of the process. In this case the bottleneck for the hole is clearing the green. Any delay there causes backups all the way back to the tee. For a par 4 to work well, the hole should be designed to allow the players to clear the green faster than it takes to tee off. Another application of the concept of having the bottleneck early on in a process is to have the bottleneck hole be the first hole. If courses were designed with the longest par 3 as the first hole, the rest of the course would likely flow smoothly.

18 Hole/Multiple Group Simulations With Deterministic Times

A full course simulation model with many groups playing in natural succession (almost a full day of play) was then built. Its design was similar to the models by Tiger, using the "gate" approach, but allowed for testing other options. The tee box, fairway shots and the green were considered gates. As before, each group waits to begin their next shots until the preceding group clears the next "gate." In this first version, a particular group's total time to tee off, time to play a fairway shot, their walking speed, and their time to clear the green was a constant for all holes. Thirty groups were sent off on a typical 6600 yard course. Each group could be characterized as "Fast" or "Slow." The Fast groups clear the tee and fairway shots in three minutes (45 seconds per shot), the green in three minutes and move at 3 mph (90 yards per minute.) Those parameters would allow each group if unimpeded to play 18 holes in 241 minutes, just about 4 hours.

The model was run with all Fast groups, then all Slow groups and, finally, with combinations of both.

All Groups Playing at the Same Pace

If each group played at the rates above and was sent out in 9 minutes intervals, every group would play in 241 minutes and there would be essentially no waiting time. With no waving up, the par 3s set the capacity of the course. The time to play each of the par threes ranged from 8.2 minutes to 8.7. As such a tee time interval of 9 was appropriate. The model was tested with other tee times with the results shown in Table 1.

With an interval lower than the cycle time of the bottleneck hole, groups will bunch and wait. The time to play steadily increases over the course of the day. The first group still plays in 241 minutes but each successive group takes longer, getting close to 5 hours to play. The graph of the results for all fast players but with an 8-minute tee interval is shown in Figure 3.

In this model, tee time intervals greater than nine minutes do nothing for pace of play if the speed is at least three miles per hour (mph). But at 2 mph, a greater interval is needed to keep the pace at 4 hours. Even a 10-minute interval is not enough, causing the pace to jump to 277 minutes, almost 40 minutes more (Figure 4).

What if all groups walked slower? Obviously the overall pace would slow. What if they played their shots slower? How much would that slow down play? Are there some shots more important than others? Is walking pace more important than shot time? This model can help with those questions. With a 9-minute interval, by

Table 1 Tee Time Interval, Average Time and Maximum Time to Play for the Last Group of the Day Tee

Time Interval	Average Time to Play	Maximum Time to Play
9	241	241
8	250	260
7	265	290

running the model with different walking speeds, we get the following statistics (90 yards per minute equates to about 3 mph and 60–2 mph) (Table 2).

Note that the unimpeded first group plays in about four and one half hours. When groups play their shots fast but walk slowly, the time to play will progressively

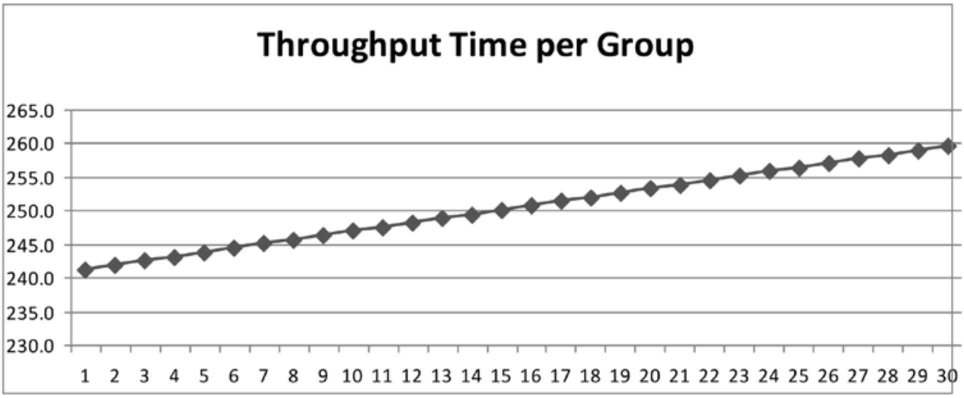

Figure 3 — Fast groups with 8-minute tee interval.

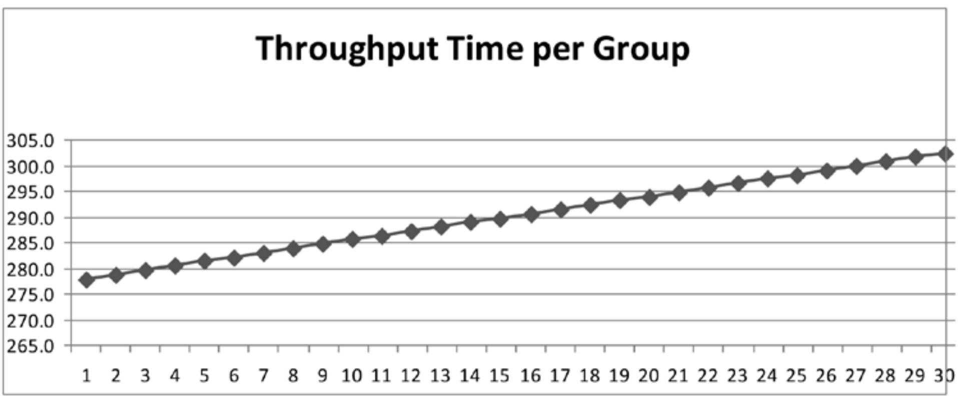

Figure 4 — Fast play with slow movement: All groups moving at 2 mph (60 yards/minute).

Table 2 Speed, Average Time and Maximum Time to Play

Speed (Yards/Minute)	Average Time	Maximum Time
90	241	241
80	251	251
70	267	272
60	290	302

increase over the course of the day from four hours to over five hours. Walking at 2 mph rather than 3 mph increased the average time by about 50 minutes and the maximum time by 60 minutes. How does that compare with slow hitting? With a nine-minute interval and groups moving at 3 mph but taking an extra minute to clear each tee and fairway shot and an extra minute to clear the green, the average time jumps to 319 and the maximum to 342! As such slow hitting on every shot is far worse than just moving slowly.

Combinations of Fast and Slow Groups

The model was run with the fifth group as a slow group (one slow group among fast groups.) The fast group was the same as above. The slow group played shots slower, cleared the green slower and/or moved slower. Various combinations of those were tested. First, movement-pace was tested. Assuming the slow groups played their shots and cleared the green as fast as the fast players but moved slower, the model found the following results shown in Table 3.

Recall that the first 4 groups, unimpeded by the slow group, played in 241 minutes. The max time is the time the slow group played. This is with only one slow group. As more slow groups are added, the figures get worse (Figure 5).

At 60 Yards/minute (2 mph) even groups who do not dawdle over their shots add more than a half hour to their round by moving more slowly. But the real tragedy is that every group after them suffers, boosting the day's average play close to

Table 3 Speed, Average Time and Maximum Time to Play

Slow Speed (Yards/Minute)	Average Time	Maximum Time	Group Max Wait
80	245	251	9
70	255	262	20
60	268	278	35

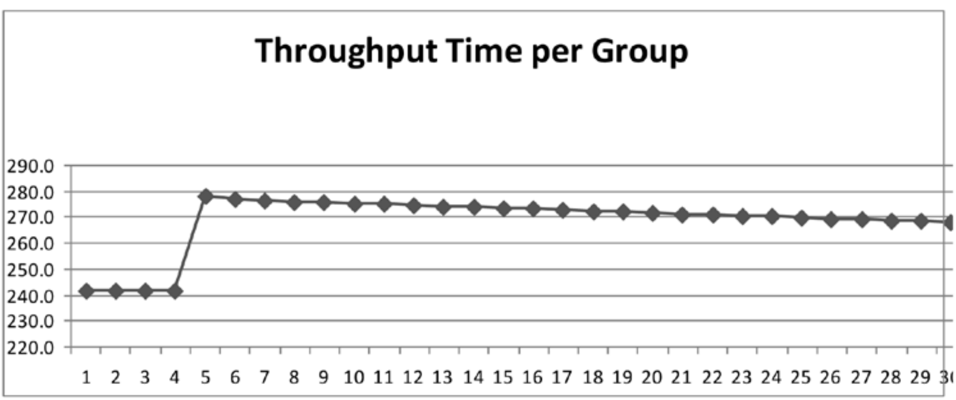

Figure 5 — One slow group moving at 2 mph (60 yards per minute).

30 minutes more than it has to be. Figure 6 shows the plot of the total time each group waits in this scenario.

The first four groups play fast and have no waiting time. The 5th group is the slow one and they do not wait either. But the 6th group is stuck. With an 8-minute tee interval, the numbers get worse (Table 4) (Figure 7).

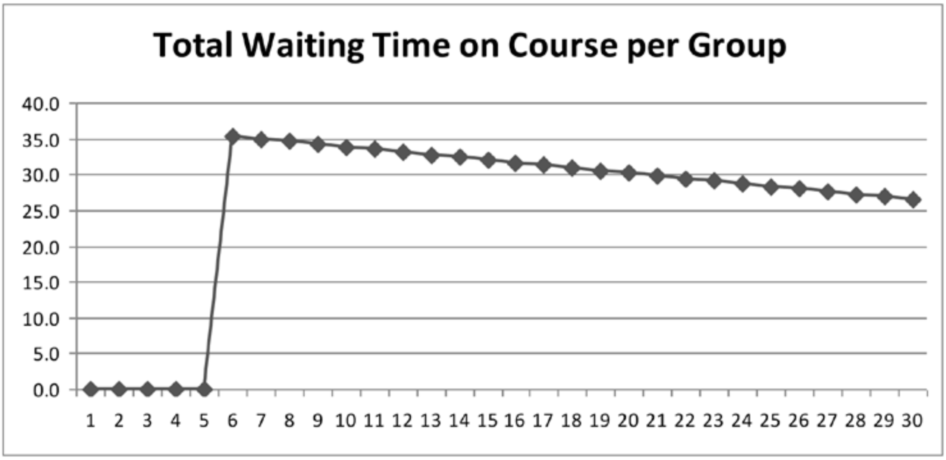

Figure 6 — Each group's total wait time.

Table 4 Speed, Average and Maximum Time to Play and Wait Time

Yards/Minute	Average Time	Maximum Time	Group Max Wait
60	281	300	54

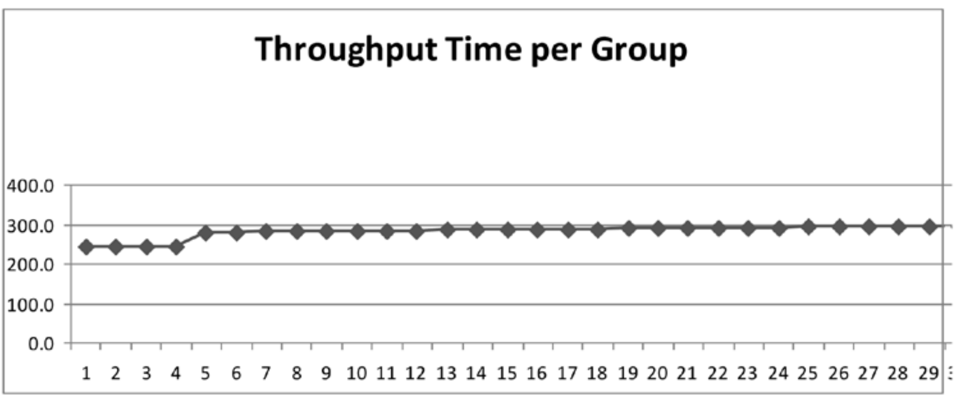

Figure 7 — 8-minute tee interval with one slow walking group.

The slow group now plays in five hours, everyone averages four hours and 40 minutes and the poor sixth group waits a total of close to one hour. That is one extra hour of standing around. There is little the following groups can do to improve things, which leads to great frustration.

With a nine-minute interval, what would happen if the slow group moved at 3 mph but hit their shots more slowly, clearing the tee, fairway or green in four rather than three minutes? In this model it turns out that it doesn't matter if we add the minute to any one of the three shot types. The results are the same (Table 5) (Figure 8).

That's understandable. We've added one minute to each hole. The extra time doesn't add much bunching. But with an 8 minutes interval, more bunching and longer times occur (Table 6).

Table 5 Speed, Average and Maximum Time to Play and Wait Time

Slow Speed (Yards/Minute)	Average Time	Maximum Time	Group Max Wait
9-min-interval 4-min clearing with 3 mph	252	259	18

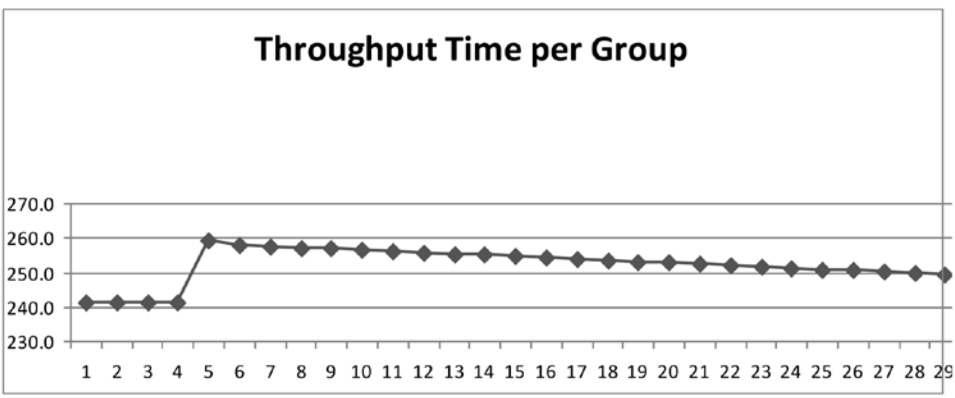

Figure 8 — One group playing one shot each hole slowly but walking fast.

Table 6 Speed, Average and Maximum Time to Play and Wait Time

	Average Time	Maximum Time	Group Max Wait
8-min-interval: 4-min clearing with 3 mph:	266	278	21

Note the difference in the graph above and the one below (Figure 9). Below each successive group is playing more slowly. That is just due to the tee interval.

Back to a 9-minutes interval, what would happen if the slow group moved at 3 mph but took 5-minutes to clear one of their shot-types, say clear the green (Table 7)?

Understandably the extra minute added another 18 (or so due to rounding for this report) minutes to the round compared with the four minute clearing run. But a better comparison is to the run with nine-minute interval, three minute clearing and only 2 mph. The results are essentially identical. That means that walking slowly (2 mph rather than 3 mph) produces the same results as dawdling on the green for two extra minutes. What if the group was fast moving but slow hitting all shots? If they took four minutes to clear each shot but moved at 3 mph, the results can be seen in Table 8 and Figure 10.

Again this is explainable in simple terms. This adds two minutes per hole more than the case of hitting only one shot slowly. But the results are pretty strong. This

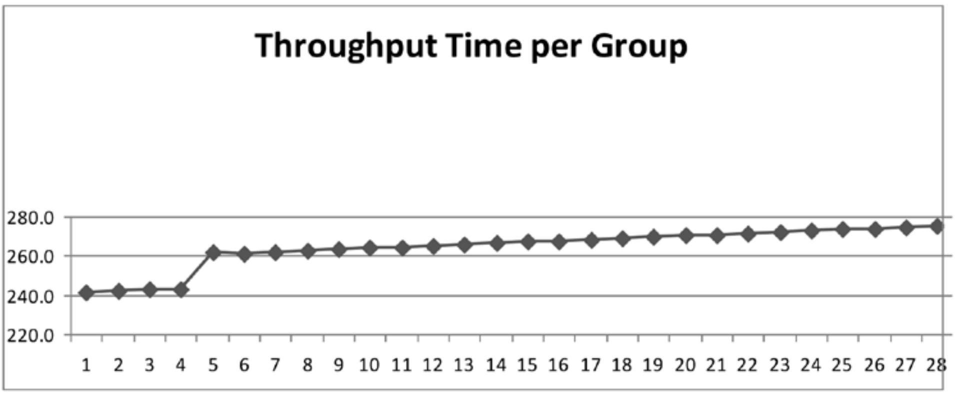

Figure 9 — 8-minute interval with one shot each hole played slowly but walking fast.

Table 7 Speed, Average and Maximum Time to Play and Wait Time

	Average Time	Maximum Time	Group Max Wait
9-min-interval 5-min clearing with 3 mph	267	279	35

Table 8 Speed, Average and Maximum Time to Play and Wait Time

	Average Time	Maximum Time	Group Max Wait
9-min-interval 4-min clearing all 3 mph:	283	295	52

leads to a five hour round for almost everyone even though everyone moved fast. The PGA Tour faces this problem. Their players move to their balls quickly but then are very deliberate in making their strokes. How bad would it be if the slow group took four minutes for clearing every shot and moved at 2 mph? The results are, as expected, pretty grim (Table 9).

The slow group played in five hours 40 minutes, the average play was over five hours and the sixth group had to suffer by waiting a total of 90 minutes.

18 Hole/Multiple Group Simulations With Variable (Stochastic) Times

The previous discussion was based on a model in which each group's times to play the various parts of the game were constant. That model was helpful in understanding the essentials of bottleneck analysis, throughput time and cycle time. The only variability introduced was that some (slow) groups took longer to play each shot or walked slower than other (fast) groups. The effect was substantial. If everyone played at the same pace and were sent off at the proper tee interval (higher for slower players), there would be no waiting. Waiting occurred when there was a difference.

In this version, variability in clearing the gates was introduced. We all experience variability. In golf we all have lost a ball, hit a provisional, or had fiercely breaking putts that resulted in three slow attempts to finish out. These and many

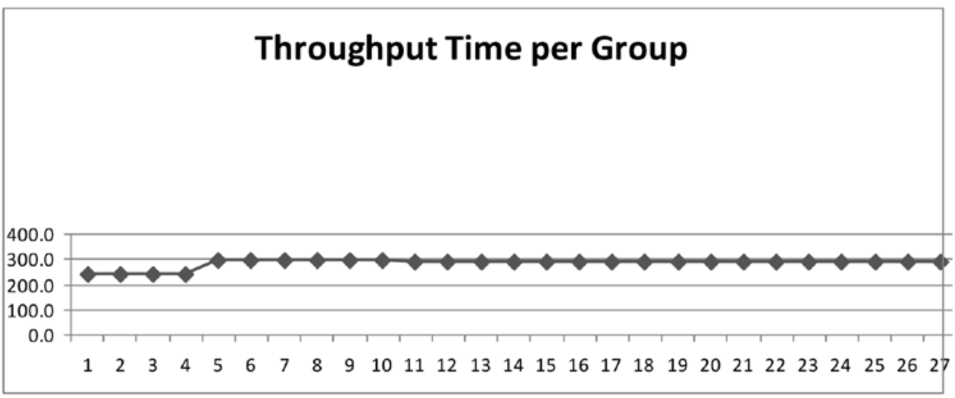

Figure 10 — All shots slow but walking fast.

Table 9 Speed, Average and Maximum Time to Play and Wait Time

	Average Time	Maximum Time	Group Max Wait
9-min-interval 4-minute clearing all 2 mph	314	340	90

other situations lead to variation in the time it takes us to play various shots and the time to finish a hole. In golf, variability can only lead to slower play. Instinct might say that the variability would average out, but it doesn't. One group's fast play does not cancel the slow play of another. Consider two groups of similar playing-time ability playing two consecutive holes. If the first group plays the first hole slowly then the next one fast and the following group plays the second slowly, the second group (because it had to wait for the first group to clear the first hole) "plays" both holes slowly. The variability doesn't cancel, it adds, it accumulates. This version of the model starts with groups of similar time-playing potential, but adds fluctuations when a shot is taken. It is assumed that variability on the slow side is more than on the fast side. There is an absolute limit as to how fast you can play but almost no limit to how slowly you can play.

Running this model with all groups of similar time-playing ability found that as you add more variability, average throughput times increased and overall waiting time increased. That was expected. What was interesting is that even when the groups were "equal", there was still a substantial amount of waiting time and that waiting times varied widely. As suggested by the discussion above, waiting time accumulates. The following results are for runs with all "fast" groups but with some variability to the shot times, green clearing times, and moving paces. All runs use a nine-minute tee interval. The first run assumed a low level of variability (nearly deterministic times), the second a moderate amount of variability, and the third a substantial amount. The average shot times, green-clearing times and paces were the same in all cases, but now varied from gate to gate. Various distributions were tried. The displayed results (Table 10) were for runs using a triangle distribution, as Tiger had used.

These are all "fast" groups. Their average times to play and move would allow them to play in four hours. As variability is added, the total time to play goes up substantially. How can this be?

First the upside bias of the time to play shots and to move raises the average somewhat. Second in a system of random events, the "negatives" are not always balanced by the "positives." Using all golfers with "four hour round" average characteristics but with modest shot and movement variance produces a maximum time of 294 minutes, nearly five hours! The sum of the maximum time to play each hole by all the groups was 290. It is not a perfect relationship, but it is clear: delays accumulate. Earlier it was pointed out that the pace for all golfers was set by the slowest group. This model indicates that the pace is set by all groups by adding the slowest play for one or a few holes of each group and not their average or better play. The pace is closer to the sum of each hole's worst group time. Everyone is part of the problem. Put another way, a group can be a "fast" four hour pace group

Table 10 Variability, Average and Maximum Time to Play

Variability	Average Time	Maximum Time
Little Variability	242	244
Modest Variability	278	294
Significant Variability	324	362

for most of the round yet still contribute to the overall slow pace by playing one or two holes slowly. Of course Tee Intervals pose an additional problem. Shortening the internal when there is significant variability makes for very long rounds. Some results assuming significant variability are in Table 11.

Variability in shot times and movement pace combined with short intervals is a recipe for disaster. Clearly it is not just the golfers. Decisions by course owners are part of the problem as well.

Back to the golfers, are there some combinations of shot time variability, green clearing variability and movement pace variability better or worse than others? Combinations were tested all using the same average values but adding some variability as indicated (Table 12).

From these figures it looks like slow hitting is worse than slow green clearance or slow movement. That is understandable since there are (in general) twice as many tee and fairway shots as greens to clear. But again the main point is that all of these runs involve all "fast" groups and the only reason the times are much higher than four hours is the variability. If we introduced "slow" players, the numbers jump even higher.

In running simulations, the models replicate a day of activity. The figures displayed here show the average values for many (1,000 in most cases) days of play. Interestingly, looking at one day at a time can be quite as instrumental as looking at the average of many days. When individual days are examined, great differences from one day to the next can be seen. Even when all things are "similar" such as having all fast players with some variability, there are days where things go smoothly by comparison and there are days when the time to play jumps way up. Some courses experience a regular, consistent pace, others good days and bad days. These can be explained by the random occurrence of some slow holes. Pin placements might slow some holes down. Even tee placements might make a

Table 11 Tee Interval, Average and Maximum Time to Play

Tee Interval	Average Time	Maximum Time
12	298	324
10	310	348
9	324	362
8	338	377

Table 12 Variability Level, Average and Maximum Time to Play

Variability Level			Average Time	Maximum Time
Shots	Green	Movement		
Low	High	Low	262	274
Low	Low	High	262	274
High	Low	Low	294	315

difference. Most likely it is the random occurrence of a few groups having a bad day. Those few groups set the pace for everyone.

Below are two pictures of individual days from the same simulation (Remember the figures presented earlier in this section are for runs of 1,000 days averaged together. These are 2 of those 1,000.) One day is good and the other is a problem. These are different only because of random events. In this first day (Figure 11), the variability starts early causing even the first group to play in more than four hours. The pace of play increases gradually throughout the day and comes close to five hours by the end of the day.

The total time each group waits for the whole round can be displayed as well. Here is that plot for the day displayed in Figure 11 (Figure 12).

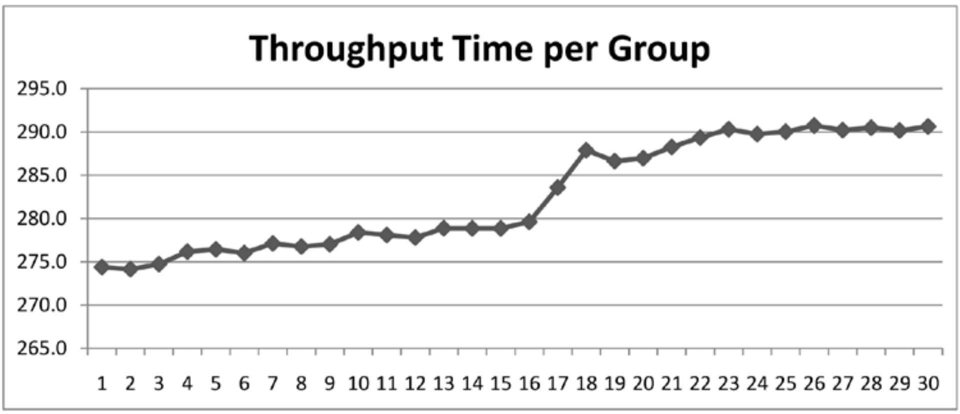

Figure 11 — One day all fast groups with modest variability.

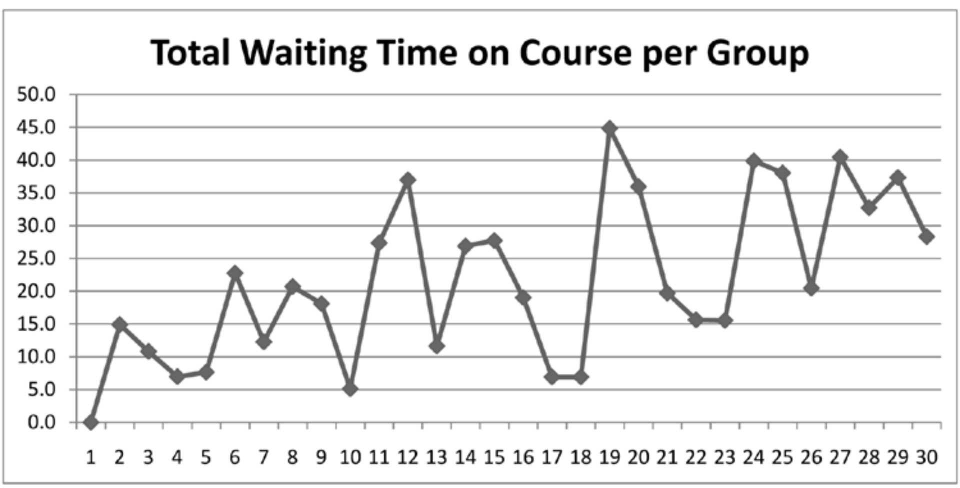

Figure 12 — Each group's total waiting time.

As can be seen, some group wait very little—as little as five minutes—and other wait as much as 45 minutes. Some groups would leave the course that day and say that although the round took too long, it wasn't a bad day since they did wait very long. Other groups would say the day was miserable, not only did the round take too long but they had to wait on almost every shot. These runs explain the predicament of many course managers when they get such conflicting responses in the same day. Here are the results for another day using the same basic information. Again these are all "fast" golfers with variability as described above. The pattern is somewhat different. The pace jumps quickly to a high level and stays there the rest of the day (Figure 13).

In this case although everyone played in essentially the same amount of time, we still see a large variation in the time each group waits (Figure 14). These are two typical days in a course's life.

What is to be taken from this? The problem is complex and it reveals itself to different parties in different ways. It has to be recognized that a multidimensional approach has to be taken to solve the problem.

The Nature of the Course

Except for the short discussion above and a mention that the first hole should be the bottleneck hole, very little has been mentioned here about the nature of the course itself. There are some things that can be done to the course to improve the pace. As mentioned above, pin and tee placements might make the course play harder or easier for groups to consistently play fast. The size of the fairway, the depth of the rough, the placement of some trees might affect pace as well. The simulation can be run with hole characteristics. Some par 4s take longer than others. Although that was not done, it would be inappropriate not to mention course management's responsibility to recognize how some of their decisions impact on pace. It is possible that they haven't given these concerns much thought. These and other factors should be considered by management.

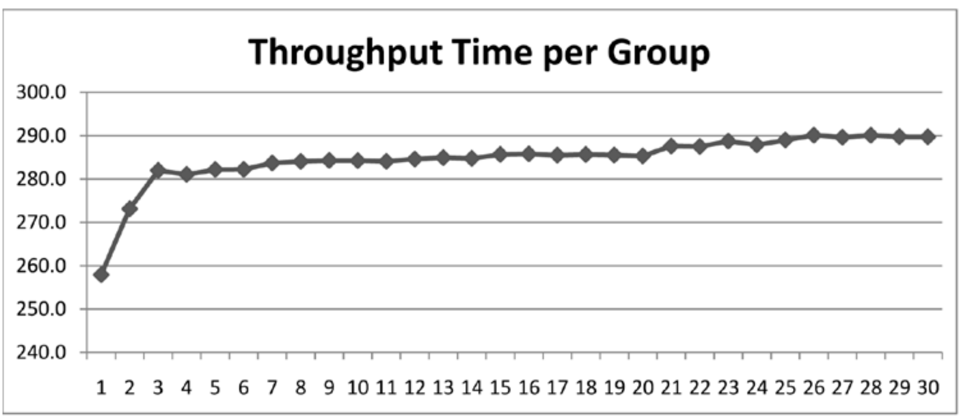

Figure 13 — Another day all fast groups with modest variability.

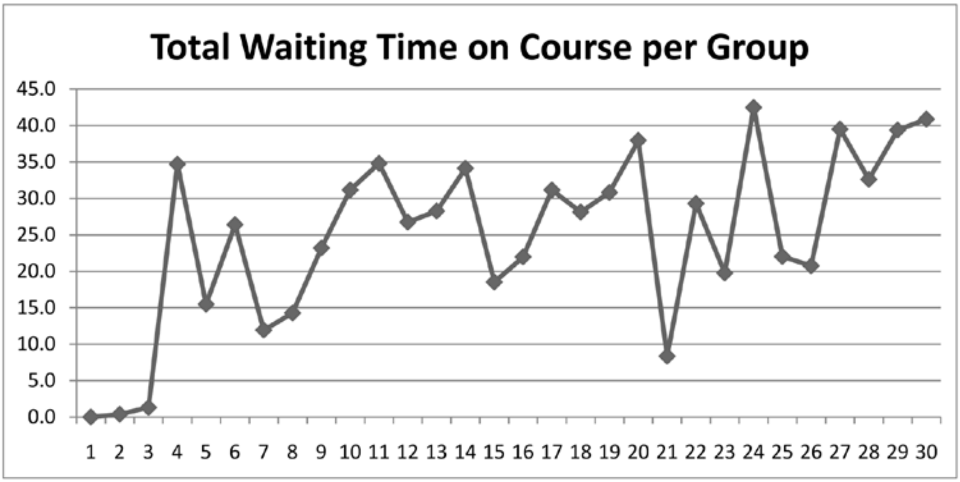

Figure 14 — Each group's total waiting time.

Pace of Play, Tee Time Intervals and Revenue Maximization

One factor course management has control over is the tee time interval. As we saw earlier, our models clearly show that the pace of play and tee time intervals are closely related. For pace of play advocates, longer intervals are better. Course managers like short intervals which lead to more golfers on the course. Does putting more golfers on the course slow down play so much that fewer rounds can be played in a day? Kimes and Schruben (2002) reported their data on the relationship between tee interval and overall time to play. Using their data, a mathematical relationship was found relating the two. It took the shape of an exponential model. That model is:

Time to Play = 240 + (14—Interval) ^ 2.7
where 240 minutes is the unimpeded time to play a round, and
Interval is the tee time interval in minutes

A tee time interval of 14 minutes would result in a 4-hour round (Table 13). Anything less than that would add minutes to the round, just a few as it drops to 13 or 12 minutes but then a substantial amount as the interval drops below nine minutes. In this model, at 8 minutes, the round will take close to 6 hours! Using the above model, a new formula was created to determine how many groups could be sent out in a 14-hour day and have all the groups complete their round.

No consideration is given to "twilight rounds" or the possibility that the pace of play picks up as the sun starts to go down (queue dependent service times so to speak.) Both of those are very real but the assumption is that they are the same for all tested cases. The number of groups that can be sent out in an hour can be found by dividing 60 minutes by the tee interval in minutes. If the interval was 10 minutes, six groups can be sent out. The shorter the interval, the higher the number of groups sent out. However the shorter the interval the longer the round and the fewer hours there'll be in the day for which all groups will complete the round. Therefore the number of groups who can complete a round of 18 holes in a day equals "the number of groups sent out per hour" times "the number of daylight hours in the day minus the time it takes to play all 18 holes." Combining those two relationships, we get:

Number of Groups = (60/Interval) * [14 hours—(240 + (14—Interval) ^2.7)/60]

Total in Day

Where Interval = Tee Time Interval

14 Daylight Hours

240 + (14—Interval) ^2.7 calculates the time to play a round in minutes

This formula then yields the following total number of groups that can be sent out for each possible tee interval (Table 14).

Table 13 Tee Time Interval and Time to Finish the Round

Tee Time Interval	Time to Finish Round
14	241
13	243
12	250
11	260
10	275
9	300

Table 14 Tee Time Interval and Total Number of Groups

Tee Time Interval	Total Number of Groups
14	42.9
13	46.1
12	49.5
11	52.8
10	55.8
9	58.1
8	59.2
7	58.4
6	4.3

From these results it can be seen that using Kimes and Schruben's figures, the "optimal" revenue strategy for this course is to have an interval of eight minutes. But that interval results in a six hour round! As such it is quite possible that in many cases, it is in management's best financial interests (at least in the short run) to have too short of a tee interval and "force" a five even a six hour round on their patrons. This poses a significant conundrum from a pace of play perspective.

To get a four-hour round, the interval would have to increase to about 12 minutes. But that reduces the number of groups who can finish in a day by about 17%. Course owners are not going to do that unless they can raise prices 17% or, by reputation, get more golfers to play on those days that aren't filled. This is a serious obstacle to pace of play advocates. If the course is full all the time, it is hard to argue for improved pace of play since the goal of any business is to maximize revenue. But if the course has trouble attracting players, then the longer tee intervals could be better. Courses that are full may try longer intervals but raise their prices to compensate for the fewer (but happier) golfers. These trade-offs are a significant key to the problem.

Bringing Back the 4-Hour Round

So what will it take to bring back the 4-hour round? What will it take to make that four hour round a maximum, not a minimum? Who has to be involved to get this done? To answer the last question first, everyone*!* If you play golf, if you manage a golf course, if you design golf courses, if you run tournaments or club events, you are part of the problem, some more so than others. But we are all part of it. But the models do give us some guidance on what has to be done.

First, tee intervals have to be set to match course and golfer characteristics to increase the chances that a four-hour pace is possible. As golfers get better at pace of play behaviors, the interval can be shortened.

Second, all golfers have to be instructed, trained, encouraged, and rewarded for moving directly to their own ball at a pace of at least 3 mph, hitting every shot in less than 45 seconds and getting their group to clear the green within three minutes every time.

Third, reduce the variability of play by reducing the time to look for a lost ball (no more than three minutes), picking up when out of the hole, and giving short putts when pace is an issue.

Fourth get course management to understand the pace consequences of their course's set up conditions, to monitor pace of play status at all times using modern technology, and reward "fast play" golfers.

The model, when run with a 3 mph pace, an average of 30 seconds to hit and no more than three minutes to clear the green, predicts 4 hours or less rounds for everyone even with a modest amount of variability. Together these factors will create an environment receptive to fast play and to golfers who would now be capable of playing quickly. All of these factors, when put into the models, lead to the creation of four hour rounds.

Theoretically there is no reason that we cannot play in three hours. As crazy as that might seem, it is not only possible but some people regularly do it. Think about it. In an 18 hole round, a typical golfer walks four miles. At 3 mph that's 80 minutes of walking. If a golfer takes 100 strokes to complete the round and no stroke takes more than 45 seconds (not too terribly fast), that's another 75 minutes. The total of those two is 155 minutes, just over two and one half hours! So why does it take so long to play? All the rest of the time is spent waiting. Waiting for the group ahead to clear, waiting for others in your group to play, waiting to find a ball, etc. Although waiting for others in your group is sometimes necessary (like on the tee or green), it can be minimized. Some things can be done simultaneously, especially for shots in the fairway. Play Ready Golf whenever you can, and "give" putts when they do not really matter. Why is one factory productive and another not? Although the workers are usually blamed, most often it is a combination of factors. Often it is the set up of the factory itself, the processes, the machines, the materials that the workers have to contend with. Sometimes the workers haven't been trained properly and do not know they are doing things wrongly. Sometime it is management not taking charge. In the golf course as factory, we have all of these. Someone has to take charge of this issue and improve each of the factors. For example, why cannot courses give preferred tee times to "fast/low variability" golfers? The models confirm that sequencing golfers from fast to slow would improve the pace significantly. Of course the models also show that even "fast" players who exhibit too much variability will hurt this strategy, so the pace will still have to be monitored. Individual golfers have to recognize how they contribute to slow play. They have to speed up. As mentioned earlier, Mateer (2010) is probably the best bible for individual golfers to follow.

Superintendents have to understand the specifics of the pace problem they face and set up their courses recognizing those issues. Yates (2011) and Southard (2010) provide probably the best guides for management to begin understanding the pace problems they face. Managers have to decide whether they want a tee interval that guarantees a five-hour round, or to choose an interval that gives the golfing public a chance at a decent pace of play. Kimes and Schruben (2002) are perhaps in the best position to explain to management the relationship between interval and pace. The information needed to "pick up the pace" now exists. We just need the will.

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