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The Tragedy of the Waves

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1. Introduction

Surfers everywhere fight for waves. This competition is inevitable as the demand for waves far exceeds the supply at most quality surf breaks near urban populations. The number of waves that a surfer will catch is a function of both the individual's characteristics and the local surf conditions. It is helpful to view surfing as a common-pool resource problem, wherein surfers compete for waves in an ocean that is available to all. Harding (1968) first addressed common-pool resource problems in his seminal work, "The Tragedy of the Commons." He argued that in a world of limited common-pool resources, "ruin is the destination toward which all men rush, each pursuing his own best interests"(p. 1244). The surfing community sees ruin today in over-populated surf breaks where the quality of the surfing experience is significantly diminished by the sheer number of surfers in the water. Surfers have developed two wave allocation strategies to address the problem: the surfer's code and localism. The code is a set of widely accepted surfing rules that govern surfer behavior, to include who has the right of way on a wave. Right of way is determined by a surfer's proximity to where the wave breaks. The surfer closest to the break has the right away and is said to have the inside position on the wave. Surfers who find themselves further down from the break are to yield to the surfer with inside position. Most surfers adhere to the code. Localism refers to a hierarchical system that allocates waves to surfers based upon seniority and skill. The system is established and enforced by locals - residents of the surrounding area who frequently surf the break. Locals enforce their control over the surf break through both verbal and physical intimidation.

The literature relating to the fight for waves comes from a wide range of disciplines and largely falls into two categories: (1) surfing specific papers that sought to mathematically model competition for waves; and (2) broader research efforts into understanding conflict in common-pool recreation resource situations. The mathematical papers have primarily relied upon game theory and linear models to explain the competition for waves. Rider (1996) was the first to view surfing as a common-pool resource problem. He modeled the competition between two surfers for a wave from a game theoretic approach and showed that individual rational behavior (attempting to catch each wave) leads to suboptimal outcomes (reduced surfing quality). Rider also suggested that surfers have addressed these suboptimal outcomes with the surfer's code and localism. Peterson (2013) extended Rider's game theory model from two to *n* surfers. He demonstrated that under certain conditions adherence to the code yields a higher number of waves than a strategy of individuals chasing each wave. Kaffine (2009) investigated the relationship between localism and the conditions at a surf break across eighty-six surf breaks in California. He discovered that localism was positively correlated with wave quality, crowd size, and distance from major cities. Daskalos (2007) investigated the impact of modernity on localism in a southern California town. He found that the increase in the number of surfers, due to the rise in popularity of surfing, had driven localism from the major breaks in the area. The interpersonal conflict literature originates from the seminal article by Jacobs and Schreyer (1980) in which they developed the most widely used definition of conflict in the recreation literature. They define conflict as "the goal interference attributed to another's behavior" (p. 369). Many researchers investigating conflict in recreational activities utilize their conflict definition and factors that they suggest lead to conflict. Thapa and Graefe (2003) explored skier-snowboarder interpersonal conflict in terms of skill level and tolerance. They discovered that less skilled skiers and snowboarders experienced more conflict than those highly skilled. They also found that the less skilled displayed less tolerance to others than the highly skilled. Interestingly, Vaske, Dyar, and Timmons (2010) came to the opposite conclusion regarding skill level and tolerance. They also studied interpersonal conflict between skiers and snowboarders, but found that more skilled skiers and snowboarders experienced more conflict that those less skilled. Tynon and Gomez (2012) examined conflict among recreation activity groups (to include surfers) at several beaches in the Hawaiian Islands. They found levels of interpersonal conflict dependent upon the residency of the groups (Hawaiians vs. tourists), gender, and activity type. They also offered two possible remedies for the conflict: temporal or spatial segregation to reduce overcrowding and increased user education to inform recreationists of acceptable behavior.

The authors of this paper sought to (1) determine the relationship between the number of waves a surfer will catch, the surfer's characteristics, and the surf conditions, and (2) utilize this relationship to explain wave allocation strategies chosen by surfers. We see this paper as the next step in mathematically modeling the fight for waves and as a bridge between the more theoretical mathematical models and the interpersonal conflict literature. Only through greater insight into what drives surfer behavior can we address larger coastal resource management issues.

We developed a discrete event simulation that models the dynamics of catching waves at a surf break and fit the model to a specific break surfed frequently by the authors, First Point. Neither wave allocation strategy is followed by surfers at First Point in the summer. Rather an individual strategy is followed where each surfer chases and catches waves without thought of the other surfers. This strategy produces chaotic and unsafe conditions in the water. Minor modifications to the simulation allowed us to model the two alternative wave allocation strategies at First Point. We then developed and implemented factorial designs for all the strategies to measure the different effects on the number of waves caught and facilitate a comparison of the strategies.

2. Surfing at First Point

First Point is located off Surf Rider Beach in Malibu, California, just north of Los Angeles. The break produces consistent, long peeling waves during the summer months, which can draw in excess of one hundred surfers to the break. The struggle to catch a wave at First Point begins as a swell passes over the reef and forms a breaking wave. Surfers scramble for position and attempt to catch the wave. The arrangement of surfers waiting for waves is referred to as the lineup. The lineup at First Point generally falls within a rectangle shaped area that starts just beyond the start of the break and extends roughly one hundred yards toward the Malibu pier. During a crowded day, the lineup tends to break into three distinct clusters centered around three takeoff points. Surfers at the first takeoff point, located in the vicinity of the reef, tend to be the most experienced and are primarily residents of Malibu, or locals. Several of them will charge for each wave, with one surfer seizing inside position and the others dropping-in later on the wave. Dropping-in on another surfer is dangerous as the surfer closest to the breaking wave is moving faster than the surfer dropping-in, creating the potential for a collision. Most surfers who drop-in take a short ride and then come off the wave to avoid the surfer with inside position. Surfers at the second takeoff point, located some thirty yards from the first, tend to be less experienced and often include non-locals of Malibu. These surfers typically are hoping for smaller waves that didn't break by the first group, but many will often drop-in on surfers from the first group already on a wave. Surfers at the third takeoff point, located at the end of the lineup near the beach, tend to be the least experienced, usually consisting of tourists. These surfers chase smaller waves that break close in to the shore, but will also drop-in on a wave that broke further out.

3. Methodology

We developed a discrete event simulation in Simio© to determine the relationship between the number of waves a surfer will catch, the surfer's characteristics, and the surf conditions. The surfer characteristics captured in the model include the individual's skill level and type, local or kook. The surf conditions captured in the model include crowd size, swell inter-arrival time, waves per swell, and capacity per wave. The simulation starts by populating First Point with a mix of locals and non-locals of varying skill levels. The surfers then paddle out to one of the three takeoff points past the breaking waves. Swells arrive periodically and produce a set of waves for the surfers to ride. Each wave passes through all three takeoff points with a finite capacity for surfers. Surfers at the first takeoff point compete for the wave, with access to the wave determined by the surfers' skill levels and an element of luck. One surfer will seize inside position with several others catching the wave further down the face. These surfers drop-in on the surfer with inside position but pull off the wave as the surfer with inside position approaches. Surfers at later takeoff points also compete for access to the wave, and several will drop-in on the surfer with inside position. Again, after a short ride, those with outside positions yield priority and get off the wave. At the end of the wave, surfers paddle back out to the lineup and select a takeoff point. Statistical accumulators count the number of waves by surfer type and skill level.

Parameter estimates for the model were gained from either direct observation of surfers at First Point or solicited from surfers with experience at the break. The number of locals was fixed as a constant, with an increasing number of non-locals for larger crowds. Some twenty-five locals surf First Point during the summer swell, with an additional twenty-five to seventy-five non-locals in the lineup. Skill levels, ranging from zero to one-hundred, were modeled with triangular distributions, with higher skill levels corresponding to higher values. Assessing the skill level of an individual surfer amongst up to one hundred others proved difficult and very subjective. Instead, the distributions' parameters (minimum, mode, and maximum) were solicited from local surfers. The surfers' estimates varied widely, but two themes recurred in our discussions with them. First, locals at First Point tend to be experienced, having learned to surf on other less crowded area breaks before moving to First Point. Second, non-locals at First Point run the gamut of skill levels, from tourists with no experience to non-local professionals. Based on the consensus of these two insights, we modeled a local's skill with a Triangular (50, 75, 100) distribution and a non-local's skill with a Triangular (1, 50, 100) distribution. We also solicited estimates for the distribution of surfers by type at the different takeoff points from local surfers. They estimated that 70% of locals set up at the first take off point with the remaining 30% at the second takeoff point. The locals further estimated that 20% of nonlocals set up at the first takeoff point, 40% at the second takeoff point, and 40% at the third takeoff point. Most locals seek potentially longer rides from the outer takeoff points, while many non-locals seek the lower level of competition for waves present at the inner takeoff points. Luck, along with skill, determines which surfers are able to seize space on a wave. Skill is paramount, but where a surfer sets up relative to where the wave breaks (what we call luck) also matters. Local surfers estimated that luck accounts for up to twenty percent of the waves a surfer catches, so we modeled it in the simulation with a discrete Uniform (0, 20) distribution. Travel times between different locations in the model were modeled as constants with the times obtained from direct observation of surfers at First Point. Wave characteristics, to include inter-arrival time per set, the number of waves per set, and the wave capacity, were also obtained from direct observation. These characteristics, which are consistent in the summer months, were modeled as constants.

Validation of the model proved problematic. Many of the surfers' characteristics and surf conditions modeled in the simulation are conceptually simple to grasp, but very difficult to measure in practice, e.g. skill level. The typical validation technique of comparing a test set of data with model output proved impossible. Instead, the authors presented both the simulation and the results to numerous local surfers familiar with First Point. These locals provided subject matter expertise validation for both the surfing dynamics captured in the simulation and the results.

Different variants of the simulation were required for each of the three wave allocation strategies, which we termed ego-centric, code-centric, and local-centric. The ego-centric model represents the status quo at First Point and was described in section two. The code-centric model differs from the ego-centric model in two ways. First, the wave capacity is reduced to one, as surfers yield to the surfer with inside position and don't drop-in on one another. Second, the distribution of non-locals shifts from the beach, as more skilled non-locals move to the first takeoff point to compete for inside position. The local-centric model also differs from the ego-centric model in two ways. First, the wave capacity is reduced to one, as the locals enforce the surfer's code under localism. Second, the luck factor for locals is increased to reflect the positional advantage they gain by intimidating non-locals.

We then developed and executed several factorial designs in order to measure the effects of surfer characteristics and surf conditions on waves caught. The proposed linear model contained three main effects (crowd size, surfer type, and surfer ability) with all possible interactions.

$$Waves = \beta_0 + \beta_1 \, Size + \beta_2 \, Type + \beta_3 \, Ability +$$

$$\beta_4 \, Size \times Type + \beta_5 \, Size \times Ability + \beta_6 \, Type \times Ability + \beta_7 \, Size \times Type \times Ability + \epsilon$$

The main effects were coded as indicator variables. Surfer skill level was coded as 0 for low skilled surfers and as 1 for high skilled surfers. Crowd size was coded as 0 for small crowds and as 1 for large crowds. Surfer type was coded as 0 for non-locals and as 1 for locals. Backwards step-wise regression was used to build the linear models.

4. Analysis and results

4.1 Ego-centric Strategy

The ego-centric strategy is the one currently adopted by surfers at First Point. All surfers compete for every wave, limited only by the capacity of the wave. Figure 1 shows the expected number of waves that a surfer will catch (medium crowd of twenty-five locals and fifty non-locals) under an ego-centric strategy. The number of waves caught increases as skill increases, as expected, but the two sigmoidal shaped curves yield several interesting insights. First, surfer type has little impact on the number of waves that a high skill surfer catches. This is a common complaint from older locals at the break who believe their seniority at First Point should grant them a majority of the waves. Second, the least skilled surfers, regardless of type, catch very few waves. Surfers in the lower two quartiles of skill catch just 1% of the waves. The scarcity of the waves combined with the dominance of more skilled surfers leaves those less skilled without waves to surf. This is a very common experience for tourists at First Point, as they watch more experienced surfers beat them time and again to every wave. Third, the most skilled surfers dominate the lineup, again regardless of type, catching the vast majority of the waves. Surfers in the upper quartile of skill catch 68% of the waves. First Point's long period between sets allows the best surfers to catch a wave and paddle back out to a takeoff point before the next set arrives.

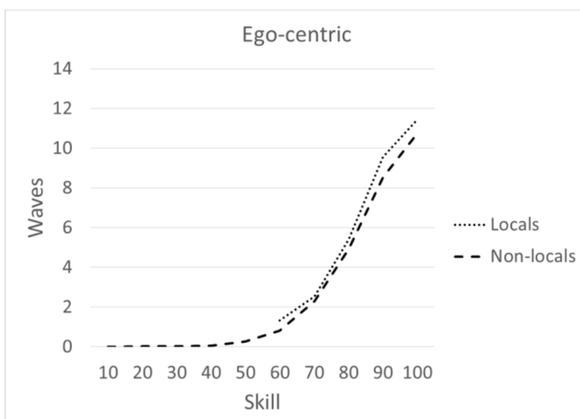

Figure 1. Waves under Ego-centric Strategy

All three main effects and two of the interactions were found to be significant. Table 1 shows the final regression output (R^2 = 0.35).

Coefficient	Estimate	Std Error	t-statistic	p-value
Intercept	0.56	0.07	8.38	0.00
Size	-0.52	0.08	-6.77	0.00
Type	2.33	0.08	29.02	0.00
Ability	3.50	0.09	37.53	0.00
Size x Type	0.45	0.10	4.47	0.00
Size x Ability	-0.76	0.11	-7.03	0.00

Table I. Effects under Ego-centric Strategy

The model suggests that under the ego-centric strategy surfers catch less waves as the crowd size increases; locals catch more waves than non-locals; more skilled surfers catch more waves than less skilled; the increase in waves due to type is more pronounced in large crowds; and the decrease in waves due to crowd size is more pronounced among more skilled surfers. Note that while the estimated coefficients for size, size and type, and size and ability are all statistically significant, none are practically significant. In contrast, both type and ability have practical significance and explain most of the waves that a surfer catches.

4.2 Code-centric Strategy

The code-centric strategy would have all surfers at First Point yielding to the surfer with inside position. This strategy would greatly reduce the number of rides available per wave, but would increase the quality of the ride for the surfer with inside position. Figure 2 shows the expected number of waves that a surfer will catch under a code-centric strategy. The two curves that we saw in Figure 1 have changed dramatically. We drew two insights from these results. First, the least skilled surfers caught an even smaller percentage of the waves than in the ego-centric strategy. Surfers in the lower two quartiles of skill saw their percentage of waves caught decrease from 1% to 0.2%. Second, surfers of both types catch far fewer waves than under the ego-centric strategy. Locals experience a 78% reduction in number of waves caught. Non-locals experience a 99% reduction in number of waves caught. It is important to note that although the number of waves caught has dropped, those catching the waves have a longer, higher quality ride, without other surfers dropping in on them.

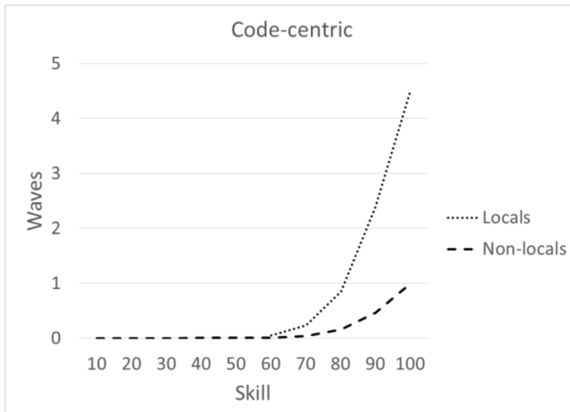

Figure 2. Waves under Code-centric Strategy

Two of the three main effects and none of the interactions were found to be significant. Table 2 shows the final regression output ($R^2 = 0.19$).

Coefficient	Estimate	Std Error	t-statistic	p-value
Intercept	0.00	0.01	0.35	0.72
Type	1.10	0.02	67.96	0.00
Ability	0.16	0.02	9.58	0.00

Table II. Effects under Code-centric Strategy

The model suggests that under the code-centric strategy locals catch more waves than non-locals and skilled surfers catch more waves than unskilled surfers. Note that although ability is statistically significant, the small size of its coefficient suggests that its practical significance is negligible. Crowd size has disappeared as a significant factor under the strategy.

4.3 Local-centric Strategy

The local-centric strategy would have locals attempt to control the allocation of waves and enforce the code. This strategy would greatly reduce the number of rides available per wave, but would increase the quality of the ride for the surfer with inside position. It would also make it more difficult for non-locals to catch waves. Figure 3 shows the expected number of waves that a surfer will catch under a local-centric strategy. These curves are similar to those we saw in Figure 2. We drew two insights from these results. First, the least skilled surfers caught the same percentage of the waves that they did under the code-centric strategy. Surfers in the lower two quartiles of skill saw their percentage of waves remain at 0.2%. Second, locals dominate non-locals under the local-centric strategy. Harassment of non-locals by locals results in locals catching 95% of the waves, with non-locals catching only 5%.

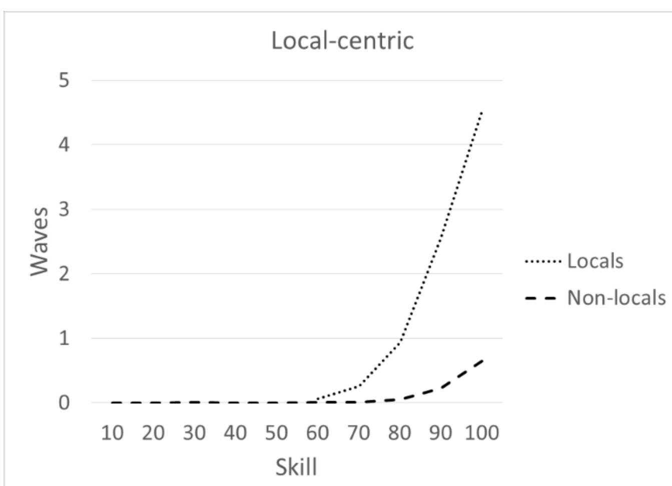

Figure 3. Waves under Local-centric Strategy

All three main effects and none of the interactions were found to be significant. Table 3 shows the regression output ($R^2 = 0.22$).

Coefficient	Estimate	Std Error	t-statistic	p-value
Intercept	0.03	0.02	1.60	0.11
Size	-0.03	0.01	-1.98	0.04
Type	1.28	0.02	76.72	0.00
Ability	0.06	0.02	3.97	0.00

Table III. Effects under Local-centric Strategy

The model suggests that under the local-centric strategy surfers catch less waves as the crowd size increases; locals catch more waves than non-locals; and skilled surfers catch more waves than unskilled surfers. Crowd size has returned as a significant factor under the strategy, but given the small size of the coefficient, does not have much practical significance. Ability remains statistically significant, but is even less practically significant than under the code-centric strategy.

5. Implications and conclusions

First Point currently operates under the ego-centric strategy of wave allocation. High skilled surfers, both locals and non-locals, capture the vast majority of the waves. Low skilled surfers catch almost no waves. This result begs the question, why do tourists (typically low skilled surfers) flock to First Point in large numbers every summer? The model doesn't provide an answer, but the authors suspect that most tourists incorrectly assume that there are waves available for them in Malibu. The transition from the ego-centric strategy to the code-centric strategy would dramatically reduce the number of waves caught, improve the length and quality of a ride, and provide locals with a greater percentage of waves. The code-centric strategy works well at less popular surf breaks, but is likely not adopted at First Point because of the large number of surfers that it would deny waves. This strategy fails to prevent the tragedy of the waves when the crowd size is too large. The unfortunate implication for coastal management is that improved education and awareness of appropriate behavior, suggested as a possible solution by Tynon and Gomez, will likely not have the desired effect at more popular spots. The transition from the ego-centric strategy to the local-centric strategy would dramatically reduce the number of waves caught, improve the length and quality of a ride, and provide locals with nearly all the waves. The local-centric strategy works well at some popular surf breaks (at least from the perspective of the locals), but is not adopted at First Point because the locals do not have sufficient incentives to enforce the strategy. The Jacob and Schreyer conflict model would suggest that the status hierarchy among locals and the difference in participation intensity between locals and non-locals would result in conflict, but localism requires locals that are willing to seize control of a break and enforce their will on wave allocation. The locals at First Point are mostly wealthy inhabitants of Malibu and do not appear willing to risk the legal consequences that could come with the required enforcement. It is even doubtful whether the locals could enforce the strategy when the crowds number more than one hundred. The tragedy of the waves exists at First Point as neither the surfer's code nor localism are preferable for a sufficient number of surfers. Harding was correct. Freedom in a commons brings ruin to all.

6. Limitations and future research

The simulation is tailored to First Point, and the authors would not suggest using the results to predict catching waves at other breaks. We do believe, however, that some of the insights gained from our analysis of the different wave allocation strategies are transferrable to other breaks. The failure of either the surfer's code or localism to emerge at First Point is explained in the output data and these explanations appear reasonable for other crowded breaks. Adopting the simulation to other breaks would not require much effort, other than interviewing locals from the break and spending some time surfing the break. Expanding the number of surf breaks modeled might also yield better insights into when the surfer's code functions and what causes localism to emerge. Finally, understanding the dynamics of wave allocation at a given surf break should help facilitate efforts to mitigate interpersonal conflict between locals and non-locals.

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