An Agent-Based Model for Camping Along the Big Long River

Team #17094
Problem B: Camping along Big Long River

Summary

We develop an agent-based model for the Big Long River management to plan the schedule of river trips. In our model, we construct artificial intelligent agents with dynamic probability algorithms to simulate the complex human-environment interactions. The criteria for an optimal schedule are high river carrying capacity and minimum visitor encounters. With Monte Carlo annealing, we then construct an evaluation function to select the optimal scheduling plan. Computer simulation shows that our model fits the criteria, stable within the constraints, and is flexible and adaptable for simulating dynamic system.

Memo for the Managers

Dear managers,

We have developed an agent-based to find the optimal schedule plan on the Big Long River. The followings are our key findings:

I. Optimal Launch Intervals

The optimal launch interval is about 16 minutes. The more boats are launched, the more likely they are to encounter each other. For the sensitive report of launching interval, see *Section 4.3 Sensitivity Analysis*.

II. Optimal Launch Combination of Rubber Raft and Motorized Boat

The optimal composition of two types of boats is 59% motorized boat and 41% rubber raft.

III. The Carrying Capacity of the River

We measure the carrying capacity of the river by the number of boats in the entire river trip system, including boats in camps and on river, at a certain time. In the optimal solution, the number of boats in the system converges to 450.

IV. Campsite Utilization

In the optimal schedule, the utility of campsites is 80%-90%. We also found out that visitors in river trip spend more time on campsites than on river, which indicates that campsites could also be the attraction sites.

V. Importance of Communication Between Management Authority and Boats

We found that it is possible to find an optimal way of making camping decisions. In the future, the management authority should consider advising boat guides on when and how to choose campsites.

Table of Content

1. Introduction

The river trip problem is set in a wildness environment, where recreational activities including rafting and camping take place. The system dynamics of such recreational activities are characterized by frequent human-environment interactions [1].

In the case of Big Long River Natural Park, visitors take river trips that require several days of camping. Given the rise in popularity of the river trips, the government agency responsible for managing this river has been asked to allow more trips to travel down the river.

However, the river trip management situation in another natural resort: Colorado River Rafting shows that over adding boat trips will result in congestion on river and in campsites. According to interviews with river trip guides, congestion has negative effects on the visitors' "wilderness experience"[2]. Congestion also leads to potential adverse effects on natural environment [3].

Therefore, the government agency of river trip management has three main goals:

- Maximize boat trip numbers during rafting season
- Minimize boat encounters on the river
- Utilize the campsites in the best way possible

Invited by the managers of the Big Long River, we developed an agent-based model to find the best schedule of boat trips, and to determine the carrying capacity of the river.

In *Section 2 Problem Layout*, we list out the assumptions and terminologies in our model. Then in *Section 3 Agent-Based Model Design*, we explain the idea and the mechanic of our model. In *Section 4 Stimulation and Results*, we discuss key algorithms, error analyses, stability, and the optimization of the model in detail. Eventually, in *Section 5 Conclusions*, we mention the general review and future research.

2. Problem Layout

2.1 Background Information

After consulting literature, we find out that in river trips, the guide on boat can decide whether to stay in a campsite based on his conversation with other boats, which indicates that they are evolved in decision making [4].

On the other hand, given the fact that trips on Big Long River ranges from 6 days to 18 days, considering the speed of the boats, motorized boat will on average travel 2~5 hours a day; for rubber raft, 3~9 hours a day. Thus we deduce that the campsite must also be the attraction spot for visitors to enjoy. Then it will make sense that the boat will stay in one campsite for more than 12 hours.

2.2 Assumptions

In our model, the basic assumptions are the following:

- Visitors are logical and all information needed is provided.
- Visitors on each boat will make decision based on the information about current situation, such as whether the campsite is occupied.
- Boat launching can only happen during time period, from 8am~4pm, and each time the possibility of launching a boat is 1/2.
- Spotting another boat 0.1 miles ahead for 4 minutes is counted as one encounter.
- Boats can only go forward.
- A campsite can hold only one boat each time, the number of hours staying in the campsite follows normal distribution N~$(20.5, 1.5)$ for motorized boats and N~$(18, 2)$ for rubber rafts.
- Each boat will attempt to find a campsite to rest for the night.

2.4 Terminology

Table of Agent Names

Cell	An Agent is a group of information and algorithms. See the details of each agent in *Section 3.3 Artificial Intelligent Agents*. Agent names throughout this paper are first letter capitalized
Camp	
Boat	
Launcher	
River	
Day	
TimeController	

Table of Variables

μ	Time interval for Launcher to decide whether to let a boat enter the river
p_1	Probability of launching 8mph boat
p_2	Probability of launching 4mph boat
p_3	Probability of launching one 8mph boat and one 4mph boat at the same time
m-motor	A random number generated by system according to normal distribution on a motorized boat's resting time in campsite
m-raft	A random number generated by system according to normal distribution on a rubber raft's resting time in campsite
m	the average time for a boat to stay at a campsite
t	Accumulated time a Boat stayed in the system
n	The time a Boat travelled on the river after its latest camping
α	Weighting parameters of t
β	Weighting parameters of n
BL	Boats Launched: the average number of boats launched per day
EC	Encounters: the average number of other boats that will be seen by a boat per day
ES	Encounter Score, a score for evaluating the optimize combination of BL and EC
Sensitivity Score	A score for evaluating the sensitivity of inputs

3. Agent-Based Model Design

3.1 Survey of Previous Literature

In previous researches, combination of agent-based model and geographic information system (GIS) are applied successfully in modeling complex wildness environment and its dynamic human-environment interactions [5]. While applying Agent-Based model, artificial intelligence (AI) is assigned to human agents as well as environmental agents [6]. Cellular automata (CA) are also suggested for simulating dynamic environmental processes over intense grid cells [4, 7].

We decide to construct an agent-based model and assign both human agents and environment agents AI. However, we did not choose Cellular automata because our model emphasizes more on interactions between artificial intelligent agents [8].

3.2 Outline of Agent-Based Model

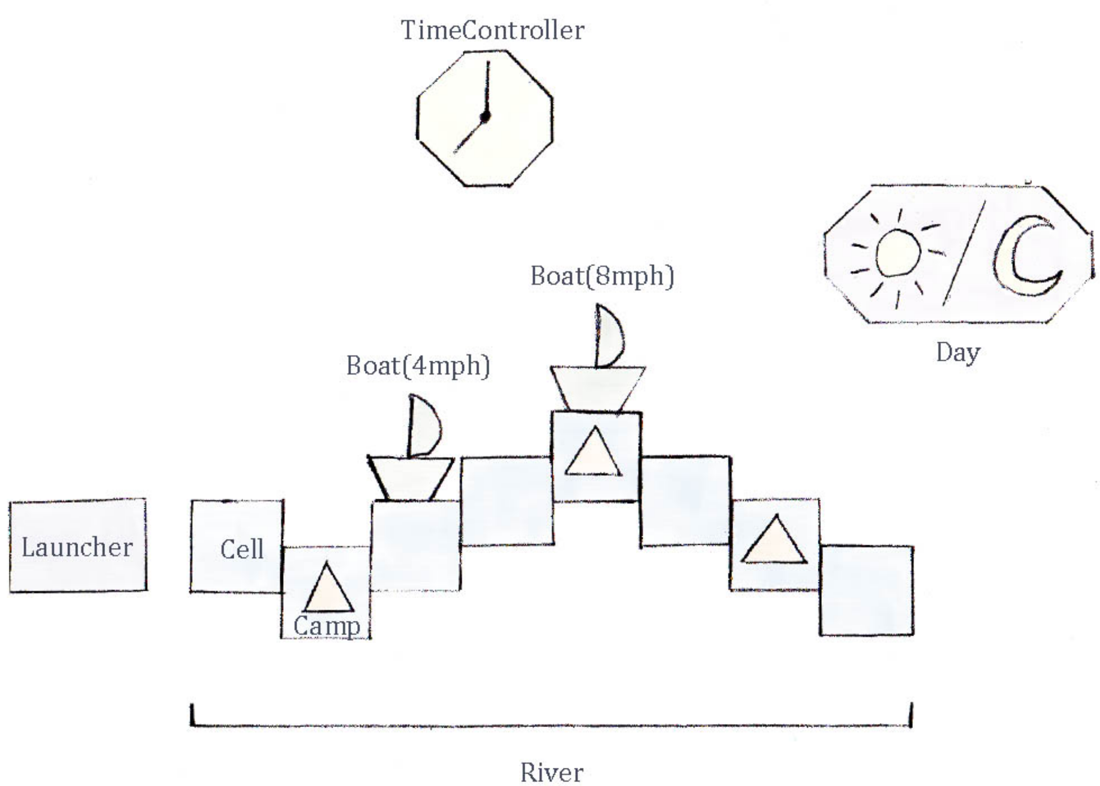

Figure 1: Conceptual graph of Agent-Based Model (this image is for idea demonstration, not for reference)

As it is showed in Figure 1, we group the Big Long River's human and natural environment into seven types of artificial intelligent agents, and assign each agent with different spatial logic. Especially, the length of Big Long River is discretized into 2000 Cells.

Then we create a virtual world, dividing continuous time over 6 month into 153,500 discrete sessions, each time session is 1.6875 minutes long.

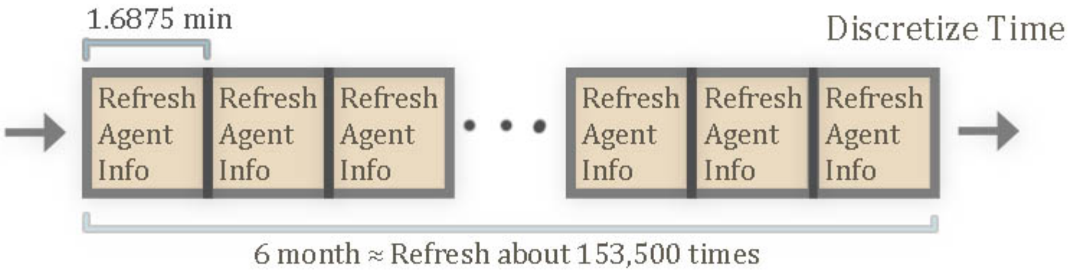

Figure 2: Discretize Time

Within each session of time seven types of agents interact according to their own spatial logic. Multiple times of interactions take place over the entire simulation duration of the model, and therefore produce a large amount of information.

3.3 Artificial Intelligent Agents

An agent is a group of information and algorithms, it exists as an entity in the virtual world of our agent-based model. The explanations of each agent type are the following:

Cell

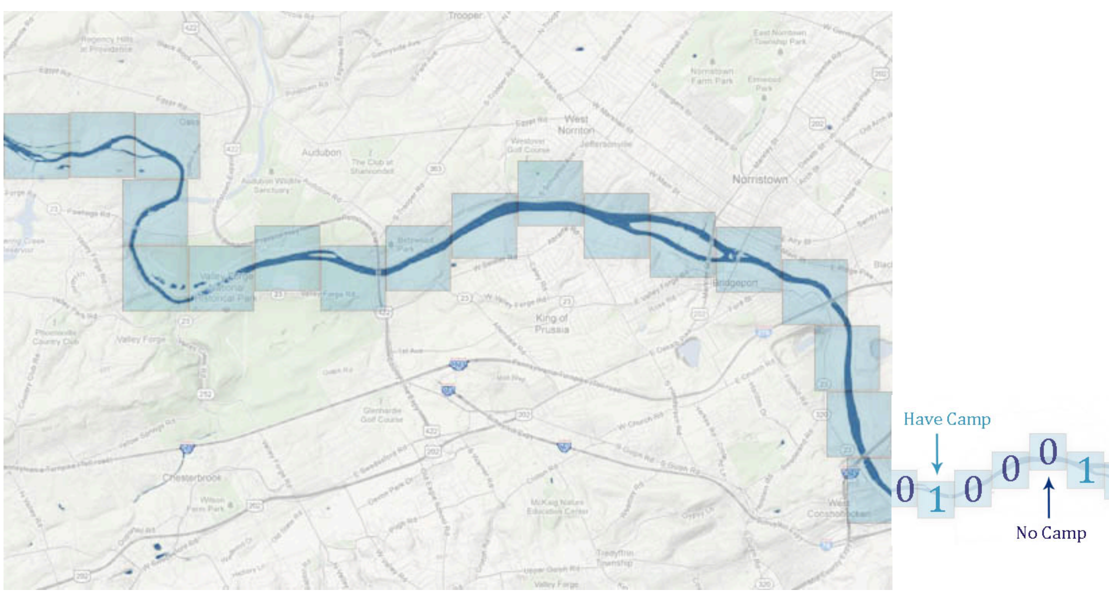

Figure 3: An example of river divided into discrete cells. Conceptual visualization on Charles River.

In our model, the Big Long River is divided into 2000 discrete Cells. Each Cell keeps track of and processes information related to natural environment, such as the Cell's id number, and whether there is campsite. Potentially, we could add GIS information into Cell as well.

Camp

The Camp agent is a sub agent of a Cell agent. It mainly stores the information about camping, it controls the length boats staying in campsites, and knows whether it is time to ask a boat to leave the campsite and continue the river trip. In our model, there are 500 campsites distributed uniformly along the river.

Boat

The Boat agent stores and process information about the attributes of boats, including, boat id, speed, number of encounters with other boats, whether the boat is in a campsite, how long it traveled since last time it rested in campsite.

There are 9 algorithms in Boat. The key algorithms are:

- Decision making algorithm: Boat decides whether to camp in a certain Cell (detailed explanation in *Section 4.1*)
- Encounter algorithm: Boat decides whether it is encountering another Boat

Launcher

Launcher represents the Big Long River management department. It stores and controls information about the scheduling of river trips, such as the number of boats launched, the combination of boat launching: one 8mph Boat, one 4mph Boat, or one 8mph Boat and one 4mph Boat.

River

River is a parental agent storing and processing information along the entire river. It contains important information about the number of Cells, Camps, the positions of boats on river, and the length of the river (225 miles). The river agent also forces the boats to move only in one direction.

Day

Since we assume that each boat will attempt to find a campsite to rest for the night, we create Day to keep track of whether it is time for visitors to rest on a daily basis.

TimeController

TimeController orders agents to interact with each other, thus stimulating the model. It ask Cell to clean up data after a Boat has moved away, ask Launcher to put more Boats on river, ask Camp to kick out Boats that rest up to *m* hours, and finally ask Boat to make movement decision.

3.4 Interactions Between Agents

Each time the system enters a new discretized time session, TimeController asks agents to interact with each other. Interactions create information flow.

Local Information Flow

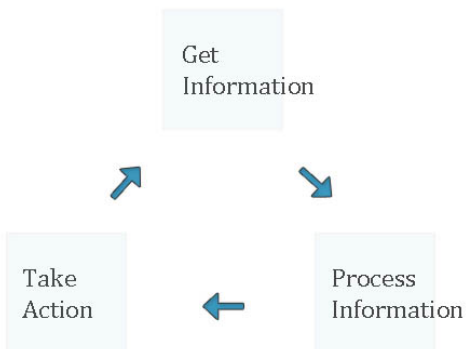

Figure 4: Local information flow of an agent within one unit time

When an agent receives the command. It (1) asks other agents for information, (2) processes information, and (3) takes actions accordingly.

When the system enters the next time session, agents repeat the processes above.

Global Information Flow

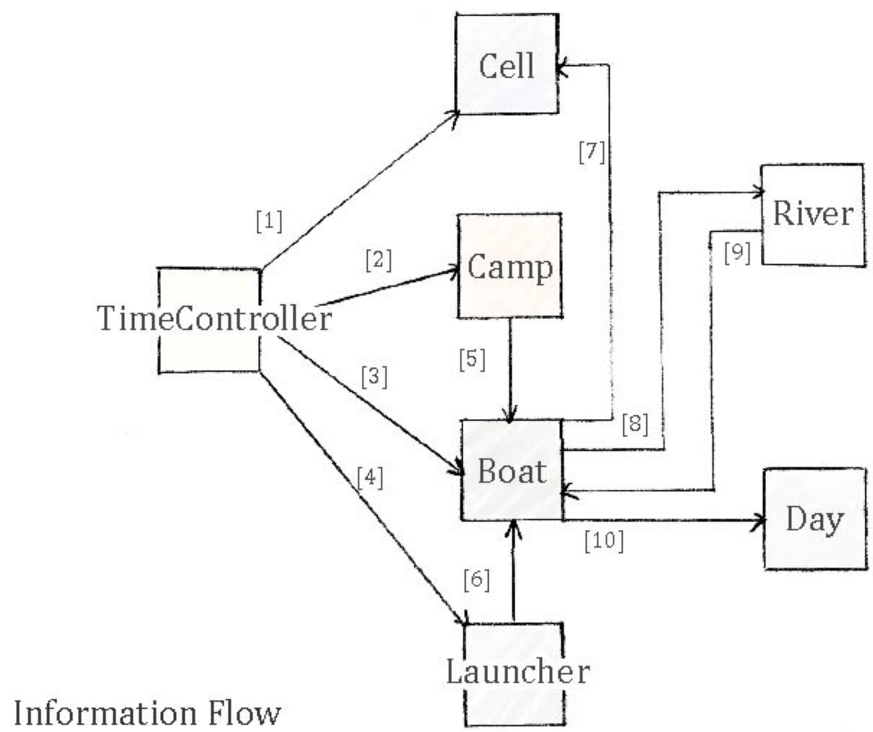

Figure 5: Global information flow of agents within one unit time

Within each time session, the information flows between agents are the following:

- [1] TimeController asks Cell to clean up data if a Boat has moved away
- [2] TimeController asks Camp to kick out Boats that rested up to *m* hours.
- [3] TimeController asks Boat to move
- [4] TimeController asks Launcher to decide whether to let more boats into the river
- [5] Camp asks Boat that rest up to m hours to leave
- [6] Launcher let more Boat into the river, if it decides so
- [7] Boat asks Cell whether this Cell has a Camp in it
- [8] Boat asks River for position information
- [9] River ask Boat to move into the next Cell
- [10] Boat asks Day whether it is nighttime

4. Stimulation and Results

4.1 Decision Making Algorithms

In our model, when a Boat is traveling on the discretized river Cells, in each time session, it is asked to make the boolean decision of whether to stay at a campsite. We assign dynamic probabilities to the answers 'yes, to stay in this campsite' and 'no, not to stay in this campsite', aiming to mimic the outcome of human decision.

Based on the assumption that during daytime, campsite seeking is less urgent, while during nighttime, all boats on Big Long River have to find campsites to rest, we separate the decision making algorithms into daytime and nighttime.

Daytime Decision Making Algorithm (8am-6pm)

Probability equation for 'yes, to stay in this campsite'

$$\mathrm{p} = \frac{\alpha}{t}(1-\frac{1}{t})(1-e^{-\beta n})$$

Probability equation for 'no, not to stay in this campsite'

$$\mathrm{q} = 1-\mathrm{p} = 1-\frac{\alpha}{t}(1-\frac{1}{t})(1-e^{-\beta n})$$

n is the time a Boat travelled on the river after its last camping. When a boat just come out from a campsite it rested: n = 0, the probability that it will stay at the same campsite again is 0. As n increases, p increases. The longer visitors traveled without rest, the more likely they will rest in a campsite.

t is the accumulated time a boat stayed in the system. As t increases, p first decreases and then increases, this mimics the behavior of a logistic map. In reality, visitors tend to show more urgent need for camping towards the end of daytime. In terms of the entire river trip, given the time frame of 6 to 18 days, the visitors tend to speed up during the last few days.

Parameters α and β represent the characteristics of visitors. The larger α and β, the visitors have greater tendency towards camping compare to boating.

Nighttime Decision Making Algorithm (6pm-8am)

Probability equation for 'yes, to stay in this campsite'

$$\mathrm{p} = 1$$

Probability equation for 'no, not to stay in this campsite'

$$q = 0$$

The probability of staying in campsite is 1, because every boat has the tendency to rest in a campsite during nighttime.

Flow Chart of Decision Making Algorithms

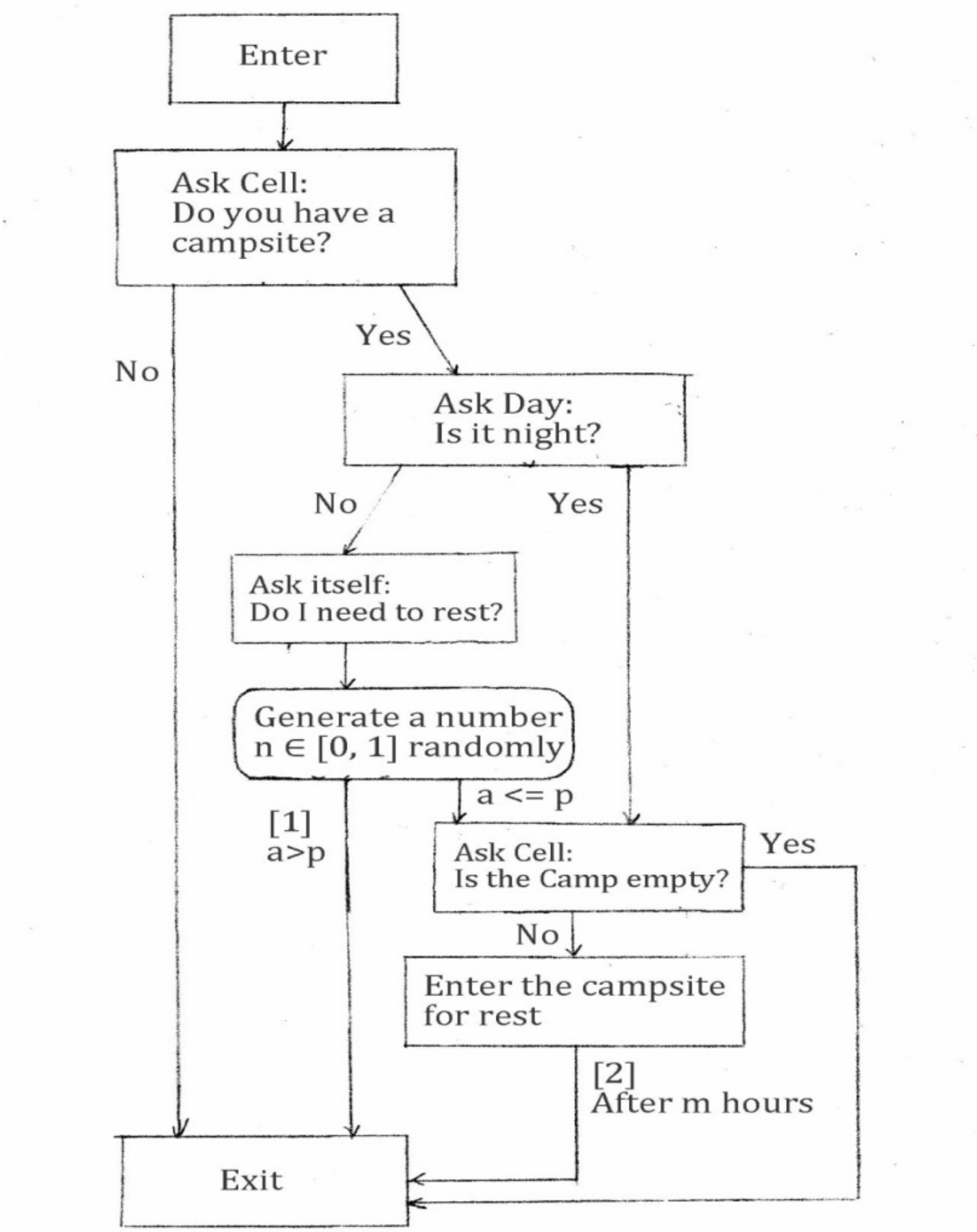

Figure 6: Flow Chart of Decision Making Algorithms

[1] *p*: the probability of 'yes, to stay in this campsite'

[2] *m*: a random number generated by system according to normal distribution on a boat's resting time in campsite

4.2 Stimulation

4.2.1 Object-Oriented Programing

Leveraging Java, we programed all our artificial intelligent agents and stimulated their interactions.

4.2.2 Model Feasibility Report

To test the feasibility of the model, we first run the stimulation with fixed inputs:

- $\mu = 20$
- $p_1 = p_2 = p_3 = 1/3$
- $\alpha = 700$
- $\beta = 0.001$

Holding α and β constant, we change the values of μ, p_1, p_2, p_3, and run the stimulation several times. After analyzing the results, we consider our model feasible for simulating the river trips on Big Long River because it meets the following constraints:

Meeting the Trip Length Constraint

97.5% of the length of boat trips always falls in the interval of 6 ~ 18 nights, when α and β are fixed.

Graph of Boats vs. Trip Length

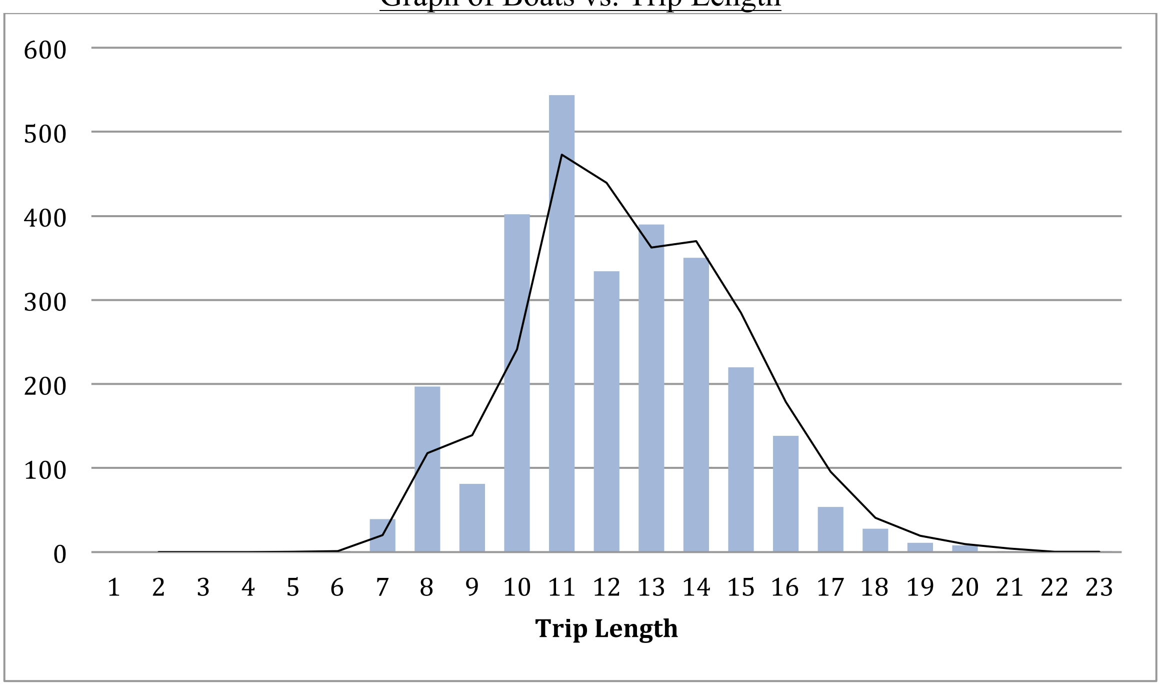

Figure 7: Graph of Boat Number vs. Trip Length. Vertical-axis: number of boats. Horizontal-axis: trip length (night)

Meeting the Campsite Capacity Constraint

In Big Long River, each campsite can host only one boat at one time, which means the total number of boats on the river cannot exceed the number of campsites at night.

Graph of Boats in River vs. Time

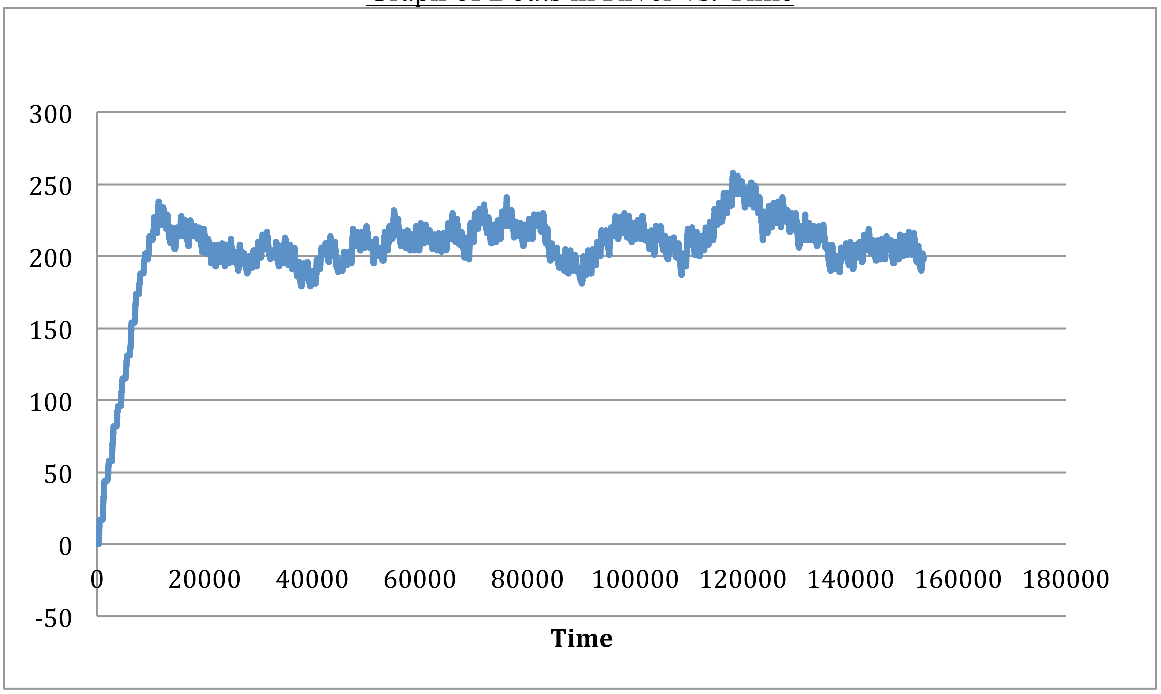

Figure 8: Graph of Time vs. Boat Number on River. Vertical-axis: Time (time sessions). Horizontal-axis: Boats in river.

In our model, the number of campsites is 500. In Figure 8, we see that the number of boats in river converges to about 200. The number of boats on river is less than the number of campsites, which agrees with our objective.

4.3 Sensitivity Analysis

To test the sensitivity of inputs, we start with 5 inputs, and 5 corresponding outputs. Holding 4 inputs constant, we tweak one of the inputs by increasing it for 20% at a time. We compare *original outputs* and *tweaked outputs* and derive the corresponding percentage change.

Since our system is very likely to generate different outputs from the same inputs for there are random factors in our system, we handle noise by repeating the tests and taking the average result.

Finally, we evaluate the sensitivity by comparing the sensitivity score. The higher the score, the more sensitive is the output corresponding to the input.

$$\text{Sensitivity Score} = |(\text{Change in outputs\%}) / (\text{Change in inputs\%})|$$

Sensitivity of Time Interval of Boat Launching

Tested by Increase μ for 20%

	Original inputs	Tweaked inputs
μ (minute)	23	23 * 1.2 = 27.6
p_1 (%)	38	38
p_2 (%)	27	27
m-motor(hour)	19	19
m-raft (hour)	18	18

	Original outputs	Tweaked outputs	Change in outputs	Score
The number of boats finishing after 18 days	1	0	-1	-
The number of boats finishing before 6 days	0	0	N/A	-
Average length of a boat trip (day)	11.1	11.2	1%	-
Average number of encounters per boat per day	0.9	0.7	-22%	1.10
Average number of boats launched per day	7.7	5.7	-26%	1.30

Sensitivity of the Probability of Launching Motorboats

Tested by Increase p_1 for 20%

	Original inputs	Tweaked inputs
μ (minute)	23	23
p_1 (%)	38	38 * 1.2 = 45.6
p_2 (%)	27	19**
m-motor(hour)	19	19
m-raft (hour)	18	18

	Original outputs	Tweaked outputs	Change in outputs	Score
The number of boats finishing after 18 days	1	1	0	-
The number of boats finishing before 6 days	0	0	N/A	-
Average length of a boat trip (day)	11.1	11.2	1%	-
Average number of encounters per boat per day	0.9	1	11%	0.55
Average number of boats launched per day	7.7	7.7	0	0

Sensitivity of the Probability of Launching Rafts

Tested by Increase p_2 for 20%

	Original inputs	Tweaked inputs
μ (minute)	23	23
p_1 (%)	38	33**
p_2 (%)	27	27 * 1.2 = 32.4
m-motor(hour)	19	19
m-raft (hour)	18	18

	Original outputs	Tweaked outputs	Change in outputs	Score
The number of boats finishing after 18 days	1	0	0	-
The number of boats finishing before 6 days	0	0	N/A	-
Average length of a boat trip (day)	11.1	10.1	1%	-
Average number of encounters per boat per day	0.9	0.9	11%	0.55
Average number of boats launched per day	7.7	7.7	0	0

4.4 Optimization and Results

4.4.1 Evaluation Function

After analyzing the results of our stimulation, we are invited by the manager of Big Long River to find an optimal scheduling of boats to meet the following goals:

- Maximize boat trip numbers
- Minimize boat encounter with other boats on the river
- Maximize the utilization of camps

To find the optimal solution, we develop an evaluation function:

Evaluation Function:

$$ES = | BL - EC |$$

Constraints:

$$\mu <= 120$$
$$\mu >= 5$$
$$m <= 30$$
$$m >= 12$$
$$p_1 + p_2 + p_3 = 1$$

ES is the Evaluation Score, the higher the ES, the more optimal is the solution. BL is the average number of boats launched per day, while EC is the average number of encounters.

We generated value for inputs 100 times randomly within the constraints and feed them to our system one by one. We then collect the outputs and feed the outputs into the evaluation function. Finally we sort the outputs by score and find the optimal solution with the highest score.

4.4.2 Optimal Solution

Optimal Solution: $\mu = 5*1.6875$mins, $p_1 = \frac{36}{99}, p_2 = \frac{10}{99}, p_3 = \frac{43}{99}$

Optimal Launch interval 2 μ

We programed Monte Carlo annealing to test the best output derived from random generated inputs. As expected, it turns out that the optimal solution derived from Monte Carlo Annealing is very similar to what we got before.

Analysis of the Optimal Solution

Graph of Boats vs. Trip Length

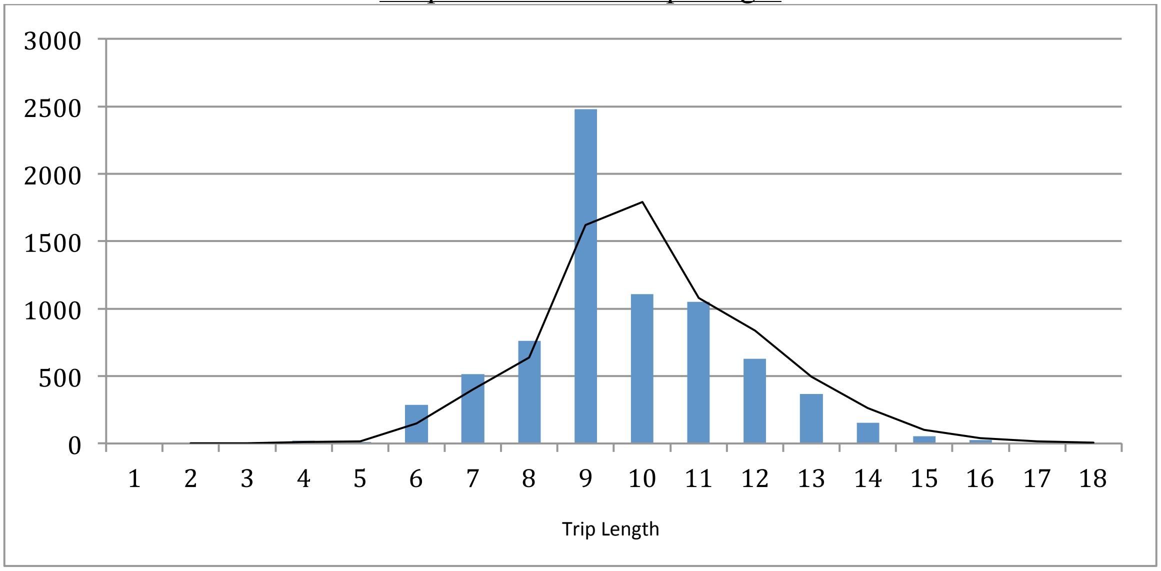

Figure 9: Graph of Boat Number vs. Trip Length. Vertical-axis: number of boats. Horizontal-axis: trip length (night)

98% of boats finish the trip in 6~18 nights, and the distribution of trip length shows that 70% of boats have the tendency to finish in 9~11 nights.

Graph of Boats in River vs. Time

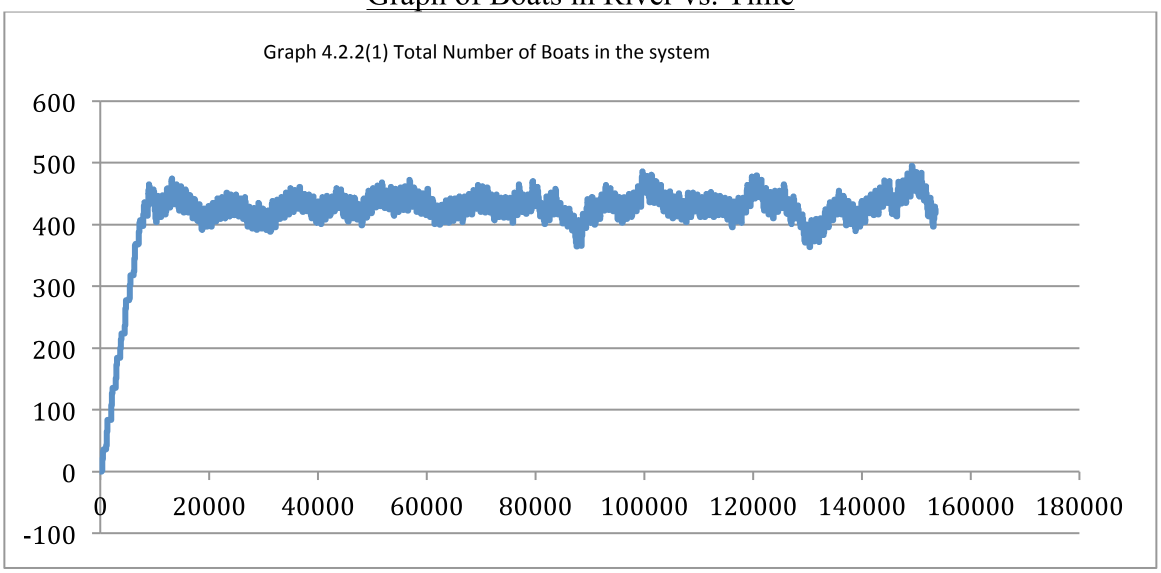

Figure 10: Graph of Time vs. Boat Number on River. Vertical-axis: Time (time sessions). Horizontal-axis: Boats in river.

In our model, the number of campsites is 500. In Figure 10, we see that the number of boats in river first increase then converge at about 450 boats. The utility of campsites is high.

Graph of Boats in River vs. Encounters

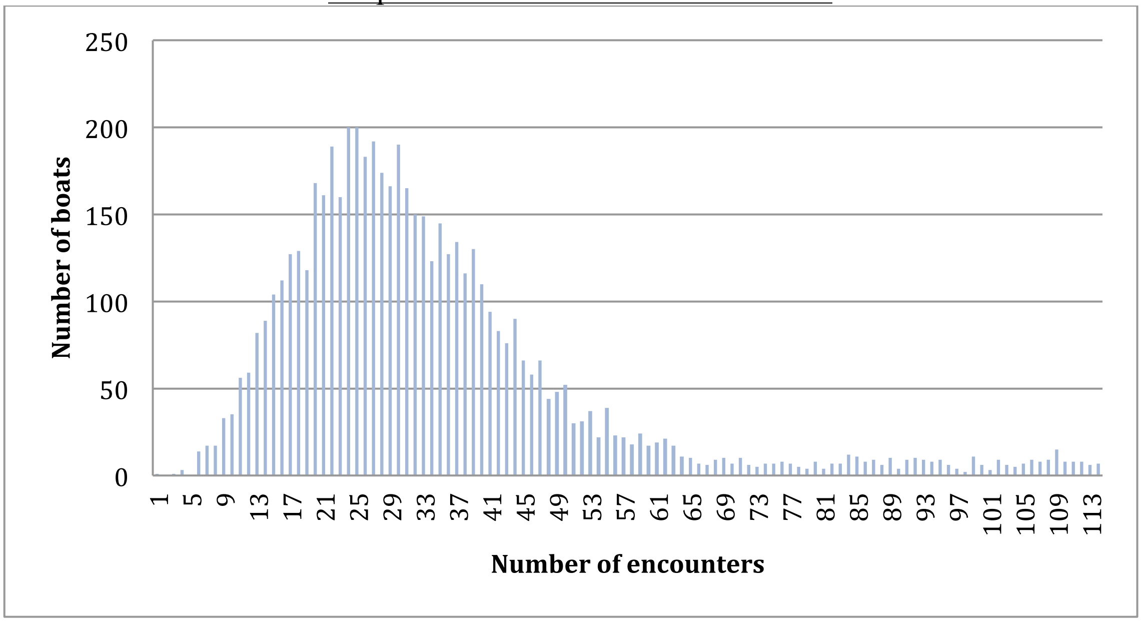

Figure 11: Graph of Boats in River vs. Encounters. Vertical-axis: Boats. Horizontal-axis: number of encounters.

Most of the boats encounter other boats average 25 times during the trip.

Graph of the Percentage of rafts and motorboats

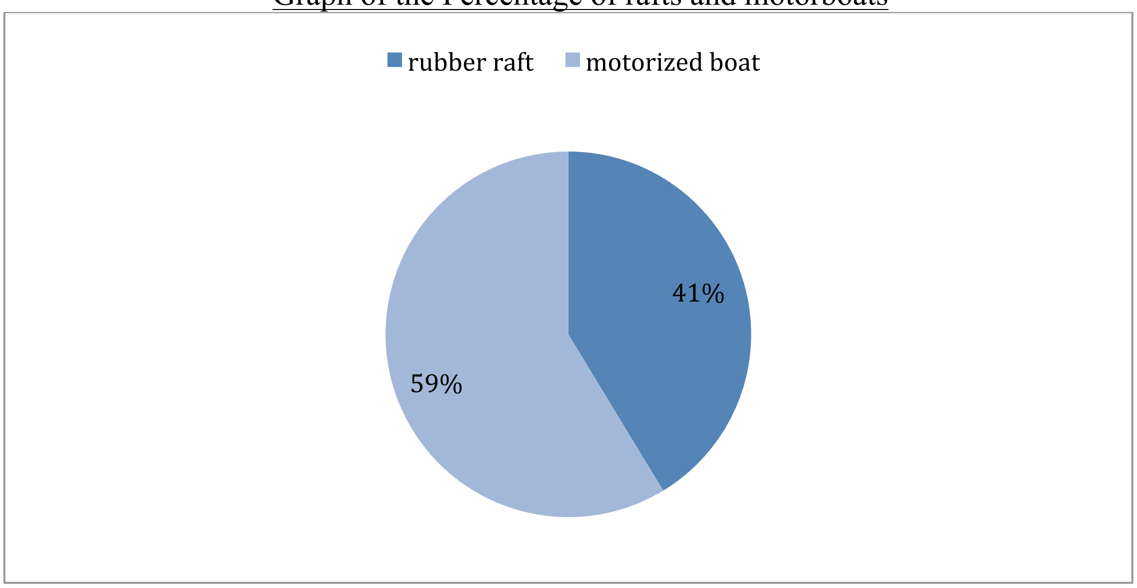

Figure 12: Graph of Boats in River vs. Encounters. Vertical-axis: Boats. Horizontal-axis: number of encounters.

The stimulated optimal composition of boats in the river is 59% motorized boats and 41% rubber rafts.

5. Conclusions

5.1 General Review

After detailed analysis of the stability and sensitivity of our agent-based model, and comparing the optimal result with the criteria given by *National Park Service 1989*[3], we conclude that our model is suitable for stimulating and optimizing the Big Long River's river trips.

5.2 Strengths and Weaknesses

Strengths

- **Adaptability**: The algorithms and information stored in each agent is adaptable to changes. Through adding and deleting algorithms or agents, the model can be adapted to simulate different environment and human behaviors. For instance, a new agent of "attraction" can be added into the model represent visitor's behavior of sightseeing.

Weaknesses

- **Lack of GIS Information**: In our current model, the discretized sections of river are uniformed, while in reality, different sections of river have different environment features.

- **Dependent on Communications**: Our model is heavily dependent on the communication of managers and boat guides when boat guides are making camping decisions. While in reality, the communication is minimum.

- **The Unverified Definition of Encounter**: We defined that a boat spotted another boat 0.1 miles ahead for 4 minutes is counted as one encounter, but such assumption is not verified.

- **Undefined Capacity of a Boat**: We did not consider how many visitors a motorized boat or a rubber raft can carry. In practice, the manager of the Big Long River may favor motorized boats because they can carry more people.

5.3 Future Work

- **Improve the Algorithms for Artificial Intelligence:** We may interview with visitors of Big Long River about their experience and camping decision-making tendency, and add new AI algorithms accordingly.

- **Include GIS Information:** We may include GIS information of the Big Long River, and assign attraction level of each campsite accordingly.

6. Reference

[1] Rooney, N., K. S. McCann, David L. G. Noakes, and Peter Yodzis. *From energetics to ecosystems the dynamics and structure of ecological systems*. Dordrecht: Springer, 2007. Print.

[2] C. A. Roberts and H. R. Gimblett, Proc. *Computer Simulation for Rafting Traffic on the Colorado River*. 5th Conf. Research on Colorado Plateau USGS, 2001, 19-30.

[3] National Park Service. *Colorado River Management Plan*. U.S. Department of the Interior, 1989.

[4] Gimblett, H. Randy. *An Intelligent Agent Based Model for Simulating and Evaluating River Trip Scenarios Along the Colorado River in Grand Canyon National Park*. Integrating Geographic Information Systems and Agent-based Modeling Techniques for Understanding Social and Ecological Processes. New York: Oxford University Press, 2001. Print. 245-275.

[5] Schechter, M. 1975. Simulation model of wilderness area use. Resources for the Future, Washington, D.C. pp. 172.

[6] Nakashima, Hideyuki, Hamid K. Aghajan, and Juan Carlos Augusto. *Handbook of ambient intelligence and smart environments*. New York: Springer, 2010. Print. 819-830

[7] Tobler, W.R. Cellular geography. In S. Gale and G. Olsson, editors, Philosophy in Geography, pages 379-386. D. Reidel, 1979.

[8] Craig Reynolds. *Individual-Based Models: an Annotated List of Links*. http://www.red3d.com/cwr/ibm.html.

7 Appendix 1: Excerpt from the Data of Simulation

Partial data for stimulation of optimal solution (original data has 7465 rows in total)

Index	Start Time (in minute)	End Time (in minute)	Total Rest Time (in minute)	Trip Length (in minute)	Number of Encounters	Boat Type 1:rubber raft 2:motorized boat	Number of Camp rested	Average Nonstop Time for Each boat
0	480.9375	16854.75	13000.5	16375.5	15	1	7	482
1	480.9375	16328.25	14161.5	15849	18	2	6	281
2	497.8125	18187.875	14316.75	17691.75	659	1	8	421
3	497.8125	14242.5	12058.875	13746.375	263	2	5	337
4	506.25	16718.0625	12838.5	16213.5	553	1	7	482
5	506.25	13791.9375	11599.875	13287.375	17	2	5	337.5
6	514.6875	16404.1875	14203.6875	15891.1875	25	2	6	281.25
7	523.125	22426.875	18530.4375	21905.4375	106	1	10	337.5
8	523.125	15862.5	13653.5625	15341.0625	127	2	6	281.25
9	540	15302.25	13076.4375	14763.9375	38	2	6	281.25
10	548.4375	16927.3125	13005.5625	16380.5625	21	1	7	482
11	548.4375	15712.3125	13478.0625	15165.5625	20	2	6	281.25
12	556.875	16284.375	14041.6875	15729.1875	23	2	6	281.25
13	582.1875	15558.75	11603.25	14978.25	147	1	6	562.5
14	582.1875	14114.25	11846.25	13533.75	20	2	5	337.5
15	607.5	19818	15837.1875	19212.1875	144	1	8	421.875
17	624.375	16797.375	12799.6875	16174.6875	39	1	7	482
16	607.5	13690.6875	11397.375	13084.875	20	2	5	337.5
19	683.4375	16383.9375	14014.6875	15702.1875	19	2	6	281.25
18	658.125	16917.1875	14573.25	16260.75	141	2	6	281.25
21	700.3125	15342.75	11269.125	14644.125	28	1	6	562.5
20	691.875	18005.625	13940.4375	17315.4375	31	1	8	421.875
23	725.625	19073.8125	14974.875	18349.875	694	1	8	421.875
22	700.3125	17278.3125	14892.1875	16579.6875	37	2	6	281.25
25	734.0625	13724.4375	11304.5625	12992.0625	19	2	5	337.5
24	725.625	13959	11547.5625	13235.0625	13	2	5	337.5
27	750.9375	16691.0625	14254.3125	15941.8125	28	2	6	281.25
26	750.9375	19737	15612.75	18987.75	28	1	8	421.875
29	793.125	13721.0625	11242.125	12929.625	18	2	5	337.5
28	793.125	15555.375	11388.9375	14763.9375	41	1	6	562.5
31	818.4375	14985	12480.75	14168.25	26	2	5	337.5
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