ISE 405 Project – Oil Blending Problem

Group 3

The Problem:

Aramco is planning to do a new strategy in which they build new tiny and partial oil and gas fields instead of increasing the production in the current fields they have. The first step is to discover areas that have a profitable underground source of crude oil. Currently Aramco produces 5,400,000 bbl/day. Shaybah Oil Field produces 1,000,000 bbl/day. It is believed that there is a nearby source from it and Aramco determined a budget of a maximum capacity of 40,000 bbl/day. They want to make sure that this new and tiny field being profitable as much as possible. Testing the plan in this field in real life is costly and needs a lot of time. So, doing a simulation for the partial field is a good solution for this situation. One stage of the field process decided to be simulated to conduct tests on it (conducting several scenarios) to maximizes the Profit. This stage is called the blending stage where the crude oil is going through three main processes: Distillation, cracking and finally blending.

Distillation is a process that assures that the crude oil is pure to guarantee the required quality. It is divided into some sub-processes: Distillation column, condenser and reflex drum as shown in Figure 1. The next process is cracking, where the crude oil must be all liquid (solids are thrown away) and that can be done by breaking the Carbon-Carbon bonds of the crude oil. The final process is the blending, where the crude oil is divided into six main categories (based on the Octan Number ON) as a result of the two previous processes. They can be represented by ***(Xij)*** Where (i) represents the input steam (2 steams) and (j) represents the final products (3 final products). Final Products are the result of blending two main categories. The three final product has a different selling price. Products 1, 2 and 3 can be sold by 25.125, 27.000 and 30.375 SR/bbl, respectively. The purpose is to increase the profit of the partial field by changing the model parameters (e.g. The cracking ratio) and the working times.

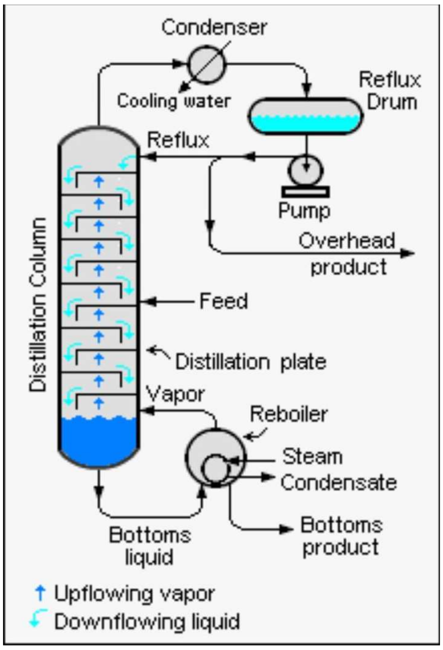

Figure 1: Simple Distillation Process

Objectives:

Simulation is an efficient tool to test and check a model and try different scenarios to have the maximum profit from the crude oil blending before building the model physically, especially for expensive models. In this project, we tested different scenarios of the working time, and the ratios of the crude oil that comes from the distillation tower to the cracker and blender to have the maximum profit and high quality from selling different products with a different octan number (ON).

Scope of The Project:

These days, oil and its derivatives are one of the most important things in our life. Cars, airplanes, electricity stations, and many products are mainly depending on the oil. Oil companies (such as Aramco) always want to find new oilfields, especially if the new oilfield gives the oil company more profit and has a large amount of oil. However, some oilfields are not profitable and might have some unwanted consequences. If an oil company has some information about a new oil source and wants to check if it will be profitable for it before doing it physically. Simulation is an efficient tool to test and check a model for many scenarios before building it physically.

System Description:

The system consists of three main steps: Distillation, Cracking and Blending.

Firstly, Distillation has three subparts, which are distillation column, condenser, and reflux drum. The oil that is extracted from the ground is a mixture of many components and cannot be separated without a specific machine. The crude oil will be separated based on its volatility and the boiling point by heating the crude oil up to 600 degrees Celsius. The mixture (crude oil) will be boiled and forms gases that will go to the vapor phase with the lowest boiling point. Also, the liquid and solid parts will be separated according to their boiling points. Then, the liquid will go the condensers, which is the next distillation step. In the condensers, the liquid will be cooled again the be transported either to the cracker or to the blender directly (with 82 ON) through the reflux drum by a specified ratio of crude oil.

The next step is cracker, where the crude oil MUST be liquid by breaking the carbon-carbon bonds by heating them in high temperature (around 816 degrees Celsius) and throw away the solids that cannot be transformed to liquids. (with 98 ON).

Finally, in the blending step, we have three different products from each process (distillation and cracking) with the same ON (82 or 98) but different in price. In blending step, we need to have finally three types of ON with the lowest price, which are (87, 89, 92) by combining two products from each previous step to have the final three products.

Initial Assumptions:

- The system services the entities that come first (FIFO).
- Crude oil is arrived by trucks.
- Each truck can carry 190 bbl.
- The whole amount of crude oil that is arrived by a single truck is considered as one entity.
- ***Xij*** is divided instantaneously during the processes.
- The cracking process is done by a single step.
- The initial distribution of the crude oil before blending is equal for each one of them through the three sequences (33.33% for each).
- The distribution of a processing time can be divided into partial sub-processes times, where the summation of the distribution parameters in the sub-processes is equal to the parameters in the main process.
- This simulation model for the tiny field is general and applicable for any other tiny fields (e.g. if a new field that can produce 800,000 bbl/day is decided to be built, 20 tiny fields can be built instead of it (each with a capacity of 40,000 bbl/day) with the same simulated model to minimize the risk of building the huge field).

Input data and its analysis:

Due to the current situation, instead of collecting data from a real system, we used some external sources that have the same data that we are concerned about. Also, we did some logical calculations to derive the model inputs.

<u>Arrival Time:</u>

The arrival time is assumed to be exponential because the exponential distribution is common in arrival events (associated with inter-arrival times). Its value is EXPO (2.5) mins because we want to utilize the capacity as much as we can (40,000 bbl). It was determined by logical calculations:

$$\frac{8(hours) * 60 \left(\frac{mins}{hour}\right)}{\left(2.5 \frac{mins}{arrival}\right)} = 192 \; arrivals$$

$$192 \left(\frac{trucks}{day}\right) * 190 \left(\frac{bbl}{truck}\right) = 36{,}480 \; bbl/day$$

36,480 bbl can be more or less (because EXPO (2.5) means that the arrival time can be 2.6, 2.45, 2.4, etc.).

Distillation Time:

According to Chemistry Libretext, distillation can take around 4 to 6 hours with no distinct pattern. This tells us that we should use subjective distribution where we only know the maximum and minimum values, which is the Uniform distribution (UNIF (4,6) hours). A sample data can be:

5.954247	4.56428	4.728143	4.316701	5.93169	4.445007	4.852887
5.123554	5.577949	4.753717	4.187497	4.998041	5.097993	5.494314
5.107494	4.000000	4.325166	4.527697	5.036051	5.781814	4.214008
5.018163	4.627791	5.136959	5.343136	4.260613	4.560432	5.424428
4.930106	4.075024	4.730169	5.859159	5.769656	4.672561	5.205273
5.891958	5.283453	4.607659	5.771716	4.413474	5.621023	5.246047
5.394288	4.920594	5.844253	5.978679	5.343467	4.896793	5.425488
5.994398	4.207365	4.774377	5.865394	4.795056	5.963197	4.478369
4.006251	4.539455	5.134961	4.029862	5.353951	5.716179	4.675555
6.000000	5.381055	5.654334	4.262929	4.329457	5.367449	5.792291
4.247337	4.323004	5.788086	5.620839	4.784009	5.197989	4.396571

However, this distillation time is for huge production capacity. It was estimated that our distillation time is 153 times less than this distillation time so:

$$UNIF\left(\frac{4(hours) * 60\left(\frac{mins}{hour}\right)}{153}, \quad \frac{6(hours) * 60\left(\frac{mins}{hour}\right)}{153}\right) \approx UNIF(1.56, 2.32)\ mins$$

The distillation process is divided into smaller processes:

Distillation Column (UNIF (0.89, 1.33))

Condenser (UNIF (0.45, 0.66))

Reflux Drum (UNIF (0.22, 0.33)).

$a_1 + a_2 + a_3 = 1.56\ mins, \quad b_1 + b_2 + b_3 = 2.32\ mins$

Cracking Time:

The cracking completion is known to be completely random, and it is around 3.4 hours (depending on the internal structure of the crude oil and its chemical characteristics). As we said before, our tiny field we simulated is around 153 times less than the usual fields:

$$EXPO\left(\frac{3.4(hours) * 60\left(\frac{mins}{hours}\right)}{153}\right) \approx EXPO(1.33)\ mins$$

Blending Time:

The blending completion is assumed also to be completely random, there is no fixed time for blending crude oil. We searched in the petroleum crude oil problems and we found that the whole blending processes take around $E_t = 1.15\, mins$ (including the transfer time between one blending steam to another). In our model, this time can be divided into three things: Blending time in the first stream for product (j), blending time in the second stream for product (j) and the transfer time between streams. The transfer time is constant, and it takes only 3 seconds to transfer from one steam to another (0.05 mins). So, the remaining time is $E_t - TT = (1.15 - 0.05)\, mins = 1.1\, mins$. The crude oil is blended into two steams to find a single product, so the blending time in a single stream is:

$$EXPO\left(\frac{1.15 - 0.05}{2}\right) mins \approx EXPO(0.55)\, mins$$

ARENA Model:

The model is built carefully (Shown in Figure 2) Covering the whole stage of blending (including the three main processes described in the project problem) and it considers also the excess amount of oil that cannot be sold (did not reach the required quality). For example, After the distillation processes, only 20% (5:1) of the crude oil will be pure liquid, so we got rid of it by using (Decide: Pure solid oil?). Also, we did the same for cracking process, the crude oil that its Carbon-Carbon bonds did not broke (2:1) is not go through the blending processes (Decide: Carbon-Carbon Bonds Broken?)

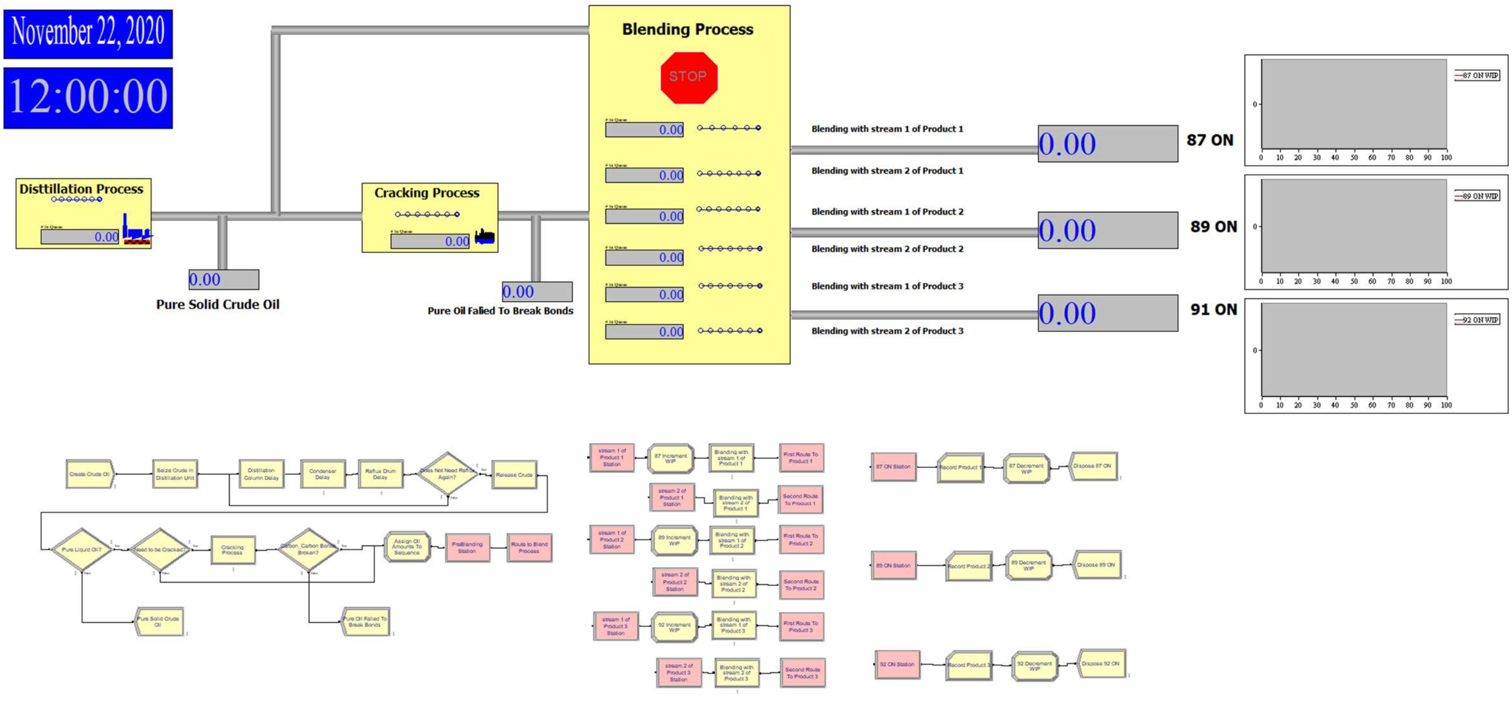

Figure 2: ARENA Model of the Project

Validation of the model:

Due to the current situations, we are going to make the first two steps:

1. Building the model that has high face validity.
2. Model assumptions validation.

These two steps are important in insuring that the credibility of the model is high and approaches the real system behaviour.

- **Building the model with high face validity**
  This can be done by involving people with experts that are concentrated on the field of interest we are working in to ensure that the level of realism is high and acceptable. So, what we did is we contacted with the College of Petroleum Engineering and Geosciences at KFUPM, and we were careful to involve people that specifically have experts and knowledge about the exact stage that we are simulating. So, we involved **Dr. Rahul N. Gajbhiye** who is an expert in the downstream of the crude oil refinery which we are simulating (downstream includes Distillation, cracking and blending). Dr. Rahul is an Assistant Professor holding a PhD. in Petroleum Engineering from Louisiana State University. He worked as a postdoctoral research associate at Tulsa University Drilling Research Project (TUDRP) at Tulsa University, Oklahoma. He also served as a Lecturer at the Department of Petroleum Engineering, Maharashtra Institute of Technology, Pune, India. Dr. Rahul is a member of the Society of Petroleum Engineering and the American Association of Drilling Engineers (AADE). He had his **PhD** of Petroleum Engineering, Louisiana State University, USA, in 2011. After we finished the model, he revised it from the beginning of the model to the end. Finally, he validated the model for us based on his experts. He suggests changing the terminology of the decide module after the distillation release process to be more general. He also suggests adding assumption to the report about the distribution of the crude oil before the blending process.

  To build a model with high face validity we may do some sensitivity analysis. After conducting several tests on the model, we found that:

  - ❖ As we decrease the ratio of the reflux decision, the waiting time increases, and the queue length increases for all processes before it.
  - ❖ As we increase the ratio of the distillation decision after releasing the crude oil, the total time in the system decreases and the number of units out decreases (the number out of the three products).
  - ❖ As we decrease the ratio of the pre-cracking decision. The utilization of the cracking processes decreases, and the number of units out increases (the number out of the three products).
  - ❖ As we increase the blending time at each process of the blending, the utilization of the blending increases and the total time in the system increases.

Based on the above statements, all the results we got from the sensitivity testing is logical and matches what really happens in real life crude oil system, which indicates that the behaviour of the model we built is close of what that one in real life.

- **Model assumptions validation**
  Our model includes three types of assumptions: Structural assumptions, data assumptions and logical assumptions.

  Structural assumptions
  We assumed that the first entity comes is first served (FIFO). This can be validated by plotting the number of entities served by FIFO vs the number of entities served by priority. Let us first understand the entity, in our model, entities do not have priorities above each other. To clarify, crude oil has equal chemical characteristics, which means that it does not make sense if we consider priority serving in our model, no entities would be served (no entity has a priority on each other). Figure 3 shows that the served entities by FIFO are increasing with time while the entities that served by priority are stacked with zero because no role differentiates them. Notice that the plot represents a single day simulation (not the whole 5 days) with an average of 8 working hours a day. The number of entities in the plot in a single day matches one random replication conducted.

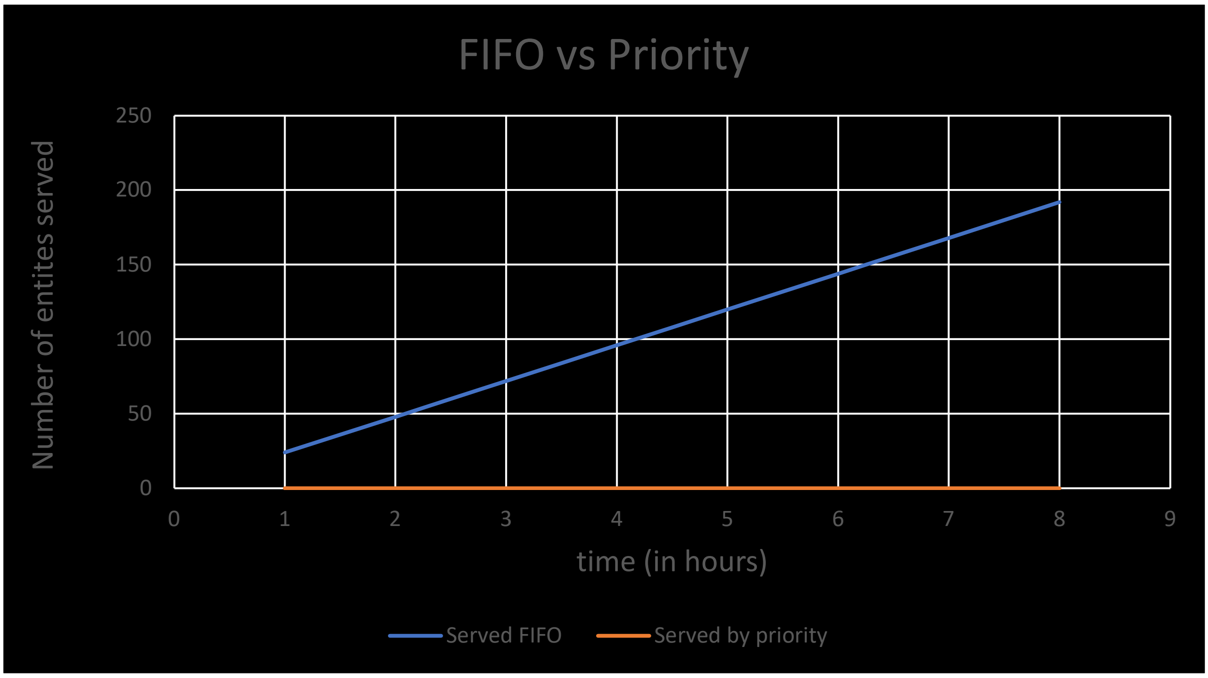

Figure 3: FIFO vs Priority Comparison

Another structural assumption is that oil is arrived by trucks. This was assumed to make the simulation discrete instead of continuous. Crude oil can be arrived by various methods as shown in Figure 4. We assumed each truck can Carry 190 bbl and this can be validated based on a validated source with high credibility. According to Freight Waves, “one tanker truck can hold about **190** barrels of oil”.

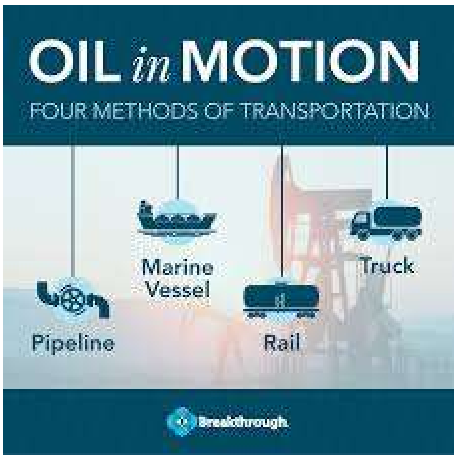

Figure 4: Crude Oil Transportation Methods

We also assumed that Xij is divided instantaneously during the processes. That is because if there was a consideration of the dividing time during the process, then the number of units out would decrease as shown in Figure 5. Notice that as we increase the consideration time, the lag increases.

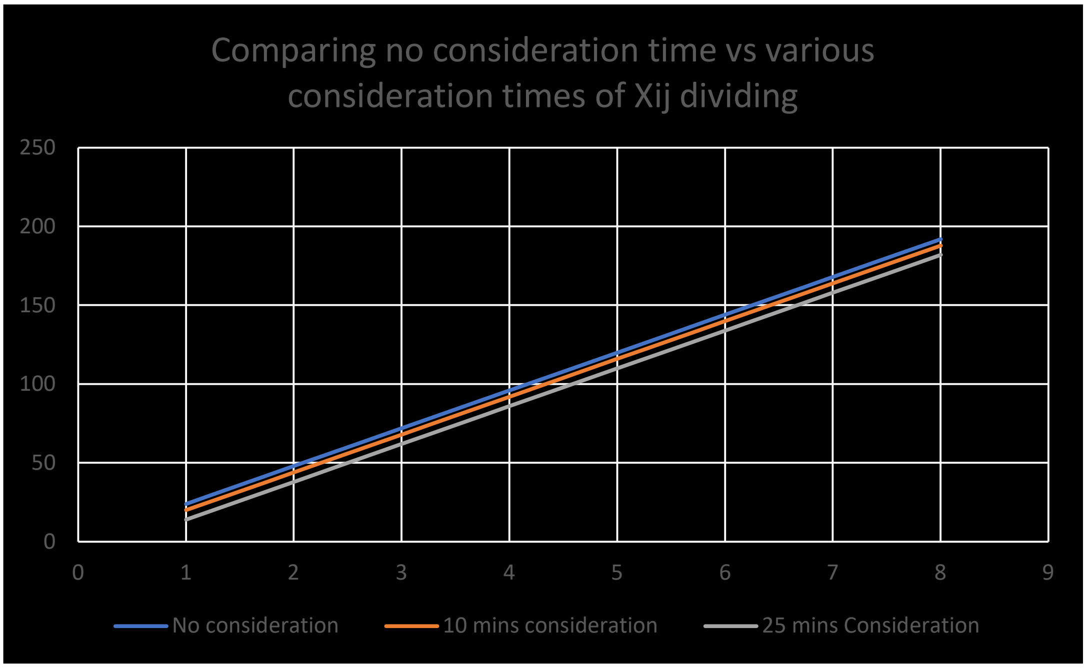

Figure 5: Comparing no consideration time vs various consideration times of Xij

Data assumptions

The uniform distribution is reliable for the distillation process because we only know the minimum and maximum values with no unique pattern of the data. The Exponential distribution is reliable for the trucks arrival time because it is famous that it is the most common distribution for arrival events. Also, Exponential distribution is reliable for the cracking processes and blending process because the completion of cracking and blending is completely random.

For validation using the goodness of fit test, is not applicable in our report because the data was not collected directly from the field due to the current situations.

The last kind of assumptions we used is **logical assumptions.** Logical assumptions are true all the time (they are valid all the time), and we put them just for more understanding of the model. They include:

- The cracking process is done by a single step.
- The initial distribution of the crude oil before blending is equal for each one of them through the three sequences (33.33% for each).
- The distribution of a processing time can be divided into partial sub-processes times, where the summation of the distribution parameters in the sub-processes is equal to the parameters in the main process.
- This simulation model for the tiny field is general and applicable for any other tiny fields (e.g. if a new field that can produce 800,000 bbl/day is decided to be built, 20 tiny fields can be built instead of it (each with a capacity of 40,000 bbl/day) with the same simulated model to minimize the risk of building the huge field).

Output Analysis and Description:

Due to the current situation, we made some assumptions (based on various trusted sources) about the true behaviour of the system so we can apply the output analysis to them. These assumptions include:

- Maximum allowable error of time is 1 min.
- The waiting time in the real system is 4.25 min.
- The total time in the real system is 6.4 min.
- The time in the queue of the distillation unit in the real system is 3.2 min.
- Maximum allowable error of the number of oil trucks is 25 trucks.
- The number of oil trucks entered in the real system is 1030 trucks.
- Maximum allowable error of WIP is 0.45.
- The value of WIP in the real system is 2.3.
- Maximum allowable error of utilization is 0.075.
- The utilization of the distillation unit in the real system is 0.75.
- The utilization of the blending machine and cracker in the real system is 0.06.

After applying the output analysis, we found:

Waiting Time:
Average: 3.82 min
Half width: 0.32
C.I.: (3.50, 4.14)
0.32 < 1 (no additional replications are needed because half width is smaller than the error)

Total Time:
Average: 6.12 min
Half width: 0.32
C.I.: (5.8, 6.44)
0.32 < 1 (no additional replications are needed because half width is smaller than the error)

Time in the queue of the distillation Unit:
Average: 3.81 min
Half Width: 0.32
C.I.: (3.49, 4.13)
0.32 < 1 (no additional replications are needed because half width is smaller than the error)

The number of oil trucks entered the system:
Average: 1053.73
Half Width: 13.82
C.I.: (1039.91, 1067.55)
13.82 < 25 (no additional replications are needed because half width is smaller than the error)

WIP:
Average: 2.45
Half Width: 0.15
C.I.: (2.3, 2.6)
0.15 < 0.45(no additional replications are needed because half width is smaller than the error)

Utilization:

The distillation Unit:
Average: 0.7881
Half Width: 0.01
C.I.: (0.7781, 0.7981)
0.01< 0.075
(no additional replications are needed because half width is smaller than the error)

The Blending Machine:
Average: 0.0647 *
Half Width: ~0.00
~0.00 < 0.075
(no additional replications are needed because half width is smaller than the error)

The cracker:
Average: 0.0550 **
Half Width: ~0.00
~0.00< 0.075
(no additional replications are needed because half width is smaller than the error)

Notice: For * & ** the utilization is close to zero. This is because, as we mentioned above that our tiny field is 153 times less the usual fields. To clarify, our model deals with a new concept (the tiny fields). So, the actual utilization would be:

- **For The blending machine:**
  $0.0647 * \frac{153}{10} = 0.98991$
- **For The cracker:**
  $0.0550 * \frac{153}{10} = 0.84150$

In addition to the output analysis, we would mention also that our model succussed highly in using its maximum capacity, which is 40,000 bbl/day, and that can be proven by:

$$1052\left(\frac{trucks}{week}\right) * \left(\frac{1week}{5days}\right) * 190\left(\frac{bbl}{truck}\right) = 39{,}976\ \frac{bbl}{day}$$

Where 1052 is the number of trucks arrived during the simulation time, and that indicates:

$$\left(\frac{39{,}976\left(\frac{bbl}{day}\right)}{40{,}000\left(\frac{bbl}{day}\right)}\right) * 100\% = 99.94\%$$

Which means our model used **99.94%** of its capacity of the real system, which indicates its efficiency.

System Improvements and the Contributions:

<u>Scenario 1:</u> Adjusting the distributing of items that go to the blending sequences

In the initial assumptions, we assumed that the entities before the blending process are distributed equally (33.33% for each) through the three sequences. We got that the number out of each product was as follows:

Product 1 (87 ON) = $49.9(amount\ in\ trucks) * 190\left(\frac{bbl}{truck}\right) = 9481\ bbl$

Product 2 (89 ON) = $53.3(amount\ in\ trucks) * 190\left(\frac{bbl}{truck}\right) = 10127\ bbl$

Product 3 (92 ON) = $51.4(amount\ in\ trucks) * 190\left(\frac{bbl}{truck}\right) = 9766\ bbl$

This numbers/week (4 weeks/month & 12 months/year), so the annual amount out is:

Product 1 (87 ON) = 455,088 bbl

Product 2 (89 ON) = 486,096 bbl

Product 3 (92 ON) = 468,768 bbl

As we mentioned in the Problem statement, Products 1, 2 and 3 can be sold by 25.125, 27.000 and 30.375 SR/bbl, respectively. So, the annual revenue is:

$$455088 * (25.125) + 486096 * (27) + 468768 * (30.375) = 38{,}797{,}506\ SR$$

Around **<u>38.8 million</u>** SR.

However, as we noticed the selling price of each product is different. We noticed that the highest selling price is for product 3 (92 ON). So, let us see what if we decreased the percentage of the product 1 and increased it for product 3:

Assume that we want to distribute the products as: 10% of (87 ON), 33.33% of (89 ON) and 56.67% (92 ON) we will get:

Product 1 (87 ON) = $14.57(amount\ in\ trucks) * 190\left(\frac{bbl}{truck}\right) = 2768.3\ bbl$

Product 2 (89 ON) = $52.07(amount\ in\ trucks) * 190\left(\frac{bbl}{truck}\right) = 9893.3\ bbl$

Product 3 (92 ON) = $87.97(amount\ in\ trucks) * 190\left(\frac{bbl}{truck}\right) = 16714.3\ bbl$

So, the annual revenue will be: (multiply each amount by 4 (weeks/month) * 12 (month/year))

$$40{,}529{,}736\ RS$$

Around **<u>40.5 million</u>** SR, the annual revenue increased by:

$$\underline{40{,}529{,}736 - 38{,}797{,}506 = \mathbf{1732230\ SR}}$$

Around **1.7 million** SR. So, we conclude that the increasing in the percentage of the third product (92 ON) would increase the revenue effectively (demand constraints should be considered).

Scenario 2: Adjusting the amount of oil that go to the cracking process

The cracker has a fixed capacity, in real fields they use 100% of the cracker capacity. In our tiny field we are simulated, the cracker capacity is around 21,000 bbl/week (represents 52.6%) of the products coming out after the distillation process. 52.6% of the entities represent 100% of the cracker capacity. Let us see what if we used 75% of the cracker capacity $\frac{21000*0.75}{1052*\frac{190}{5}} * 100\% = 39.4\%$ (represents 39.4% of the entities).

We get:

The number out is increased by 2 only (380 bbl). So for the final products is:

Product 1 (87 ON) = $53.5(amount\ in\ trucks) * 190\left(\frac{bbl}{truck}\right) = 10165\ bbl$

Product 2 (89 ON) = $58.5(amount\ in\ trucks) * 190\left(\frac{bbl}{truck}\right) = 11115\ bbl$

Product 3 (92 ON) = $57.6(amount\ in\ trucks) * 190\left(\frac{bbl}{truck}\right) = 10944\ bbl$

So, the annual revenue will become:

$$\underline{\mathbf{42,620,382}\ \boldsymbol{SR}}$$

Around **42.6 million** SR, the annual revenue increased by:

$$\underline{42{,}620{,}382 - 38{,}797{,}506 = \mathbf{3,822,876}\ \boldsymbol{SR}}$$

Around **3.8 million** SR. We conclude that using less capacity of the cracker would highly result in increasing the annual revenue. That is because fewer products would be disposed as the result of the disability of carbon-carbon bonds breaking (quality constraints should be considered of course).

Scenario 3: Adjusting the working times of the system

There are two main systems of working time in the oil fields:

1. The usual one (5 days, each with 8 working hours) the average working time is 8 hours.
2. 5 days as follows: 4, 12, 12, 12, 4 hours, the average working time is around 8.8 hours.

In our simulation model, we run it in the second system (8.8 hours) because it is used in the Aramco oil field, and it considers every overtime hour at 1.5 usual hours. So, the total time of working in (4 12 12 12 4) system is 50 usual working hours. Workers are paid 110 SR/hour as an average. So, assuming 50 workers the company would pay them **13.2 million SR.** In the usual system, workers work for 40 hours only. The company would pay them **10.56 million SR**. So, the company losses around 2.64 million SR using the second system. However, let us see if the revenues in the second system cover the loss in the worker salaries with overtime. Let us run the model for 8 hours shift for 5 days (instead of 8.8 hours for 5 days):

The number out decreased by 97 (18430 bbl) and for the final products as follows:

Product 1 (87 ON) = $45.5(amount\ in\ trucks) * 190 \left(\frac{bbl}{truck}\right) = 8645\ bbl$

Product 2 (89 ON) = $48.2(amount\ in\ trucks) * 190 \left(\frac{bbl}{truck}\right) = 9158\ bbl$

Product 3 (92 ON) = $46.73(amount\ in\ trucks) * 190 \left(\frac{bbl}{truck}\right) = 8879\ bbl$

So the annual revenue will become:

$$\underline{\mathbf{35,240,220}\ \boldsymbol{SR}}$$

Around **35.5 million**. If the company used the usual system, they would loss:

$$38{,}797{,}506 - 35{,}240{,}220 = 3{,}557{,}286\ RS$$

They loss around 3.56 million, but we should not forget that using the first system would save 2.64 million, so the **final loss would be around 0.92 million.**

We conclude that using (4 12 12 12 4) is better than the usual working times system.

Therefore, **we contributed in:**

- Increasing the annual revenue of the tiny field by adjusting distributing of items that go to the blending sequences
- Increasing the annual revenue of the tiny field by adjusting the amount of oil that go to the cracking process
- Supporting the company policy of using the (4 12 12 12 4) working hours system

Recommendations:

- ❖ Running the simulation model with larger number of replications will give more accurate (e.g. less half widths)
- ❖ Using the second system working hours (4 12 12 12 4) will have better net revenue to the company.
- ❖ The third product (ON 92) have the best revenue, the company should increase it to have better net revenue (with considering other constrains)
- ❖ Adjusting the ratio of the oil that comes from the distillation tower to the cracker will gives a better revenue to the company.