



# Simulation Project Report

HARMONY DENTAL GROUP

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**EGRM 6681: Simulation**

# PRESENTATION REPORT

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## **EXECUTIVE SUMMARY**

In this project, the Harmony Dental Group is taken as a case study for applying simulation modeling. The Harmony Dental Group is a dental office and the hygiene practices of the office are the main focus of study. The project can be considered to be composed of two main phases: the first, data collection and analyzation, and the second: model building, validation, and performance analysis. Real-time and real-world data was collected from three different days a week (Monday, Thursday, and Saturday) at two different times each day (morning and afternoon) for three consecutive weeks. 203 total data points were collected for patient arrival times and service times were recorded for at least 43 patients for eight process steps. Distributions were fitted to each of these data sets, with the fitness increasing as the data was divided into subcategories. The interarrival times for each of the three hygienists are examples of arrival data that passed the Chi-Square test. Check-in, adult cleaning, and child cleanings are examples of service data steps whose data distributions were statistically significant. Descriptive statistics and ANOVA is performed on these data sets as well to gain a better understanding of the model that results.

A simulation model is built in ARENA which mimics the entire hygiene servicing process at the Harmony Dental Group: adult cleanings, adult scaling and root planeing, children cleanings, and children sealants. Numerous types of modules are used in the design of the model: create, assign, decide, record, read/write, etc. The model underwent numerous revisions as its results were compared with both the data sets and real life. In the final revision of the model, it runs smoothly and yields results consisted with the office's hygiene performance. Overall, the office came into this project happy with its hygiene performance but curious about the capabilities of such data analysis and modeling. The model is validated using statistics such as tests of normality, homogeneity tests, and Kruskal-Wallis tests. Next, the model's performance is analyze and, as already stated, proves to be consistent with expected values.

## **1. INTRODUCTION**

The Harmony Dental Group (THDG) is located in Norwalk, CT and has been in business since 2005. The office employs five dentists, six hygienists, three dental assistants, and four front desk staff. They provide services in general dentistry, periodontics, implantology, cosmetic dentistry, restorative dentistry for adults and pediatric dentistry for children. The office is fully paperless, equipped with the newest technologies in 3D imaging and also has a Cerec CNC to make porcelain dental crowns. Due to the different specialists available in the practice they rarely have to refer out patients for procedures. To accommodate patients' busy schedules they offer late hours on certain days and are also open on the weekend for Saturday appointments. Scheduling for a given day of the week largely remains constant though and will be treated as such in this analysis. In other words, a hygienist's schedule every Monday is mostly the same; and although his or her schedule on Thursdays may differ from Monday, it is constant across Thursdays. The office clearly runs on a schedule but it should also be noted that the office rarely has a walk-in patient seeking care (and during the days of our data collection we observed zero walk-ins). The staff also offers financial plans and assistance with insurance claim submittals.

## **2. PROJECT FOCUS AREA & GENERAL ASSUMPTIONS**

Our team seeks to analyze the daily processes at the Harmony Dental Group. Although the office has a wide variety of services performed including the several doctors employed, this project focuses on standard dental hygiene. The reason for this is that the number of procedures, and the wide variation between lengths of each, a doctor can perform is vast and complicated. Customer arrival data and service data has been collected and will be reviewed. The arrival data is analyzed based on the service duration, the inter-arrival times, and the patients' wait times. Each of these three categories is analyzed in subgroups of the arrival data including adult versus children appointments, morning versus afternoon/evening appointments, hygienist 1 versus hygienist 2 versus hygienist 3 appointments, and Tuesday versus Thursday versus Saturday appointments. As stated in the introduction, a total of six hygienists are employed by the office but only two or three work at a time each day. As such, this analysis will focus on the schedules of three different hygienists on Tuesdays, Thursdays, and Fridays. An important thing to note at this time is that data collection of this type is not a typical practice at the Harmony Dental Group. As such, and this will be explained further in the Objectives Section, one goal of this project is to encourage the investment of resources into data collection and analyzation methods moving forward. In other words, this project is being done with the hope that the Harmony Dental Group will find value in such analysis and want to continue collecting and analyzing larger sets of data. Another benefit to collected more data is that they will be able to take a more granular approach to the analysis. For example, categories of the arrival data are examined such as adult versus child and morning versus afternoon, but there were not enough data points collected to break it down one additional level and look at childcare in the afternoon versus childcare in the morning versus adult care in the afternoon versus adult care in the morning, etc. If that level of detail was used in this analysis, far less than thirty data points would exist in the majority of the subgroups and that would likely increase the uncertainty and variation of the model and analysis. Therefore, the arrival data is broken down into major categories as previously explained; it is just important to note that an even more detailed and granular approach is possible to be taken.

## **3. PROBLEM STATEMENT**

Overall, the office is happy with hygiene performance but curious about the capabilities of simulation modeling.

## **4. OBJECTIVES**

First and foremost, one goal of this project is to gain experience in simulation modeling that can be applied in real-world career scenarios. Even though the focus of this project is on a service-based company, the lessons learned and concepts used can be applied directly to manufacturing environments as well. Another goal of this project is to utilize and gain experience with software modeling and statistics tools such as Arena, Input Analyzer, Excel, and Minitab or SPSS. Arena will be used largely in the second phase of this project whereas Input Analyzer and Excel were used largely in this initial report.

Another important set of objectives deal directly with the business unit itself; in other words, the high-level objective of this project is that the Harmony Dental Group will learn, change, and apply value as a result. In order to accomplish this, data was collected and analyzed with the goal of providing recommendations for improvement in the following areas:

- Processes
- Material and personnel allocation
- Scheduling and time utilization
- Communication

Making such recommendations is the goal of this entire project and not necessarily the initial report. That being said, the data collection and analysis contained in this initial report surely tells some tales that will be explored and explained later.

Finally, as stated previously, another main goal of this project is to encourage the continued use of data analyzation by the Harmony Dental Group. The data collection and analyzation that occurred as a result of this project is something not normally done by the Harmony Dental Group. It is our belief, however, that much value resides in this data and therefore it should be utilized by the office. Certain computer software systems exist to map out and time their processes and relevant steps just as was done in this report. Although implementing such practices would require capital investment and changes in culture, we believe the benefits outweigh the costs.

## **5. SYSTEM ANALYSIS**

### **5.1. OFFICE LAYOUT & EXTERNAL ENVIRONMENT**

The office has a very simple layout that is shown in Figure 1 below. The areas and rooms are all marked on the diagram and many areas also labeled with process steps that occur there to help correlate the layout with the process flow diagram shown in Figure 2.

Customers enter the office through a door towards the left of the suite and approach an L-shaped front desk. The half of the desk facing the entrance is typically dedicated for patient check-in whereas the other half of the desk facing the main hallway is typically used for check-out. Once the customer checks-in, he or she can wait, if necessary, in the waiting area which includes a couch, television, refrigerator with water and soft beverages, and a coffee maker. Once ready, the hygienist will call for the patient, bring them back to an operatory, take x-rays in the x-ray room if necessary, and perform the necessary treatment. Sterilization and other miscellaneous office tasks are completed in the lab while office and procedural supplies are kept all across the office with no standard or known locations (an easy area for improvement it seems).

In terms of external environment and location, the office is located directly off of Exit 16 on Interstate-95 in Norwalk, Connecticut. The Harmony Dental Group occupies a suite on the second floor of an office building that they share with another dental office, a dental lab, a chiropractor, a naturopathic doctor, an insurance broker, and an architect's office. With such close proximity to I-95, the office is located on a very busy corner of East Avenue with other small office buildings and residences in the immediate surrounding area.

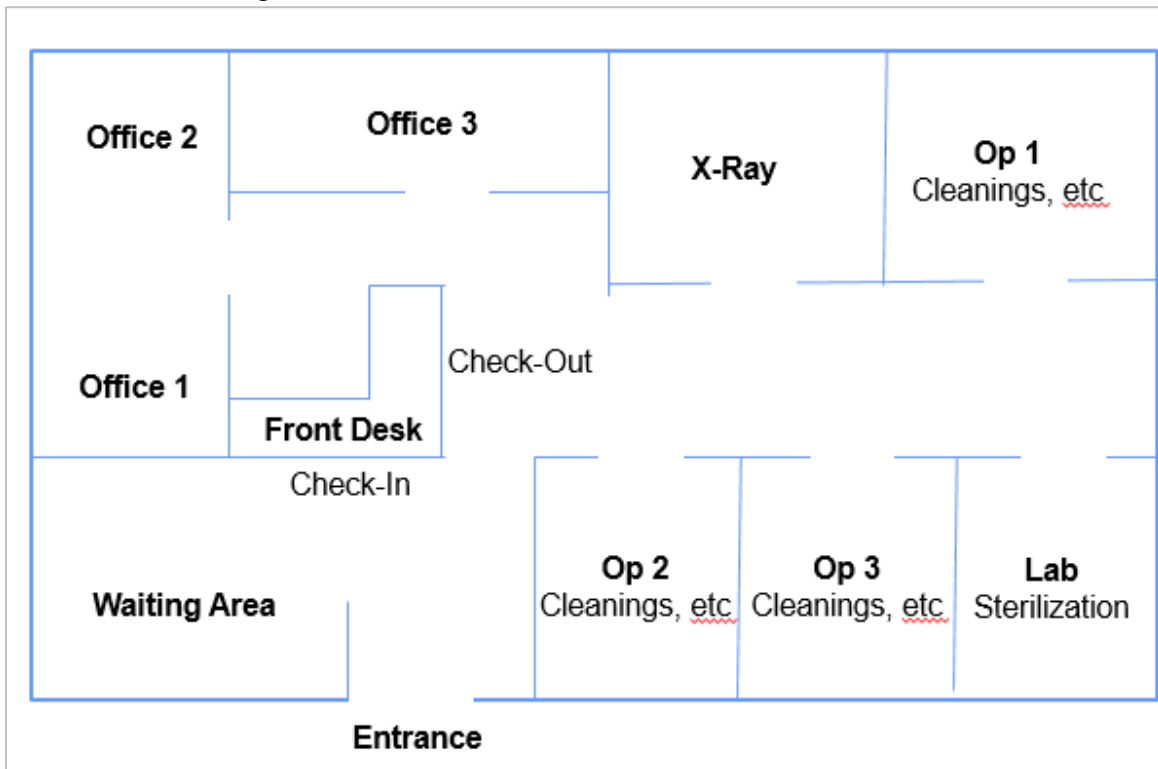


Figure 1: Layout of Office

## 5.2. GRAPHICAL REPRESENTATION OF SYSTEM

### 5.2.1. MAIN PROCESS FLOW CHART

The next important step in defining and describing our system is to show a graphical representation of it. Figure 2 shows a Process Flow Diagram (PFD) of the focus area of the system for this project. Once the patient arrives, they check-in as was explained in the previous section. From there, this project observes two main types of patients: hygiene and restorative. Hygiene refers to basic cleaning services whereas restorative refers to more complex procedures performed by doctors and not examined in this project. As a result, one will note that the restorative path in the diagram flows directly to the doctor exam process step. In reality, this leap is much more complicated and involves many different types of procedures that this project does not cover. For hygiene, patients are first categorized by age (adult or child) and then treatment type. For children, treatment types can be either a routine cleaning or sealants. For adults, on the other hand, the treatment can be a routine cleaning or scaling and route planeing.

At that point, those receiving a routine cleaning, whether they are children or adults, may or may not receive x-rays in a separate room based on their medical history. After receiving the x-rays (or not), the cleaning is performed and a doctor exam is performed at the conclusion of the appointment once a hygienist can find a doctor (we found this metric to have a high variation and therefore be a focus moving forward). For children getting sealants or adults getting scaling and root planeing, those procedures are performed without preceding x-rays or a following doctor exam. At the very end of the appointment, the checkout. It should be noted here that although sealants and scaling and root planeing are shown here, they are only included in the service data. In other words, the arrival data is missing the categorization of regular cleaning versus sealants versus scaling and root planeing.

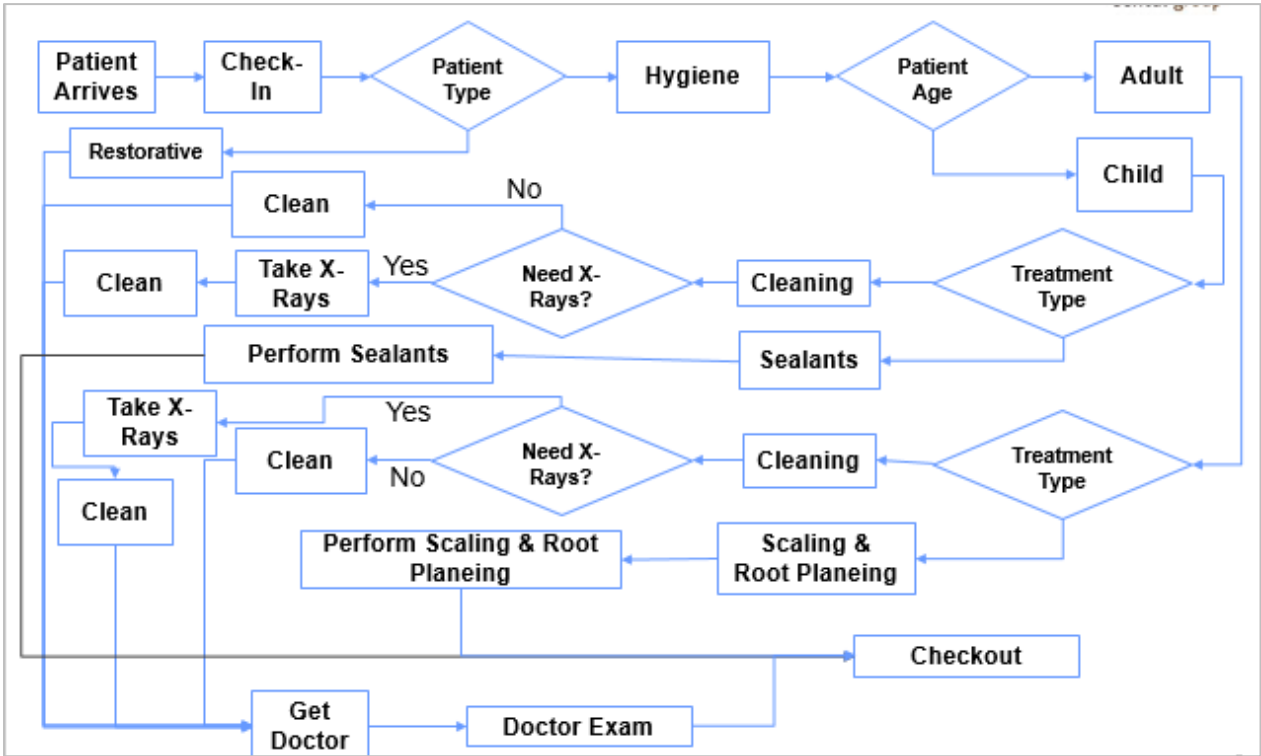


Figure 2: Main Process Flow Diagram

5.2.2. SUBSYSTEMS

For as complicated as the main process flow diagram looks at first, it’s quite simple to understand once explained. This project takes this graphical approach one step further as the process is broken down into subsystems as well.

The check-in and check-out processes, for example, can be found in Figure 3 and Figure 4 below. Most people are familiar with check-in and check-out procedures at doctor and dental offices. As seen below, such subsystems include the steps of asking for the patient’s name, entering data in the computer such as insurance, billing, scheduling, and dismissal.

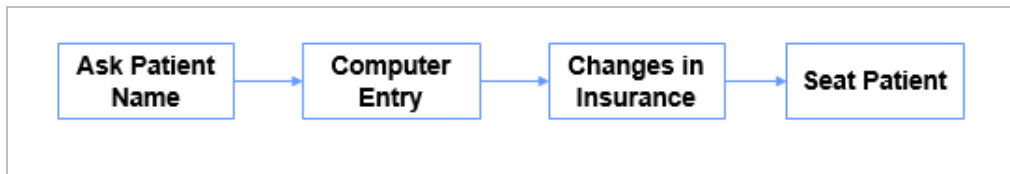


Figure 3: PFD for Check-in Subsystem

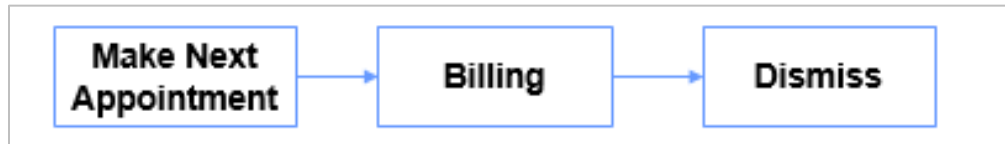


Figure 4: PFD for Check-out Subsystem

The other subsystems studied and mapped out in this report include room preparation, room cleanup, and instrument sterilization. Proper workplace hygiene and cleanliness are the focus of these procedures for sure.

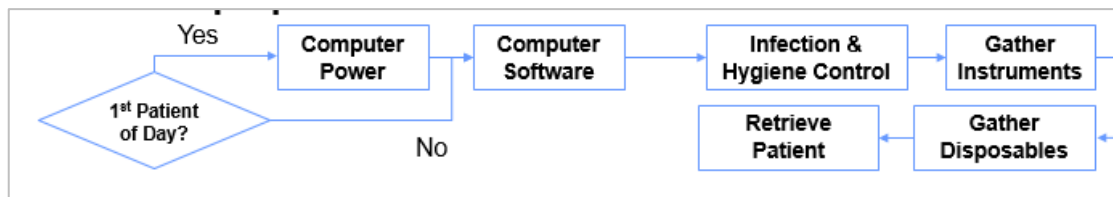


Figure 5: PFD for Room Preparation Subsystem



Figure 6: PFD for Room Cleanup Subsystem

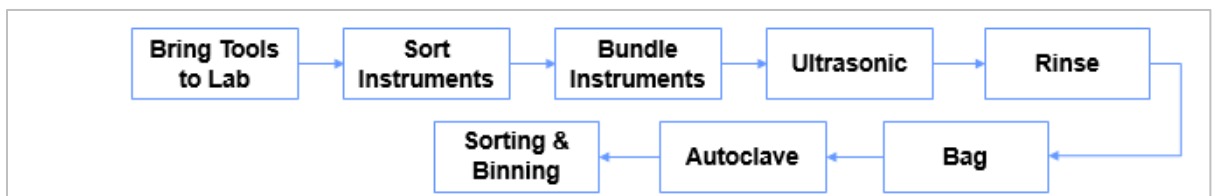


Figure 7: PFD for Instrument Sterilization Subsystem

While these subsystems do exist, they are not applicable to the final model. For example, the room preparation, room cleanup, and instrument sterilization process steps are all performed by the same person in a row: the hygienist. Therefore, the steps are combined in the model and included in the overall cleaning process module. This is how the service data was collected so that the model would be accurate.



### 5.3. VARIABLES

While no variables were used in the final Arena simulation model, examples of some can be considered to be:

- **Patient arrival time (duration, wait-time, inter-arrival time)**  
Data consist of patient arrival time, patient waiting time and patient departure time. From these data, we found out inter arrival time. All above mentioned data are in minutes.
- **Weather**  
Weather plays vital role in our simulation model. If there are any disruptions due to weather then it would lead to delay in arrival or may be cancellation of appointment.
- **Proportions**  
As adults take longer time for check-up compared to children, this fact will influence our simulation model. So, proportion adults to children on a day will determine total number of patients attended.
- **Staffing**  
It is essential to have sufficient staff at hospital to provide expedited service. If delays are avoided, then more patients can be accommodated in a day.
- **Cost**  
Cost also determines the number of patients arrive to the hospital. If cost is less then more patients prefer to come to hospital.
- **Contractors**  
Hospital require contractors for better staffing and maintenance of hospital. This variable does not affect directly but indirectly helps to improve performance of model.

### 5.4. ELEMENTS

Although not all of these are included in the model, elements of the system include but are not limited to:

- **Dentists**
- **Dental Hygienists**
- **Dental Assistants**
- **Financial Coordinator**
- **Scheduling Coordinator**
- **Office Manager**
- **Front Desk Staff**
- **Waiting Room**
- **Computer Hardware & Software**
- **Operatory**
- **Sterilization Area**
- **Inventory Storage**
- **X-Ray Machine/Room**
- **Instruments**
- **Tooling**
- **Ultrasonic cleaning machine**
- **Autoclave**
- **Disposables**

Our model consist of two doctors who takes care all the patients. We have three hygienists who take care of categorized patients. Hygienist 1 only takes care of children and other two take care of adults. As seen in the facility layout, there are three operatories for cleaning, one for each hygienist.

## 5.5 PARAMETERS

The parameters include:

- **Number of:**
  - **Hygienists**

In our simulation model we have 3 hygienists. Of those three hygienists, one hygienist is exclusively assigned for children and other two hygienists for adults.
  - **Operatory**

As we have three hygienists, each require one operatory to take care of patients. So we have three operatories.
- **Scheduled appointment length**

Hospital schedules 30 minutes appointment to children and one hour appointment to adults. This allocation of time is based on previous data available with hospital.
- **Hours of operation**

Hospital has varied working hours on different days. But on an average hospital operate for 9 hours.
- **Inventory storage locations**

## 5.6. FEEDBACK & CAUSAL RELATIONS

Several causal relations exist in the process steps previously shown and explained. To start, patient age is a big determining factor. As was already explained briefly, children can, and often do, receive different treatments than an adult. For example, the process flow diagram showed that a child can receive sealants whereas an adult can receive scaling and route planeing. In addition, children are allotted thirty minutes for a standard cleaning or sealants appointment whereas an adult is allotted sixty minutes for a typical cleaning or scaling and route planeing appointment. Such distinctions make the cause and effect relationship clear with regards to patient age and the succeeding process steps. Another important major example is the initial patient type: hygiene or restorative. If the patient is a restorative patient, this project ignores the service-data aspect. If the patient is a hygiene patient, this project further examines.

This previous example brings up an important note to make with respect to causal relations: that most steps in the process flow need to occur when they are designated. In other words, the order of operations matters! For example, in the instrument sterilization subsystem, the ultrasonic bath must be done before the autoclave.

## 5.7. SYSTEM PERFORMANCE METRICS

Metrics are used to measure performance over time and monitor progress towards achieving key goals. For this project, metrics that will be considered consist of:

- Arrival Data
  - Appointment duration (average, maximum, minimum, etc)
  - Inter-arrival time (average, maximum, minimum, etc)
  - Patient wait-time (average, maximum, minimum, etc)
- Service data
  - Check-in time (average, maximum, minimum, etc)
  - Take X-ray (average, maximum, minimum, etc)
  - Scaling & route-planing (average, maximum, minimum, etc)
  - Cleaning time (average, maximum, minimum, etc)
  - Sealants time (average, maximum, minimum, etc)
  - Data collection time (average, maximum, minimum, etc)
  - Time needed to find doctor for consult (average, maximum, minimum, etc)
  - Time needed for doctor consult (average, maximum, minimum, etc)

Other variables that are touched upon or are recommended by the project group for the Harmony Dental Group to consider include:

- Average number of patients (per day)
- Proportions of:
  - Adult versus Children
  - Cleanings versus Restorative
  - Cleanings versus sealants, etc
- Percentage/number of:
  - Patients who come back
  - Patients who schedule services on top of cleanings
  - Patients who receive fluoride with their cleaning
- Customer feedback
  - Check-in time (average, maximum, minimum, etc)
  - Take X-ray (average, maximum, minimum, etc)
  - Scaling & route-planing (average, maximum, minimum, etc)
  - Cleaning time (average, maximum, minimum, etc)
  - Sealants time (average, maximum, minimum, etc)
  - Data collection time (average, maximum, minimum, etc)
  - Time needed to find doctor for consult (average, maximum, minimum, etc)
  - Time needed for doctor consult (average, maximum, minimum, etc)

## 5.8. CONSTANTS

The constants considered in this project include, but are not limited to:

- Location
  - Number of rooms
  - Number of floors
- Health laws and regulations

Location is an easy-to-understand example of a constant as changing the location (either moving or modifying the current location), would require a significant investment in capital which is not a desire of the practice at this time.

## 5.9. CONSTRAINTS

The constraints considered in this project include, but are not limited to:

- Financial
- Schedule
- Location
- Staff availability
- Insurance plans

Financial constraints are typically at the forefront of focus for any office or business. They have to manage and handle their budget and vast collection of expenses they incur. This project does not dive deep into the cost and budget control of the Harmony Dental Group but it does recognize the importance of such matters.

Schedule is typically another major constraint for companies. They must work their planning around the availability of their staff and the availability and desires of their patients or clientele (in addition to syncing their schedule with many other factors).

## 6. INPUT DATA COLLECTION AND ANALYSIS

### 6.1 ARRIVAL DATA

We collected data for nine days with 10 hours per day on Monday, 10 hours per day on Thursday and 6 hours per day Saturday. We noted the Inter-arrival Time, customer appointment time, Arrival time, patient being seated time, patient type, scheduled departure time, patient departure time, scheduled duration, and actual duration time.

**Times of Observations:**

Monday February 5, 2017	9am-7pm
Thursday February 9, 2017	8am-6pm
Saturday February 11, 2017	8am-2:30pm
Monday February 13, 2017	9am-7pm
Thursday February 16, 2017	8am-6pm
Saturday February 18, 2017	8am-2:30pm
Monday February 20, 2017	9am-7pm
Thursday February 23, 2017	8am-6pm
Saturday February 25, 2017	8am-2:30pm

We collected a total 203 data points and broke down further to different categories:

Raw Arrival Data Points	
# Adults	145
# Child	59
Hygienist 1	93
Hygienist 2	62
Hygienist 3	49
Morning	97
Afternoon/Evening	107
Monday	79
Thursday	68
Saturday	57
<b>Total Data Points</b>	<b>203</b>

**Figure 8:** Data Point Count Summary for Raw Arrival Data Points

A screenshot of a small portion of the rows of the raw arrival data can be seen below with all of column headers in Figure 9.

Patient Numbr	Date	Day	Hygienist #	Appointment Time	Patient Arrival Time (Actual)	Time Patient Seated	Time of Day	Patient Type	Scheduled Departure Time	Patient Departure Time (Actual)	Scheduled Duration (hrs)	Actual Duration (hrs:mins)	Actual Duration (mins)	Inter-Arrival	Wait Time
1	Monday, February 06, 2017	Monday	2	9:00:00 AM	8:55:00 AM	9:05:00 AM	Morning	Adult	10:00:00 AM	9:57:00 AM	1:00:00	0:52:00	52		5
2	Monday, February 06, 2017	Monday	1	9:30:00 AM	9:25:00 AM	9:29:00 AM	Morning	Child	10:00:00 AM	10:02:00 AM	0:30:00	0:33:00	33	30	0
3	Monday, February 06, 2017	Monday	1	10:00:00 AM	10:00:00 AM	10:00:00 AM	Morning	Child	10:30:00 AM	10:28:00 AM	0:30:00	0:28:00	28	35	0
4	Monday, February 06, 2017	Monday	2	10:00:00 AM	10:02:00 AM	10:02:00 AM	Morning	Adult	11:00:00 AM	11:00:00 AM	1:00:00	0:58:00	58	2	0
5	Monday, February 06, 2017	Monday	1	10:30:00 AM	10:25:00 AM	10:31:00 AM	Morning	Child	11:00:00 AM	10:55:00 AM	0:30:00	0:24:00	24	23	1
6	Monday, February 06, 2017	Monday	2	11:00:00 AM	10:58:00 AM	11:01:00 AM	Morning	Adult	12:00:00 PM	11:53:00 AM	1:00:00	0:52:00	52	33	1
7	Monday, February 06, 2017	Monday	1	11:00:00 AM	11:05:00 AM	11:05:00 AM	Morning	Child	11:30:00 AM	11:30:00 AM	0:30:00	0:25:00	25	7	0
8	Monday, February 06, 2017	Monday	1	11:30:00 AM	11:35:00 AM	11:36:00 AM	Morning	Child	12:00:00 PM	11:59:00 AM	0:30:00	0:23:00	23	30	1
9	Monday, February 06, 2017	Monday	2	1:00:00 PM	12:52:00 PM	12:59:00 PM	Afternoon/Evening	Adult	2:00:00 PM	1:50:00 PM	1:00:00	0:51:00	51	17	0
10	Monday, February 06, 2017	Monday	1	1:00:00 PM	1:00:00 PM	1:03:00 PM	Afternoon/Evening	Child	1:30:00 PM	1:30:00 PM	0:30:00	0:27:00	27	8	3

**Figure 9:** Screenshot of Raw Arrival Data

The raw arrival data contained the following twelve columns:

- Patient Number
- Date
- Day
- Hygienist # (1, 2, or 3)
- Appointment Time
- Patient Arrival Time
- Time Patient Seated
- Time of Day (Morning or Afternoon/Evening, day split at 1:30pm)
- Patient Type (Adult or Child)
- Scheduled Departure Time
- Patient Departure Time
- Scheduled Duration

From these columns, an additional three columns were calculated, added to the data set, and served as the primary measures of arrival data.

- Actual Duration
- Inter-Arrival Time
- Wait Time

The process of analyzing the arrival data remained the same throughout the different categorical breakdowns that occurred. As a reminder, the following four categorical studies were done as a result of having these different classifications:

- Tuesday versus Thursday versus Sunday
  - Actual Appointment Duration
  - Inter-Arrival Time
  - Wait-Time
- Morning versus Afternoon/Evening
  - Actual Appointment Duration
  - Inter-Arrival Time
  - Wait-Time
- Hygienist 1 versus Hygienist 2 versus Hygienist 3
  - Actual Appointment Duration
  - Inter-Arrival Time
  - Wait-Time
- Adult versus Child
  - Actual Appointment Duration
  - Inter-Arrival Time
  - Wait-Time

To start, the data was separated into the respective categories just mentioned. Descriptive statistics were calculated and then an outlier analysis was performed on each data set. Descriptive statistics were calculated again on the new refined data sets and then compared with the originals. Finally, ANOVA comparison of means were conducted in Microsoft Excel to compare the relevant times of each subcategory. If, for example, the ANOVA test comparing the wait-time of children versus adults proves the means of the two samples are not statistically different, those data sets were combined to create a new data set before using input analyzer. Input analyzer was then finally used to graph the distribution of the appropriate sets.

Let us first take a look at the descriptive statistics before and after outlier analysis for each of the four categorical studies.

	Before Outlier Analysis									After Outlier Analysis								
	Inter-Arrival (min)			Actual Duration (min)			Wait Time (min)			Inter-Arrival (min)			Actual Duration (min)			Wait Time (min)		
	Mon	Thurs	Sat	Mon	Thurs	Sat	Mon	Thurs	Sat	Mon	Thurs	Sat	Mon	Thurs	Sat	Mon	Thurs	Sat
Mean	18.17	21.94	19.35	39.65	48.82	48.11	0.68	0.59	2.47	17.65	21.94	19.35	39.65	49.25	46.86	0.43	0.41	0.41
Median	19.5	22	7.5	40	52	50	0	0	0	19	22	7.5	40	52	49.5	0	0	0
Standard Deviation	13.86	17.53	20.88	12.66	10.41	14.95	1.44	1.37	9.13	13.19	17.53	20.88	12.66	9.86	11.71	0.90	0.88	1.11
Range	57	58	57	53	42	98	7	8	50	50	58	57	53	39	45	4	4	7
Max	57	58	57	62	62	118	7	8	50	50	58	57	62	62	65	4	4	7
Min	0	0	0	9	20	20	0	0	0	0	0	0	9	23	20	0	0	0
2.5*SD	34.64	43.83	52.20	31.66	26.02	37.38	3.59	3.43	22.82	32.97	43.83	52.20	31.66	24.65	29.28	2.26	2.19	2.77
Upper Bound	52.81	65.77	71.55	71.30	74.85	85.49	4.28	4.02	25.29	50.63	65.77	71.55	71.30	73.90	76.14	2.68	2.60	3.18
Lower Bound	0	0	0	7.99	22.80	10.73	0.00	0.00	0.00	0	0	0	7.99	24.60	17.57	0	0	0
Count	76	65	54	79	68	57	79	68	57	75	65	54	79	67	56	75	66	54
#Outliers	1	0	0	0	1	1	4	2	3	0	0	0	0	0	0	0	0	0

Figure 10: Descriptive Statistics for Arrival Data: Monday versus Thursday versus Sunday

	Before Outlier Analysis						After Outlier Analysis					
	Inter-Arrival (min)		Actual Duration (min)		Wait Time (min)		Inter-Arrival (min)		Actual Duration (min)		Wait Time (min)	
	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
Mean	20.76	18.36	47.03	42.24	0.37	2.27	20.76	18.36	46.12	42.67	0.19	0.79
Median	21	13.5	49	44	0	0	21	13.5	49	44	0	0
Standard Deviation	17.46	16.45	14.30	12.29	0.92	7.83	17.46	16.45	11.87	11.77	0.46	1.64
Range	54	58	102	53	5	50	54	58	49	43	2	8
Max	54	58	118	62	5	50	54	58	65	62	2	8
Min	0	0	16	9	0	0	0	0	16	19	0	0
2.5*SD	43.64	41.11	35.75	30.72	2.31	19.58	43.64	41.11	29.67	29.42	1.14	4.11
Upper Bound	64.40	59.47	82.78	72.96	2.67	21.85	64.40	59.47	75.79	72.08	1.33	4.90
Lower Bound	0	0	11.28	11.52	0.00	0.00	0	0	16.44	13.25	0	0
Count	88	107	97	107	97	107	88	107	96	106	91	104
# Outliers	0	0	1	1	6	3	0	0	0	0	0	0

Figure 11: Descriptive Statistics for Arrival Data: Morning versus Afternoon/Evening

	Before Outlier Analysis									After Outlier Analysis								
	Inter-Arrival (min)			Actual Duration (min)			Wait Time (min)			Inter-Arrival (min)			Actual Duration (min)			Wait Time (min)		
	Hyg 1	Hyg 2	Hyg 3	Hyg 1	Hyg 2	Hyg 3	Hyg 1	Hyg 2	Hyg 3	Hyg 1	Hyg 2	Hyg 3	Hyg 1	Hyg 2	Hyg 3	Hyg 1	Hyg 2	Hyg 3
Mean	21.46	18.60	14.85	36.22	51.53	51.45	1.97	1.00	0.27	21.46	18.60	13.11	35.17	51.53	51.81	0.49	0.78	0.17
Median	23	10	9	31	51.5	53	0	0	0	23	10	6	31	51.5	53	0	0	0
Standard Deviation	14.95	19.14	15.00	15.23	6.98	6.54	7.81	1.78	0.86	14.88	19.14	12.62	12.12	6.98	6.09	1.17	1.34	0.52
Range	57	58	55	109	28	28	50	8	5	57	58	51	56	28	25	7	5	2
Max	57	58	55	118	65	62	50	8	5	57	58	51	65	65	62	7	5	2
Min	0	0	0	9	37	34	0	0	0	0	0	0	9	37	37	0	0	0
2.5*SD	37.36	47.84	37.51	38.07	17.45	16.35	19.52	4.46	2.15	37.20	47.84	31.54	30.30	17.45	15.22	2.93	3.35	1.30
Upper Bound	58.82	66.44	52.36	74.28	68.99	67.80	21.49	5.46	2.42	58.66	66.44	44.65	65.46	68.99	67.03	3.42	4.14	1.46
Lower Bound	0	0	0	0.00	34.08	35.10	0.00	0.00	0.00	0	0	0	4.87	34.08	36.60	0	0	0
Count	90	58	47	93	62	49	93	62	49	90	58	45	92	62	48	90	60	48
# Outliers	0	0	2	1	0	1	3	2	1	0	0	0	0	0	0	0	0	0

Figure 12: Descriptive Statistics for Arrival Data: Hygienist 1 versus Hygienist 2 versus Hygienist 3

	Before Outlier Analysis						After Outlier Analysis					
	Inter-Arrival (min)		Actual Duration (min)		Wait Time (min)		Inter-Arrival (min)		Actual Duration (min)		Wait Time (min)	
	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Mean	22.53	17.68	28.59	51.35	1.63	1.14	22.40	17.68	28.42	50.50	0.48	0.51
Median	23	10.5	28	52	0	0	23	10.5	28	52	0	0
Standard Deviation	14.24	16.77	6.50	10.25	6.40	5.68	14.24	16.77	4.63	6.94	1.21	1.14
Range	57	58	49	84	40	50	57	58	24	28	7	5
Max	57	58	58	118	40	50	57	58	40	62	7	5
Min	0	0	9	34	0	0	0	0	16	34	0	0
2.5*SD	35.60	41.93	16.26	25.64	16.01	14.20	35.60	41.93	11.58	17.34	3.01	2.84
Upper Bound	58.13	59.60	44.85	76.99	17.63	15.34	58.00	59.60	40.00	67.84	3.50	3.35
Lower Bound	0	0	12.34	25.72	0.00	0.00	0	0	16.84	33.16	0	0
Count	59	136	59	145	59	145	59	136	57	144	57	144
# Outliers	0	0	2	1	2	1	0	0	0	0	0	0

Figure 13: Descriptive Statistics for Arrival Data: Child versus Adult

Most of the statistics for each subcategory are fairly close to one another, with several exceptions that could've been expected. For example, the mean values for adult and children appointment duration are vastly different as children are known to take less time and are therefore allotted 30-minutes less than adults. Relationships like this are why we then test the means of these subcategories using ANOVA so that we know which subcategories are truly statistically different. Those subcategories that prove to be not statistically different will be combined back together and ultimately reflect the raw arrival data with outliers removed.

For the ANOVA tests, the following hypothesis test applies:

$$H_0: \mu_1 = \mu_2 = \dots = \mu_k$$

$$H_1: \text{The means are not equal}$$

As such, when the p-value from the ANOVA test for each sub category is less than 0.05, the null hypothesis is rejected and the conclusion that the means are not equal is made. When the p-value from the ANOVA test is greater than 0.05, it can be stated the means of the various sub-categories are statistically indifferent. As a result, the data is lumped together and said to follow the distribution and analysis done on the raw arrival data set (with outliers removed of course).

The results from the ANOVA tests are pasted below and grouped by category. The categories are identified in the Figure number and the variable being measured (duration, inter-arrival, wait-time) is identified in the top right of each screenshot. Please note the screenshots appear small to save space but can be enlarged or zoomed in on to view when needed.

Duration							
SUMMARY							
Groups	Count	Sum	Average	Variance			
Mon	79	3132	39.64556962	160.3599			
Thurs	47	2364	50.29787234	71.9963			
Sat	14	639	45.64285714	103.9396			
ANOVA							
Source of Variation	SS	df	MS	F	P-value	F crit	
Between Groups	3395.4157	2	1697.7078	13.5452	0.0000	3.0622	
Within Groups	17171.1200	137	125.3366				
Total	20566.5357	139					
						Level of significance	0.05

Figure 14: ANOVA Results for Arrival Data: Monday versus Thursday versus Saturday (Duration)

Inter-Arrival							
SUMMARY							
Groups	Count	Sum	Average	Variance			
Mon	39	722	18.51282051	172.8354			
Thurs	20	470	23.5	300.8947			
Sat	18	323	17.94444444	410.4085			
ANOVA							
Source of Variation	SS	df	MS	F	P-value	F crit	
Between Groups	399.1951	2	199.5975	0.7668	0.4681	3.1203	
Within Groups	19261.6880	74	260.2931				
Total	19660.8831	76					
						Level of significance	0.05

Figure 15: ANOVA Results for Arrival Data: Monday versus Thursday versus Saturday (Inter-Arrival)

Wait-Time							
SUMMARY							
Groups	Count	Sum	Average	Variance			
Mon	37	22	0.594595	1.0811			
Thurs	38	11	0.289474	0.4815			
Sat	54	22	0.407407	1.2271			
ANOVA							
Source of Variation	SS	df	MS	F	P-value	F crit	
Between Groups	1.7786	2	0.8893	0.9202	0.4011	3.0681	
Within Groups	121.7717	126	0.9664				
Total	123.5504	128					
						Level of significance	0.05

Figure 16: ANOVA Results for Arrival Data: Monday versus Thursday versus Saturday (Wait-Time)



Duration						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Morning	33	1490	45.15151515	155.8201		
Afternoon	69	2985	43.26086957	132.1368		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	79.7964	1	79.7964	0.5711	0.4516	3.9361
Within Groups	13971.5468	100	139.7155			
Total	14051.3431	101				
Level of significance						0.05

Figure 17: ANOVA Results for Arrival Data: Morning versus Afternoon (Duration)

Inter-Arrival						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Morning	7	160	22.85714286	173.1429		
Afternoon	107	2112	19.73831776	292.0063		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	63.9086	1	63.9086	0.2237	0.6371	3.9258
Within Groups	31991.5300	112	285.6387			
Total	32055.4386	113				
Level of significance						0.05

Figure 18: ANOVA Results for Arrival Data: Morning versus Afternoon (Inter-Arrival)

Wait-Times						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Morning	34	8	0.235294118	0.1854		
Afternoon	31	15	0.483870968	0.7247		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.0020	1	1.0020	2.2658	0.1373	3.9934
Within Groups	27.8596	63	0.4422			
Total	28.8615	64				
Level of significance						0.05

Figure 19: ANOVA Results for Arrival Data: Morning versus Afternoon (Wait-Times)

Duration						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Hyg 1	26	951	36.57692308	160.6538		
Hyg 2	62	3195	51.53225806	48.7448		
Hyg 3	21	1110	52.85714286	29.6286		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4656.3625	2	2328.1813	32.5476	0.0000	3.0820
Within Groups	7582.3531	106	71.5316			
Total	12238.7156	108				
Level of significance						0.05

Figure 20: ANOVA Results for Arrival Data: Hygienist 1 versus Hygienist 2 versus Hygienist 3 (Duration)

Inter-Arrival						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Hyg 1	14	312	22.28571429	118.2198		
Hyg 2	19	481	25.31578947	470.1170		
Hyg 3	24	250	10.41666667	136.7754		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2649.1341	2	1324.5670	5.4414	0.0070	3.1682
Within Groups	13144.7957	54	243.4221			
Total	15793.9298	56				
Level of significance						0.05

Figure 21: ANOVA Results for Arrival Data: Hygienist 1 versus Hygienist 2 versus Hygienist 3 (Inter-Arrival)

Wait-Time						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Hyg 1	27	10	0.37037037	0.4729		
Hyg 2	34	33	0.970588235	2.2112		
Hyg 3	21	3	0.142857143	0.2286		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	10.3568	2	5.1784	4.5537	0.0134	3.1123
Within Groups	89.8383	79	1.1372			
Total	100.1951	81				
Level of significance						0.05

Figure 22: ANOVA Results for Arrival Data: Hygienist 1 versus Hygienist 2 versus Hygienist 3 (Wait-Time)

Inter-Arrival						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Child	59	1329	22.52542373	200.2881		
Adult	14	231	16.5	352.2692		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	410.8018	1	410.8018	1.8008	0.1839	3.9758
Within Groups	16196.2119	71	228.1157			
Total	16607.0137	72				
Level of significance						0.05

Figure 23: ANOVA Results for Arrival Data: Child versus Adult (Inter-Arrival)

Wait-Time						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Child	18	8	0.444444444	0.6144		
Adult	48	20	0.416666667	0.8440		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.0101	1	0.0101	0.0129	0.9099	3.9909
Within Groups	50.1111	64	0.7830			
Total	50.1212	65				
Level of significance						0.05

Figure 24: ANOVA Results for Arrival Data: Child versus Adult (Wait-Time)

A lot of graphs results from the ANOVA tests but the results can be explained fairly simply if we break it down by category. For the comparison of different days (Tuesday, Thursday, Friday), the null hypothesis was rejected for appointment duration only. As such, the means for inter-arrival times and wait-times proved to be statistically similar. Once you group them together for those two respective variables, you end up with the initial raw data set with outliers removed (which will be shown soon). For interarrival times, there proved to be no statistical difference between the different days or times of day. For the comparison between hygienists, on the other hand, the samples for all three variables proved to be statistically different from one another. As such, the data sets for the hygienists cannot be combined and must be analyzed separately. This makes sense since you expect some variation in the performance of hygienists. Even more so, this makes sense because certain hygienists see different ratios of children and adults, with one hygienist being the only primary child care provider.

In the comparison between children and adults, ANOVA was not run on duration for the reason that it is known to be different. For inter-arrival times and wait-times, however, there proved to be no statistical difference between children and adults. Finally, for the comparison between the first half of the day (morning) and the second half of the day (afternoon/evening), all three variables proved to be indifferent across the categories. In other words, there was no statistical difference in duration, inter-arrival time, or wait-time between the morning and the afternoon/evening.

With a large number of the comparisons folding back into the raw arrival data after the ANOVA allowed for the combining of data sets, let us look at the descriptive summary of the initial raw data set containing all data points besides outliers.

	<b>Inter-Arrival (min)</b>	<b>Actual Duration (min)</b>	<b>Wait-Time (min)</b>
<b>Mean</b>	19.96	44.89	1.16
<b>Median</b>	18	48	0
<b>Standard Deviation</b>	17.27	12.08	5.03
<b>Range</b>	58	49	50
<b>Max</b>	58	65	50
<b>Min</b>	0	16	0

**Figure 25:** Descriptive Summary for All Arrival Data (Outliers Removed)

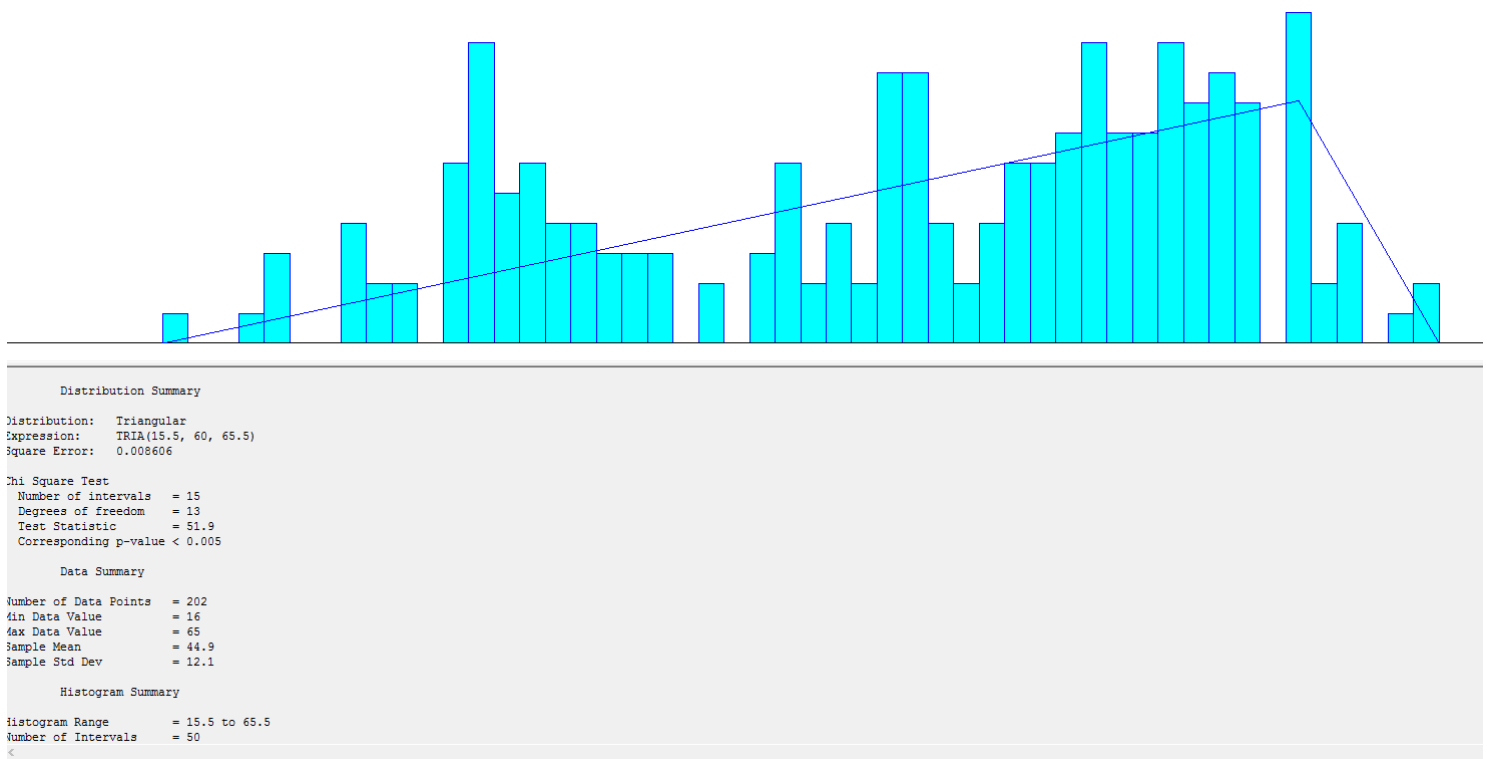
We can now start looking at the distribution fitting from Input Analyzer for each of the final data sets. To summarize, the following subcategorizations of the main data sets were combined back to resemble the main data set:

- Tuesday versus Thursday versus Saturday
  - Inter-Arrival Times
  - Wait-Times
- Adult versus Child
  - Inter-Arrival Times
- Wait-Times
- Morning versus Afternoon
  - Duration
  - Inter-Arrival Times
  - Wait-Times

The remaining categorizations were kept and will be shown separately in input analyzer:

- Tuesday versus Thursday versus Saturday
  - Duration
- Hygienist 1 versus Hygienist 2 versus Hygienist 3
  - Duration
  - Inter-Arrival Times
  - Wait-Times
- Adult versus Child
  - Duration

Let us start by looking at the distribution fitting from Input Analyzer for the full data set with outliers removed.



**Figure 26:** Distribution Fit from IA for Duration (All Data)

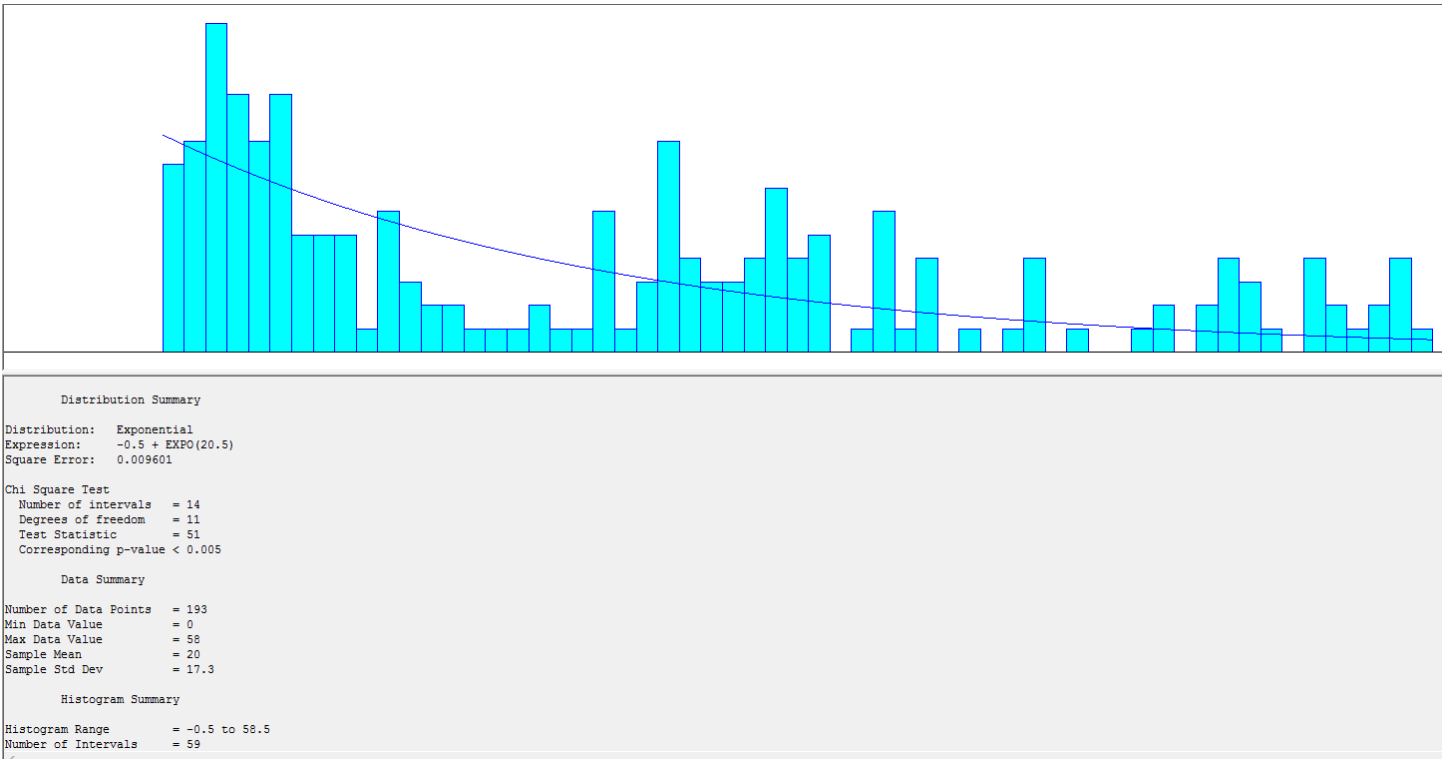


Figure 27: Distribution Fit from IA for Inter-Arrival Time (All Data)

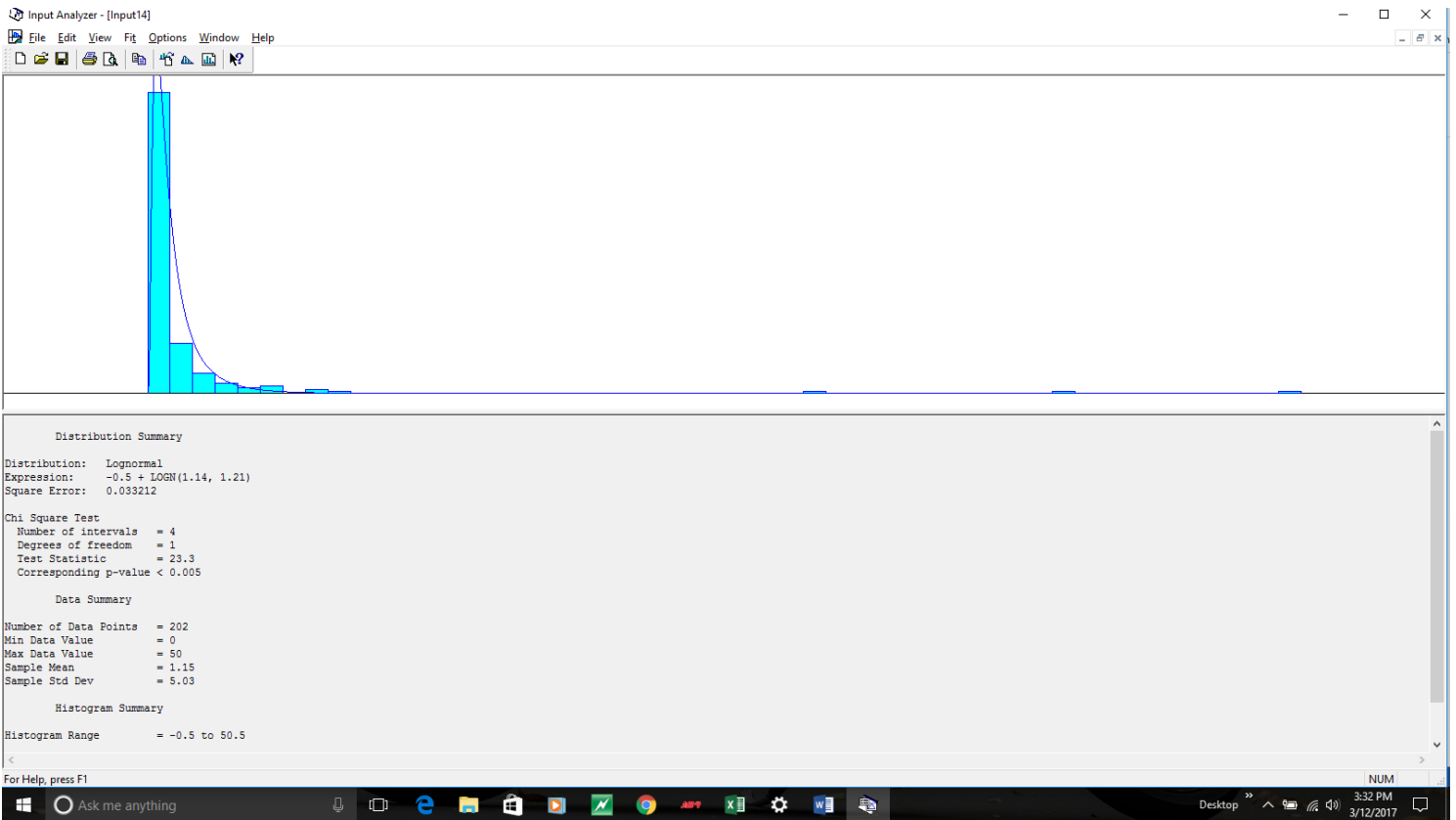
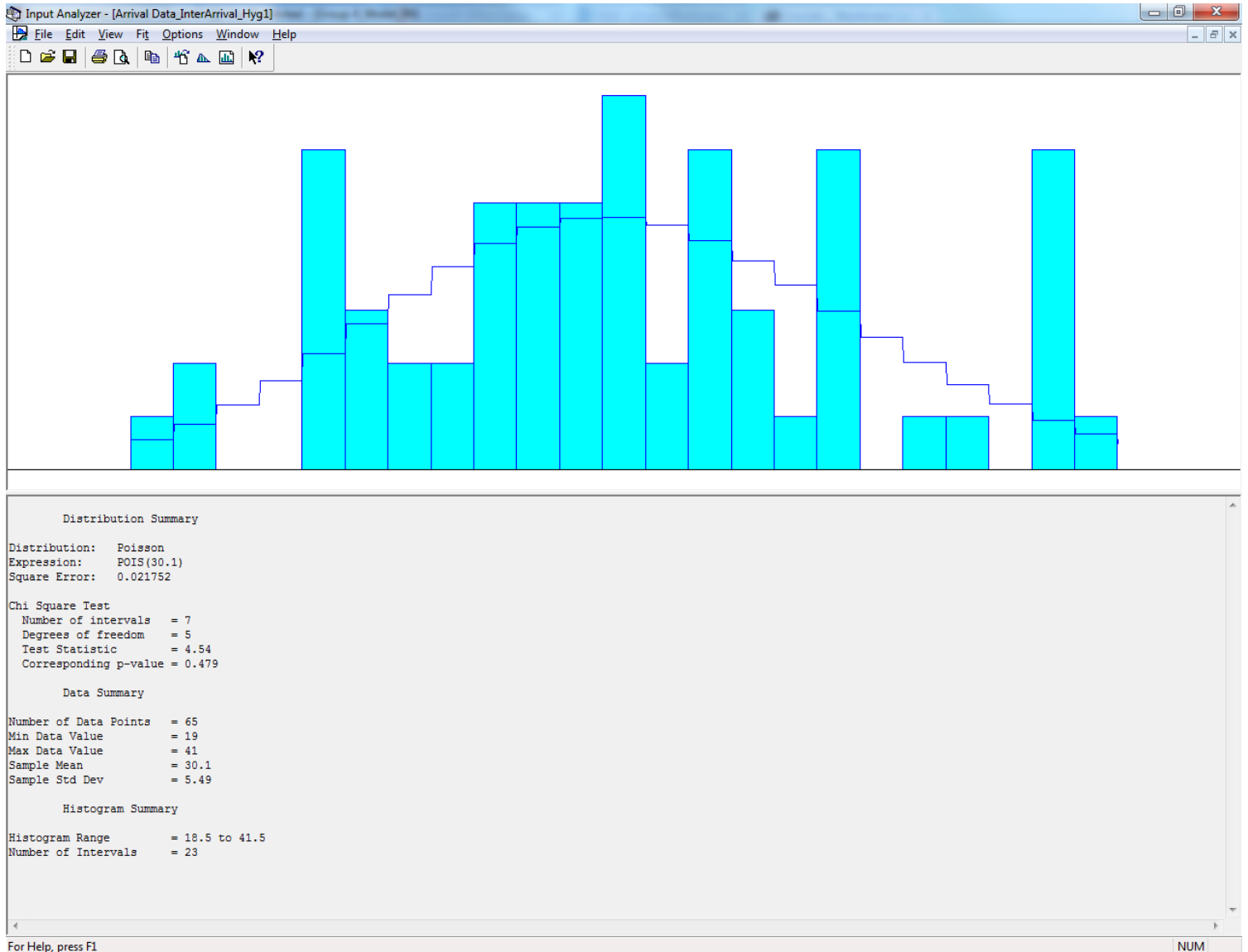


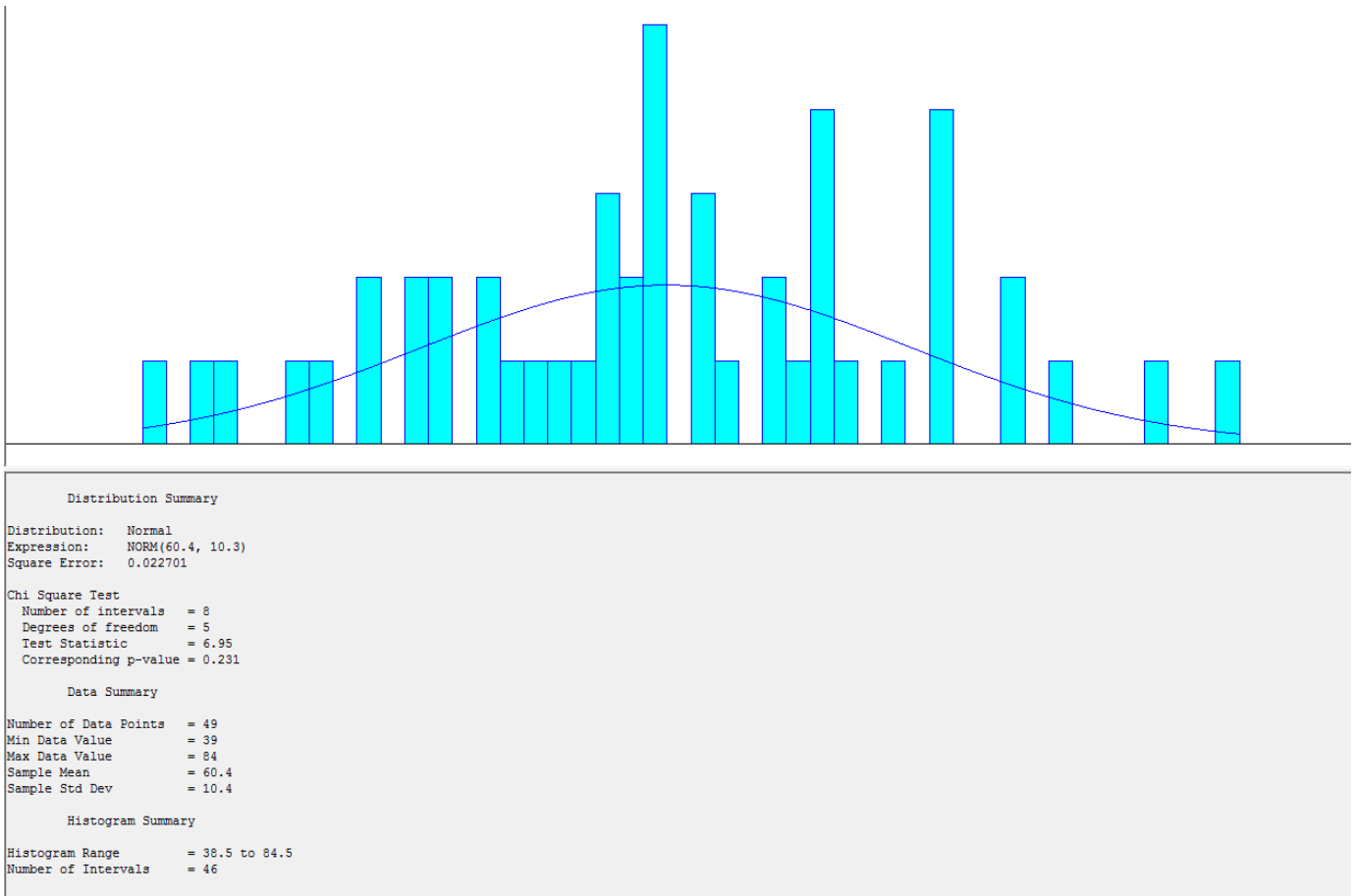
Figure 28: Distribution Fit from IA for Wait Time (All Data)

The fact that a large portion of our categorical groupings follow these distributions and that none of the distribution fittings look particularly good, we continue to dive deeper into the data and look at some more of finer categorical fittings.

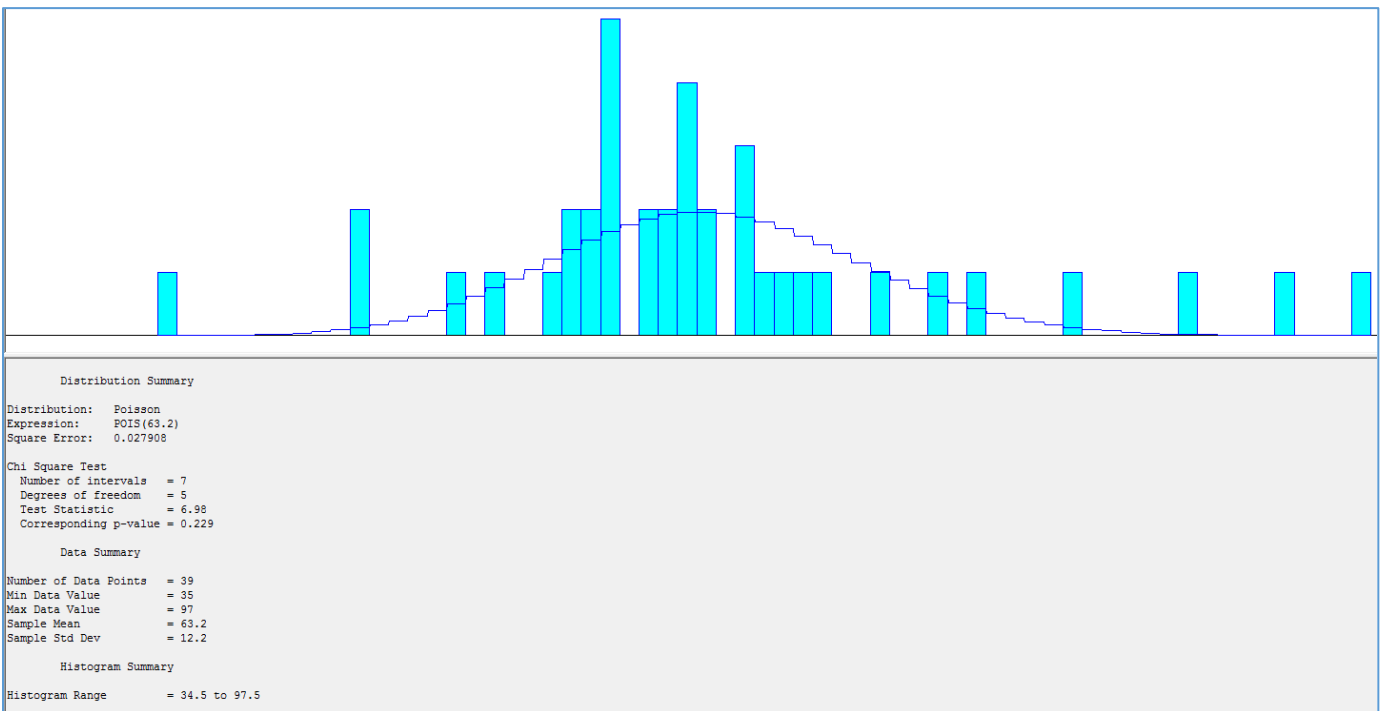
Examples of the fitting distributions used in the final model can be found below:



**Figure 29:** Distribution Fit from IA for Hyg1 Interrival



**Figure 30:** Distribution Fit from IA for Hyg2 Interrival



**Figure 31:** Distribution Fit from IA for Hyg3 Interrival

A large trend we saw was that the finer in detail we went, the better fitting the distributions were. Of course this was only true for some of the categories as some were proven different using ANOVA. This was what allowed us to end up with the distributions needed for the final model.

## 6.2 SERVICE DATA

For the service data, data was collected across the same days for eight different process steps. The process steps that data is recorded for, with 43 data points for each process step total, include check-in (timed in seconds), take x-ray (timed in minutes), scaling and route planeing (minutes), cleaning (minutes), sealants (minutes), data collection (minutes), find doctor for consult (minutes), and doctor consult (minutes). A picture of the raw data with the outliers highlighted in red can be seen below in Figure 31. All of these process steps correlate to the process flow diagrams covered in the earlier sections.

Patient Number	Check-In (seconds)	Take X-Ray (mins)	Scaling & Route Planing (mins)	Cleaning (mins)	Sealants (mins)	Data Collection (mins)	Find Doctor for Consult (mins)	Doctor Consult (mins)
1	16	1.5	40	36	19	7	5	6
2	16	3.5	44	15	15	4	9	5
3	18	4.7	30	36	16	4	4	8
4	10	3.4	38	36	15	4	2	2
5	17	4.8	39	27	18	7	1	5
6	3	4.7	42	40	9	7	10	10
7	21	4.1	38	29	18	7	6	7
8	17	2.5	40	36	12	6	7	8
9	11	3.5	41	31	19	1	8	8
10	26	4	47	41	14	7	4	10
11	24	5	39	24	18	4	9	2
12	25	4.8	25	32	14	4	8	8
13	21	3	44	22	17	7	10	10
14	11	3.1	41	35	18	6	9	7
15	52	4.8	44	31	16	10	3	9
16	23	3.5	45	20	19	5	6	6
17	10	4.9	44	43	19	5	6	10
18	19	4.2	44	37	12	3	3	5
19	28	5	44	25	25	7	8	15
20	24	5	43	26	16	3	2	8
21	15	5	38	33	16	5	7	10
22	10	3.6	38	32	12	7	1	6
23	60	3.1	39	22	13	5	2	5
24	19	3.4	56	25	12	4	4	5
25	17	7	43	50	16	5	4	9
26	18	4.6	40	23	14	4	5	5
27	18	4.8	40	34	18	7	9	6

Figure 32: Screenshot of a Portion of Raw Service Data with Outliers Highlighted



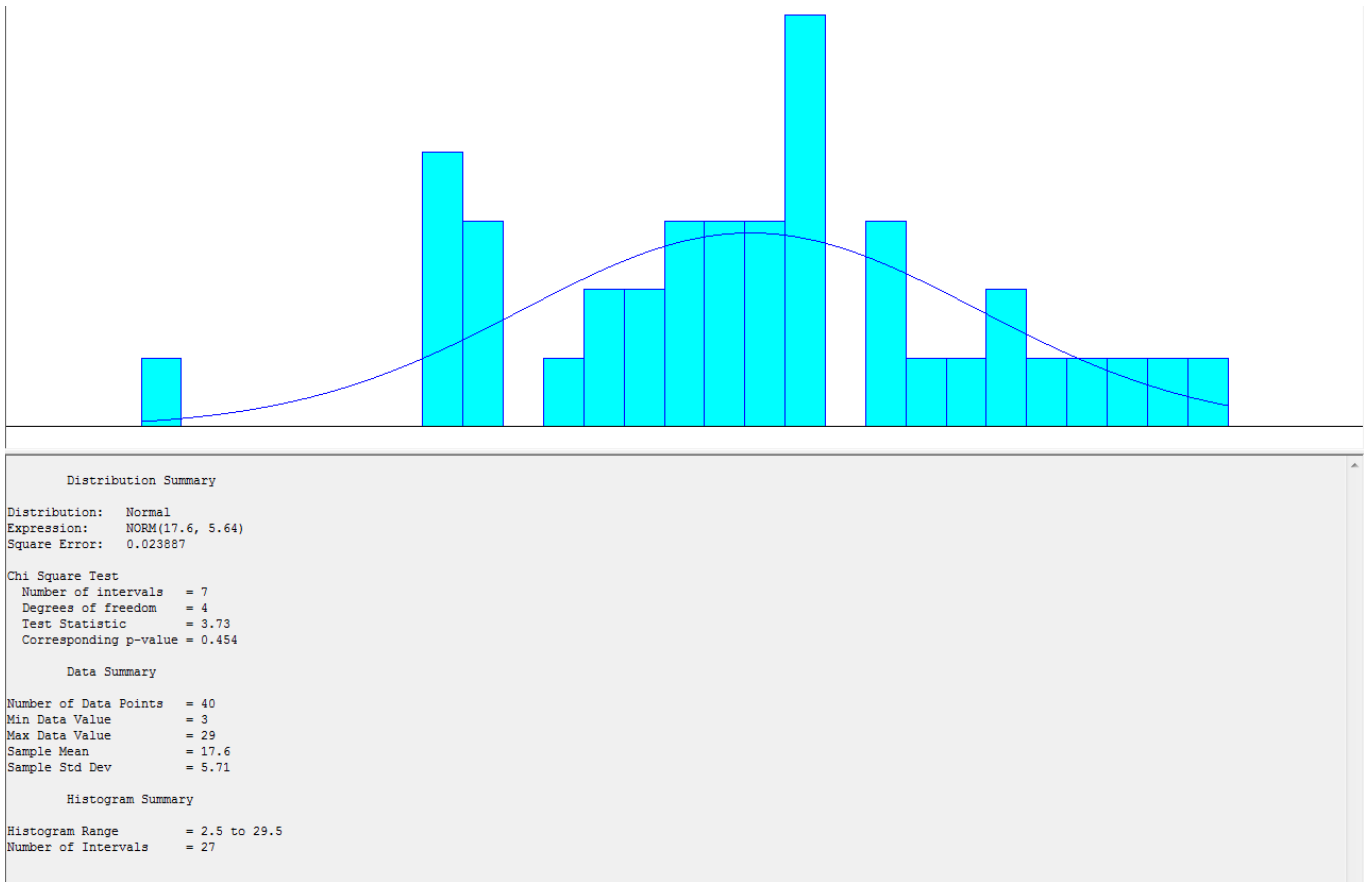
The descriptive statistics and outlier analysis summary is shown below in Figure 32.

Check-In (seconds)	Take X-Ray (mins)	Scaling & Route Planing (mins)	Cleaning (mins)	Sealants (mins)	Data Collection (mins)	Find Doctor for Consult (mins)	Doctor Consult (mins)	
21.79	4.01	41.65	31.86	15.86	5.16	5.14	7.26	Mean
18	4	41	32	16	5	5	7	Median
18.25	1.00	6.25	8.06	3.29	1.86	2.76	2.41	Standard Deviation
117	5.5	43	37	16	9	9	13	Range
120	7	68	52	25	10	10	15	Max
3	1.5	25	15	9	1	1	2	Min
45.62	2.51	15.63	20.16	8.23	4.66	6.89	6.03	2.5*SD
67.41	6.52	57.28	52.02	24.09	9.82	12.03	13.28	Upper Bound
0.00	1.51	26.02	11.70	7.63	0.50	0.00	1.23	Lower Bound
1	2	2	0	1	1	0	1	# Outliers
After Outlier Analysis								
19.45	4.00	41.41	31.86	15.64	5.05	5.14	7.07	Mean
18	4	41	32	16	5	5	7	Median
10.01	0.82	4.09	8.06	3.00	1.72	2.76	2.11	Standard Deviation
57	3	26	37	15	6	9	8	Range
60	5	56	52	24	7	10	10	Max
3	2	30	15	9	1	1	2	Min

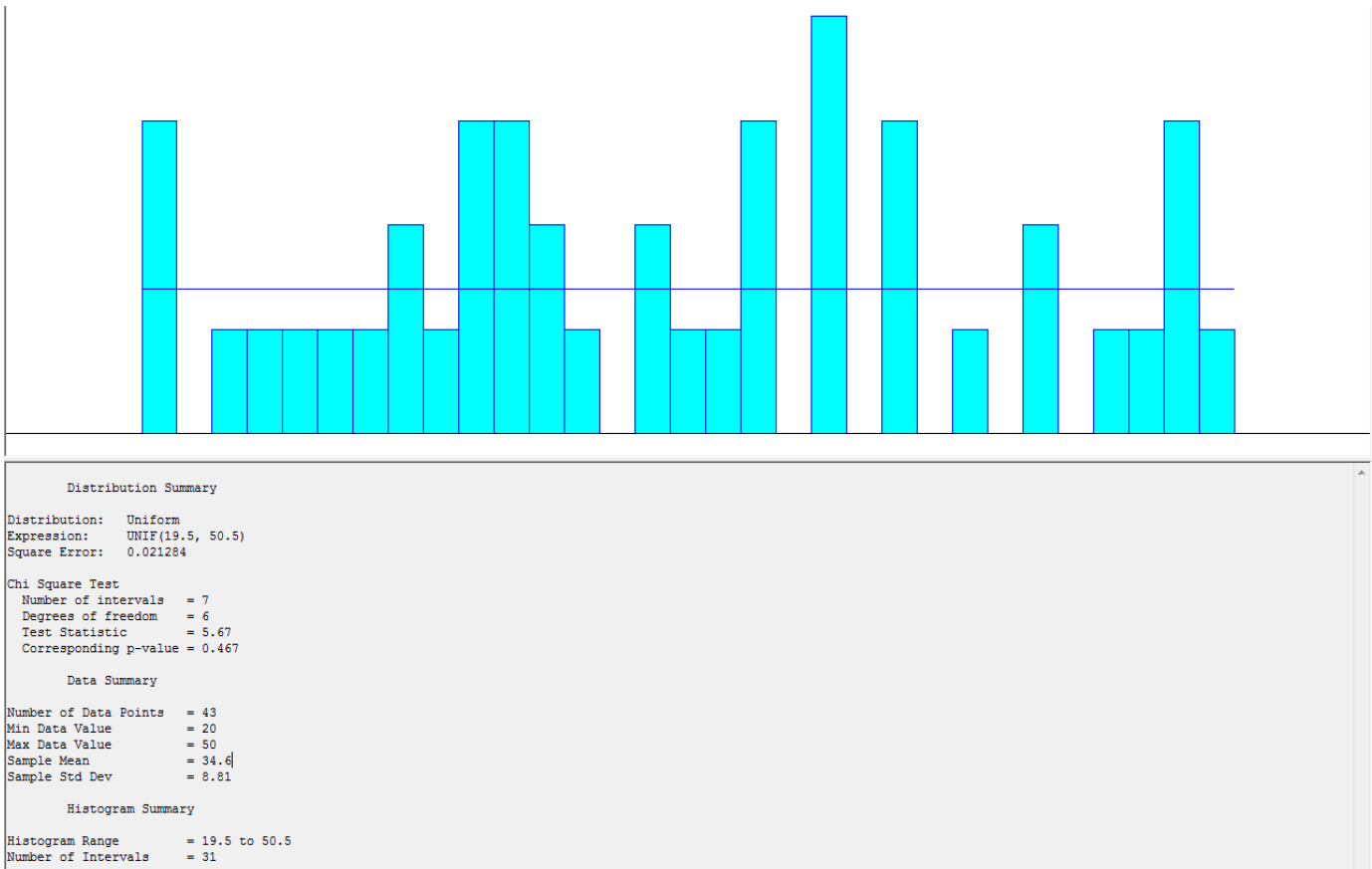
Figure 33: Descriptive Statistics Summary Shown Before-and-After Outlier Analysis

Finally, the fitting distribution plots from Input Analyzer for each of the process steps is shown below. Of course, outlier analysis was performed on every process step prior to using Input Analyzer and fitting distributions.

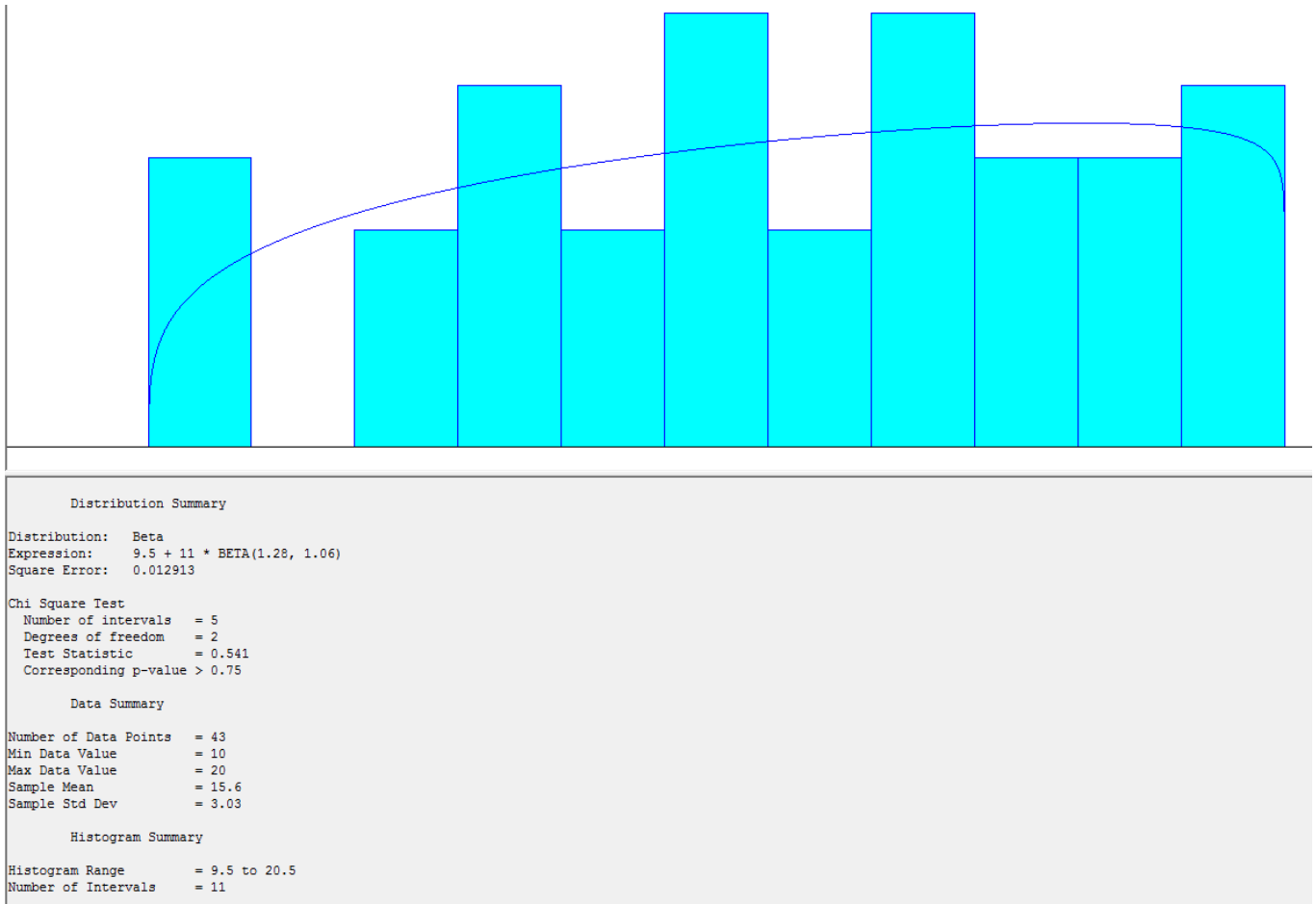
As a summary of all of the fitting distributions for service data shown below, they can be classified by whether or not their fitting proved statistically significant. In other words, which of the fitting distributions had p-values that were greater than 0.05? The check-in, adult cleaning, child cleaning, doctor, consult, find doctor, and scaling and root planeing all had fitting distributions with p-values greater than 0.05. Their distributions were statistically valid. That being said, several were not. The sealants and take x-rays processes had distributions that proved to be statistically invalid (their p-values were less than 0.05).



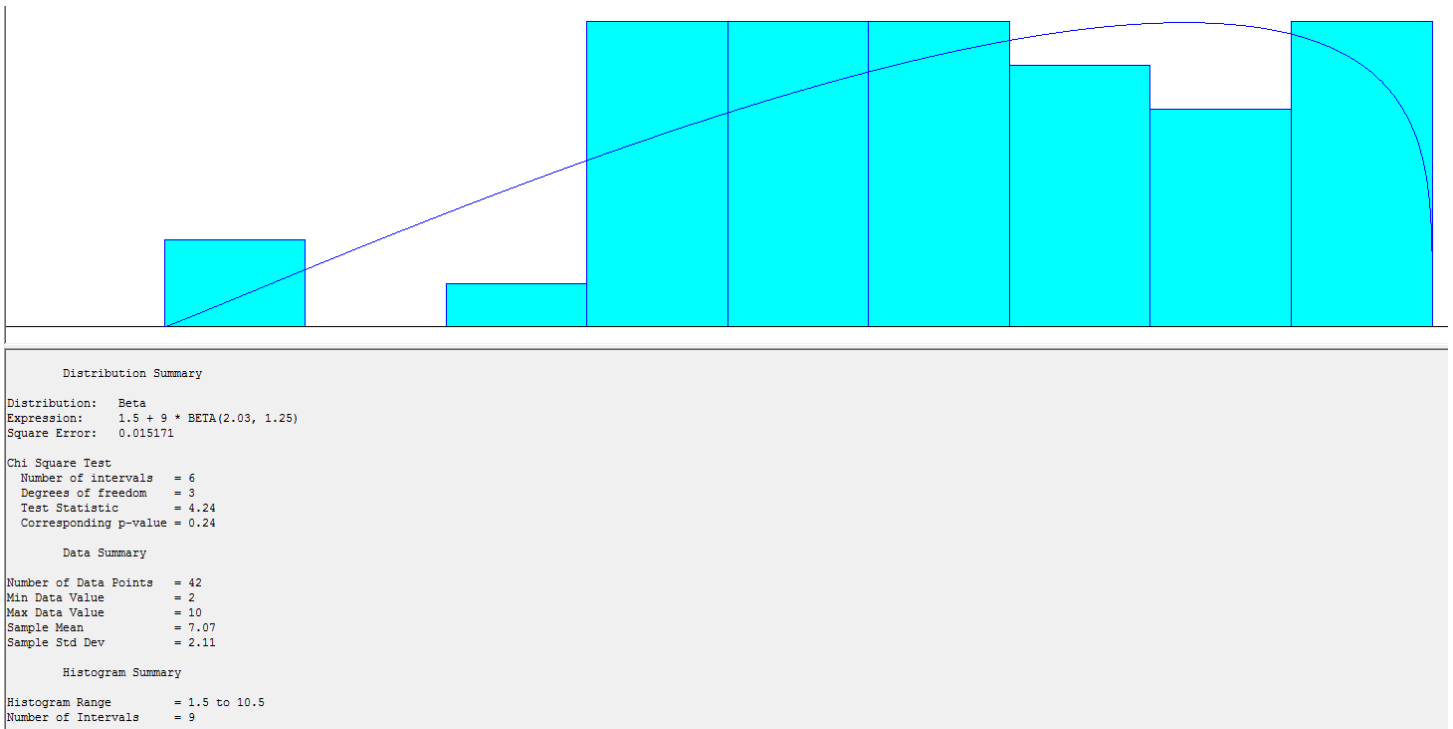
**Figure 34: IA Fitting Distribution for Check-In**



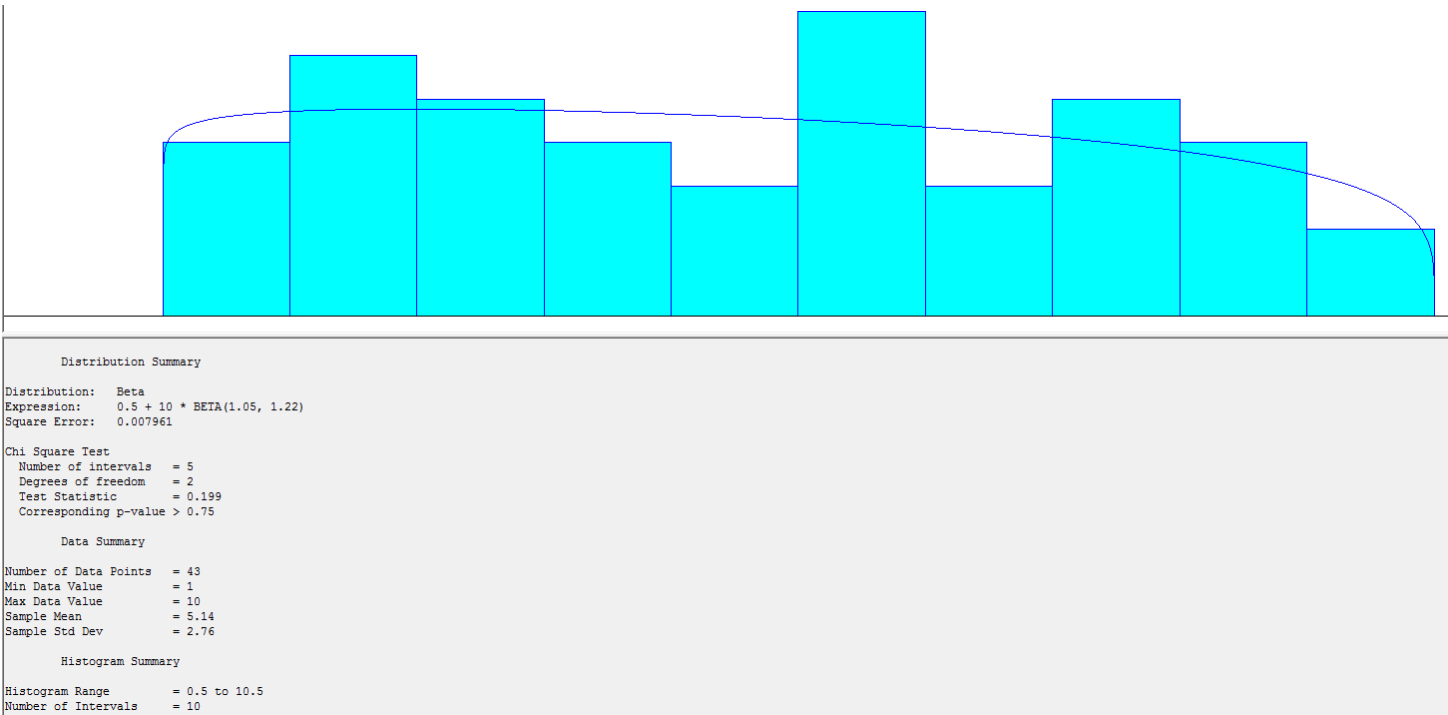
**Figure 35: IA Fitting Distribution for Adult Cleaning**



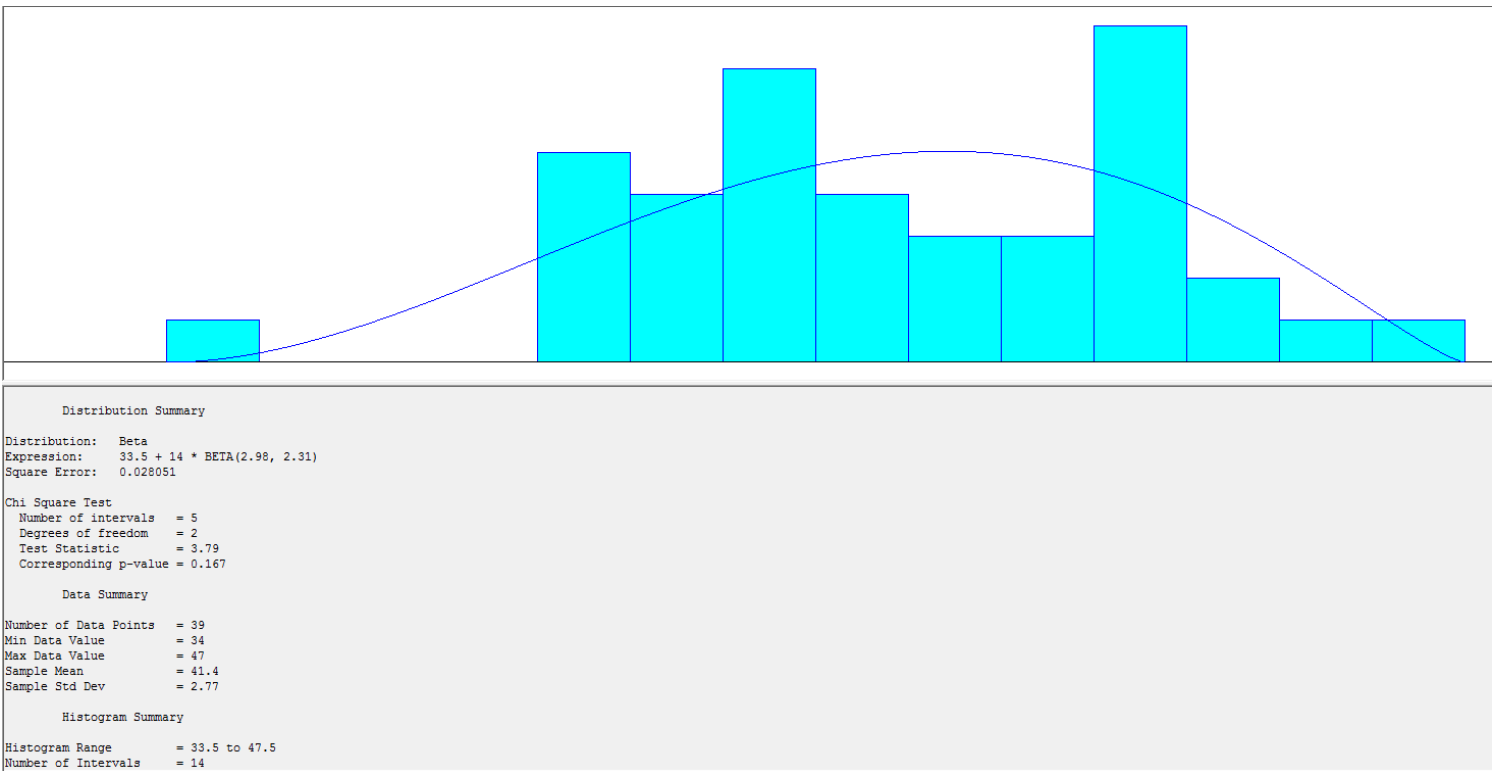
**Figure 36: IA Fitting Distribution for Children Cleanings**



**Figure 37: IA Fitting Distribution for Doctor Consult**



**Figure 38: IA Fitting Distribution for Find Doctor**



**Figure 39: IA Fitting Distribution for Scaling & Route Planeing**

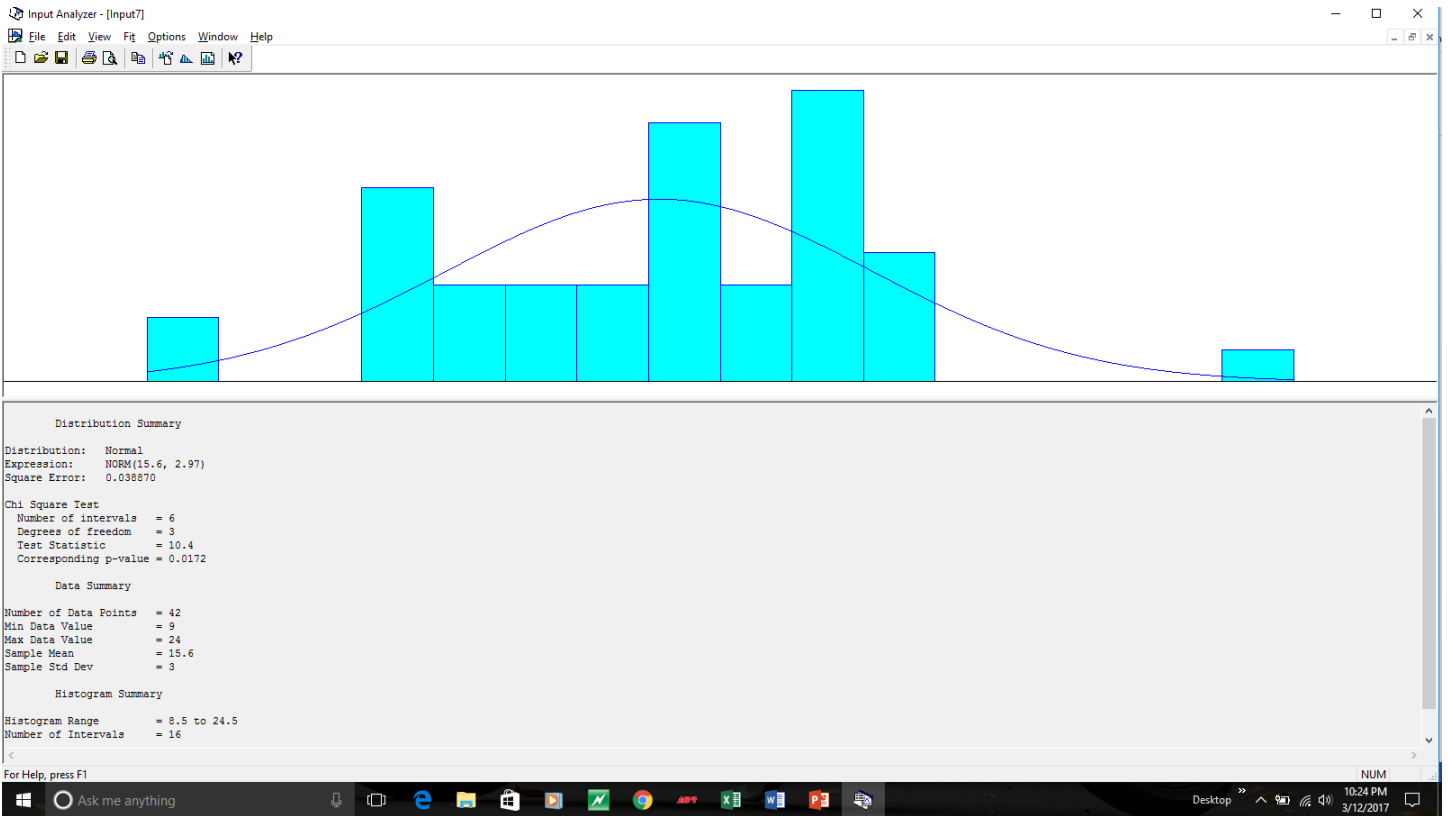


Figure 40: IA Fitting Distribution for Sealants

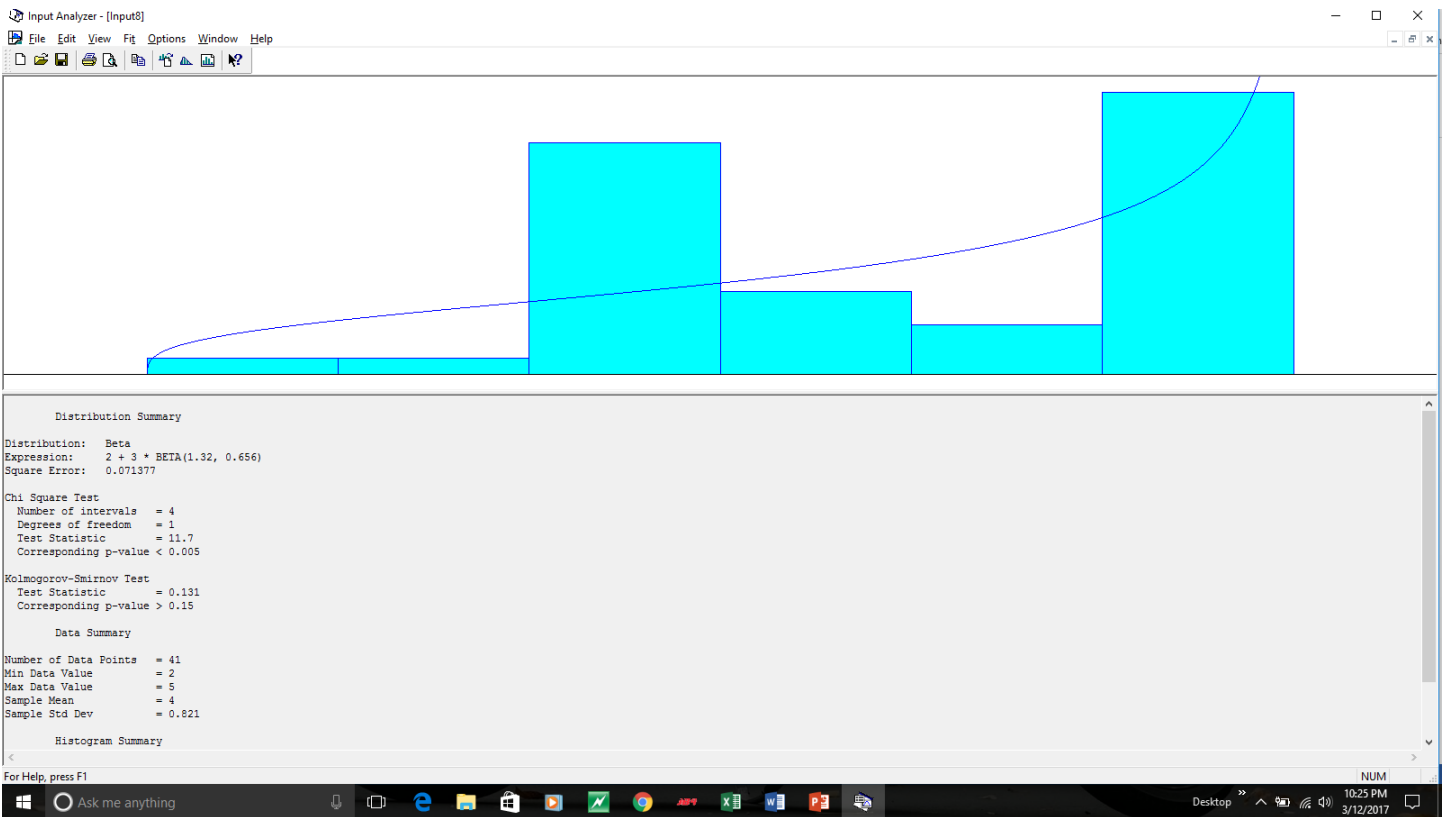


Figure 41: IA Fitting Distribution for Take X-Ray

## 7. ARENA SIMULATION MODEL

### 7.1 FINAL MODEL

The final simulation model of the hygiene practices at the Harmony Dental Group can be seen in the figures below. Due to the fact that the legibility of the individual modules is not great as a result of the screenshot, additional zoomed-in screenshots of the model are also included. Again, please note that all of the subsystems aforementioned are included in process module blocks below. For example, the cleaning of instruments and the room by the hygienist is included in the overall cleaning process.

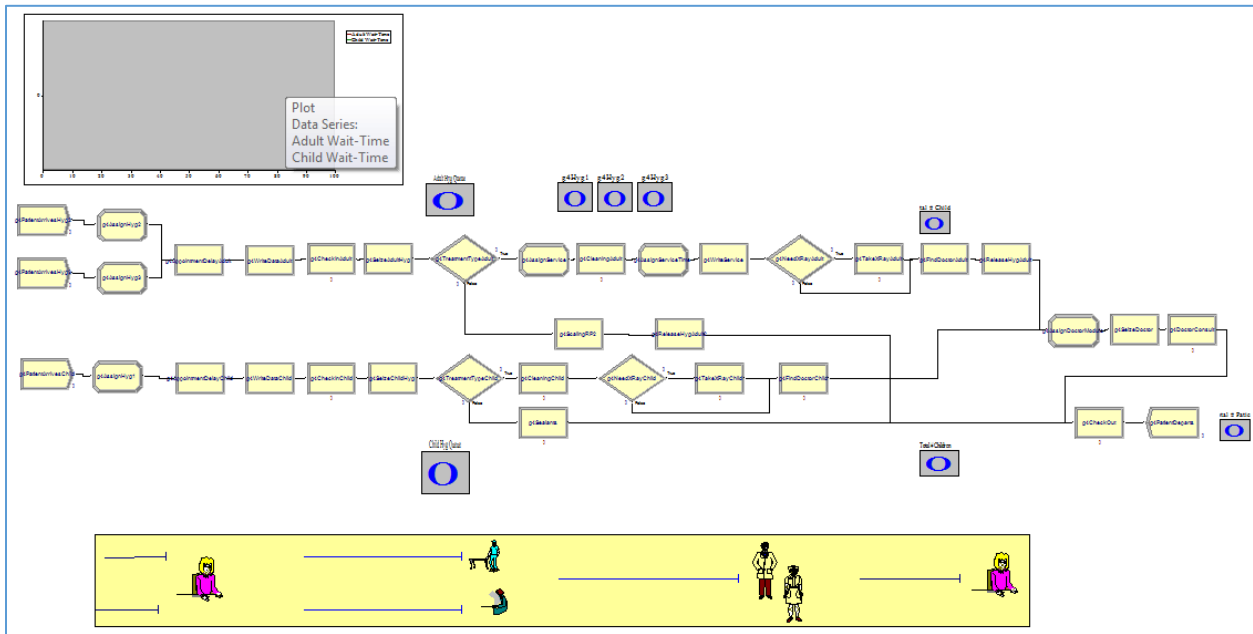


Figure 42: Final Revision of Model, Idle State

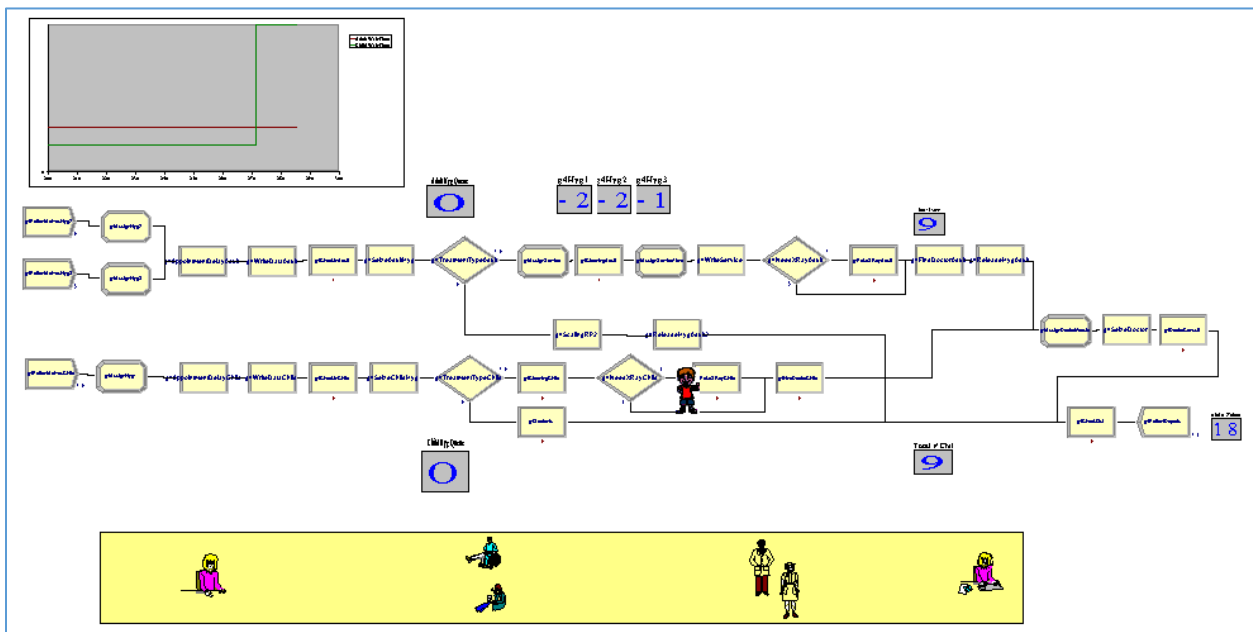
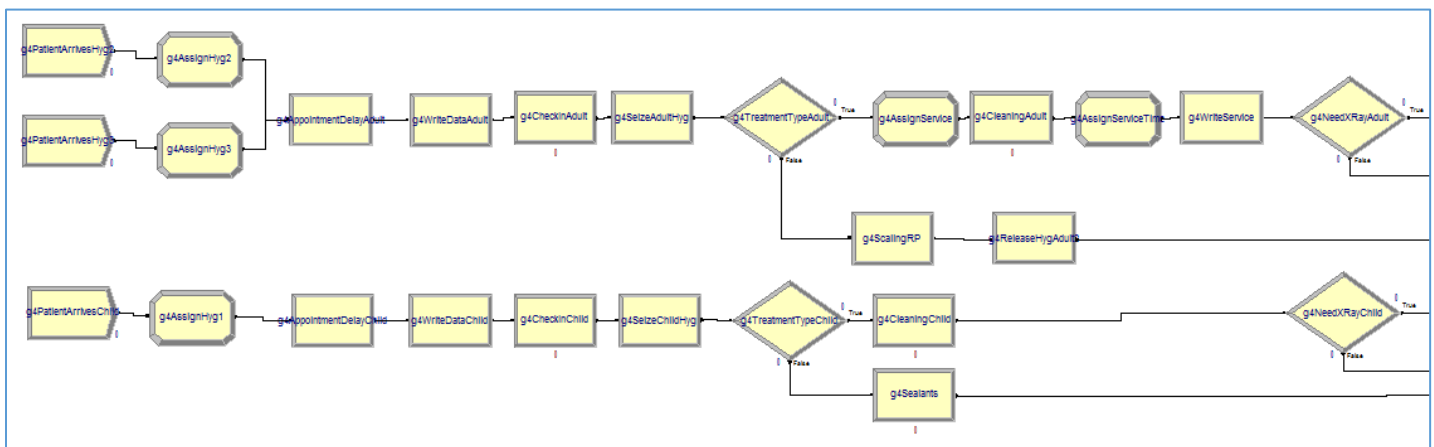


Figure 43: Final Revision of Model, Screenshot during Run

The figures below show zoomed-in views of each of the following sections of the model: the arrival and check-in process followed by the treatment type decision (first section), and the relevant service and doctor consult modules followed by check out and departure (second section).

In the first section of the model, there is a create module for the arrival of patients for each of three hygienists. As previously explained, the interarrival times for the different days and times that data was collected proved to be statistically indifferent. The arrival times for patients pertaining to the respective hygienists did prove to be statistically different so we modeled it as such. From there, a hygienist is assigned to each patient: Hyg1 for children and Hyg2 or Hyg3 for adults. For each patient who arrives, a delay module is included to simulate tardiness caused by the office or patient (this distribution was based on real data collected in terms of appointment actual start time when compared with scheduled start time). Before the treatment decide modules, the check-in process occurs with the receptionist and read/write modules are in-line to export arrival data. Both decide modules use percentages based on the data to split the adults and children between the two respective paths. 90% of adults and 95% of children receive cleaning; the remaining adults receive scaling and root planeing and the remaining children get sealants. From there, the respective processes are performed for both adults and children. For adults, we chose the cleaning process as the service we would collect simulation data for so several more modules (assign, read/write, etc) are included in the cleaning loop for that reason.



**Figure 44:** Zoomed-In View of First Section of Model

In the second section of the model picture below, we'll focus on the remainder of the cleaning loops since the scaling and root planeing loop as well as the sealants loop both go directly to checkout (they do not get x-rays or a doctor consult). For both adults and children, a decide module with a 50% true condition exists for an x-ray requirement (50% is based on the fact that patients come twice a year and receive x-rays yearly). If an x-ray is needed, it is taken. Finally, a doctor consult is needed to finish every cleaning appointment so the hygienist finds a doctor, the checkup is performed, the patient checks out and departs.

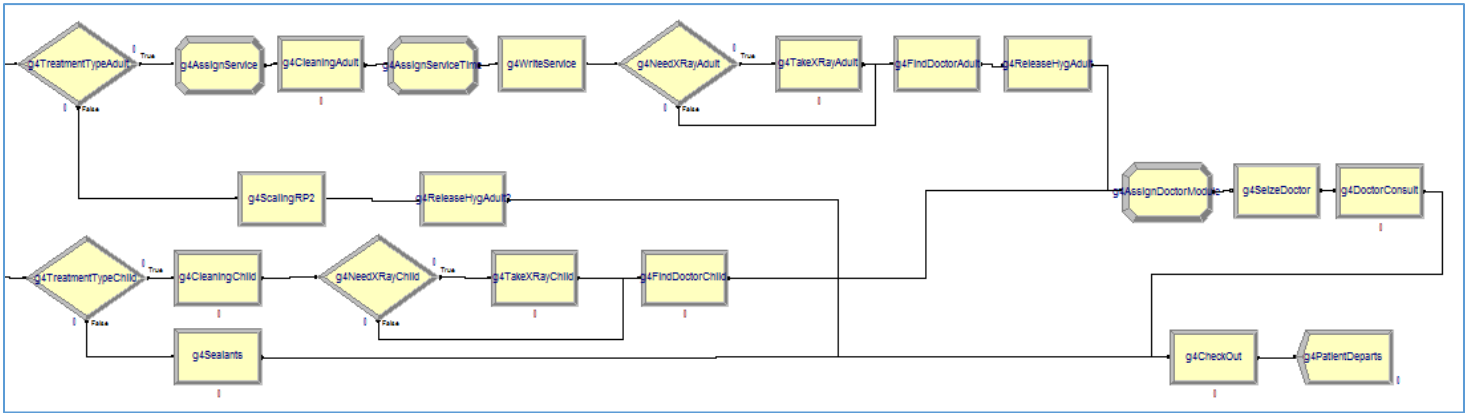


Figure 45: Zoomed-In View of Second Section of Model

## 7.2 ANIMATION

The final simulation model contains two-dimensional (2D) animation for the queue at various stages, the entities (customers), and the resources (receptionist, hygienist, and dentists). There are two different entities assigned pictures: adult patients and child patients. The standard picture of a man was used from the current picture library for adult patients and a custom child picture was uploaded into Arena for children patients. For the resources, pictures related to, and mostly applicable to, the health care field were selected from one of several different libraries in Arena. Several screenshots showing the animation selections can be found below.

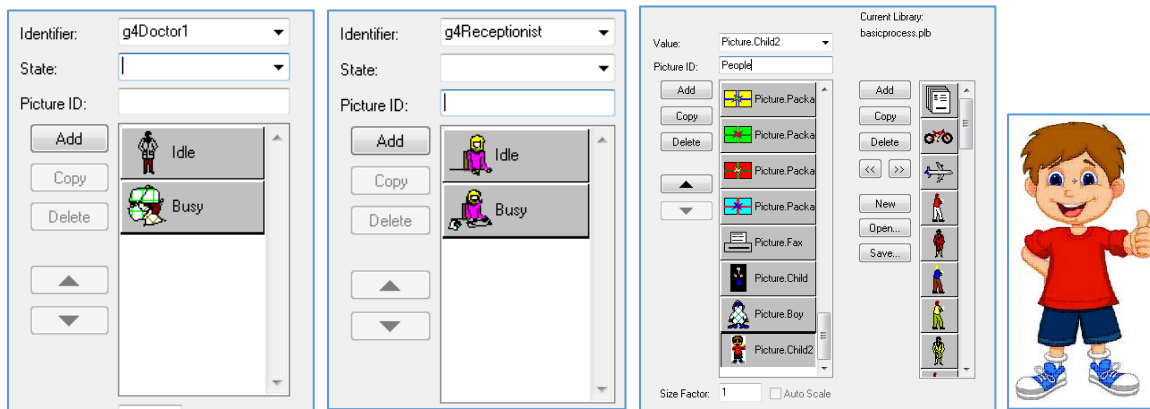


Figure 46: Screenshots of Examples of Resource and Entity Pictures

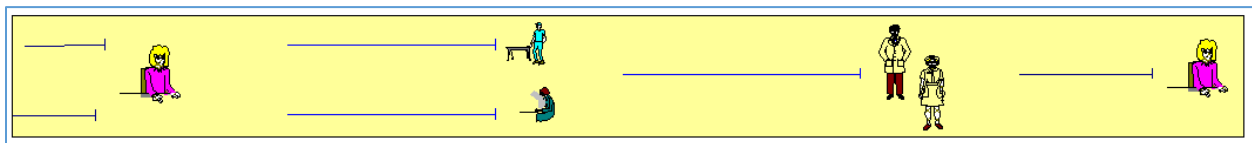


Figure 47: Screenshot of Queue Animation Setup

## 7.3 TOOLS USED FOR TROUBLESHOOTING

Other things added to the model include variable counters and plots. A plot of average wait time at check-in with two series (one for adults, one for children) was created since wait-time is obviously a key factor. In



addition, variable counters played a large role in helping us troubleshoot the resource allocation issues. Such counters include the state of each of the hygienists, the queue of adults, the queue of children, and the total throughput.

## 8. MODEL VALIDATION & PERFORMANCE ANALYSIS

### 8.1 MODEL PROGRESSION & REVISIONS

The first part of model validation is the natural progression and development of the model. Upon initial development of the model, it was run and compared with the real-world data collected at the dental office. Certain inconsistencies in the model performance such as far-off values for timed processes, excessively long queues at certain stages, or resource allocation problems cause for revisions to be made to the overall model setup and logic. Resource allocation was the biggest issue we ran into regarding the assignment of hygienists for the patients; the split of patients between adults and children complicated this area and resulted in the testing of numerous different assignment logics. The final model, which was the seventh major revision, uses two sets of hygienists (one consisting of Hyg1 for children only and one containing Hyg2 and Hyg3 for adults) that are then assigned to the entering patients. The first and third revision of the model are pictured below and can be compared with the final (seventh) revision pictured above to show the progression of the model through the validation phase.

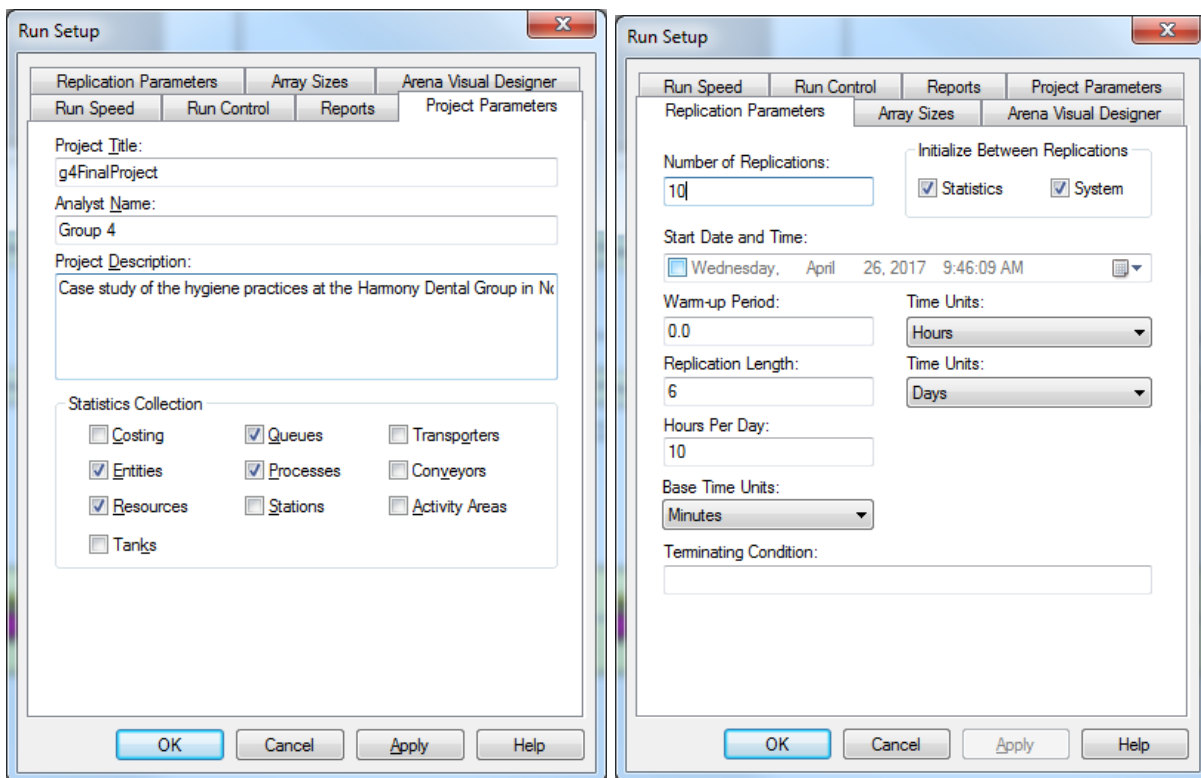


Figure 48: Project and Replication Parameters

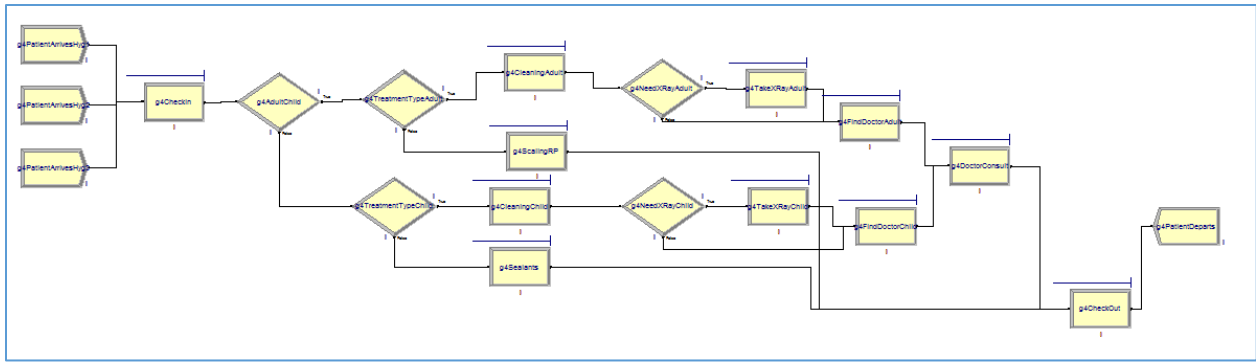


Figure 49: Initial Revision of Model, Idle State

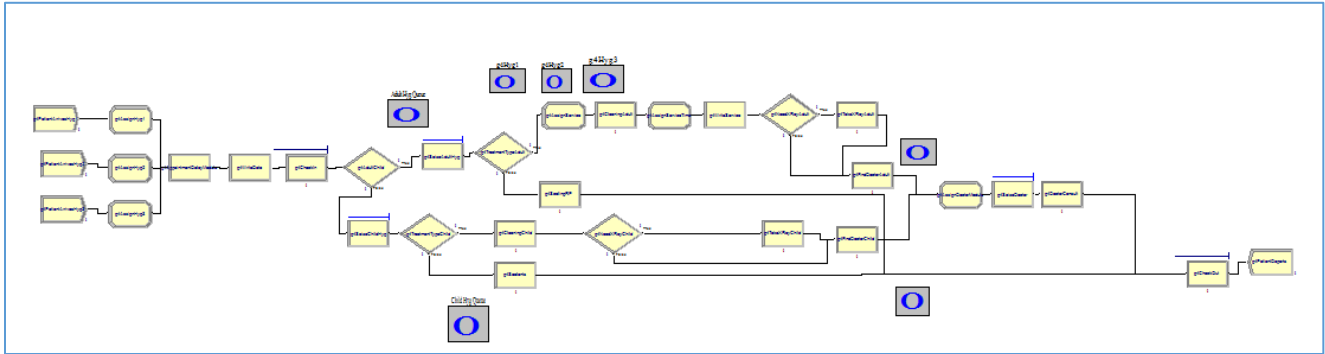


Figure 50: Third Revision of Model, Idle State

## 8.2 MODEL VALIDATION USING STATISTICS

The next step in model validation is using statistics to analyze and compare the actual and simulation data sets. Interarrival simulation data sets were created for both adult patients and children patients. In addition, a service simulation data set was created from the model for adult cleanings. The reason this particular process was chosen was because adults are the primary focus of the practice and cleanings are the primary focus of this project.

For each of the three instances where actual data sets can be compared to simulation data sets (adult interarrival times, children interarrival times, and adult cleaning service times), statistical tests were run. To start, tests of normality were run for each and the results are pasted below.

Tests of Normality						
	Kolmogorov-Smirnov <sup>a</sup>			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SimAdultInter	.075	110	.169	.987	110	.376
Act Adult Inter	.085	110	.047	.976	110	.048

a. Lilliefors Significance Correction

Figure 51: Normality Test Results for Adult Interarrival Times

Tests of Normality						
	Kolmogorov-Smirnov <sup>a</sup>			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ActChildInter	.089	65	.200 <sup>*</sup>	.969	65	.107
SimChildInter	.096	65	.200 <sup>*</sup>	.972	65	.150

\*. This is a lower bound of the true significance.  
a. Lilliefors Significance Correction

**Figure 52:** Normality Test Results for Children Interarrival Times

Tests of Normality						
	Kolmogorov-Smirnov <sup>a</sup>			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SimCleaning	.094	43	.200 <sup>*</sup>	.946	43	.043
ActCleaning	.100	43	.200 <sup>*</sup>	.960	43	.134

\*. This is a lower bound of the true significance.  
a. Lilliefors Significance Correction

**Figure 53:** Normality Test Results for Adult Cleaning Times

As seen by the results from the normality tests, the significance value is greater than 0.05 for every data set besides the actual data set of adult interarrival times. Even the actual adult interarrival times have a significance value that is close to 0.05 (0.047). If we assume the value is greater than 0.05 since it is so close, we will proceed to a homogeneity test for each. The results of the homogeneity tests can be seen below.

Test of Homogeneity of Variances			
AdultInter			
Levene Statistic	df1	df2	Sig.
6.754	1	192	.010

**Figure 54:** Equal Variance Test for Adult Interarrival Times

Test of Homogeneity of Variances			
ChildInter			
Levene Statistic	df1	df2	Sig.
.036	1	260	.850

**Figure 55:** Equal Variance Test for Children Interarrival Times

Test of Homogeneity of Variances			
Cleaning			
Levene Statistic	df1	df2	Sig.
.502	1	216	.479

**Figure 56:** Equal Variance Test for Adult Cleaning (Service) Times

As seen in the homogeneity results, children interarrival times and adult cleaning service times have significance values over 0.05. Again, the significance value for adult interarrival times is less than 0.05 with a value of 0.01. As such, the Kruskal-Wallis test is required for this data. What this also means is that our previous assumption that the data was normal was invalid since we need to now perform Kruskal-Wallis test anyway. The results of the test can be found below.

Kruskal-Wallis Test			
Ranks			
	GroupIDAdultInter	N	Mean Rank
AdultInter	.00	110	103.31
	1.00	84	89.89
	Total	194	

Test Statistics <sup>a,b</sup>	
	AdultInter
Chi-Square	2.726
df	1
Asymp. Sig.	.099

Figure 57: Kruskal-Wallis Test for Adult Interarrival Times

### 8.3 PERFORMANCE ANALYSIS

The final step in this section is to review the performance of the system and the results from the simulation. Ten replications were run with each replication simulating a full week of six business days (five during the week and one on the weekend). Metrics important to the Harmony Dental Group include total time in the system per entity (cycle time) for both children and adults, wait time, and hygienist utilization.

To start, total cycle time per entity can be examined. The average cycle times for children (Hyg1), adults served by Hyg2, and adults served by Hyg3 are 35.1, 53.7, and 53.8 minutes, respectively. These figures largely make sense and are certainly reasonable. Hyg1 only serves children which are allotted half hour appointments so a total cycle time average of 35.1 minutes is reasonable and not far off the mark of performing to schedule. Hyg2 and Hyg3 perform cleanings on adults only who are allotted hour-long appointment times. As such, their respective cycle time averages of 53.7 and 53.8 minutes are not only reasonable, but less than what they should be (these hygienists are performing better than to schedule).

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
	g4CustomerChild	35.1161	1.47	31.5827	38.2523	17.0905
g4CustomerHyg2	53.7067	2.67	47.0413	57.4328	29.0155	79.5395
g4CustomerHyg3	53.8578	2.99	48.2400	60.3884	33.3684	79.2026

Figure 58: Total Cycle Time per Entity

Another initial area of concern for the office is customer wait time. The office initially reported customer wait time of up to twenty or thirty minutes. That being said, our simulation model did not seem to return wait-time as an area of concern but there does seem to be a reasonable explanation why. In collecting the

data for the three hygienists, not many patients were late nor did hygienists run past schedule often. In addition, it should be noted that a customer arriving before their scheduled appointment time is not considered waiting. To the office, waiting is considered to be the appointment actually starting after the scheduled time. These delays were analyzed during data collection and were included in the delay module in the model to mimic such tardiness. Finally, the few cases that did result in certain delays were removed as a result of outlier analysis. All that being said, the total wait times per entity for adults and children were small. Another reason for this could be because the model does not include the wide-varying restorative procedures performed by dentists. The same logic can be applied to the average waiting time and number waiting for the queue.

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
g4CustomerChild	1.7891	0.93	0.6587	4.3977	0.00	19.1561
g4CustomerHyg2	1.3725	0.60	0.5057	3.2793	0.00	11.6316
g4CustomerHyg3	0.8136	0.64	0.00	2.6753	0.00	11.5155

Figure 59: Wait-Time per Entity

Queue						
Time						
Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
g4CheckInAdult.Queue	0.3331	0.19	0.01417640	0.8378	0.00	4.8145
g4CheckInChild.Queue	0.5028	0.12	0.1798	0.7320	0.00	5.6067
g4CheckOut.Queue	0.1932	0.05	0.0923	0.2927	0.00	6.2855
g4SeizeAdultHyg.Queue	0.5011	0.53	0.00	1.9041	0.00	11.6316
g4SeizeChildHyg.Queue	1.2793	0.89	0.03400185	3.5598	0.00	19.1561
g4SeizeDoctor.Queue	0.04696341	0.03	0.00	0.1118	0.00	4.0627
Other						
Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
g4CheckInAdult.Queue	0.01123665	0.01	0.00049617	0.02932283	0.00	2.0000
g4CheckInChild.Queue	0.01738989	0.00	0.00599497	0.02562081	0.00	1.0000
g4CheckOut.Queue	0.01241159	0.00	0.00569392	0.01853899	0.00	2.0000
g4SeizeAdultHyg.Queue	0.01753952	0.02	0.00	0.06664266	0.00	1.0000
g4SeizeChildHyg.Queue	0.04605150	0.03	0.00113340	0.1351	0.00	1.0000
g4SeizeDoctor.Queue	0.00290839	0.00	0.00	0.00708208	0.00	1.0000

Figure 60: Queue Results

The next thing to look at for performance analysis of the model is the service time statistic for the various processes. With cleanings being the primary focus of this project, let us start by looking at the average cleaning times. For adults, the average cleaning time was 35.4 minutes whereas for children it is 15.7 minutes. The dental office advised that these simulated averages are right on par with the actual averages for adult and children. Again, finding a doctor can be an area of concern as seen in the case of the children; waiting on average five minutes isn't terrible but can be better.

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
g4CheckInAdult	0.6341	0.19	0.3421	1.1359	0.04035878	5.1714
g4CheckInChild	0.7985	0.13	0.4816	1.0611	0.05893937	5.8392
g4CheckOut	2.8193	0.23	2.3742	3.4085	0.5178	7.9635
g4CleaningAdult	35.4054	2.16	30.6377	40.7645	19.5086	50.4904
g4CleaningChild	15.7303	0.60	14.6470	17.4739	9.6543	20.4449
g4DoctorConsult	7.0015	0.22	6.4660	7.3139	2.2133	10.4783
g4FindDoctorChild	5.3274	0.31	4.5199	6.0540	0.5258	10.3835
g4Sealants	8.0494	6.33	0.00	20.7681	0.00	20.7681
g4TakeXRayAdult	4.0588	0.28	3.1752	4.4941	2.0079	4.9995
g4TakeXRayChild	4.0418	0.14	3.5307	4.1674	2.2156	4.9991

Figure 61: Service Time Statistics for Processes

Utilization is the next important metric that can be analyzed in terms of model performance. Here we are most concerned with hygienist utilization. Hyg1, Hyg2, and Hyg3 report an average scheduled utilization of 0.765, 0.728, and 0.6835, respectively. These utilizations are realistic but could certainly be improved. As a result, scenarios will be explored where a hygienist is both added and removed from the current structure. The receptionist and doctors are more under-utilized as the model does not capture all of their responsibilities and duties. For example, the doctors' average utilizations are both around 20%; the remaining 80% of the time is spent on restorative treatments.

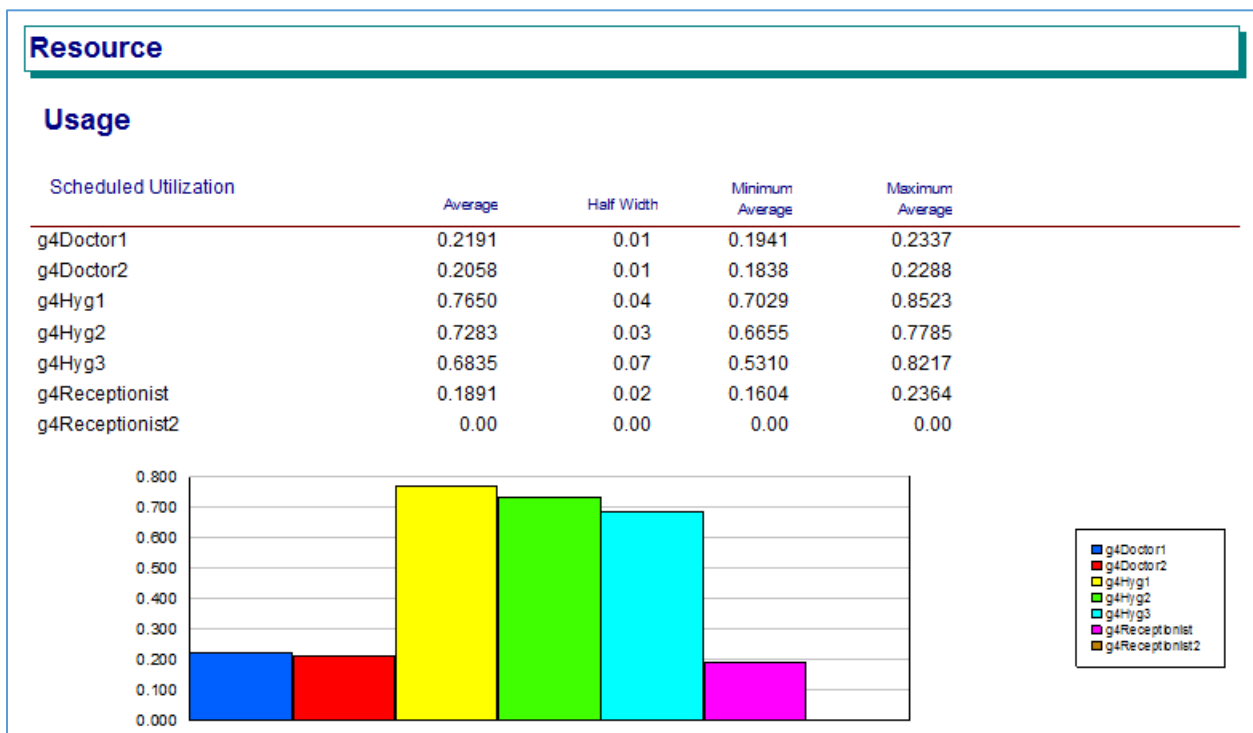


Figure 62: Resource Utilization Results

Finally, the throughput can be considered. On average, twenty adults were checked in per day and twenty children were checked in per day. With two hygienists serving adults who are allotted sixty-minute sessions and one hygienist cleaning children's teeth during 30-minute sessions, this makes sense. Furthermore, the office concludes this is approximately how many cleanings they do per day with three hygienists staffed as modeled.

Number Out	Average	Half Width	Minimum Average	Maximum Average
g4CheckInAdult	20.5000	0.61	19.0000	21.0000
g4CheckInChild	20.6000	0.50	20.0000	22.0000

**Figure 63:** Throughput Results

## 9. PROPOSED POLICY IMPLICATIONS

After analyzing the model’s performance in the previous section, changes can be proposed and alternate scenarios can be explored. In the next section, numerous scenarios will be considered with some more logical than others. Before certain scenarios are proposed, it is important to note the system’s performance was very good overall. With the fact that the office reports running a tight hygiene schedule, this makes sense. That being said, what would happen if a hygienist called out for a day? What would happen if another hygienist was hired (though the current utilization without an increase in arrivals would suggest it wouldn’t be effective)?

The biggest goal of this project was to show the value of simulation modeling to the Harmony Dental Group. With respect to the model though, certain goals include studying how hygienist utilization and cycle time are affected by staffing decisions. As already mentioned, it is not uncommon for the group to end up one hygienist short before a fully scheduled next day. When that’s the case, can the two hygienist pick up the slack or does it make sense for the office to contract out and hire a temporary hygienist for the day (as they often do)? Such a scenario is something that can be easily tested using process analyzer.

Another thing that can be studied is average appointment (cycle) time of each hygienist compared to the scheduled amount of time. Hygienist 1 only sees kids on certain days such as those included in this model and therefore all of the appointments are half-hour long. Hygienist 2 and Hygienist 3 only see adults so their appointments are always an hour long. Hygienist 1 averaged a 35-minute cycle time which is a bit slower than planned, The other two hygienists, on the other hand, averaged better than the time allotted. As a result, one potential recommendation for real-world consider could be lengthening the amount of time scheduled for children.

## 10. TEST OF POLICY IMPLICATIONS

### 10.1 SCENARIO ANALYSIS USING PROCESS AND OUTPUT ANALYZER

Process Analyzer allows us to create different Scenario’s to analyze results of the changes:

Scenario 1 – Base Line Model\_R7

Scenario 2 – Add additional Receptionist

Scenario 3 – Add additional Hygienist 1 = Total 2

Scenario 4 - Add Additional Hygienists 2 = Total 2

Scenario 5 – Add additional Hygienists 3 = Total 2

Scenario 6 – Add additional Receptionist & all Hygienists



Scenario 7 – remove Hygienists 3 (all other hygienists 1)

Scenario 8 – remove Hygienists 3 and add additional 2 Hygienists 2 = Total 4

Scenario 9 - remove Hygienist3 and add 2 Hygienists 2 = Total 3

Scenario Properties				Controls					Responses								
S	Name	Program File	Reps	g4Receptionist	g4Hyg1	g4Hyg2	g4Hyg3	Num Repts	g4Checkin Adult.Wait	g4Hyg1 Utilizatio	g4Hyg2 Utilizatio	g4Hyg3 Utilizatio	g4Receptionist.Utili	g4CustomerChild.	g4CustomerHyg2	g4CustomerHyg3	
1	g4BaseSene	1 : Group 4_Model_R7.p	10	1.0000	1.0000	1.0000	1.0000	10	0.333	0.765	0.728	0.683	0.189	35.116	53.707	53.858	
2	g4Scenario 2	1 : Group 4_Model_R7.p	10	2.0000	1.0000	1.0000	1.0000	10	0.012	0.744	0.722	0.665	0.095	33.212	53.217	52.500	
3	g4Scenario 3	1 : Group 4_Model_R7.p	10	1.0000	2.0000	1.0000	1.0000	10	0.369	0.372	0.732	0.678	0.192	33.744	53.959	52.929	
4	g4Scenario 4	1 : Group 4_Model_R7.p	10	1.0000	1.0000	2.0000	1.0000	10	0.306	0.765	0.663	0.053	0.189	35.147	52.279	52.811	
5	g4Scenario 5	1 : Group 4_Model_R7.p	10	1.0000	1.0000	1.0000	2.0000	10	0.306	0.765	0.626	0.377	0.189	35.147	52.279	52.811	
6	g4Scenario 6	1 : Group 4_Model_R7.p	10	2.0000	2.0000	2.0000	2.0000	10	0.019	0.377	0.365	0.322	0.097	32.883	52.047	52.342	
7	g4Scenario 7	2 : Group 4_Model_R7.p	10	1.0000	1.0000	1.0000	0.0000	10	0.393	0.746	0.997	0.000	0.178	33.688	142.803	136.705	
8	g4Scenario 8	2 : Group 4_Model_R7.p	10	1.0000	1.0000	4.0000	0.0000	10	0.306	0.765	0.345	0.000	0.189	35.147	52.279	52.811	
9	g4Scenario 9	2 : Group 4_Model_R7.p	10	1.0000	1.0000	3.0000	0.0000	10	0.306	0.765	0.460	0.000	0.189	35.147	52.279	52.811	

Figure 64: Scenarios Table

The figure above shows numerous scenarios that were tested. Again, some of these scenarios have more feasibility than others. In other words, some of these scenarios are not truly part of our exploratory proposed policy implications. Let us discuss those that are truly of concern. For example, g4Scenario7 shows the event when Hyg3 calls out but the schedule and demand stay the same. As can be seen in the chart and the box plot below, the utilization for Hyg2 increases to 0.997 and the average cycle times sky rocket as well. Theoretically, the model shows it's possible but in reality, it's very hard for one hygienist to cover two times the number of adults typically scheduled in a day. This is why the office always uses contracting firms to fill voids when necessary. Next up, we can examine g4Scenario4 or g4Scenario5, both of which show the hiring of an additional hygienist for adult cleanings. The utilizations drop dramatically whereas the cycles times largely remain the same. This makes sense since adding an additional hygienist wouldn't necessarily decrease the cycle times (assuming only one hygienist works on each patient). Next, g4Scenario2 shows the case where an additional receptionist is hired. While this may actually be a feasible recommendation for the office, the model doesn't suggest it as a result of the receptionist's other duties not being considered in the model.



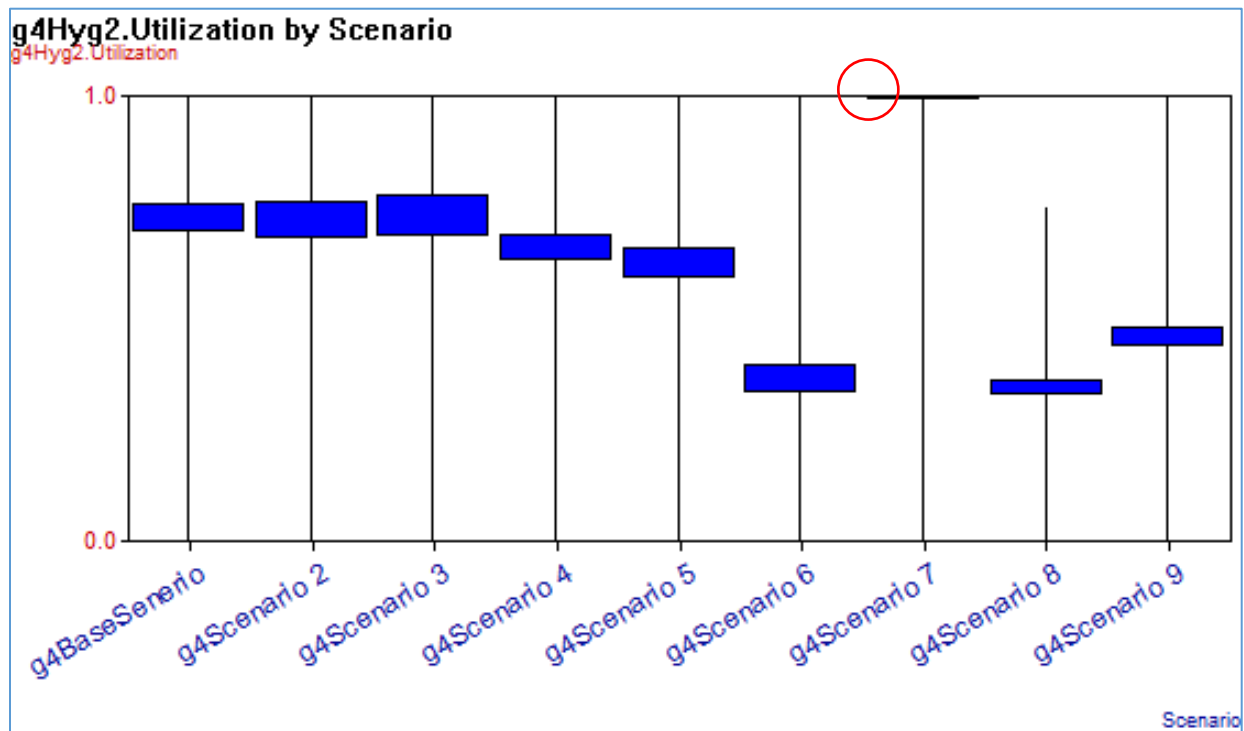


Figure 65: Boxplot of Scenarios for Hyg2 Utilization

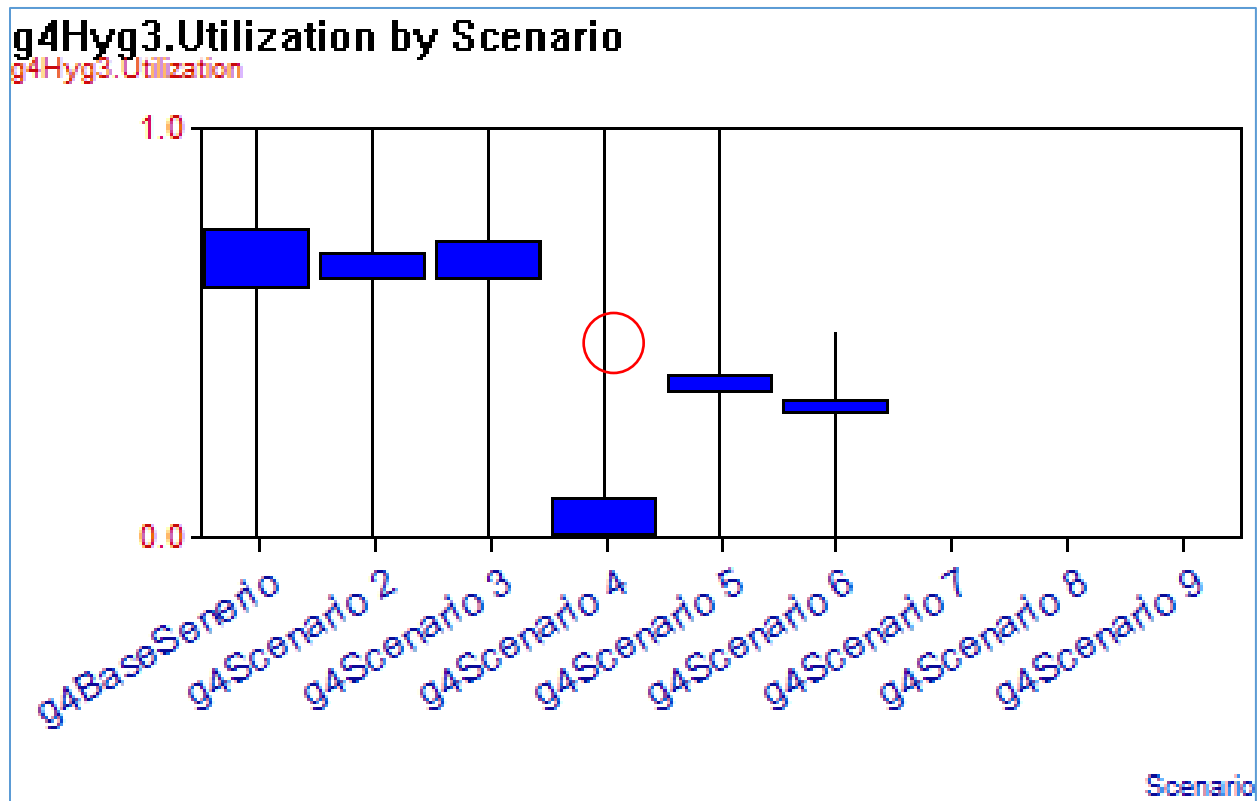


Figure 66: Boxplot of Scenarios for Hyg3 Utilization

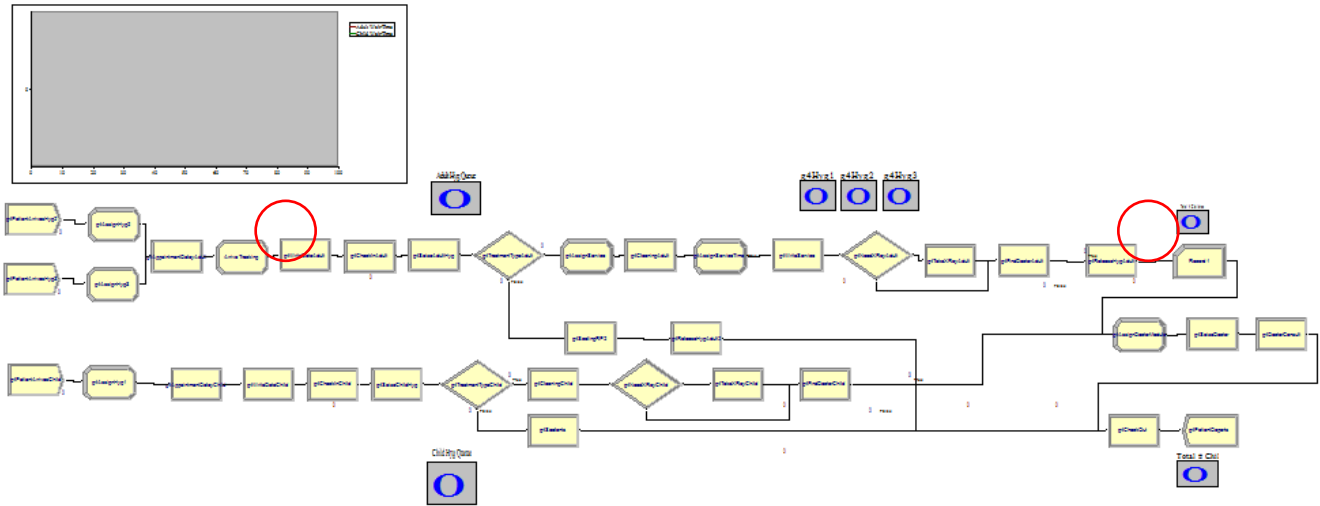
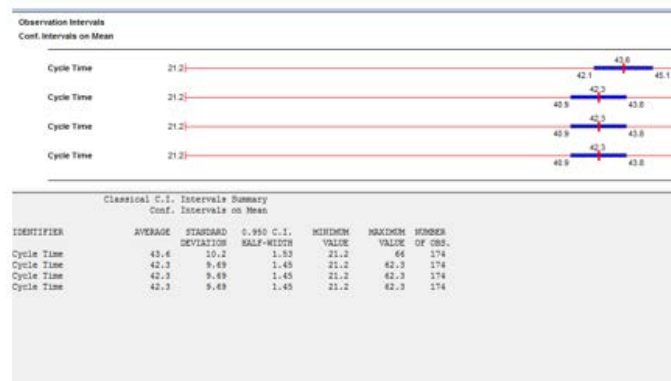
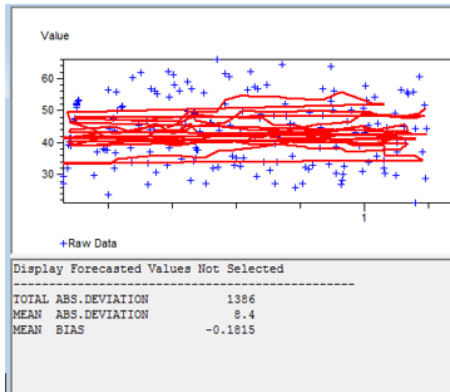


Figure 67: Final Model Using Output Analyzer to Record Cycle Time

Statistic - Advanced Process				
	Name	Type	Tally Name	Tally Output File
1	Scenario Base	Tally	Cycle Time	C:\Users\drowe1\Desktop\out11
2	Scenario 2_2	Tally	Cycle Time	C:\Users\drowe1\Desktop\out12
3	Scenario3_3	Tally	Cycle Time	C:\Users\drowe1\Desktop\out13
4	Scenario 4_4	Tally	Cycle Time	C:\Users\drowe1\Desktop\out14
5	Scenario 5_5	Tally	Cycle Time	C:\Users\drowe1\Desktop\out15



Moving Averages of Cycle Time

Using Output Analyzer comparing the base model we found that the Null Hypothesis failed to reject so adding other Hygienists or Receptionist will not statistically make a difference.

## 11. CONCLUSION

Overall, this project was a great success. In the first half of the project, we were able to apply the tools and lessons we learned from class to a real-world simulation problem. Arrival data and service data were successfully gathered in quantities exceeding those required. A full dental process was successfully simplified and mapped by a team of engineering graduate students. Descriptive statistics, ANOVA, and fitting distributions in Input Analyzer were heavily utilized in the data collection and analysis section of this report. In the future finishing of this project, further statistical analysis may be done on respective categories of arrival data as well as service data in Minitab. Some of the results in Input Analyzer at the finer process step levels look good and pass the Chi-Square test of distribution fitment but others don't. When the corresponding p-value of the Chi-Square test is below 0.05 in the preceding screenshots, the best fit curve found by Input Analyzer is proven to be a bad statistical fit. In other words, it wouldn't be of much use to make predictions based on. Check-in, adult cleaning, child cleaning, doctor consult, find doctor, and scaling and root planeing all have distributions that pass the Chi-Square test of distribution fitment. With the slight trend of seeing better fits at finer levels, it is our recommendation to the Harmony Dental Group to collect as much data as possible so that more data points can be analyzed. For example, the final model uses interarrival data for each of the three individual hygienists. Each of these three distributions had p-values in the Chi-Square test over 0.5 (0.479, 0.231, 0.229). Again, the interarrival data collections divided by day of the week and time of day were combined because they proved to be statistically indifferent.

In the second half of this report, the data collected and analyzed in the first half of the report was used in the building and running of the final simulation model. The fitting distributions previously discussed were used in the model. The model underwent numerous revisions as its behavior was adapted to reflect that of real life. Common sense checks and balances along the way led to the refinement of the model. Next, the model was validated using simulation data that was generated by the model run. The actual and simulation data sets were tested for normality and homogeneity where needed. Adult interarrival times were the only group of data sets that required a Kruskal-Wallis test. Next, the performance of the model was evaluated using Arena's numerous performance metrics. Cycle time, wait time, cleaning time, and queue are several examples of metrics that were reviewed. Utilization metrics showed that the lowest utilization of the three hygienists was Hyg3 with 0.68. Hyg1 had the highest utilization of 0.76. Finally, Arena's Process Analyzer was used to study numerous scenarios that encompass common and applicable staffing considerations.

In conclusion, this project was a great success. In addition to the proven validity of the model, the lessons learned in class were reviewed and utilized in a real-world example. The value of simulation model should be clear and it is our hope that the Harmony Dental Group will continue collecting and analyzing data.