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The Programmatic Generation of Discrete-Event Simulation Models from Production Tracking Data

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ABSTRACT

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Simulation Models from Production
Tracking Data

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Discrete-event simulation can be a useful tool in analyzing complex system dynamics in various industries. However, it is difficult for entry-level users of discrete-event simulation software to both collect the appropriate data to create a model and to actually generate the base-case simulation model. These difficulties decrease the usefulness of simulation software and limit its application in areas in which it could be potentially useful.

This research proposes and evaluates a data collection and analysis methodology that would allow for the programmatic generation of simulation models using production tracking data. It uses data collected from a GPS device that follows products as they move through a system. The data is then analyzed by identifying accelerations in movement as the products travel and then using those accelerations to determine discrete events of the system. The data is also used to identify flow paths, pseudo-capacities, and to characterize the discrete events. Using the results of this analysis, it is possible to then generate a base-case discrete event simulation.

The research finds that discrete event simulations can be programmatically generated within certain limitations. It was found that, within these limitations, the data collection and analysis method could be used to build and characterize a representative simulation model. A test scenario found that a model could be generated with 2.1% error on the average total throughput time of a product in the system, and less than 8% error on the average throughput time of a product through any particular process in the system. The research also found that the time to build a model under the proposed method is likely significantly less, as it took an experienced simulation modeler .4% of the time to build a simple model based off a real-world scenario programmatically than it did to build the model manually.

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1 INTRODUCTION

1.1 Background

Discrete-event simulation software has proven to be a reliable tool for system improvement, because it is able to assist a user in identifying and solving problems. An accurate simulation model also gives the user an opportunity to explore a defined system or test “what-if” scenarios without having to invest the time and money that would be necessary to test out different scenarios on the actual system. These benefits are infrequently realized in industry, because entry-level users of discrete-event simulation software find it difficult to gather the data necessary to create a simulation and also have difficulty using correctly gathered data to create a base case scenario. Without the base-case scenario it is difficult to explore the system or test “what-if” scenarios using simulation.

However, if discrete-event simulation software were able to reduce the amount of training, experience, and time necessary to create accurate simulation models, then a discrete-event simulation tool would be useful for a larger subset of people. The use of discrete-event simulation tools would likely increase due to the more favorable balance between the time invested in creating the model and the benefits of the insight gained from the model.

1.2 **Objective**

The purpose of this thesis is to develop methods for collecting and analyzing product location data as it moves through production in order to programmatically create discrete-event simulation models. The research answers the following questions:

1. Can timestamp and location data collected through a GPS tracker be used to facilitate programmatic model creation?
2. Can programmatic model creation tools be used to facilitate model creation in a way that product flow and processing is determined through analysis of a sample of product location data as it moves through a system?
3. Can the lead time required to create an accurate simulation model be reduced by using automated data collection and programmatic model creation?
4. What types of data are ignored or unachievable through this form of analysis?

1.3 **Justification**

The following two problems are currently experienced by users that are beginning to use discrete-event simulation software:

1. The data collection phase of a project does not always occur in the same time period as model creation, which often results in inaccurate model results.
2. The user experiences a high lead time from the start of model creation to getting results of simulated what-if scenarios.

Currently discrete-event simulation software has a steep learning curve, which necessitates large amounts of training and/or expertise in order to produce models that can accurately depict the real-world scenario that is being simulated. Over the years many changes have been made in various discrete-event simulation software packages to try to reduce the learning curve, and enhance the ability of an entry-level user. These changes have managed to decrease the amount of coding experience and other skills necessary to model common scenarios. However, many entry-level users of discrete-event simulation software still become discouraged by the amount of training, experience, and, most importantly, time that is necessary to achieve worthwhile simulation results. By supplying a possible solution to this difficulty the usefulness of simulation software can be enhanced. However, this research does not presume that training and experience will no longer be useful, as any significant modifications of the base case will have to be done by a more experienced modeler.

1.4 **Limitations**

This research is limited to the scope of systems where the products physically move through a set of processes. It also does not attempt to include in the generated simulations the actions of indirect resources on the product. Therefore, this method would be ineffective in instances where indirect resource capability is the main objective of simulation, and would be more effective where throughput and bottleneck analysis is the desired result of simulation. For additional limitations of method see section 5.3 Limitations of Algorithm.

1.5 **Glossary of Terms**

Computer Simulation: A computer model that is made to represent or mimic an actual system. The model is then used to draw inferences on the behavior of the actual system.

Discrete-Event Simulation (DES): A subset of computer simulation that is involved in modeling systems where events drive the system. This is in contrast to other forms of computer simulation including fluid simulation, stress simulation, and others where events do not drive the simulation.

Processor: A step in a system in which the product is contained for a determined interval of time. This step differs from a queue, because although the interval of time may be non-constant it is not considered waiting time. Movement of an item between system steps is also modeled as a processor in this research.

Product: The item that moves through the system. This is the part of the system in the research that is tracked using a GPS tracking system.

Queue: A step in the system where the time can be classified as waiting time. The waiting time could be determined be either a downstream or upstream process.

Route: The specific series of processors and queues that the product moves through in the system. The route can be constant or variable. Different products may experience different routes or routing as they move through the system.

System: The aggregate of all non-product items making up a model.

2 LITERATURE REVIEW

2.1 Problem Definition

There is an abundance of articles both within academia and from without that highlight the problem that is being addressed by this thesis. A particularly good article highlights the amount of time in a simulation model that is spent collecting, analyzing, and inputting data into the simulation model (Skoogh, 2012). This article makes the following noteworthy observation:

> However, despite its potential, industries worldwide have not adopted DES completely in their production development process. One reason is arguably that production simulation projects tend to be slow in providing clients with model results. This is a significant disadvantage, since manufacturing development and design projects usually rely on rapid responses from analyses. Hence, renouncing precision in favor of quick response, organizations are tempted to choose less complex tools. (Skoogh, 2012)

This observation is helpful in defining the problem that DES is currently experiencing. The lead time between starting the analysis and getting results seems to be prohibitively long for many potential users. This article also mentions that "activities in the input data management process constitute around one third of the total time consumption in DES projects." This is important, because the proposed data collection and analysis portion of this research aims to reduce both that time and the model creation time in the total time of a DES project. It is clear that a problem currently exists, because of the long lead time in DES projects. It is also clear that resolving this problem could lead to DES being used more frequently as a tool.

2.2 **Programmatic Model Generation**

Programmatic model generation is a topic that has been explored in a variety of other articles. One article, “Stochastic generation of discrete-event simulation models,” identifies the different steps that are necessary in creating models (Huber, 2008). These steps are identified as the following: definition of input parameters, model hierarchy creation, component placement, component linkage, and variable variation. This research attempts to programmatically accomplish each of the steps as outlined in this previous research. For similar research that has been done to programmatically create models for forms of data analysis other than simulation see Section 2.4 Creating Models from GPS Data.

2.3 **Data Collection for Simulation Models**

Many articles have identified data collections methods for the successful creation of statistically representative simulation models. An article, “Automated input data management: Evaluation of a concept for reduced time consumption in discrete event simulation,” proposes an idea that attempts to reduce the amount of time that is necessary for data input in creating a simulation model (Skoogh, 2012). The idea presented is a complicated system that allows for real-time simulation updates. The system derived in this research accomplishes a similar goal to the solution that will be proposed, but seems to do it in a much more intrusive manner to an operation than would be feasible in many manufacturing environments.

2.4 **Creating Models from GPS Data**

There are a few articles of research that have used GPS data to create models of real-world scenarios, but they were not creating discrete-event simulations. Most of these articles dealt with analyzing traffic flow patterns, and creating models of traffic networks. Programmatically modelling traffic networks actually has many similarities to programmatically generating discrete-event simulations, because they both must identify when events happen, how long they take, and how objects move between those events. There were a couple interesting articles that attempted to use GPS data to create models of traffic flow.

One article was using GPS data to try to identify the most efficient traffic route and then compared that route to those that people chose manually (Spissu, 2011). This article establishes some of the difficulties with using GPS data from the modelling of routes. It found the following:

> Although GPS-based data collection and, in particular, smart phone data collection have been shown to offer a number of advantages in the present and earlier studies, some technological limitations still affect data quality. In this work, 42% of the reported trips could not be associated with the corresponding routes mostly because of canyon effects, signal reflex, and user carelessness. (Spissu, 2011)

The findings from that article make it clear that care must be taken when using GPS to ensure that data is collected in areas where its limitations can be reduced.

Another article was attempting to estimate travel time of routes through an arterial network of roadways (Pan, 2007). The difficulty with this task is that arterial roadways have many stops signs, stop lights, and congestion that makes classifying that time difficult. The planned stoppages (i.e. stop signs and stop lights) were classified in the research as links. The method of the research was to use continuously sampled GPS data to identify when a vehicle was decelerating and then attributed any time between that deceleration and the next acceleration to the closest link (Pan, 2007). That link was then characterized by an average of the experienced times during the sample. This article proposes some similar concepts to those that are being presented in the current research, because the current research also uses acceleration to identify when an object is in a new process. The current research then associates the time between that acceleration and the next acceleration as belonging to the process. This article found that it was able to determine the link time (the time between when a person started decelerating at a stop sign or stoplight to when they finished accelerating afterwards) with about 5.5% error using data collected with a GPS data collection system.

2.5 GPS Accuracy

This research depends on a data collection tool that can provide a coordinate position. Specifically this research used GPS coordinates to define product movement through a system. In order to know the limitation of this research it is necessary to know the limitation of the devices that were used in collecting the data. The tool's limitations directly influenced the types of systems that can use the proposed methodology to create a simulation model. The current accuracy of a worst-case scenario for uncorrected civilian GPS coordinates at a 95% confidence level is 7.8 meters (Department of Defense, 2008). However, if one uses multiple satellites, augmentation services, or other correction methods it is realistic to achieve accuracies within a few centimeters (NGS, 2014). Therefore, it is reasonably possible to use this method on systems where the significant distance between processes is greater than the limitation of the data collection tool, which is a few centimeters. Other methods could be used to gather this type of data including ultrasonic methods, RF mapping, etc., but those methods, due to their less developed nature, weren't explored in this research. GPS is especially useful because of the active development that is occurring in this area. With newer GPS satellites that are currently in development, it is anticipated that uncorrected civilian GPS accuracy will drop to 0.63 meters

(United States Air Force, 2014). The current research used uncorrected GPS coordinates, which resulted in significant error in scenarios with movement on a small scale.

Various research articles have used a similar GPS data collection method. One such research article found that a GPS data collection system could be used to adequately gather location and timestamp data to track the usage of construction equipment on a construction site (Pradhananga, 2013). That research acknowledged that there are multiple approaches that could be used to collect location data, and that each has benefits and limitations. However, as it states:

> GPS is well known to work independently (defined as a device that may not require any other installation of technology on a project site, other than a device on the resource to track it) and provide real-time data (defined as equal or greater than 1 Hz data update rate)… GPS devices are also affordable and easy to install. The data it provides can also be analyzed with relative little computational effort. For these reasons, this work presents the implementation of GPS technology for tracking the location of construction equipment as it relates to work sampling, including cyclic activities which are very common in earth moving operations. (Pradhananga, 2013)

Similar benefits are recognized in the current research by using GPS instead of other methods for tracking location. Another finding from that same research was the observed accuracy that was achieved with low-cost GPS systems, which was 0.68-4.36 meters (Pradhananga, 2013). It found the following:

> In sum, the GPS data loggers were found to perform better under clear view of sky while the performance degraded with increasing obstacles. The standard deviations were high compared to the value of the mean in all cases, indicating that the readings were not consistent and can vary significantly. It should also be noted that error rates vary among data loggers. The above error tests, however, provide a general idea of what data low-cost easy-to-install GPS data can provide. (Pradhananga, 2013)

From this analysis it would seem that either a higher quality GPS device would need to be used in order to get data using a GPS for a small scale system, or the GPS device would need to be better than the low-cost option used in the aforementioned research.

2.6 **Multi-Resolution Modeling**

An interesting caveat to this research is the capability to automatically do multi-resolution simulation modeling. The idea of multi-resolution modeling is presented in the article "Using dynamic multiresolution modelling to analyze large material flow systems" (Dangelmaier, 2004). This article introduces the idea of multi-level simulation modeling. It also presents the idea of model scope indication by view distance in the model. This suggests that representative simulation models can be achieved by increasing the scope in one area of the simulation that is crucial to the modeler while decreasing the scope in other areas. This concept may be a possibility for the simulation models created using the method that are proposed in this thesis.

3 METHODOLOGY

3.1 Introduction

The methodology for developing an algorithm for programmatically generating discrete-event simulation models from production tracking data was separated into the following three sequential phases:

Phase 1 – Development of Model Creation Algorithm

Phase 2 – Development of Data Collection System

Phase 3 – Scenario Testing

3.2 Development of Model Creation Algorithm

This phase of research is concerned with being able to replicate a manually generated simulation model using a programmatic model creation algorithm. For this phase a simple test case was generated in simulation software. The software used in the research was FlexSim, which is a discrete-event simulation software provided by FlexSim Software Products, Inc. The model was a simple system with six processing steps. The model included the following basic procedures: processing steps, multiple exit locations, route reentry, route consolidation, route splitting, probabilistic routing, and variable processing times. The model was developed in order to create data that would be used to try to programmatically mimic the original model. The dataset was created from the model by recording the absolute x, y, and z location to a general origin and the time of every product in the system for every second that the model ran. The dataset included data for 100 products as they went through the modeled system. This data was then saved in .csv format and imported into excel for data analysis.

Once the dataset was gathered from the initial model, an Excel VBA-based algorithm was written to comb through the data to attempt to identify the original processes and routing. For more information about the data analysis algorithm see section 4.1 Data Analysis Algorithm. This algorithm was then capable of identifying the steps in the system, a distribution that characterized the processing times of each step, the capacity of each step, and the routing through the system. The model was then analyzed to determine the accuracy of the programmatically generated model to the original simulation model using some key output characteristics, which included the average processing times of each processing step in the model and the average throughput for each step in the model. The results of those comparisons can be found in section 4.3.1 Generated Simulation. After developing the programmatic model creation algorithm it was important to determine the limitations of the algorithm. These limitations and their significance were explored and the results are found in section 5.3 Limitations of Algorithm. Phase 1 was finished once the algorithm was created and the limitations identified.

3.3 **Development of Data Collection System**

The data collection system was developed to provide the following information about a product at a constant interval as it moved through the system:

1. Unique Product Identifier – An indexed number for each product observed.
2. Longitude – The longitudinal position of the observed product at a given time.
3. Latitude – The latitudinal position of the observed product at a given time.
4. Product Type Identifier – An indexed number for each product type observed.
5. Timestamp – The time (in seconds) since the beginning of observation

Once this information was collected the longitude and latitude were converted to X and Y coordinates based off of an origin at the first position of the first observed product. The calibration time was also removed from the beginning of the dataset. Once these steps were done this information created a collection of data points that looked similar to the example in Table 3-1.

Table 3-1: Example of Data Gathering Tool Output

Item	X	Y	Type	Time
1	0	0	1	12
1	1.519118	-1.61331	1	13
1	3.038236	-3.22662	1	14
1	1.082859	-6.48886	1	15
1	-2.39164	-8.1378	1	16
1	-20.7806	-17.7902	1	17
1	-35.695	-25.7936	1	18
1	-62.5246	-33.7249	1	19
1	-74.4397	-33.6527	1	20
1	-95.1282	-33.5273	1	21
1	-103.901	-33.4741	1	22
1	-115.156	-33.4058	1	23
1	-115.419	-33.4042	1	24

3.4 **Scenario Testing**

Scenario testing was done in an attempt to verify the capability of the proposed methodology. Two scenarios were developed in order to test the data collection system and the simulation software data translator that was used to build the models from the data analysis algorithm output.

The first test scenario was done on a large scale by identifying a driving route between two locations. The route went through stop signs and traffic lights, which broke the route into multiple steps. The route was driven three times in order to act as three products moving through the system. The route was done on a large scale in order to determine the accuracy of model creation where the amount of tool induced variability was minimal. The actual time for each segment was recorded during each route. The car was also GPS tracked during each route. The aggregated GPS data was then sent through the programmatic model creation algorithm in order to create a representative model, and to identify the various segments. The programmatically identified time for each segment was then compared to the recorded time. The distribution of average trip times was also compared to the distribution of calculated trip times. The results of this scenario can be found in section 4.3.2 Scenario 1 – Car Route.

The second scenario that was analyzed was to determine if the GPS data collection system would be accurate enough in a small production system. This scenario was setup by creating five production steps in a small room. The products moved through the system according to an established model. The time spent in each location was determined variably by predetermined distributions. Once the system was setup, five products were tracked using GPS as they moved through the system. The aggregated GPS data for the five products was then sent through the model generation algorithm to create a simulation model to represent the predefined system. The similarity between the programmatically created model and the predefined system was then analyzed. The analysis of this scenario can be found in section 4.3.3.

4 RESULTS AND ANALYSIS

4.1 Data Analysis Algorithm

To convert GPS data to a discrete-event simulation model it is necessary to run the data through an algorithm that makes calculations and crucial assumptions. The algorithm calculations can be broken into three major steps, which are the following:

1. Identify the various process steps.
2. Characterize each of the identified steps.
3. Identify the path the products take as they flow through the process.

As the algorithm moves through these calculations it makes many assumptions. Knowing the implicit assumptions in the calculations is a critical factor in creating an accurate model using the algorithm described below.

4.1.1 Identifying Process Steps

The first step in the algorithm is to identify the process steps. This is the most robust part of the model generation algorithm, because it is the one with the least presumptive assumptions. This step can be broken down into the following minor steps for each observation:

1. Create a chart of the difference in the absolute value of the instantaneous acceleration of the object as it moves through time.

This step is done by finding the distance that a tracked product traveled between each data point, and then finding the difference between that calculated point and the previous calculated point. This gives the instantaneous velocity of the product at each time interval. Then the acceleration is found by calculating the difference between those velocities. When charted this gives a chart that should look something like the graph in Figure 4-1.

Figure 4-1: Acceleration in Time of a Product and Cutoff Point

2. Determine the differential acceleration cutoff point.

This cutoff point determines the scope of the resulting model. The lower the cutoff point the more processes we are likely to create from the data, because it will be more sensitive to change. The higher the cutoff point the less likely we are to experience processes that are driven by noise in the data. Therefore, the cutoff point should be chosen in a position where it is less than all relevant accelerations, but is higher than all accelerations that are a result of noise. An example of such a cutoff is shown in Figure 4-1.

3. Determine the location sensitivity measure.

This sensitivity is basically a location sensitivity. A location sensitivity measure must be used because exactly the same GPS locations are unlikely in simultaneous observations. Therefore, one must be willing to group processes that start and end in similar areas as the same process. Therefore, a location setting of one would mean that if a process was found that started within one distance unit of an existing process, and ended within one distance unit of the same existing process, then it would be considered the same process.

4. Split each observation into its respective processes using the acceleration cutoff point.

If the acceleration is above the cutoff point, then the points before the cutoff point are considered a separate process than the points after the cutoff point. For each of the identified processes calculate a processing time, by subtracting the last time in the process by the first time in the process. Also determine the process starting point by the first GPS coordinate, and it's ending point using the last GPS coordinate.

5. Using the location sensitivity measure, group similar processes between observations.

Use the methods described in detail in the next section, which allow for stochastic representation of the process.

These steps use the GPS data, and a couple cutoff points to programmatically break the data into the various processing steps that the product experienced during the observed run.

4.1.2 Characterizing Process Steps

The next step in the data analysis algorithm was the need to characterize each of the process steps that were identified. This process can be done in the following, not necessarily sequential, steps:

1. Identify a stochastic representation of the processing time for each step

This can be done in a variety of ways. The data could be run through a system that identifies a distribution with the highest goodness of fit. The distribution could then be sampled from for the stochastic representation. However, in this research it was instead determined to generate a stochastic representation whose method could be applied to any situation and adequately represent the sample. The distribution is described in detail in Appendix D, but it is basically determined by placing 20% of the area under the probability density curve as a uniform distribution between the observed minimum and the data point at the 20th percentile of the data. Then doing likewise for each 20th percentile above that until the last uniform distribution is located between the 80th percentile of data and the maximum. This distribution does not give a perfect representation of the data. However, given the other much more important assumptions used in this generation algorithm this assumption does not seem egregious.

2. Identify if the process is deterministic or indeterministic

The classic examples of both would be a step with a defined process time being deterministic, and a step that acts as a queue being indeterministic. This research does not attempt to create a method to identify if a process is deterministic or indeterministic. It assumes that every process is deterministic. However, this assumption does limit the effectiveness of the algorithm in creating exactly representative simulation models. This step might be achieved by using the methods explained in section 4.4.1.3. Processing Time vs. Delay Time Identification.

3. Identify a pseudo-capacity of each step

This step can only be done if the sample was taken from sequential products. It is done by looking at each process step at each unit of time and finding the time unit where the maximum number of products were in the process step. That maximum can then be considered a pseudo-capacity of that step in the system. This method is extremely limited, because it is only an estimated capacity based off of observation, and not necessarily the true limit of the particular step's capability. A true capacity would reflect how many units a step could handle in isolation, however this method creates a capacity that only reflects the experienced maximum in the sample, and not a true maximum. This method will underestimate the true capacity of any step where it's capacity is being limited by another step in the system. Therefore, if capacity considerations are an important in the desired outcome of the model it would be prudent to adjust the capacities of the steps of the generated model to more accurately reflect the observed real-world scenario.

4.1.3 Identifying Product Flow

The next step in the data analysis algorithm is creating the flow by which the products move through the process steps of the system. This is done by accomplishing the following two tasks:

1. Identify the flow paths

To identify the flow paths it is necessary to recognize the path that each observed product experienced as it moved through the system. The method to determine paths is to create a list of the orders a product went through. Once this list is generated for each product we can then make sure to send the simulation program the necessary information to make the connections between those events. The output shown in Table 4-1 does this in the columns labeled “IN” and “OUT”.

2. Characterize the flow paths

This is the more difficult of the two tasks associated with creating the flow paths. This step attempts to identify the logic by which a product decides which step to move to when there are multiple options. This is not an issue when one step moves to only one other step. But in other situations, such as which step to proceed to in a situation where one step can go to multiple other steps, the characterizing of the logic associated with that particular flow is important in order to accurately reflect the real-world scenario. In order to simplify the model generation algorithm it was assumed that the generated models relied on probabilistic routing. In other words it was assumed that, in a situation where a split in routing occurred after a step, a defined percentage went down each route. If this algorithm was used on a system with multiple product types, then each product type’s flow would be generated independently. This would be done by creating probabilistic routing for each case. The algorithm would then be able to split routing by product type by sending 100% of a theoretical product type 1 to one step and 100% of a theoretical product type 2 to another step. The assumption of probabilistic routing allows us to analyze the data by looking at every time an observation left a particular step and then develop a percentage from the results of where the observations ended up going. This method is not complete as a lot of routing is not done in a probabilistic manner. However, one could develop methods to identify various other types of routing such as first available or round-robin (see section 5.3.1.2. Probabilistic Flow).

4.1.4 Algorithm Output Capability

Using the methods in the algorithm it is possible to generate an output that looks something like Table 4-1. Table 4-1 is the output generated for the car route scenario (see Section 4.3.2).

Table 4-1: Output of the Data Analysis Algorithm from the Car Route Scenario

Process	Start X	End X	Start Y	End Y	Angle	Length	IN	OUT	Times	Distributions	Pseudo-Capacity
0	0	-145.78	0	325.3091	114.1385	356.4799	test|-1`1		37~37~48	fivepointdistribution(37~37~37~39.2~43.6~48)	3
1	-146.535	74.68844	371.9068	694.5784	55.56544	391.225	test|0`0.6667		12~31	fivepointdistribution(12~15.8~19.6~23.4~27.2~31)	2
2	131.5003	857.4866	700.4009	698.6524	-0.13799	725.9884	test|1`1		45~15	fivepointdistribution(15~21~27~33~39~45)	2
3	930.8949	1321.835	696.8568	695.7362	-0.16423	390.9417	test|2`1~13`1		8~9~8	fivepointdistribution(8~8~8~8~8.4~9)	2
4	1396.76	1765.415	695.787	689.7104	-0.94433	368.7053	test|3`0.6666		8~12	fivepointdistribution(8~8.8~9.6~10.4~11.2~12)	2
5	1839.646	2203.096	688.7353	680.8994	-1.23508	363.5344	test|4`0.5		8	fivepointdistribution(8~8~8~8~8~8)	1
6	2255.831	2648.232	679.9061	669.3899	-1.53513	392.542	test|5`1~4`0.5		10~15	fivepointdistribution(10~11~12~13~14~15)	2
7	2683.38	2746.572	667.9305	39.19389	-84.2607	631.9042	test|6`1~14`1		20~18~18	fivepointdistribution(18~18~18~18.4~19.2~20)	2
8	2746.214	2744.277	-20.1294	-950.257	269.8807	930.1292	test|7`0.6667		22~23	fivepointdistribution(22~22.2~22.4~22.6~22.8~23)	1
9	2744.241	2368.044	-976.235	-1047.52	190.7297	382.8907	test|8`1~16`1		15~18~20	fivepointdistribution(15~16.2~17.4~18.4~19.2~20)	2
10	2336.078	1072.152	-1047.12	-1037.96	179.5844	1263.959	test|9`1		29~27~15	fivepointdistribution(15~19.8~24.6~27.4~28.2~29)	2
11	1009.297	352.4403	-1036.97	-1041.03	180.3541	656.8693	test|10`1		16~19~22	fivepointdistribution(16~17.2~18.4~19.6~20.8~22)	2
12	341.7351	49.22311	-1041.31	-1044.54	180.6324	292.5298	test|11`1	test|-2`1	22~25~23	fivepointdistribution(22~22.4~22.8~23.4~24.2~25)	2
13	-156.655	581.5314	372.2545	674.5336	22.26856	797.6786	test|0`0.3333		23	fivepointdistribution(23~23~23~23~23~23)	1
14	1562.073	2637.7	671.7496	655.1939	-0.88181	1075.754	test|3`0.3333		23	fivepointdistribution(23~23~23~23~23~23)	1
15	2746.353	2745.21	7.54237	-380.19	269.8312	387.7336	test|7`0.3333		9	fivepointdistribution(9~9~9~9~9~9)	1
16	2745.062	2744.242	-443.339	-975.382	269.9117	532.0429	test|15`1		13	fivepointdistribution(13~13~13~13~13~13)	1

The simulation software package is then required to have a translator that takes these simulation outputs and programmatically create the steps and flow for the model (see Table 4-2).

Table 4-2: Algorithm Output Usage in Model Input

ALGORITHM OUTPUT DATA	FLEXSIM MODEL INPUT DATA
Process Unique Identifier	Object Name
Start X	Object X Position
Start Y	Object Y Position
Angle	Object Z Rotation
Length	Object Length
In	Object Input Connections, Input Object Flow Logic, Source Locations
Out	Sink Locations, Object Flow Logic
Distributions	Object Processing Time
Pseudo-Capacity	Object Max Content

A translator was developed for the FlexSim simulation software package that took the data and generated a model within the software. The FlexSim translator code can be found in Appendix C – FlexSim Data Translator. The translator followed the following logical steps in creating the model from the output data:

1. Create the object in the model
2. Name the object
3. Position, rotate, and elongate the object so it is in the correct visual space between the start and end points
4. Apply the output processing time to the object
5. Apply the pseudo-capacity amount to the object
6. Create sources and sinks in the model
7. Connect the objects using the output flow path
8. Apply the flow logic to the object

Once the translator was created it was possible to collect raw GPS data using the data collection tool, analyze it using the data analysis algorithm tool, and then make that output into a model using the FlexSim data translator tool. This completed the steps necessary to programmatically generate a simulation model from raw GPS data.

4.2 **Data Gathering Tool Variation**

The data gathering tool uses GPS to identify latitude and longitude coordinates at a given time interval for the duration of the product's time in the system. These latitudes and longitudes were then converted to a coordinate system with the origin being the first recorded location of the first observed product. GPS was chosen over other coordinate location identification methods due to its developed nature and accessibility for most parties. The GPS used in the experiments was the GPS chip in an off-the-shelf cellular phone. This GPS technology was intentionally picked, because it fairly represents the inaccuracies in results that could be expected from many GPS systems. Given the variability from the tool itself it was determined that the algorithm, in order to be useful, would have to be able to deal with the inaccuracies created by the tool. Therefore, the two aforementioned scenarios were developed to test the accuracy of the GPS data gathering tool.

4.3 **Scenario 1 - Car Route**

The first scenario used a car route around a large rectangular area (2800’ x 1800’), with the minimum distance between changes in acceleration being about 100’. The setup of the scenario was described in Chapter 3. In doing some pre-experiment trials it was noted that a warmup period was required in order to calibrate the device. In the experiment a calibration period of 30 seconds was used at the beginning of each trial. Those calibration observations were then discarded from the data. Once the experiment was setup and a suitable location determined, the experiment was run. Figure 4-2 is a scatterplot of the location of the vehicle during the two

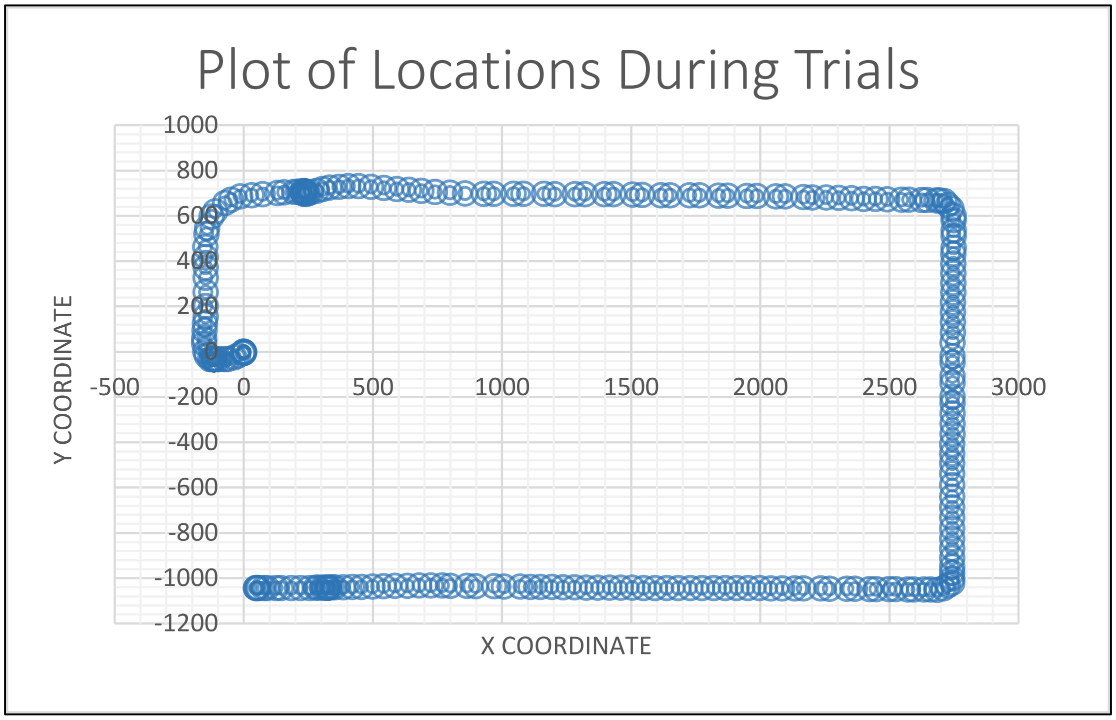


Figure 4-2: Scatterplot of Coordinate Locations During Trial 1

trips. From the scatterplot one can somewhat visually see the transitions between processes in the system. Once this data was gathered it was input into the model generation algorithm that was previously developed. The accuracy of the model generated in this scenario is explored further in section 4.3.2. This experiment seemed to suggest that when used on a large scale the accuracy of the GPS was not an inhibiting factor in the accuracy of the programmatically generated model. This suggests that the GPS tool would be, at least partially, capable of being used in conjunction with the model generation algorithm to create models with movements that occur on a large scale like simulations of transportation, supply-chain, logistics, etc.

4.3.1 Scenario 2 - Walking Route

The first scenario was successful in determining that in a situation where the scale of movement was fairly large the accuracy of the GPS tool was not a significant factor. The purpose of the second scenario was to determine the effect that variation in the tool had on the algorithm's model output when the movements between processes were smaller. This scenario was done in an area that was about 20'X20', and the minimum distance between steps was about 10'. The smaller distance between changes in velocity made it so that any inaccuracy of the GPS tool would be more pronounced in the data that was collected. The accuracy of the programmatically generated models is explored further in section 4.3.3.

4.3.2 Limitations of Data Gathering Tool

It was observed that the accuracy of the GPS data gathering tool could play a significant role in the accuracy of the programmatically generated model. As seen in scenario 2, the variation observed in the programmatically generated model was more than the variation that was inherent in the process itself.

GPS accuracy is a factor of the device itself, as some GPS devices are more accurate than others. The GPS device used in this research was not the market leader in accuracy, so it would be feasible that greater accuracy could be achieved through a more precise and accurate GPS system. The necessary amount of precision would be dependent on the physical scale of the subject system, and the desired accuracy of the generated model. For instance, a system could be in a small physical area where the GPS inaccuracy causes 10% more variation than would be expected in the system. If in such a system the desired result was to determine if a simple change would change the output of the system and the change caused a 100% increase in output, then it may be reasonable to accept the inaccuracy of the GPS for the sake of further analysis. However, that would have to be determined based on the risk tolerance of the person or organization that is creating the simulation.

In order to determine the amount of variation that is being caused by the device it would be necessary to do the following things:

1. Create a sample system where movements were on the same physical scale that would be used in the subject system.
2. Apply sample speeds or delay times to each process in the sample system. This can be done by sampling from a distribution or using a flat time.
3. Move the GPS device through the sample system.
4. Analyze the gathered data using the data analyzer.

5. Determine the variation caused by the inaccuracy of the GPS tool in the programmatically generated model by comparing the processing times in the sample system to the processing times in the programmatically generated model.
6. Considering desired outcomes of the simulation model, determine if the tool accuracy is unbearably high for the subject models physical scale.

Using this method it seems possible to determine if a specific GPS tool is accurate and precise enough to be used in the method proposed in this research. If the above method suggests that it is not suitable, then one could look into more accurate and precise GPS devices. If no GPS device seems to work, then it would be necessary to gather coordinate locations in some other way. This could feasibly be done using RFID mapping or by using a barcode scanner as a product enters and exits a station and associating that station with a coordinate location. Each of these techniques could be used with the same data analysis and model generation techniques to programmatically generate a model. The difficulty with the alternative data gathering methods is that they would require additional steps or resources that would not be necessary if one would be able to use the simpler GPS data gathering method.

4.4 **Programmatically Generated Model Accuracy**

One of the important findings from this research is the accuracy that might be achieved in various settings using the proposed data analysis algorithm. Each of the three subsequent scenarios attempted to identify the possibilities and limitations of the proposed algorithm.

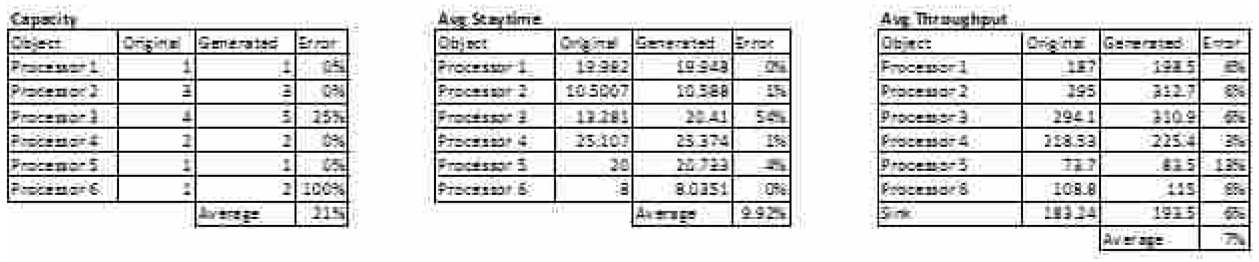
4.4.1 Generated Simulation

To create the data analysis algorithm a model was created in FlexSim, a simulation software package. The model looked like what is seen in Figure 4-3 and had characteristics as described in . A function was then written to get location data for 100 products as they moved

Table 4-4: Characteristics of Manually Generated Original Model

Object Characteristics	Inputs	Outputs	Processing Time	Capacity
Source		Processor 1		
Processor 1	Source	Processor 2	triangular(15, 25.0, 20.0, 0)	1
Processor 2	Processor 1,Processor 6	Processor 3	bernoulli(50, 10, 11, 0)	3
Processor 3	Processor 2	Processor 4, Processor 5	exponential(10, 3, 0)	4
Processor 4	Processor 3	Processor 6, Sink2	25	2
Processor 5	Processor 3	Sink 1	20	1
Processor 6	Processor 4	Processor 2	8	1
Sink	Processor 4, Processor 5			

Table 4-3: Error of Characteristics of Programmatically Generated Model



Capacity

Object	Original	Generated	Error
Processor 1	1	1	0%
Processor 2	3	3	0%
Processor 3	4	5	25%
Processor 4	2	2	0%
Processor 5	1	1	0%
Processor 6	1	2	100%
		Average	21%

Avg Staytime

Object	Original	Generated	Error
Processor 1	19.982	19.948	0%
Processor 2	10.5007	10.588	1%
Processor 3	13.281	20.41	54%
Processor 4	23.107	23.374	1%
Processor 5	20	20.733	4%
Processor 6	8	8.0351	0%
		Average	9.92%

Avg Throughput

Object	Original	Generated	Error
Processor 1	187	198.5	6%
Processor 2	295	312.7	6%
Processor 3	294.1	310.9	6%
Processor 4	218.33	225.4	3%
Processor 5	73.7	83.5	13%
Processor 6	108.8	115	6%
Sink	183.34	193.5	6%
		Average	7%

through the simulation. This data was then fed into the data analysis algorithm. The output of the data analysis algorithm was then fed back into FlexSim by using the "FlexSim Data Translator" code in Appendix C. The characteristics of this programmatically generated model were then compared against the characteristics of the initial model, and a percent error was calculated. Then both the models were run for 100 replications of 4000 time units, and some critical statistics were compared. The comparison of characteristics and comparison of critical statistics, with their resultant percent error, can be found in Table 4-3. The visual comparison of the simulation models can be seen in Figure 4-3. This data suggested an average 21% error in estimating capacity, 9.92% error in estimating time within a step, and 7% accuracy in estimating the throughput of a step. The error could be reduced even further in estimating the time within a step if the distributions had been generated after checking for outliers. This would have resulted in less than 1% error. The algorithm also created the exact flow from step to step within the simulation.

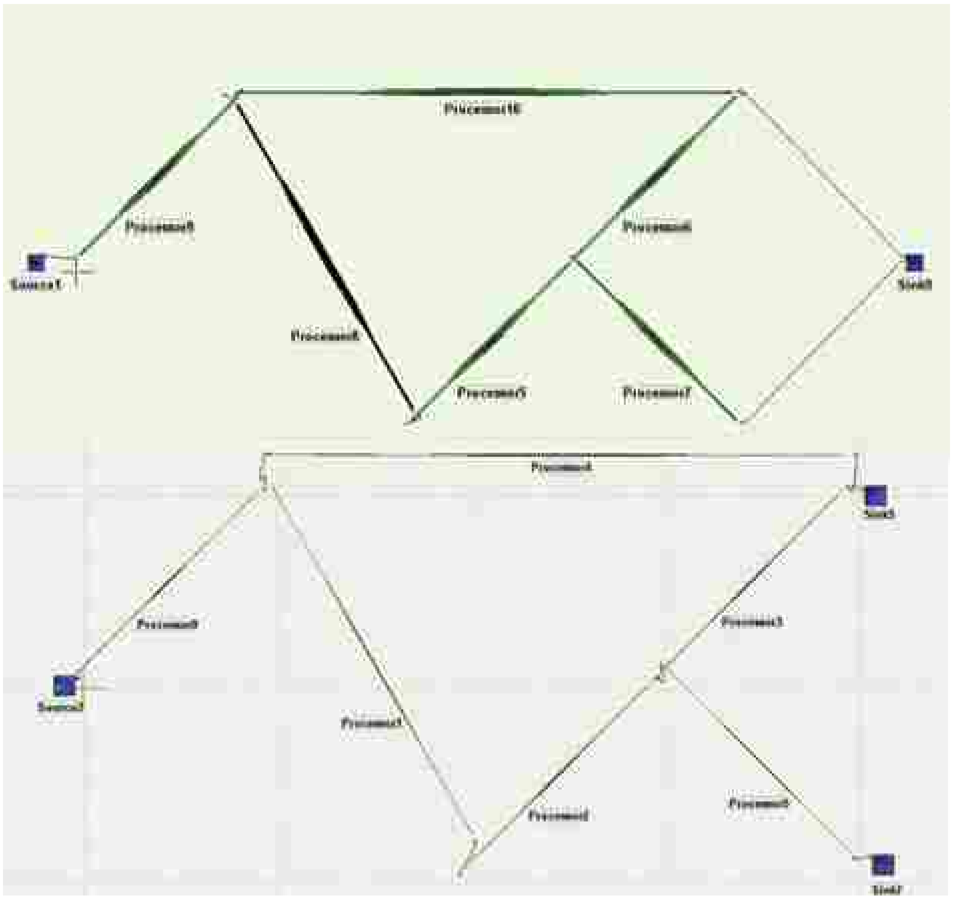


Figure 4-3: Original (Top) and Programmatically Generated (Bottom) Simulations

These results were encouraging, because it meant that the algorithm was able to create a fairly accurate representation of an original system using just the location data of the items as they moved through the system. The minimal size of the error was especially impressive considering the use of an overly simplistic distribution (see Appendix D).

4.4.2 Scenario 1 - Car Route

The setup of this scenario is described earlier, but the results showed that, when the variation of the GPS is minimal when compared to the scope of the movement, it is possible to create a fairly accurate simulation model to represent the system. When performing this experiment the time in each segment of the car route was recorded. These times were then used to create a simulation model using traditional model-building techniques and a simulation model using the proposed methodology. The average times recorded for each segment of the drive where then compared against the averages for each time segment from the manually and programmatically generated simulation models (see Table 4-5 and

Table 4-6). The time to create the programmatically generated simulation model was also compared against the time to create the manually generated simulation model. The model building time for the programmatically generated simulation model was about 5 seconds. The model building time for the manually generated simulation model was about 20 minutes. The model building in both cases was done by someone experienced with the simulation software. However, in the case of the programmatically generated model this experience was not necessary, because the user had to merely run the function, and then select the output file created by the data analysis algorithm. In this situation the time to create the programmatically generated simulation model was just .4% of the time necessary to create the manually generated simulation model, or 240X faster. However, it is likely that the relationship between programmatic and manual model building time is not linear, because the program will take around 5 seconds regardless of the scope of the model, and manual building time is highly dependent on the scope of the model.

Table 4-5: Comparison of Observed and Generated Simulation Processing Times

			Observed			Observed Average	Generated Simulation					Simulation Average	% Error
Process	Input	Output	Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5		
Process 1		2	37.0	37.0	43.0	39.0	37.0	37.0	37.0	37.0	37.0	37.0	5.1%
Process 2	1	3	58.0	29.0	52.0	46.3	48.5	55.0	42.6	45.0	23.0	42.8	7.6%
Process 3	2	4	33.0	35.0	32.0	33.3	31.2	28.1	40.0	30.1	28.2	31.5	5.4%
Process 4	3	5	43.0	45.0	42.0	43.3	40.3	41.3	40.5	40.1	40.6	40.5	6.4%
Process 5	4	6	59.0	60.0	58.0	59.0	68.3	60.9	62.8	67.7	57.1	63.4	7.4%
Process 6	5		22.0	24.0	22.0	22.7	22.6	22.1	24.9	22.3	24.8	23.3	3.0%
Total			252.0	230.0	249.0	243.7	247.9	244.4	247.7	242.2	210.8	238.6	2.1%

Table 4-6: Comparison of Observed and Manual Simulation Processing Times

			Observed			Observed Average	Manual Simulation					Simulation Average	% Error
Process	Input	Output	Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5		
Process 1		2	37.0	37.0	43.0	39.0	40.9	40.6	38.0	39.7	41.2	40.1	2.8%
Process 2	1	3	58.0	29.0	52.0	46.3	45.9	32.3	57.7	40.1	45.4	44.3	4.4%
Process 3	2	4	33.0	35.0	32.0	33.3	32.4	32.7	32.4	33.3	32.5	32.6	2.1%
Process 4	3	5	43.0	45.0	42.0	43.3	45.3	43.9	42.3	44.1	42.3	43.6	0.6%
Process 5	4	6	59.0	60.0	58.0	59.0	60.1	59.3	60.0	58.3	59.2	59.4	0.6%
Process 6	5		22.0	24.0	22.0	22.7	21.5	23.0	22.6	23.3	22.7	22.6	0.3%
Total			252.0	230.0	249.0	243.7	246.2	231.7	253.0	238.7	243.3	242.6	0.5%

From this experiment it is evident that the algorithm was capable of generating a fairly accurate simulation model when paired with the data collection system. There was significant error (2.1-7.6%) between the generated model and the real-world system, and it is more than the error that existed in the manually generated simulation model (.3-4.4%). However, it is feasible to think of situations where the higher error could be traded off for the much faster model-building capabilities of the algorithm.

4.4.3 Scenario 2 - Walking Route

The last scenario's purpose was to test the robustness of the generated algorithm on a small scale, where the system was near the edge of the accuracy of the GPS tool. In this scenario the data was collected over five trials, using the flow and processing times characterized in Table

Table 4-7: Characteristics of Walking Route System.

Process	Input	Output	Processing Time	Capacity
Source		Process 1		
Process 1	Source	Process 2	60	1
Process 2	Process 1	Process 3	normal(120,30)	1
Process 3	Process 2	Process 4, Process 5	normal(90,30)	1
Process 4	Process 3	Process 5	75	1
Process 5	Process 3, Process 4	Sink	120	1
Sink	Process 5			

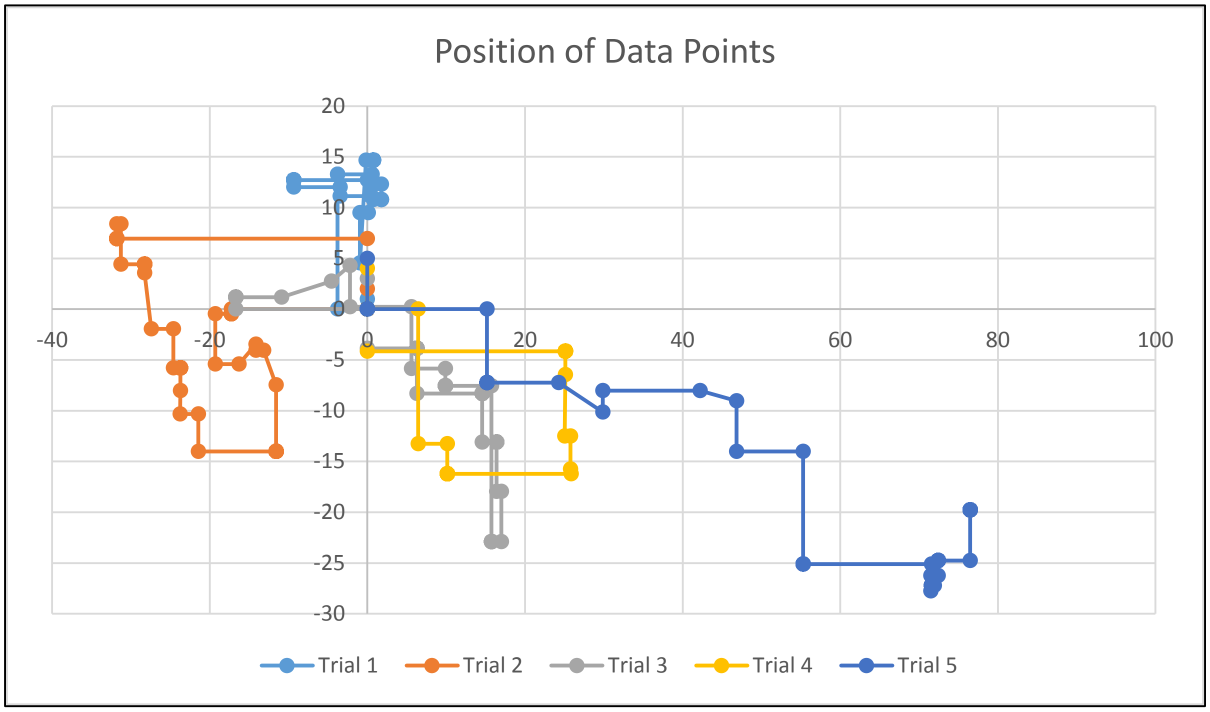


Figure 4-4: Position of Data Points in Scenario 2 Trials

4-7. When this data was then input in the data analysis algorithm, the algorithm was unable to create a model that resembled the original system. This was largely due to the inability of the GPS tool to be accurate to the precision necessary in the system. When the locations of each trial were plotted, it was apparent that the tool was not capable of the precision necessary in this system (see Figure 4-4). Therefore, at this level of detail it was not possible to create a model that completely reflected the original system.

This scenario's experiment shows that the data-gathering tool that was used had limited ability to create useful data on this size system. These limitations could be analyzed and overcome as described in section 4.2.3.

4.5 **Capability of Proposed Model-Building Methodology**

The proposed model-building methodology is capable of creating simulation models that are fairly accurate in representing their real-world scenarios. However, the accuracy of the simulation models is highly dependent on the comparative accuracy of the GPS data collection tool in relation to the size of the subject system. As such, this methodology will likely become more effective as the accuracy of such tools increases.

The results show that this methodology can produce simulations with error on system throughput time at about 2% and error on an individual process time between 3% and 8% (see Section 4.3.2). However, this methodology is not particularly good at estimating the true capacity of individual processes in a system, as it was only capable of determining capacity with a higher average error of 21% (see Section 4.3.1). This is the result of only being able to determine capacity based off of observed limits in the context of the system instead of a processes limit in isolation. The accuracy of other statistics was not analyzed as part of the research. Therefore, the accuracy of additional statistics from a given model would have to be tested against real-world observations to determine if the model was representative.

4.6 **Time-Savings of Proposed Model-Building Methodology**

The proposed model-building methodology seems to be successful in reducing the time and software knowledge necessary to create a working model of a system. It does seem possible to programmatically accomplish many of the model-building steps. From the car route scenario (see Section 4.3.2) it was observed that the time to build a complete model manually with an experienced modeler was about 240X longer than the time it took to build that model using the proposed programmatic model-building methodology. It was also observed that the time difference would increase non-linearly as each additional process would take much more time to manually add to a simulation than each additional process would take to add programmatically. A significant amount of the time difference is caused by the automated fitting of data using the "Five-Point Distribution" (see Appendix D) instead of manually fitting each set of data to a distribution. However, time savings were accomplished in each part of the model-building process.

5 CONCLUSIONS

5.1 Limitations of Algorithm

The models generated using the proposed algorithm have many limitations. These limitations are caused by the nature of the technique and by simplifying assumptions made within the proposed algorithm.

The limitations caused by the simplifying assumptions of the proposed algorithm are not a reflection of the method, but rather are a reflection of the limited scope of this research. Therefore, these particular limitations could be overcome through further research. The limitations caused by simplifying assumptions of the proposed algorithm include the following:

- Limited to a single type of product or item moving through the system
- Limited to probabilistic flow
- Identifying the differences between queues and processors

The limitations caused by the proposed methodology would be more difficult to overcome with the current method, because the proposed method has no identifiable means of overcoming these limitations. The limitations caused by the technique itself include the following:

- Ignoring resources in the system
- Differentiating setup times within a process
- Inability to produce models for immobile systems

5.1.1 Algorithmic Limitations

Algorithmic limitations are limitations that are self-imposed on the presented research in order to create a reasonable scope, and could be overcome in a fairly straightforward way with additional research.

Single Product Type

The proposed algorithm was limited to being able to handle systems with a single type of product or item. This limitation is merely a simplifying assumption of the research, as the method could be expanded to systems that handle many different types of products. In order to do that, the products would not only need a unique identifier attached to them as they move through the system, but would also require a product type identifier that was unique to each product type. Each product type could then be analyzed separately to determine flow. Pseudo-capacity could be determined by finding a maximum number of each product that is ever in a process at a time, and the maximum number of the combined products that is ever in the process at a time. This could then be used to calculate a pseudo-capacity of the process given any product mix. Further research could identify ways to more effectively handle systems with multiple product types.

Probabilistic Flow

The proposed algorithm is limited to dealing with systems where flow is determined in a probabilistic manner, or at least can be accurately represented in a probabilistic manner. A system with this type of flow would send all the output of one process to the subsequent processes using a fairly consistent percentage to each subsequent process. This is a significant limitation, because it is common for a system to include at least one instance where flow can’t be accurately depicted using probabilistic flow. A few common exceptions to this type of flow are systems where flow is determined by sending the product to the first available subsequent process, sending the product to subsequent processes in a round-robin manner, or sending the product to a queue with the shortest waiting time. Each of these types of system flow could be accurately identified in the proposed method, but the proposed algorithm only attempts to identify the method for characterizing probabilistic flow. Each alternative flow method would not be too difficult to implement in the algorithm, because once identified most simulation software packages have built-in methods for building models with different flow characteristics. Therefore, it would be necessary to identify the type of flow, include this information in the algorithm output, and then adjust the software translator in order to include the information in the programmatically generated model.

The first available flow method could be identified using a similar data gathering and analysis method as presented in this research. Flow could be identified as “first-available” by determining if the products used that method in the system. This would be done by looking to see if the product predictably moved to the first available subsequent process. Availability of subsequent processes would have to be determined by their pseudo-capacity, which may not be completely accurate. However, a confidence level could be determined to estimate the flow type as “first-available” if most of the time it did seem to use that method. The outlier instances could then be used in a feedback loop to accurately adjust the pseudo-capacities.

The round-robin type of flow could be determined in a similar method. It could be determined if the products moved from the process to the subsequent process by going to the next possible subsequent process each time a product left the process. This could be combined with the method for identifying the first-available type of flow in order to create first-available round-robin flow, which is a common type of flow in many systems.

Other system flow types could be identified, and methods could be developed to identify flow types and include them in the data analysis and model generation algorithm. Each of the mentioned system flow characteristics could be included in the algorithm, but were not in order to limit the scope of this particular research.

Processing Time vs. Delay Time Identification

One limitation inherent in the data collection method is an inability to instinctually identify the difference between the time a product spends in the system being processed, and the time a product spends in the system waiting or being delayed. This inability is caused by the product constantly sending only movement location data while it is being tracked regardless of whether it is simply waiting for availability. This limitation is slightly overcome in the proposed algorithm by assuming that certain statistical representations of processes are more likely for queues than processing steps, and in such a case the object should be modeled as a queueing step in the system. This could also be overcome by identifying the subsequent steps after a process, the flow of the system, and determining if the product is not moving to the subsequent step because of a limit of the pseudo-capacity. If so, then the process would be modeled as a queue in the system. If not, then the process would be modeled as a processing step in the system.

5.1.2 Methodical Limitations

Methodical limitations are those that are imposed by the proposed methodology. Most of the methodical limitations are caused by the data collection method.

Modeling of Resources

One important limitation of the proposed methodology is the inability to account for additional resources that are often required in a system. For instance, often an operator is shared between machines and acts as a constraint on the system. This methodology would not be able to accurately create models programmatically for systems where the resources play a significant role in constraining the operation of the system. This limitation could feasibly be overcome by tracking the location of the resources in the system and allocating them according to their location, but this is not within the scope of this research.

Differentiating Setup Time from Process Time

Another limitation inherent in the data collection method is the inability to differentiate between setup time and process time in a system. Unless the product moves between the setup time and process time, there is no way to distinguish the difference between the two. This limitation would be difficult to overcome purely using a tracking system, but could be overcome with a hybrid system. A hybrid system would use a different data gathering method, but employ the same data analysis and model building techniques proposed in this research. One example of a hybrid system would be using a bar code scanner to track when a product enters a process, when it starts processing at that process, and when it leaves each process in the system. The processes would then be given a coordinate location. Data would then be generated to show the coordinate location of the product at intervals during its time in the system. This data could then be fed into the data analysis tool, and would allow for the separation of the setup and processing times in the programmatically generated simulation.

Immobile Systems

The most obvious limitation of the proposed methodology is that the product must physically move through the system, and that the movement through the system must be representative of the processes being performed on the product. This is not true for every system. Many systems have the product stationary and the work is done by resources moving to the product. Some systems are hybrids where a part moves into a station where various tasks are performed, and then it moves to the next station where various tasks are performed. In such a hybrid situation it would be possible to create an initial model using this method, and then build it out with the station details manually. The proposed data analysis method could also be adapted to analyze data on events and tagged locations of a product in a system instead of physical location, but that is not within the scope of this research.

5.2 **Summary**

The proposed model generating methodology consists of the data gathering tool, data analysis algorithm, and simulation software data translator.

The data gathering tool is a GPS device that is attached to a product as it moves through a system, and has a web browser that can access a PHP page with the code in Appendix A. The data gathered in the tracking tool includes a unique identifier of the product being tracked, a GPS latitude and longitude of the current position of the device, a unique identifier that distinguishes product type, and the number of seconds that have elapsed since tracking began. This data is captured at a consistent interval until the product has left the subject system.

The data gathered from the data gathering tool is used as input for the data analysis algorithm. The data analysis algorithm assumes that changes in velocity of the object are correlated with transitions between different steps in the system. Basically, the data gathering tool attempts to convert the flow of the product through the system into discrete events that the product experiences. This is accomplished by identifying processes that start and end when a product experiences a period of acceleration above a defined threshold. The output of the data analysis algorithm defines the location, flow, processing, and pseudo-capacity for a collection of system processes.

The output of the data analysis algorithm is then translated by the simulation software data translator. In this research a data translator was written for FlexSim simulation software. The data translator takes the data analysis algorithm output and uses it to create a simulation.

By following these steps it is possible to create a simulation from product tracking data. The accuracy of the model is not necessarily as good as it would be if the model was created manually. However, for large simulation models the model-building time using this methodology is significantly lower, because the model is programmatically built. Therefore, in order to determine if this methodology would be practical a user of simulation software would have to weigh the cost of time against the cost or inaccuracy. A user could also use the aforementioned model building methodology to quicken the model building time by using the algorithm to create a model with the basic logic, and then edit the model to add any custom logic. By doing this the user could use the advantageous elements of the algorithm, but not be limited by as many of the limitations.

There are many limitations to this model building methodology, as discussed in section 5.3. However, even with these limitations there seems to be a place for this methodology within the set of useful simulation model building methodologies.

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APPENDICES

APPENDIX A. DATA COLLECTION TOOL CODE

The location of an object was gathered by accessing a PHP page from a GPS device attached to the product that had a web browser. The PHP page had the code attached below. The page would then give the coordinate location of an object at the user-defined time interval until it had reached the user-defined number of instances. The raw data was then processed manually into the format that was required by the data analysis algorithm tool. The code is as defined below, which is mostly derived from a stack overflow article answer (daniellmb):

A.1. Code - Location.php

```
<?php
if (isset($_POST['submit'])) {
        $howoften = $_POST['howoften'];
        $howmany = $_POST['howmany'];
?>
<html xmlns="http://www.w3.org/1999/xhtml">
<head>
<title>Geolocation API Demo</title>
</head>
<body>
<div id="message"></div>
<script>
x=0;
function successHandler(location) {
   var message = document.getElementById("message"), html = [];
   html.push(location.coords.longitude, ",");
   html.push(location.coords.latitude, ",");
   html.push(x,"|");
   message.innerHTML = message.innerHTML + html.join("");
}
function errorHandler(error) {}
function myTimer() {
        x=x+1
        if (x==<?php echo $howmany; ?>) {
                clearInterval(myVar);
        }
        navigator.geolocation.getCurrentPosition(successHandler, errorHandler);
}
var myVar = setInterval(function(){myTimer()},<?php echo $howoften; ?>);
</script>
</body>
</html>
<?php
}
else {
?>
<form action="" method="post">
        How Many: <input type="text" name="howmany"><br>
        How Often: <input type="text" name="howoften"><br>
        <input type="submit" name="submit" value="Submit">
</form>
<?php
}
?>
```

APPENDIX B. DATA ANALYSIS ALGORITHM TOOL CODE

The “Data Analysis Algorithm Tool Code” was written in Excel VBA syntax. It contains a module and a form. Also included is the code for a PHP page that the module uses to create distributions for the processing steps.

B.1. Code - DataAnalysis Module

```
Public test_distance As Double
Public test_time As Double
Public test_acceleration As Double
Public increment_time As Double
Public fNameAcceleration As String
Public fNameTime As String

Dim last_location(2) As Double
Dim x As Double
Dim y As Double
Dim z As Double
Dim currentTime As Double
Dim rowCount As Double
Dim itemRow As Integer
Dim temp_double As Double
Dim temp_boolean As Boolean

Dim itemNumber As Integer
Dim startX As Double
Dim startY As Double
Dim inProcessor As Integer
Dim processorNumber As Double
Dim numberOfProcessors As Integer
Dim processorDistanceStart As Double
Dim processorDistanceEnd As Double
Dim dataArray() As Double
Dim processorArray() As Double
Dim timeArray() As Double
Dim inProcessorArray() As Integer
Dim processorInOut() As Double
Dim flowLogic() As Integer


Dim concatenateIn As String

Sub DataAnalyzer()
'delete other worksheets
   Application.DisplayAlerts = False
   On Error Resume Next
   Sheets(3).Delete
   Sheets(2).Delete
   On Error GoTo 0
   Application.DisplayAlerts = True
'start code
   rowCount = Range("A1000000").End(xlUp).Row

   test_distance = 1
   test_time = 1
   test_acceleration = 1

   'x location
   last_location(0) = -100
   'y location
   last_location(1) = -100
   'type
   last_location(2) = -1
'
' DataAnalyzer Macro
'
   Range("A1").Select
   Selection.SpecialCells(xlCellTypeConstants, 23).Select
   Selection.Copy
   Sheets.Add After:=ActiveSheet
   ActiveSheet.Paste
   Application.CutCopyMode = False
   ActiveWorkbook.Worksheets(2).Sort.SortFields.Clear
   ActiveWorkbook.Worksheets(2).Sort.SortFields.Add Key:=Range("D2:D" & rowCount) _
      , SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
   ActiveWorkbook.Worksheets(2).Sort.SortFields.Add Key:=Range("A2:A" & rowCount) _
      , SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
```

```
ActiveWorkbook.Worksheets(2).Sort.SortFields.Add Key:=Range("E2:E" & rowCount) _
    , SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With ActiveWorkbook.Worksheets(2).Sort
    .SetRange Range("A1:E" & rowCount)
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
Sheets(2).Select
Sheets(2).Name = "Analyzed Data"
Range("F1").Select
ActiveCell.FormulaR1C1 = "Distance"
Range("G1").Select
ActiveCell.FormulaR1C1 = "Velocity"
Range("H1").Select
ActiveCell.FormulaR1C1 = "Acceleration"
Columns("F:H").Select
Selection.ColumnWidth = 12.43
'fix some cells
Range("f2:h2").Value = 0
'put in the distance,velocity, and acceleration
Range("F3").Select
ActiveCell.FormulaR1C1 = _
    "=R[-1]C+SQRT(((RC[-4]-R[-1]C[-4])^2)+((RC[-3]-R[-1]C[-3])^2))"
Range("F3").Select
Selection.AutoFill Destination:=Range("F3:F" & rowCount)
Range("F3:F" & rowCount).Select
Range("G3").Select
ActiveCell.FormulaR1C1 = "=RC[-1]-R[-1]C[-1]"
Range("G3").Select
Selection.AutoFill Destination:=Range("G3:G" & rowCount)
Range("G3:G" & rowCount).Select
Range("H3").Select
ActiveCell.FormulaR1C1 = "=abs(RC[-1]-R[-1]C[-1])"
Range("H3").Select
Selection.AutoFill Destination:=Range("H3:H" & rowCount)
'set a default test acceleration by normalizing the data and then finding outliers
Dim groupSize As Integer
Dim groupMean(9) As Double
Dim theRange As String

groupSize = rowCount / 10
For x = 0 To 9
```

```
        theRange = Range("h" & ((x * groupSize) + 2) & ":h" & (((x + 1) * groupSize) +
1)).Address
        groupMean(x) = Application.WorksheetFunction.Sum(Range(theRange)) / groupSize
    Next
    For x = 0 To 9
        Range("I" & (x + 2)).Value = groupMean(x)
    Next
    increment_time = Range("e3").Value - Range("e2").Value
    test_acceleration = Application.WorksheetFunction.Quartile_Inc(Range("I2:I11"), 1) - (1.5 *
(Application.WorksheetFunction.Quartile_Inc(Range("I2:I11"), 3) -
Application.WorksheetFunction.Quartile_Inc(Range("I2:I11"), 1)))
    X_CreateAccelerationChart
    X_CreateTimeChart
    settings.Show
End Sub

Sub DataTests()
    'do all the tests according to the sensitivities
    For x = 2 To rowCount
        temp_boolean = False
        'do the acceleration test
        If IsNumeric(Range("H" & x).Value) Then
            temp_double = Range("H" & x).Value
        Else
            temp_boolean = True
            temp_double = 0
        End If
        If temp_double > test_acceleration Or temp_boolean = True Then
            temp_boolean = True
        Else
            temp_boolean = False
        End If
        Range("I" & x).Value = temp_boolean
        'do the time test
        temp_boolean = False
        For y = 1 To (test_time / increment_time)
            If ((x - y) < 1) Or (Range("D" & (x - y)).Value <> Range("D" & x).Value) Then Exit For
            If Range("I" & (x - y)).Value = True Then temp_boolean = True
        Next y
        If temp_boolean = True Then
            Range("J" & x).Value = False
        ElseIf Range("I" & x).Value = True Then
            Range("J" & x).Value = True
        Else
            Range("J" & x).Value = False
        End If
        'do the distance test
        If (Range("d" & x).Value <> last_location(2)) Then
            Range("K" & x).Value = True
            last_location(2) = Range("d" & x).Value
        Else
            If (Range("I" & x).Value = True) And (Sqr(((Range("b" & x).Value - last_location(0)) ^
(2)) + ((Range("c" & x).Value - last_location(1)) ^ (2))) > test_distance) Then
                Range("K" & x).Value = True
                last_location(0) = Range("b" & x).Value
                last_location(1) = Range("c" & x).Value
            Else
                Range("K" & x).Value = False
            End If
        End If
        'see when all the tests pass
        If (Range("I" & x).Value = True And Range("J" & x).Value = True And Range("K" &
x).Value = True) Or Range("a" & x).Value <> Range("a" & (x - 1)).Value Then
            Range("L" & x).Value = True
        Else
            Range("L" & x).Value = False
        End If
    Next x
    ProcessorCreate
    End Sub

Sub ProcessorCreate()
    'create a sheet to store the runtimes
    Sheets.Add After:=ActiveSheet
    Sheets(3).Select
    Sheets(3).Name = "Processors"
    Cells(1, 1) = "Number"
    Cells(1, 2) = "Start X"
    Cells(1, 3) = "End X"
    Cells(1, 4) = "Start Y"
    Cells(1, 5) = "End Y"
    Cells(1, 6) = "Angle"
    Cells(1, 7) = "Length"
    Cells(1, 8) = "IN"
    Cells(1, 9) = "OUT"
    Cells(1, 10) = "Times"
    Sheets(2).Select
    'redim dataArray to put data in it
    ReDim dataArray((rowCount - 1), 4)
    For x = 0 To (rowCount - 2)
        dataArray(x, 0) = Cells(x + 2, 1)
        dataArray(x, 1) = Cells(x + 2, 2)
        dataArray(x, 2) = Cells(x + 2, 3)
        dataArray(x, 3) = Cells(x + 2, 5)
        dataArray(x, 4) = Cells(x + 2, 12)
    Next x
    'processorNumber for processor #
    processorNumber = 0
    currentTime = 0
    startX = Range("b2").Value
    startY = Range("c2").Value
    For x = 0 To (rowCount - 2)
        If dataArray(x, 4) = True Then processorNumber = processorNumber + 1
    Next x
    'size the processor array
    ReDim processorArray(processorNumber, 6)
    ReDim timeArray(processorNumber, 1000)
    ReDim inProcessorArray(processorNumber, 1000)
    'fill the arrays
    For x = 0 To processorNumber
        For y = 0 To 6
            processorArray(x, y) = -100
        Next y
        For y = 0 To 1000
            timeArray(x, y) = -100
            inProcessorArray(x, y) = -100
        Next y
    Next x

    'find the max time
    maxTime = 0
    For x = 0 To (rowCount - 1)
        If (dataArray(x, 3) > maxTime) Then maxTime = dataArray(x, 3)
    Next x
    timeArraySize = maxTime * (1 / increment_time)
    Dim locationAtTime() As Double
    ReDim locationAtTime(timeArraySize, processorNumber)
    'go through the data array
    numberOfProcessors = processorNumber
    processorNumber = 0
    For x = 0 To (rowCount - 2)
        If dataArray(x, 0) <> itemNumber Then
            itemNumber = dataArray(x, 0)
            startX = dataArray(x, 1)
            startY = dataArray(x, 2)
            currentTime = dataArray(x, 3)
            inProcessor = -1
        ElseIf x = (rowCount - 2) Or dataArray((x + 1), 4) = True Then
        For z = 0 To numberOfProcessors
          processorDistanceStart = Sqr(((processorArray(z, 1) - startX) ^ (2)) +
    ((processorArray(z, 3) - startY) ^ (2)))
          processorDistanceEnd = Sqr(((processorArray(z, 2) - dataArray(x, 1)) ^ (2)) +
    ((processorArray(z, 4) - dataArray(x, 2)) ^ (2)))
          If processorDistanceStart < test_distance And processorDistanceEnd < test_distance
    Then
            processorNumber = z
            startX = dataArray((x + 1), 1)
            startY = dataArray((x + 1), 2)
            'need to record the inProcessor in another array
            For y = 0 To 1000
              If inProcessorArray(processorNumber, y) = -100 Then Exit For
            Next y
            inProcessorArray(processorNumber, y) = inProcessor
            inProcessor = processorNumber
            'record the times in another array
            For y = 0 To 1000
              If timeArray(processorNumber, y) = -100 Then Exit For
            Next y
            timeArray(processorNumber, y) = dataArray(x, 3) - currentTime
            currentTime = dataArray(x, 3)
            Exit For
          ElseIf processorArray(z, 1) = -100 Then
            processorNumber = z
            processorArray(processorNumber, 0) = processorNumber
            processorArray(processorNumber, 1) = startX
            startX = dataArray((x + 1), 1)
            processorArray(processorNumber, 2) = dataArray(x, 1)
            processorArray(processorNumber, 3) = startY
            startY = dataArray((x + 1), 2)
            processorArray(processorNumber, 4) = dataArray(x, 2)
            'need to record the inProcessor in another array
            For y = 0 To 1000
              If inProcessorArray(processorNumber, y) = -100 Then Exit For
            Next y
            inProcessorArray(processorNumber, y) = inProcessor
            inProcessor = processorNumber
            'record the times in another array
            For y = 0 To 1000
              If timeArray(processorNumber, y) = -100 Then Exit For
            Next y
            timeArray(processorNumber, y) = dataArray(x, 3) - currentTime
            currentTime = dataArray(x, 3)
            Exit For
          End If
```

```
            Next z
        Else
            'add to the array with the items current
            timePos = dataArray(x, 3) * (1 / increment_time)
            locationAtTime(timePos, processorNumber) = locationAtTime(timePos,
processorNumber) + 1
        End If
    Next x
'print the processor array data to the sheet
    Sheets(3).Select
    For x = 0 To numberOfProcessors
        For y = 0 To 5
            If processorArray(x, y) <> -100 Then Cells(x + 2, y + 1).Value = processorArray(x, y)
        Next y
    Next x
    'calculate the angles and lengths
    y = Range("A1000000").End(xlUp).Row
    For x = 2 To y
        Range("f" & x).Formula = "=IF(B" & x & ">C" & x & ",DEGREES(ATAN((E" & x & "-
D" & x & ")/(C" & x & "-B" & x & ")))+180,DEGREES(ATAN((E" & x & "-D" & x & ")/(C" &
x & "-B" & x & "))))"
    Next x
    For x = 2 To y
        Range("g" & x).Formula = "=SQRT(((C" & x & "-B" & x & ")^2)+((E" & x & "-D" & x &
")^2))"
    Next x
'print the inProcessorArray
    ' y=lastrow
    z = y
    ReDim processorInOut((y - 2), 1)
    ReDim flowLogic((y - 2), (y - 2))
    'change this so that it compares the number of processors out
    For x = 0 To z - 2
        For y = 0 To 1000
            'concatenate them all
            'And InStr(concatenateIn, timeArray(x, y)) = False
            If timeArray(x, y) <> -100 Then
                If inProcessorArray(x, y) <> -1 Then
                    processorInOut(x, 0) = processorInOut(x, 0) + 1
                    processorInOut(inProcessorArray(x, y), 1) = processorInOut(inProcessorArray(x, y),
1) + 1
                    'increment an array of size (# of processors)X(# of processors), so that we can
determine later how many went where
                    flowLogic(inProcessorArray(x, y), x) = flowLogic(inProcessorArray(x, y), x) + 1
                End If
            End If
        Next y
    Next x
    'find sources and sinks
    For x = 0 To z - 2
        If (processorInOut(x, 0) - processorInOut(x, 1)) > 0 Then
            Range("i" & (x + 2)).Value = "test|-2`" & Round(((processorInOut(x, 0) -
processorInOut(x, 1)) / processorInOut(x, 0)), 4)
        End If
    Next x
    'put in a unique list
    For x = 0 To (z - 2)
        For y = 0 To 1000
            If timeArray(x, y) <> -100 And InStr(concatenateIn, "~" & inProcessorArray(x, y)) =
False Then
                If (inProcessorArray(x, y) >= 0) Then
                    If (processorInOut(inProcessorArray(x, y), 1) = 0) Then
                        percentFlow = 1
                    Else
                        percentFlow = Round((flowLogic(inProcessorArray(x, y), x) /
processorInOut(inProcessorArray(x, y), 1)), 4)
                    End If
                    concatenateIn = concatenateIn & "~" & inProcessorArray(x, y) & "`" & percentFlow
                Else
                    concatenateIn = concatenateIn & "~" & inProcessorArray(x, y) & "`" & 1
                End If
            End If
        Next y
        concatenateIn = Mid(concatenateIn, 2)
        Cells(x + 2, 8) = "test|" & concatenateIn
        concatenateIn = ""
    Next x
'print the time array data to the sheet
    For x = 0 To (z - 2)
        For y = 0 To 1000
            If timeArray(x, y) <> -100 Then
                If timeArray(x, y) <> -1 Then
                    concatenateIn = concatenateIn & "~" & timeArray(x, y)
                Else
                    concatenateIn = concatenateIn & "~" & "Source"
                End If
            End If
        Next y
        concatenateIn = Mid(concatenateIn, 2)
        Cells(x + 2, 10) = concatenateIn
        concatenateIn = ""
    Next x
```

```
  'find the pseudo-capacity of each processor
  Dim processorCapacity() As Integer
  ReDim processorCapacity(z - 2)
  For t = 0 To UBound(locationAtTime, 1)
    For x = 0 To (z - 2)
      If (locationAtTime(t, x) > processorCapacity(x)) Then processorCapacity(x) =
locationAtTime(t, x)
    Next x
  Next t
  'put the pseudo-capacity in column L and label the column
  For x = 0 To (z - 2)
    Cells(x + 2, 12) = processorCapacity(x)
  Next x
  Cells(1, 12) = "Pseudo-Capacity"
  'Get the number of processors that we have
  y = Cells(Rows.Count, "A").End(xlUp).Row - 2
  'Go through each processor and create a web query to ge the distribution
  For x = 0 To y
    Range("K" & (x + 2)).Select
    With ActiveSheet.QueryTables.Add(Connection:= _
      "URL;http://www.descreye.com/distribution-fitting.php?processing_times=" &
Range("J" & (x + 2)).Value _
      , Destination:=Range("$K$" & (x + 2)))
      '.CommandType = 0
      .Name = Range("J" & (x + 2)).Value
      .FieldNames = True
      .RowNumbers = False
      .FillAdjacentFormulas = False
      .PreserveFormatting = True
      .RefreshOnFileOpen = False
      .BackgroundQuery = True
      .RefreshStyle = xlInsertDeleteCells
      .SavePassword = False
      .SaveData = True
      .AdjustColumnWidth = True
      .RefreshPeriod = 0
      .WebSelectionType = xlAllTables
      .WebFormatting = xlWebFormattingNone
      .WebPreFormattedTextToColumns = True
      .WebConsecutiveDelimitersAsOne = True
      .WebSingleBlockTextImport = False
      .WebDisableDateRecognition = False
      .WebDisableRedirections = False
      .Refresh BackgroundQuery:=False
    End With
  Next x
```

```
   SaveSheetCSV
End Sub

Sub X_CreateAccelerationChart()
   Dim accelerationChart As Object
   'get the number of rows of the first item
   Sheets(2).Select
   For x = 2 To rowCount
      If (Range("a" & x).Value <> Range("a" & (x + 1)).Value) Then Exit For
   Next
   Range("H1:H" & x).Select
   ActiveSheet.Shapes.AddChart2(227, xlLine).Select
   ActiveChart.SetSourceData Source:=Range("'Analyzed Data'!$H$1:$H$" & x)
   Range("I2").Select
   ActiveCell.FormulaR1C1 = test_acceleration
   Selection.AutoFill Destination:=Range("I2:I" & x), Type:=xlFillDefault
   Range("I2:I21").Select
   ActiveSheet.ChartObjects(1).Activate
   Set accelerationChart = ActiveSheet.ChartObjects(1).Chart
   accelerationChart.SeriesCollection.NewSeries
   accelerationChart.FullSeriesCollection(2).Values = "='Analyzed Data'!$I$2:$I$" & x
   accelerationChart.FullSeriesCollection(2).XValues = "='Analyzed Data'!$E$2:$E$" & x
   accelerationChart.SetElement (msoElementChartTitleAboveChart)
   accelerationChart.ChartTitle.Text = "Acceleration"
   fNameAcceleration = ThisWorkbook.Path & "\acceleration.gif"
   accelerationChart.Export fileName:=fNameAcceleration, FilterName:="GIF"
   ActiveSheet.ChartObjects(1).Delete
End Sub

Sub X_CreateTimeChart()
   Dim timeChart As Object
   Dim lastRow As Integer
   Dim lastTime As Double
   lastTime = 0
   y = 2
   'create the data for the chart
   'clear j column
   Range("j:j").Value = ""
   'get the number of rows of the first item
   Sheets(2).Select
   For x = 3 To rowCount
      If (Range("a" & x).Value <> Range("a" & (x + 1)).Value) Then Exit For
      If (Range("h" & x).Value > Range("i" & x).Value) Then
         Range("j" & y).Value = Range("e" & x).Value - lastTime
         lastTime = Range("e" & x).Value
         y = y + 1
```

```
        End If
    Next x
    'get the last row
    lastRow = Range("J1000000").End(xlUp).Row
    'set the current line
    Range("K2:K" & (y - 1)).Value = test_time
    'make the scatterplot
    Range("J2:J" & lastRow).Select
    ActiveSheet.Shapes.AddChart2(240, xlXYScatter).Select
    ActiveChart.SetSourceData Source:=Range("'Analyzed Data'!$J$2:$J$" & lastRow)
    ActiveChart.SeriesCollection.NewSeries
    ActiveChart.FullSeriesCollection(2).Values = "='Analyzed Data'!$K$2:$K$" & (y - 1)
    ActiveChart.ChartTitle.Text = "Time Values"
    fNameTime = ThisWorkbook.Path & "\time.gif"
    ActiveChart.Export fileName:=fNameTime, FilterName:="GIF"
    ActiveSheet.ChartObjects(1).Delete
End Sub

Sub SaveSheetCSV()
    Dim fNameTable As String
    fNameTable = ThisWorkbook.Path & "\table.csv"
    Sheets(3).SaveAs fileName:=fNameTable, FileFormat:=xlCSV
End Sub


Sub DeleteCreatedSheets()
    Application.DisplayAlerts = False
    On Error Resume Next
    Sheets(3).Delete
    Sheets(2).Delete
    On Error GoTo 0
    Application.DisplayAlerts = True
End Sub
```

B.2. Code - Settings Form

```
Private Sub cmd_submit_Click()
    test_acceleration = settings.inp_acceleration.Value
    test_distance = settings.inp_distance.Value
    test_time = settings.inp_time.Value
    DataAnalysis.DataTests
    settings.Hide
    Kill (fNameAcceleration)
    Kill (fNameTime)
```

```
End Sub


Private Sub inp_acceleration_Change()
   If IsNumeric(settings.inp_acceleration.Value) = True Then
      test_acceleration = settings.inp_acceleration.Value
      DataAnalysis.X_CreateAccelerationChart
      DataAnalysis.X_CreateTimeChart
      img_acceleration.Picture = LoadPicture(fNameAcceleration)
      img_time.Picture = LoadPicture(fNameTime)
   End If
End Sub


Private Sub inp_increment_Change()
   increment_time = settings.inp_increment.Value
End Sub

Private Sub inp_time_Change()
   If IsNumeric(settings.inp_time.Value) = True Then
      test_time = settings.inp_time.Value
      DataAnalysis.X_CreateTimeChart
      img_time.Picture = LoadPicture(fNameTime)
   End If
End Sub

Private Sub UserForm_Initialize()
   settings.inp_increment.Value = increment_time
   settings.inp_acceleration.Value = test_acceleration
   settings.inp_distance.Value = test_distance
   settings.inp_time.Value = test_time
   img_acceleration.Picture = LoadPicture(fNameAcceleration)
   img_time.Picture = LoadPicture(fNameTime)
End Sub

Private Sub UserForm_Terminate()
   Kill (fNameAcceleration)
   Kill (fNameTime)
End Sub
```

B.3. Code - Distribution-Fitting.php

```
<?php
```

```
function get_quartile($Array, $Quartile) {
  $pos = (count($Array) - 1) * $Quartile;

  $base = floor($pos);
  $rest = $pos - $base;
  if( isset($Array[$base+1]) ) {
    $return_value = $Array[$base] + $rest * ($Array[$base+1] - $Array[$base]);
  } else {
    $return_value = $Array[$base];
  }
  //echo $return_value."<br>";
  return $return_value;
}


$times = $_REQUEST['processing_times'];
$times = explode('~',$times);
sort($times);

$quartile = array();
$quartile['0']=get_quartile($times,0);
$quartile['.2']=get_quartile($times,.2);
$quartile['.4']=get_quartile($times,.4);
$quartile['.6']=get_quartile($times,.6);
$quartile['.8']=get_quartile($times,.8);
$quartile['1']=get_quartile($times,1);

$distribution_text = "fivepointdistribution(";
foreach ($quartile as $value) $distribution_text.="~".$value;
$distribution_text.=")";
$distribution_text = str_replace("(~","(",$distribution_text);
echo "<table><tr><td>".$distribution_text."</td></tr></table>";
?>
```

APPENDIX C. FLEXSIM DATA TRANSLATOR CODE

The “FlexSim Data Translator Code” allows FlexSim to translate the data output by the “Data Analysis Algorithm Tool Code” into the simulation software package. It includes two functions that make this possible. One is the function that creates the model, and that is called modelimport. The other function, fivepointdistribution, allows the use of the previously discussed and custom five-point distribution in FlexSim. The code for each function is written in FlexSim’s own language, FlexScript.

C.1. Code - FlexSim Function: ModelImport

```
/**Custom Code*/
nodeinsertinto(model());
setname(last(model()), "ModelData");
treenode ModelData = node("/ModelData",model());
string fileName = filebrowse("*.csv","Model Data CSV",pdir());
importtable(ModelData,fileName,0,0);
int numberOfProcessors = content(ModelData);
//create the processors
for (int x=2; x<=numberOfProcessors; x++) {
	createinstance(node("/fixedresources/Processor",library()),model());
	treenode processor = last(model());
	string processorName =
concat("Processor",numtostring(getnodenum(rank(rank(ModelData,x),1))));
	double processorLength = getnodenum(rank(rank(ModelData,x),7));
	double processorAngle = getnodenum(rank(rank(ModelData,x),6));
	double processorXLoc = getnodenum(rank(rank(ModelData,x),2));
	double processorYLoc = getnodenum(rank(rank(ModelData,x),4));
```

```
        string processorDistribution = concat("return
",getnodestr(rank(rank(ModelData,x),11)),";");
        double processorMaxContent = getnodenum(rank(rank(ModelData,x),12));
        processorDistribution = stringreplace(processorDistribution,"~",",");
        //adjust for bad positioning
        processorYLoc =
((processorLength*sin(degreestoradians(processorAngle)))/2)+processorYLoc;
        processorXLoc = processorXLoc-((processorLength/2)-
((processorLength/2)*cos(degreestoradians(processorAngle))));
        //set everything
        setname(processor, processorName);
        setsize(processor, processorLength,.1,.1);
        setrot(processor,0,0, processorAngle);
        setloc(processor,processorXLoc,processorYLoc,0);
        setnodestr(node(">variables/cycletime",processor),processorDistribution);
        setnodenum(node(">variables/maxcontent",processor),processorMaxContent);
}
//create the sinks
for (int x=2; x<=numberOfProcessors; x++) {
        string flowString = getnodestr(rank(rank(ModelData,x),9));
        //this data is a string with the port to connect followed by the percentage of the inputs
flow that goes to the current object
        //cut the fluff part
        if (stringlen(flowString)>0){
                flowString = stringcopy(flowString, 6,stringlen(flowString)-6);
                int sep = stringsearch(flowString,"`",0);
                string inputProcStr = stringcopy(flowString,1,sep);
                int inputProc = stringtonum(inputProcStr);
                double inputProb =
stringtonum(stringcopy(flowString,sep+2,(stringlen(flowString)-sep)-1));
                createinstance(node("/fixedresources/Sink",library()),model());
                treenode newSink = last(model());
                setname(newSink, concat("Sink",numtostring(x)));
                setloc(newSink, getnodenum(rank(rank(ModelData,x),3))+1,
getnodenum(rank(rank(ModelData,x),5)),0);
                treenode inProcessor = rank(model(),x+2);
                contextdragconnection(inProcessor,newSink,"A");
                //add a label to the inProcessor with the amount of it that goes to this sink
                addlabel(inProcessor,"Sink",inputProb);
        }
}
//create the connnections
for (int x=2; x<=numberOfProcessors; x++) {
        string flowString = getnodestr(rank(rank(ModelData,x),8));
        //this data is a string with the port to connect followed by the percentage of the inputs
flow that goes to the current object
        //cut the fluff part
        int flowStringLen = stringlen(flowString);
        flowString = stringcopy(flowString, 6,flowStringLen-5);
        //go through the string making each connection
        int found = 0;
        string currentString = "";
        int sep = 0;
        string inputProcStr = "";
        int inputProc = 0;
        double inputProb = 0;
        while (found>=0) {
                found = stringsearch(flowString,"~",0);
                if (found>0) {
                        currentString = stringcopy(flowString,1,found);
                }
                else {
                        currentString = flowString;
                        found=-1;
                }
                //this is now just a incoming connection and a probability, seperate those
                sep = stringsearch(currentString,"`",0);
                inputProcStr = stringcopy(currentString,1,sep);
                inputProc = stringtonum(inputProcStr);
                inputProb =
stringtonum(stringcopy(currentString,sep+2,(stringlen(currentString)-sep)-1));
                //we should now have the input object and the probability to go to the current
object from the input object
                //make the connection
                if (inputProc>=0) {
                        //it is a processor
                        treenode inProcessor = rank(model(),inputProc+4);
                        treenode outProcessor = rank(model(),x+2);
                        contextdragconnection(inProcessor,outProcessor,"A");
                        addlabel(inProcessor,concat("Flow",numtostring(x)),inputProb);
                }
                else {
                        //it is a source
                        createinstance(node("/fixedresources/Source",library()),model());
                        treenode newSource = last(model());
                        setname(newSource, concat("Source",numtostring(x)));
```

```
				setloc(newSource, getnodenum(rank(rank(ModelData,x),2))-1,
getnodenum(rank(rank(ModelData,x),4)),0);
				setvarstr(newSource,"interarrivaltime","return 0;");
				//create connections
				treenode outProcessor = rank(model(),x+2);
				contextdragconnection(newSource,outProcessor,"A");
			}
			//set the probability flow function

			//take off the current part of the flowString
			if (found>=0) flowString = stringcopy(flowString,found+2,(stringlen(flowString)-
found-1));
		}
}
//use the labels to create the flow probabilities
string starter = "double randomnum = uniform(0.0, 100.0, 0);double total = 0.0;";
for (int x=2; x<=numberOfProcessors; x++) {
		treenode proc = rank(model(),x+2);
		double remaining = 1;
		string flowCode = starter;
		for (int y=1;y<=content(labels(proc));y++) {
			if (stringsearch(getnodename(label(proc,y)),"Sink",0)>=0) {
				double percentage = getlabelnum(proc,y)*100;
				flowCode = concat(flowCode,"total += ",numtostring(percentage),";if
(randomnum <= total) return ",numtostring(y),";");
				remaining = 1-(percentage/100);
			}
			else {
				double percentage = getlabelnum(proc,y)*100;
				flowCode = concat(flowCode,"total +=
",numtostring(percentage*remaining),";if (randomnum <= total) return ",numtostring(y),";");
			}
		}
		flowCode = concat(flowCode,"return 1;");
		switch_flexscript(getvarnode(proc,"sendtoport"),1);
		setvarstr(proc,"sendtoport",flowCode);
		buildnodeflexscript(getvarnode(proc,"sendtoport"));
}
```

C.2. Code - FlexSim Function: FivePointDistribution

```
/**Custom Code*/
int quartile_end = duniform(2,6);
int quartile_beg = quartile_end-1;
double ran
domnumber = uniform(parval(quartile_beg),parval(quartile_end));
return randomnumber;
```

APPENDIX D. FIVE-POINT DISTRIBUTION

D.1. Explanation

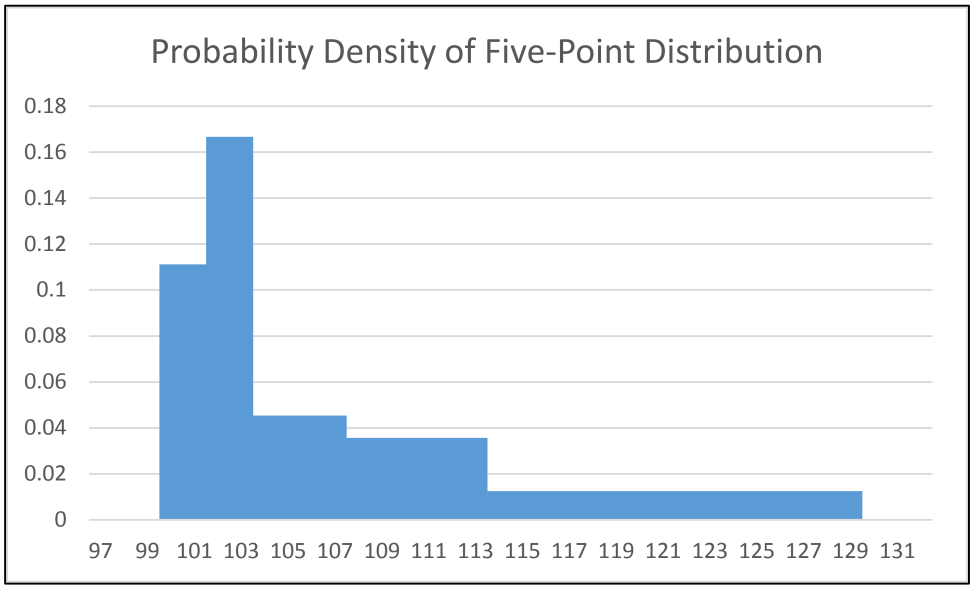
The proposed "five-point distribution" is merely a collection of 5 uniform distributions that are used to approximate a more advanced statistical distribution. In order to create the distribution six percentiles in the data are found; 0, .2, .4, .6, .8, 1. For instance, assume the following was an observed data set:

106, 110, 108, 100, 103, 101, 114, 102, 102, 103, 108, 100, 114, 105, 113, 104, 111, 104, 104, 100, 114, 100, 101, 114, 110, 102, 100, 109, 119, 100, 107, 122, 106, 103, 103, 102, 101, 102, 114, 114, 102, 110, 105, 100, 129, 107, 103, 111, 111, 113

The six percentiles calculated would be the following:

100, 101.8, 103, 107.4, 113, 129

The probability density curve of the resultant distribution looks like what is seen in the figure on the following page.



Probability Density Function of the Example Five-Point Distribution.

To sample from this distribution two random numbers are then generated the first is a random number sampled from a uniform distribution between 0 and 1. That random number is then used to determine what range will be used for the second random number. In the example if .22 was our first random number, then the second random number would be sampled from a uniform distribution between 101.8 and 103. That number would then be the sample from the distribution.

There are a few advantages and disadvantages to using this distribution. One advantage is the all-encompassing nature of the distribution. This distribution adapts to the dataset, so it can fit the distribution regardless of the skew or normality. This advantage also makes fitting data to the distribution very simple. Six quick calculations provide all the information that is necessary to create the distribution. One disadvantage of the distribution is that it is less precise than a better fitted distribution. It also would have difficulty with any data that has more than two modes, because using only five uniform distributions would not approximate a bimodal distribution as effectively. This could be done by using more uniform (i.e. ten) distributions to represent the bimodal data. This would be using the same concept but use ten points instead of five.