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COMPUTER SIMULATION OF A MOBILE EXAMINATION CENTER

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ABSTRACT

The National Health and Nutrition Examination Survey (NHANES), sponsored by the United States Centers for Disease Control and Prevention (CDC), uses large custom-built Mobile Examination Centers (MECs) to gather confidential data on the residential population of the United States. The data are used to generate national statistics and standards on health and nutrition for the nation. CDC is also exploring a community-based health examination survey designed to produce health statistics for smaller areas or defined populations, tentatively called the Community Health and Nutrition Examination Survey (CHANES), which would consist of a smaller self-contained MEC. In this paper, we describe a CHANES MEC simulation model built based on actual field data. The model is used to demonstrate how layout and staffing decisions could be evaluated for benefit/cost tradeoff analysis.

1 INTRODUCTION

The National Health and Nutrition Examination Survey (NHANES), conducted by the National Center for Health Statistics (NCHS), is the only population-based survey of its kind and is used to generate national statistics and standards on health and nutrition for residents of the United States. NCHS is one of the Centers under the United States Centers for Disease Control and Prevention (CDC). NHANES consists of custom-built Mobile Examination Centers (MECs), which are currently made up of four semi-truck trailers with specialized passageways that connect them when parked. When all trailers are parked and connected at a site, the MEC is essentially a small clinic that obtains confidential data by performing standardized medical tests on randomly chosen non-institutionalized US residents in that geographical area. Residents are chosen by a multi-stage probability sampling process, using US Census data. Participation is voluntary, so residents can always refuse to participate. Moreover, once in the MEC, survey participants can refuse any exam at any time, resulting in the loss of crucial data; so full participation is strongly encouraged. All information collected is completely confidential and cannot be linked back to an individual.

A current initiative within the CDC allows for a smaller data collection effort, tentatively called the Community Health and Nutrition Examination Survey (CHANES), which would consist of a smaller MEC that could concentrate on specific populations or communities throughout the country. The CHANES MEC would consist of only one trailer and not require any external power, plumbing, or telephone connections.

A computer simulation model was developed to help determine the MEC layout that would provide the most efficient design and use of resources, as well as assist in planning decisions. The computerized MEC model, using the commercial simulation package Arena (Version 5.0), was used to simulate patient flow through various proposed exams. The model enables ease of exam room addition and deletion in order to analyze how exam flow will be affected by the changes. Additionally, the model will determine changes to overall time in the exam center as affected by modifying staff schedules. For example, the model can allow one to estimate exam completion rates with different configurations and staff and how any changes will affect the overall MEC data and results.

Similar simulation models have been designed previously with increasing success, especially in the past decade, on various projects for medical facilities – involving mostly staffing decisions and profit margins. While a government project would not require profit, shrewd allocation of financial resources is still of utmost importance. Most simulation projects on medical facilities were done for emergency rooms, since allocation of time and resources is most critical in emergency situations. However, wise allocation of time and resources is also important in any type of medical, office, or business operation. While a visit to the NHANES MEC is not an emergency situation, there are still common elements as well as the ideal optimization of time and resources. The major differences between an emergency room and a MEC visit are the method of treatment and type of arrival. There is never any treatment performed during a MEC visit, with the exception of an emergency situation requiring CPR or similar action. Visits to the MEC are scheduled in batch arrivals, whereas emergency room personnel have no way of knowing when a 'wave' will arrive. While there were similarities to the MEC setting in some of the other models completed, there remained significant differences. The CHANES model will never require hospitalization or any type of overnight or extended stay, nor does the model plan for emergency situations. In the history of NHANES, emergency situations have happened so rarely as to have negligible effect on the data collection.

Kirtland et al. (1995) were able to use simulation to reduce patient throughput times and determine the appropriate staffing levels at the facility in question. Rossetti, Trzcinski, and Syverud (1999) completed a simulation model concerned mainly with staffing schedules, involving a 24-hour emergency care facility with approximately 165 patients per day utilizing 34 beds in 4 distinct care areas. Sepulveda et al. (1999) developed a model that attempted to analyze patient flow throughout a "full service" cancer treatment center, including the impacts of floor layout changes and various scheduling options, as well as the requirements of a new building. A project very similar to this MEC model was recently completed by Ramis, Palma, Estrada, and Coscolla (2002) who presented a generic simulator to be used for a network of standardized clinic laboratories.

Most models completed for medical facilities had the same goals: reduce the time spent by a patient in the exam center, maximize the use of center staff, and use the output to guide investment (budget) decisions. All projects were beneficial in many ways, including being used to guide allocation of resources and funding.

The rest of the paper is organized as follows. The next section discusses the system and assumptions made. The simulation model and analyses completed are described in Section 3; while section 4 states the conclusions drawn and the recommendations made, in addition to providing implications and suggestions for future research.

2 SYSTEM DESCRIPTION

The CHANES MEC model used for this paper was developed using Arena software (Kelton et al. 2002). More details are provided in Osidach (2003). The model involved only five stations, or exams, but it can easily be modified. The five exams included in the model were Anthropometry, Blood Pressure, Dental, Personal Interview, and Venipuncture/Phlebotomy. These five exams would provide the most benefit to the overall population, as they provide data that can be used across all age groups. Figure 1 shows a sample trailer layout that could be utilized to administer these exams.

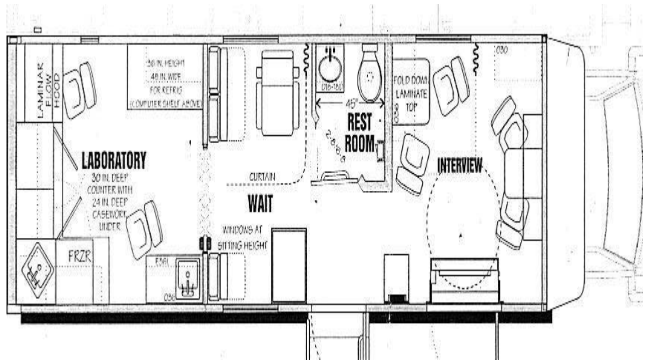

Figure 1: Sample CHANES MEC Layout

The simulation model was designed with the human technicians as resources but, unlike true resources, humans cannot function at 100% overall efficiency.

Since no treatment is done in a MEC, the data collection cannot refer to "patients". Instead, an individual from whom data is collected is referred to as a "Sample Person" or "SP". If a condition requiring medical attention or assistance is found, the SP will be referred to his/her local clinic or family practitioner.

The model can be modified to show the change in flow when changing the number of SPs arriving or the number of technicians working during a session. The model can also be used to estimate the changes in overall time spent by SPs in the exam center when different exams are added or deleted. Finally, the model investigates the feasibility of increasing the number of SPs processed in a given session, as well as changes in the overall time spent by the SP in the MEC with different staffing configurations.

The model assumes that all technicians will have skills to be able to administer all exams and that everyone invited to the exam center will be eligible for every exam. It was also assumed that SPs would arrive at the scheduled start time with a variation following a normal distribution of mean 15 minutes and standard deviation 5 minutes. With further regards to the start time, it was assumed that the age distributions of scheduled SPs would follow the same parameters as previous NHANES and that the time for an SP to change into a standard gown or shirt immediately after arrival is fixed. The probability distributions on the various age groups visiting the MEC can be modified later, for whatever reason, as the age or type of SPs can be modified as a controllable input variable if necessary.

The time for technicians and SPs to move to the next exam can be assumed to be negligible, since the exam center space will be so small. The input data was assumed to follow previous NHANES exam completion data. To implement the model in reality, more recent data would be required of NCHS before the model is utilized. Finally, emergency situations are assumed to be negligible, as their occurrence has been so rare in actual survey history such that data collection was inconsequentially affected.

3 SIMULATION MODEL

The goals of the system design for the simulation model were to be able to examine the feasibility of the CHANES unit design, as well as analyze staffing requirements and what type of process times for completion of data collection can be anticipated. The results should provide important information to assist in planning and staffing.

The system configurations included changing exam times as well as number of technicians/staff on duty, and the output will show the average time spent by SPs at each station and in the entire MEC to complete all exams. All input analyses and exam time distributions were determined through data taken from previously completed surveys and can easily be modified later.

The probability of age group arrivals was determined using past survey data, since examinations have historically been geared towards specific age groups. The probability of an SP being in the age group of 6 – 19 years, AgeTwo, was the highest, followed closely by the probability of being an age of 20 – 39 years, AgeThree, and then of being in AgeFour (40 – 59 years). There was a much smaller probability of being in AgeOne (2 months – 5 years), an even lower probability of being in AgeFive (60 – 74 years), and a lower still probability of being in AgeSix, the oldest group at 75 years and above. Specific probabilities follow in Table 1.

Table 1: Probabilities of Age Groups

Age	One	Two	Three	Four	Five	Six
Prob	0.12	0.27	0.25	0.22	0.08	0.06

Due to a lack of any data concerning an actual CHANES operation, the “best-fit” distribution for exam completion times was determined using previous NHANES data. The same distribution was used among age groups for each exam for simplification purposes. Different replications were run, while changing chances or entities or wait times to see if the results seemed reasonable (based on previous NHANES experience). Changes were observed in the overall time to process 15 or 20 SPs in the exam center, as well as in the overall utilization of the technicians. When changing input data, the biggest changes in output were always seen in the overall time in the MEC and the technician utilization. The model was then used to process only 3, 4, 5, 7, or 10 SPs to observe the overall time in exam center changes, while varying the number of technicians from 3 to 5. Those numbers seemed to make the most sense, due to the realistic idea of having the smallest number of people in the MEC while processing the greatest number of SPs.

For sensitivity analysis, the model was run using a normal distribution for all exams, and then run using the best-fit distributions for various exams, as determined by the Arena input analyzer. The model ran with 15 or 20 SPs entering the MEC system, based on the general NHANES scheduling system of 10+ SPs per session. A batch arrival was utilized, again based on previous NHANES scheduling. The model ran with 3, 4, or 5 technicians and 15 or 20 SPs scheduled with both normal and best-fit exam completion time distributions. Scheduling 15 or 20 SPs was used strictly for sensitivity analyses on the exam completion distributions. The results of all replications run with 15 or 20 SPs and the normal versus best-fit distributions showed overall results with no significant difference in average overall time spent in the MEC, technician efficiency, and percentage of technician idle time. The mean values and standard deviation of exam completion times for all age groups per exam are listed (in minutes) in Table 2.

Table 2: Exam Completion Parameters by Age Group

Age →	One	Two	Three	Four	Five	Six
Exam	Mean (sd)	Mean (sd)	Mean (sd)	Mean (sd)	Mean (sd)	Mean (sd)
Anthro	6.3 (2.64)	7.1 (1.75)	6.9 (2.10)	7.5 (2.19)	7.9 (1.72)	7.8 (2.63)
Blood Press.	5.6 (2.99)	13.3 (7.25)	12.9 (3.44)	13.7 (3.88)	18.3 (5.19)	18.9 (5.97)
Dental	2.2 (1.19)	4.7 (1.80)	8.5 (3.01)	7.9 (2.73)	7.4 (2.56)	6.9 (2.92)
Inter-View	1.5 (0.63)	20.2 (5.57)	8.8 (2.77)	5.2 (2.52)	6.4 (5.36)	5.6 (2.40)
Phleb.	6.2 (2.49)	7.4 (3.83)	7.7 (2.68)	8.7 (3.36)	8.2 (3.21)	9.1 (3.20)

The model was then run with smaller numbers of SPs scheduled, to see if there was any difference or change. Scheduled were 3, 4, 5, 7, or 10 SPs with 3, 4, or 5 technicians staffing the MEC. It appeared to make the most sense to schedule staggered batch arrivals, to account for ‘no-shows’ and various other unaccounted-for events. The model would have to be adjusted and utilized along with the CHANES project, once implemented, to fully determine the accuracy of these results. Scheduling only 3 SPs was not considered, since realistically it would leave too great a risk of high technician idle time in the case an SP (or two or more) did not arrive for exams as scheduled.

The best configuration(s) were determined using the statistics returned by Arena, focussing specifically on technician utilization. However, technicians are not machinery in this model, but rather human workers. Therefore, the best configuration is not quite so clear-cut; we must account for human fatigue, in addition to taking into account a general ‘comfort level’ in the MEC. While it is possible to process 10 individuals quickly and efficiently in a simulation, in reality it would make for a very uncomfortable situation in the MEC, based on the space and size limitations. Many SPs often arrive with family members or friends, which would make for a stifling environment with 10 SPs scheduled and everyone bringing at least one other body (which does happen in actual survey operation). Furthermore, with 10 SPs on board, there would also be a significantly increased SP waiting time resulting in a higher total time spent in the MEC. Finally, technician workload, or utilization, would be very high; this is good when dealing with machinery or true resources, but not necessarily for humans. Consequently, the notion of scheduling more than 7 SPs per session was also dismissed.

The controllable input variables were the number of technicians and number of SPs per session, while the fixed input parameters were the scheduled start time (batch arrivals), distribution around scheduled start time (iid for each SP), check-in time, number and type of exams, as well as the exam layout within the trailer. The fitted model inputs were the probability of general Type/Age of SP per session (based on previous NHANES data) and the exam completion time distribution (again based on previous NHANES data). The output performance measures of interest, returned by Arena, were Exam usage, Overall time in exam center for all SPs to complete all exams, and Technician (resource) utilization. All analyses and results for this model were determined by session.

3.1 Results

The base CHANES model was exactly the same for each replication, but the distribution times at each exam were changed (from normal to best-fit) for sensitivity analysis. The model was first run for 20 replications, and then for 100 replications to increase precision. The model results showed that the BloodPressure exam had the highest utilization, causing a bottleneck/backlog, which is exactly the way it operated in reality on previous surveys. This was due mostly to the fact that a physician administered the Blood Pressure exam, while s/he also went into a general health examination – this can easily be adjusted if the exam is kept to blood pressure readings only. Animation also indicated the most utilized exams, providing "face validation" of the model.

The results are shown in Tables 3 and 4. "TechU" is the technician utilization which was calculated using values returned by the Arena software. The "Time, Mean" column is the mean time (in minutes) for the model to process all SPs.

Tables 3 and 4 indicate that the difference between the model with normally distributed exam times and the one with best-fit exam time distributions is relatively minor.

Table 3: Results of Different Configurations, 20 reps

Dist	Techs	SPs	TechU Mean	TechU StdErr	Time Mean	Time StdErr
Norm	5	20	0.704	0.011	279	6.0
Var	5	20	0.696	0.009	281	5.0
Norm	4	20	0.827	0.009	296	5.0
Var	4	20	0.847	0.011	289	4.7
Norm	3	20	0.932	0.006	350	4.4
Var	3	20	0.928	0.006	351	4.1
Norm	5	15	0.709	0.013	209	5.5
Var	5	15	0.704	0.010	210	4.0
Norm	4	15	0.823	0.010	226	4.1
Var	4	15	0.830	0.005	221	3.6
Norm	3	15	0.913	0.007	267	3.2
Var	3	15	0.919	0.006	266	3.0

Table 4: Results of Different Configurations, 100 reps

Dist	Techs	SPs	TechU Mean	TechU StdErr	Time Mean	Time StdErr
Norm	5	20	0.707	0.005	278	2.7
Var	5	20	0.709	0.004	277	2.4
Norm	5	15	0.705	0.006	210	2.5
Var	5	15	0.702	0.004	210	1.9

3.2 Optimal Configuration

The overall time in the exam center for 15 and 20 SPs was used as a general starting point to determine the feasibility of processing that many SPs in a given time. To determine the "best" configuration [x (unknown) SPs scheduled to arrive at y (different unknown) intervals with z (third unknown) techs working], various configurations were run while varying the number of SPs scheduled and the number of technicians on staff for a specific session.

Generally, the smaller number of bodies in the exam center, the better. Starting with 3 technicians, the model was run to determine the time it would take to process 4, 5, and 7 SPs. The same was done with 4 and 5 technicians, while never having less than or equal numbers of SPs enter as technicians working.

Although sensitivity analyses had already been done on the exam time distributions while processing 15 or 20 SPs, the model was run utilizing the normal distributions as well as the various exam completion distributions again to see if there would be any difference for smaller numbers of SPs. At first glance, there appeared to be a difference, but after running the numbers through the Arena input analyzer, it was found that there was no significant difference. The results are shown in Table 5.

Thus, all other trials and replications were then run using only the model utilizing the normal exam time distributions As stated previously, models using the exact same number of SPs as techs were not considered, nor were

Table 5: Results With Less SPs, 100 reps

Dist	Techs	SPs	TechU Mean	TechU StdErr	Time Mean	Time StdErr
Norm	3	7	0.879	0.004	131	1.3
Var	3	7	0.878	0.004	131	1.2
Norm	4	7	0.792	0.006	110	1.5
Var	4	7	0.793	0.005	109	1.3

models scheduling 10 SPs. The results, based on 100 replications for each model, are given in Table 6. The information is listed in accordance with number of technicians and number of SPs scheduled, using the same data described previously. The batch arrival was assumed to account for a difference in arrival times of up to 10 minutes, to theoretically account for late arrivals. The results indicate statistically significant differences between the performances of the configuration considered.

Table 6: Results for 'Optimal' Staffing and Scheduling

Techs	SPs	TechU Mean	TechU StdErr	Time Mean	Time StdErr
3	4	0.810	0.006	81	1.1
3	5	0.847	0.004	97	1.1
3	7	0.879	0.004	131	1.3
4	5	0.756	0.006	82	1.1
4	7	0.792	0.006	110	1.5
5	7	0.669	0.006	105	1.6

As alluded to earlier, a "common sense" method of validation was used, based on past experience, since the results of this model cannot be validated directly (CHANES is not yet in operation). Based on previous NHANES, the general bottleneck was always the Blood Pressure exam, which was also the case here. The Blood Pressure exam utilization in the simulation model was up to 0.40 higher than the other exams. The model outputs generally reflected actual field summary results, and the animation reproduced actual NHANES field operations.

To determine the best (or most effective) configuration, a simple benefit-cost ratio analysis was completed. For example, if 7 SPs could be processed 25 minutes faster than another configuration, but the technician idle time was 25% greater, is it the best configuration? The answer is relative to the worth of that 25 minutes in monetary terms.

When dealing with health or medical care, a benefit-cost ratio is difficult to determine, based on the subjectivity of assigning monetary worth. Health quality is a desirable objective, but not easily measured in economic terms. What's desirable, and worth a high dollar amount, to one person may not have as much monetary worth to another. Additionally, it is very difficult to assign a monetary worth to good health or good health care that applies across all boundaries (such as age or race). To calculate benefit-cost ratios, the normal rule is to compare benefits to all costs, but the benefits are not easily defined for NHANES or CHANES. The SPs benefit individually by receiving quality medical test results, which is only a fraction of the overall benefit to the US population or, in this case, community. The ultimate issue, of course, is whether the benefits (or net revenues, which would not apply to a nonprofit MEC) from any period justify the initial investment. The initial investment, or start-up cost, of a MEC would be very high relative to the continuing operating costs. Therefore, arguably, the initial investment cannot be reasonably considered when determining the benefit-cost ratio for any given exam session. It makes more sense, for the purposes of this model, to simply utilize a given time frame, and consider only the costs relative to that time frame. A benefit-cost ratio (Benefit/Cost = B/C) was completed relative to an exam session, with corresponding assumptions made. This provides the advantage of comparing the sessions on a common scale, ranking the configurations in order of relative merit, and directly shows whether the configuration is worthwhile (Neufville, 1990).

To determine the worth, or benefit, of an exam session, all test results were assumed to have the same value to the CDC and consequently the same value relative to each other. It was also assumed that all technicians are similarly valued equally. A further assumption was that the technicians and the data collection are of equal worth. Finally, for simplification, the cost of the technician idle time was considered as the only cost.

Time is also an important consideration, as the SPs should be processed with as little waiting time as possible. Therefore, the benefit-cost ratio should incorporate the overall time in the MEC. Thus, we took the benefit-cost ratio per session as follows:

$$B/C = \frac{\text{(number of SPs)}}{\text{(number of technicians)(\%idle)(average time in MEC)}}.$$

The standard error on the mean overall time in the exam center is fairly close, right around 1 minute, for all configurations. Simply using the values listed in Table 6 will return a reasonable estimate of the B/C ratios for the different configurations, results of which are displayed in Table 7.

Table 7: Benefit-Cost Ratio Analysis (Estimates)

Techs	SPs	Tech Idle(%)	Avg time T	StdErr of (T)	Mean B/C est
3	4	0.190	81	1.1	0.087
3	5	0.153	97	1.1	0.112
3	7	0.121	131	1.3	0.147
4	5	0.244	82	1.1	0.062
4	7	0.208	110	1.5	0.076
5	7	0.331	105	1.6	0.040

Based on these very simple numbers, the best configuration appears to be the 3 Technician 7 SP combination, with a benefit-cost ratio per time of 0.147. In reality, however, could 3 technicians be reasonably expected to consistently process 7 SPs? Utilizing, again, the percentage of idle time, an estimate of the idle time per session or per hour can be calculated:

- Idle time (percentage): (1 - 0.879) = 0.121
- Mean time in exam center, 3/7 config: 131 minutes

- Standard Error of Mean time: 1.3 minutes
- Avg Idle time with 3/7 config: (131 x 0.121) = 15.9

Ergo, the technicians would be idle for an average of 16 minutes per 131 minute session or about 7 minutes per hour. This seems reasonable, but more substantial input from NCHS managers would be required before actual implementation of this particular scheduling configuration. Additionally, NHANES has historically operated with significantly less technicians than SPs scheduled with no ill effects on SP waiting time. Again, this configuration seems reasonable, based on past observational data.

We then conducted more formal statistical calculations to distinguish differences between various configurations. Batching was used to calculate new B/C ratios, in order to have more normally distributed output samples, so that confidence intervals would be more likely to be at their pre-specified (e.g. 95%) level. In particular, for all of the configurations considered, the 100 replications were batched into 10 groups of 10. A mean overall time in the exam center was determined for each of the 10 batches, each of which was used to determine the corresponding B/C ratio per batch.

To get a confidence interval for each configuration B/C, the batched B/C values per configuration were used to get the results listed in Table 8. The results can be more clearly viewed in Figure 2.

Table 8: Benefit-Cost Ratio Analysis (95%CI)

Config	1	2	3	4	5	6
B/C	0.087	0.113	0.147	0.063	0.077	0.041
StdErr	.0015	.0019	.0013	.0009	.0012	.0007
95% CI	.0033	.0043	.0029	.0021	.0026	.0016

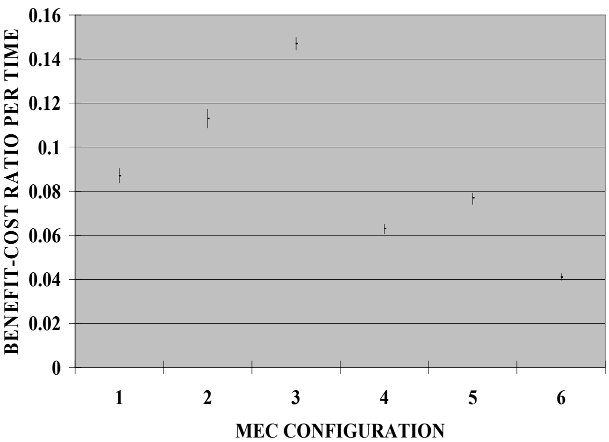

Figure 2: Benefit-Cost CIs per Configuration

At this point, configurations are labelled as follows.

- Configuration 1: 3 Techs, 4 SPs
- Configuration 2: 3 Techs, 5 SPs
- Configuration 3: 3 Techs, 7 SPs
- Configuration 4: 4 Techs, 5 SPs
- Configuration 5: 4 Techs, 7 SPs
- Configuration 6: 5 Techs, 7 SPs

From the confidence intervals already determined, there is fairly strong evidence that the configurations are statistically distinguishable at the 95% confidence level, with possible exceptions of (1 versus 5) and (4 versus 5). However, to be even more precise on the differences between the various configurations, paired-t analyses were done using the batched ratios. The results are shown in Table 9 and Figure 3. The data confirm that the order implied by Table 8 and Figure 2 is in fact statistically significant at the 95% confidence level. As clearly shown in both Figures 2 and 3, the best MEC configuration, based on the very simply defined Benefit/Cost ratio, would be 3, followed in declining order by 2, 1, 5, 4, and lastly 6.

Table 9: Paired-T Results for B/C Ratio Analysis

Compare	Mean diff.	CI (+/-)		Compare	Mean diff.	CI (+/-)
1:1-2	-.0259	0.0024		9:2-6	0.0717	0.0034
2:1-3	-.0599	0.0021		10:3- 4	0.0840	0.0020
3:1-4	0.0241	0.0023		11:3- 5	0.0702	0.0013
4:1-5	0.0103	0.0023		12:3- 6	0.1060	0.0015
5:1-6	0.0458	0.0026		13:4- 5	-.0138	0.0018
6:2-3	-.0340	0.0027		14:4- 6	0.0217	0.0015
7:2-4	0.0500	0.0025		15:5- 6	0.0355	0.0014
8:2-5	0.0362	0.0030				

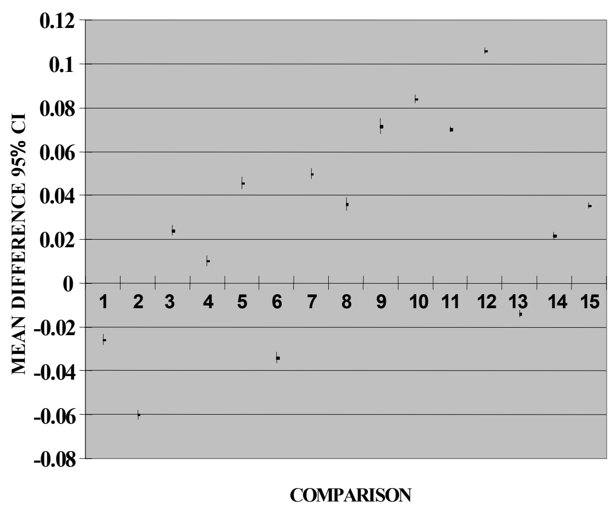

Figure 3: Paired-t Analysis Confidence Intervals

Crucial input from other areas of NCHS is required, however, to determine an equitable "most important" factor – perhaps the SP waiting time is more important than technician utilization/efficiency. Perhaps all subsections of the survey design team will agree that technician efficiency and budget concerns are of utmost importance.

4 CONCLUSION

A simulation model of a proposed CHANES exam center was completed and is flexible enough to easily accommodate different configuration proposals. In this paper, five medical examinations or tests were included, with the assumption that all technicians (or employees) in the exam center could administer any of the five examinations. The model was run with normal distributions and also with alternate distributions as a sensitivity analysis, with little or negligible difference in overall results.

The benefit-cost analysis results indicate that the best configuration would be the system using 3 technicians while scheduling 7 SPs, assuming all SPs arrive for the session. Although the overall time in the exam center was the highest, the idle time of the technicians was the lowest.

Since technicians are not machines, however, some adjustment may be necessary to account for unanticipated ergonomic problems. Having 3 technicians working each session is also advantageous due to the very limited space available – having more than 3 employees on board may cause other unanticipated problems. Historically, NHANES has operated with significantly fewer technicians than exam rooms and SPs, with no overall detrimental effects on excessive SP waiting time.

Additionally, if the Blood Pressure exam is modified to include only a blood pressure reading, rather than also a general health analysis, it will greatly reduce the time spent in that exam and cut down on the overall time in the exam center. Moreover, if the MEC is to be used on only a subgroup of the population, the age distributions can be modified as an input variable. In reality, all results may change with the addition or deletion of certain examinations and consensual input from NCHS management.

Furthermore, the importance of technician efficiency, SP wait time, and server (exam) utilization must be carefully considered in relation to each other. From a budgetary standpoint, technician efficiency would be the most important factor. From a customer service standpoint, minimizing SP waiting times would be most important. Yet from an operations standpoint, utilization of servers (exams) and maximizing data collection would have dominance. A compromise must be achieved between management, budget, and operations to determine an agreeable medium for a truly optimum MEC.

Finally, in realistic operation for CHANES, it would be best to stagger examination appointments so that no one SP is kept waiting excessively. It would also be best to stagger appointments or batch arrivals. The overall time spent in the exam center for the 3 technician, 7 SP configuration was just over 2 hours, on average. It would be beneficial to split a regular workday, assumed to be 8 hours, to accommodate. It may be possible to have more than 3 technicians on staff, allowing unique workdays with staff staggered throughout the MEC session times. A session would not be a regularly scheduled time period, but one adjusted according to the estimated times returned by the simulation model. For example, the results in Tables 5 and 6 indicate that for 3 technicians, a batch arrival of 7 SPs could be scheduled approximately every 2.2-2.5 hours, whereas scheduling a batch arrival every 2 hours or so would work best for 4 technicians working the shift. While the session utilizing 5 technicians and 7 SPs would be the most time effective, it would be most wasteful in terms of technician idle time, as well as involve a very crowded examination center. A full benefit-cost analysis would have to be completed, however, working closely with NCHS management on input and most desirable outcome parameters, before any configuration is dismissed absolutely.

4.1 Future Work

Now that a working simulation model has been designed, other configurations can be implemented and tested. If more time is needed for initial check-in, that can easily be modified. If different distributions of arriving SPs are necessary, the type and/or age of SPs is controllable as an input parameter. If exam protocols are changed such that an exam takes significantly less or more time to administer, the overall exam distributions can be changed accordingly. Just using the mean and standard deviation should provide a reasonable approximation, since the model appears to be relatively insensitive to deviations from the normal distribution fit for the exam completion times. Finally, in considering changes in the exam configuration, it should be kept in mind that since the exam center space is so limited, any exam involving large or bulky equipment would displace space for another exam and cut down on the overall number of exams to be included.

More research is needed, involving input from NCHS survey planners, to realistically utilize this simulation model for CHANES. A more systematic analysis of the tradeoffs would be necessary, as the overly simplified B/C ratio presented here is meant to be only one illustration of the usefulness of the simulation model in supporting managerial decision-making. Additionally, much more in-depth modeling would be necessary to extend the concepts to the full-scales NHANES, due to the more extensive number of exams and the variation in technician skills, as well as the variation in SP exam eligibility. The model and results thus far, however, provide a very good starting point.

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