

## A 3-Step Approach for Introducing Computer-Aided Ergonomics Analysis Methodologies

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**Abstract.** The first step of the methodology focuses on air traffic controllers situated at a workstation within an Air Traffic Control (ATC) room. The 3D CAD software RAMSIS uses manikins to represent subjects under study. Using this software, three air traffic controllers of different heights were added. The three air traffic controllers were modeled sitting at their workstation in different positions while doing typical on-shift duties, including reaching for a phone and looking at each of the three monitors at their workstation. The Joint Capacity analysis tool in RAMSIS was used to study which joints face the most discomfort on each air traffic controller. It was found that the hip joints and the shoulder joints unanimously faced the highest amount of fatigue in this setting. Suggested modifications to the control room include adjustable desks, monitors, and chairs so that different air traffic controllers can be accommodated. Potential discomfort for air traffic controllers facing ergonomic issues on the job can create vulnerabilities that extend to the public. In second step, an analysis tool is introduced for analyzing the obstruction on the window caused by computer monitors in the Air Traffic Control room. Obstruction analysis was done to investigate the need for a reorganized workspace considering the user's need to see out the window to perform their job tasks and to decrease the need for repetitive standing to see out the window. It was found that approximately 40% of the window is obscured by the monitors and therefore the monitor configuration should be changed. The projected change to a three-in-a-row monitor setup decreased the obstruction to the window and therefore improved the ergonomic setup of the workstation. In step 3, a RAMSIS simulation and analysis of the forklift blind spots helps provide improved safety for the forklift operation. A camera system with two different view angles is added to aid the forklift operator. Analysis leads to conclusions that using the camera system eliminates the forklift blind spot and allows for safer forklift operation.

**Keywords:** Repetitive task, Forklift, Vision blind spots, RAMSIS

## **1. Overview of Three Steps in Computer-Aided Ergonomics Analysis**

Three steps are outlined in the form of cases that are described to introduce a methodology for ergonomics analysis. RAMSIS software is shown for design using computer-aided ergonomics and digital human modeling. In the first step, a joint capacity analysis is done for air traffic controllers and improved air traffic control room design. The three air traffic controllers were modeled sitting at their workstation in different positions while doing typical on-shift duties, including reaching for a phone and looking at each of the three monitors at their workstation. The Joint Capacity analysis tool in RAMSIS was used to study which joints face the most discomfort on each air traffic controller. In the second step, in similar work setting, an obstruction analysis is conducted for the air traffic controllers. Obstruction analysis was done to investigate the need for a reorganized workspace under the consideration of the user's need to see out the window to perform their job tasks and to decrease the need for repetitive standing to see out the window. Certain properties of the eyes can be simulated (Bubb, 2007; Karoui & Kuebler, 2019). At that time Bubb showed examples eye tracing research and gave consideration for future industrial applications. In the third step, vision-related simulations are again considered. This time the vision-related simulation is used for simulating the operating circumstance of forklift operator. Vision and blind spots are considered for redesign, awareness and hazard mitigation. A wireless camera system is incorporated with a system perspective on awareness and mitigation of hazards associated with the blindspots that are traditionally present in forklift operator experiences.

### **1.1 Step 1 Computer-Aided Ergonomic Analysis**

Ergonomics is the study of adapting the workplace environment to the worker's needs. Proper ergonomic design increases the efficiency and productivity of the worker, and should be considered early in development process for all workplace settings (van der Muelen & Seidl, 2007; Duffy, 2007; Demirel & Duffy, 2007). The purpose of this first step is to introduce an ergonomic assessment of air traffic controllers' joint analysis in an air traffic control room setting.

The design and analysis for this study was performed using 3D Digital Human Modeling (DHM) tool RAMSIS. This CAD software represents subjects under study as manikins, and allows the user to manipulate their behavior in the environment. For this study, RAMSIS was used to model air traffic controllers sitting at a workstation.

### **1.2 Step 1 Problem Statement**

This first step showed ergonomic risks that are found in air traffic controllers sitting at a workstation in an Air Traffic Control (ATC) room. Three manikins: one tall, one medium, and one short in height, were altered to reach for the phone, while simultaneously looking at three different computer screens at their work station. The discomfort percentage rating for every combination was tabulated. The purpose of this study is to diagnose what joints have the highest ergonomic risk factors in this sitting position.

The motivation to study the design of the ATC room, and of the controllers at the workstation is public safety during air transport. Controllers direct aircraft during

flight, and prevent collisions among multiple aircraft at landing/take-off stations. An improperly designed workstation or poor equipment can distract the controller or cause loss of situational awareness. A traffic controller not comfortable at their station can also face long-term consequences such as fatigue, pain and discomfort, which can ultimately lead to musculoskeletal disorders.

The ATC Room is an environment where repercussions of improper ergonomics can extend beyond injuries of the controllers, to the fatalities of many people. Serious accidents have occurred when the environment of the traffic control tower was not factored into design. USAir Flight 1493 in 1991 cited ergonomics within the control tower to be a contributing factor of aircraft collision (USAir Flight 1493, 2019). The controller that guided this 1493 flight faced glare from the lights of a nearby building, and had a poor vantage point from the tower she sat in. This ultimately caused two planes to collide with each other.

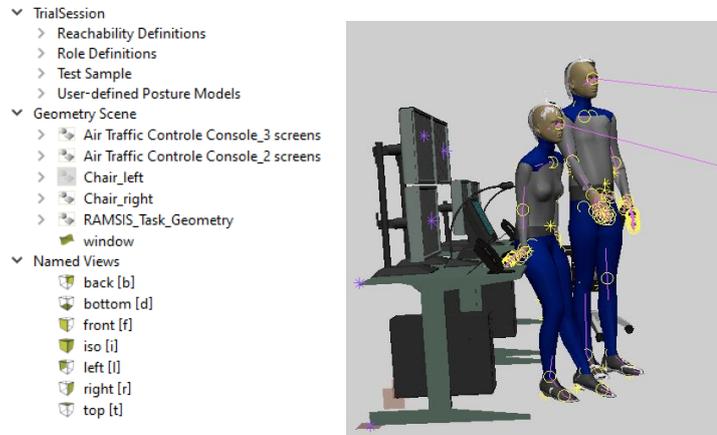
### **1.3 Procedure**

#### **Loading the Software**

To launch the RAMSIS program, the “launchNextGenAutomotive.bat” file is launched from the RAMSIS zip folder. After the RAMSIS program loads, the RAMSIS Air Traffic Control Room session is launched by navigating to *File>Load Session*, selecting the folder “session\_AirTrafficControlCenter”, then pressing OK. The window will load the air traffic control room environment with the manikins and workstation geometry, as shown in Fig. 1. It is helpful to adjust the render style to “Shaded” through *View>Render Style* on the top menu bar so that the user can easily see and alter the manikins accordingly.

#### **Menu Navigation**

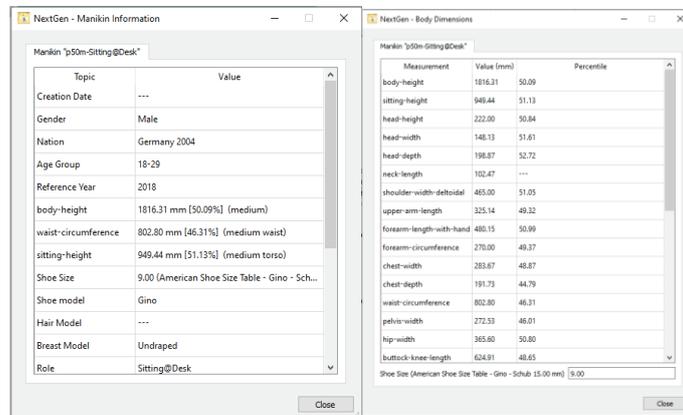
As shown in Fig. 1, there are three major sections in the structure tree (sidebar on the left-hand side of the program). These three sections include “TrialSession”, “Geometry Scene”, and “Named Views”. The “Geometry Scene” folder shows all the CAD files that represent the manikins and workstation objects. The “Named Views” folder has pre-set views that the user can click on to change the orientation and view.



**Fig 1.** The general structure tree, and the manikins loaded at the ATC station.

### Manikin Characteristics

It is important to know the manikin information and body dimensions to create an optimal working environment for them. As shown in Fig. 2, the “Manikin Information”  button and the “Body Dimensions”  buttons are used to access this information. Important variables to look for when considering the analysis of these manikins include the sitting height, leg room, and reach.



**Fig. 2.** The manikin information and body dimensions windows.

### Moving Manikins to Sitting Position

For the purposes of this study, the manikins were studied in a sitting position. The manikins are made to sit using the posture calculation  button, and “Yes to All” is applied to the pop-up that inquires about restarting the calculation without pre-adjust-

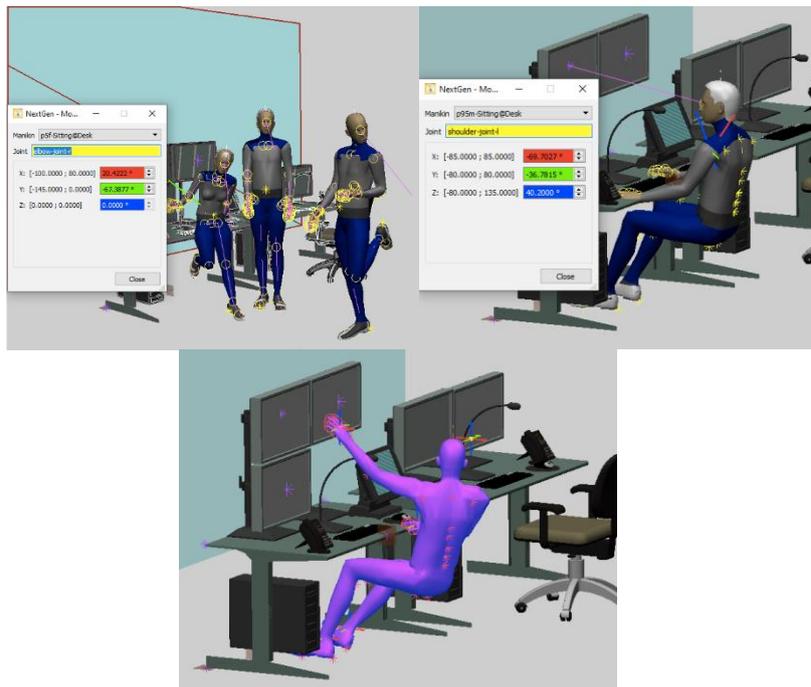
ment. At the Status at the bottom of the window, the status “Posture Calculation Successfully Completed for all Manikins” is reported. After the posture calculation is performed, the window will reveal the manikins sitting down.

### Altering the Manikin’s Joint Positions

Demonstrations of alterations to the manikin’s joints are shown in Fig. 3. The *TrialSession>”Test Sample”> Sitting@Desk* subfolder contains the biometric information, postures, task, and skeleton points of the manikins.

The manikin’s joints are adjusted by clicking the joint  button. In the pop-up window, the joint location is changed by clicking on the manikin’s joint, and dragging one axis of the joint coordinate system to the desired position. (Alternatively, the joint position can be altered by manually supplying the manikin’s joint name found under the “Skeleton Points” subfolder and entering  $[x,y,z]$  coordinates, or using the mouse scroll bar to gradually change coordinates.)

One of the most useful tools to rapidly change the position of the manikin’s joints is the reverse kinematics  button. This allows the user have the manikin reach or look at an object simply by clicking and dragging axes of a coordinate system that appears at a joint. (To toggle out of the reverse kinematics section, *Operations>Select* is used.)



**Fig. 3.** The left and middle images depict the alteration of the manikin’s joints. The right image shows the implementation of the reverse kinematics tool.

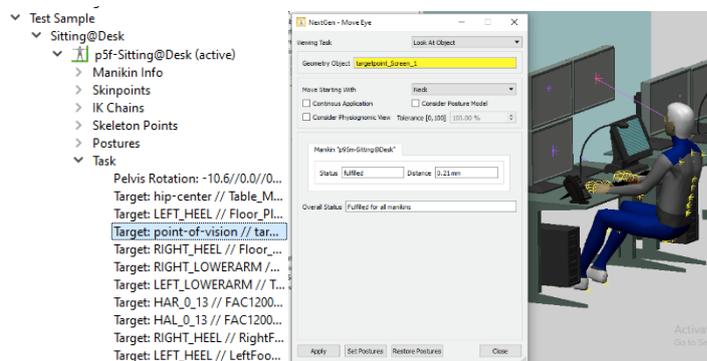
### Manikin-Object Interaction

A manikin can be modeled to interact with a workstation object (“Env. Object”) by utilizing information from the structure tree. The manikin can be changed to interact with an object by altering the Task>Target that corresponds to that specific manikin’s name and body part. The name of any Environmental Object can be found by right-clicking it, and selecting “Show Selected Object in Structure Tree”.

For example, the user can make a manikin look at the right-hand computer screen by obtaining the name of that screen from the structure tree (e.g. “target-point\_Screen\_1”). To make a manikin look at this screen as its target point, the “Task” folder under the manikin’s name in the structure tree is expanded to show the “Target: point-of-vision” task. Reference the left image on Fig. 4. This target is right clicked to select Object properties, and the Env. Object section is changed to “target-point\_Screen\_1” in the resulting pop-up window. When a posture calculation is run, the manikin’s view will update to look at the desired screen.

The “Move eye”  button from the menu can be used to alter if the manikin looks at an object or looks in a certain direction. Their entire head will move to look at the object if “Move Starting With: Neck” is selected. Reference the middle image in Fig. 4.

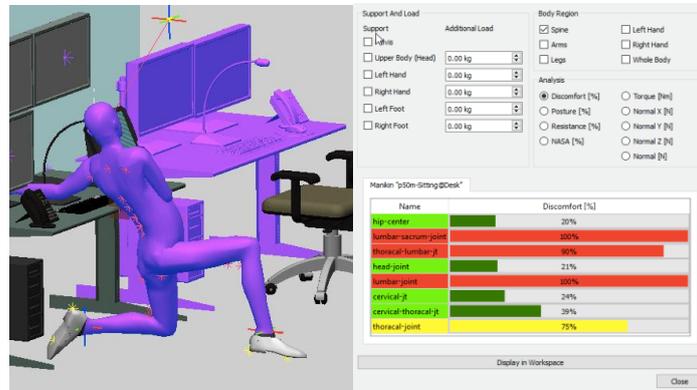
Lastly, the internal view  button allows the user to see the objects from the manikin’s eyes and is useful in positioning the manikin. Reference the right image in Fig. 4.



**Fig. 4.** The left image shows where the point of vision is set in the structure tree. The middle image shows the manikin being altered to look at an object using the Move Eye tool. The right image shows the Internal View feature to view the environment through the manikin’s eyes.

### Analysis Tool: Joint Capacity Analysis

The analysis tool that was used to conduct this study was the joint capacity analysis tool, as shown in Fig. 5. The Joint Capacity Analysis button  is found within the analysis tools, and supplies the user with calculations of discomfort, posture, and resistance for any joint on the manikin.



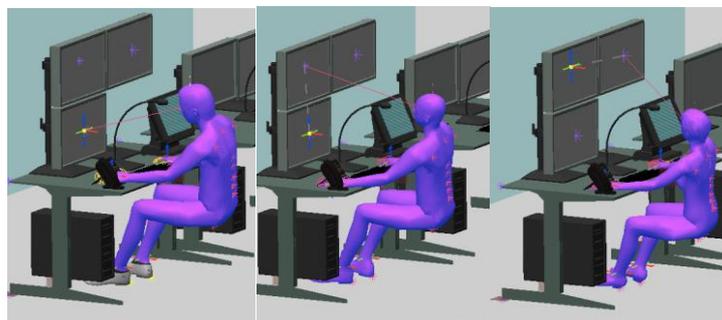
**Fig. 5.** The left image shows the manikin contorted in an awkward position, and the right image shows the resulting discomfort percent rating for the spinal region.

#### 1.4 Discussion of Step 1 Joint Analysis in Computer-Aided Ergonomics

##### Analysis Setup

Each of the three manikins supplied in the ATC Room session were modified to reach for the phone to their left, while simultaneously looking at each of the three screens, for a total of 72 runs between all three manikins. The purpose of this analysis was to understand what joints are impacted the most by sitting in this position and what environmental objects may cause most stress on joints. Additionally, the reason that manikins of three different sizes were studied was to see what biometric characteristics could potentially influence discomfort on joints.

The manikins were moved into the desired position by using the Inverse Kinematics tool and the Move Eye functions. The inverse kinematics tool was used to model the manikin reaching for the phone as shown in Fig. 6. The “Move Eye” function was used to model the manikin viewing at the various screens (the Environment Objects with targetpoint\_Screen, targetpoint\_Screen\_1, targetpoint\_Screen\_2). Then, the joint capacity analysis was performed. Fig. 5 in the previous section shows what a joint calculation looks like.



**Fig. 6.** From left to right: Manikins p95-m, p50m, and p5f reaching for the phone and looking at the screen in front of them

### **Analysis Results**

The discomfort percent (%) ratings for all three manikins under study is shown in a bar chart below. The abscissa depicts the discomfort percentage (from the joint capacity analysis tool), and the ordinate depicts the manikin's joint under study. Within each joint category, there are three different colored bars, representing which computer screen was reviewed while the manikin was reaching for the phone.

The takeaways from the results are:

- The largest and most unanimous ergonomic risk to the manikins are the discomfort found in the right hip, left hip, and left shoulder joint. These three joints had a discomfort rating of 100% no matter what manikin was under study. This means that the manikin's height (or other biometric characteristics) had no influence on these three joints ranking as the highest ergonomic risks and most important ergonomic risks to ameliorate.
- Of the joints with discomfort percentages less than 100%, the tallest user (p95m) was often the least comfortable, or had the highest discomfort percent rating. This manikin is tall and the data suggests that he has to make more adjustments to his environment (such as the desk or chair) than the shorter manikins to feel comfortable.
- Changing the computer screen the manikin looked at while reaching for the phone had negligible impact on the discomfort rating percent for every manikin's joint (varied by one percent at most). This suggests that reaching for the phone had the negative impact on the manikins' joints, and not the computer monitor placement for this combination of movements. (The computer monitor placement could definitely factor into discomfort in combination with other movements!)

### **Suggested Modifications**

From the results of this study, several modifications can be suggested to improve this workstation. When viewing each joint under this particular study, it is evident that the highest discomfort rating is in the hip joints and left shoulder joint.

Environmental changes that can be made to make the workstation more comfortable include changes to the chair, desk, and monitors. To address the discomfort in the lumbar joint and lumbar sacrum joints, the manikins should have a chair with backing that can support lower back curve, and should recline between 100 and 110 degrees. The desk and chair should be adjustable in height so that the arms aren't forced into an awkward position and the shoulders are properly supported, especially for the manikin that is taller in height. For the shoulder joints, the amount of time the manikin has to reach to use the phone should be minimized. If possible, the use of a remote headset can prevent constant reaching.

Some that the manikins should make to their own posture are having their forearms angled slightly downward on the keyboard to ease the stress on the shoulders and elbows. When the baseline aircraft control room session was loaded as-is and a joint capacity analysis was performed on all of the manikins, all of the manikins had a moderate discomfort rating (70-80%) within both shoulder joints. This suggests that the manikins need to be sitting in a more neutral position even before reaching for the phone.

## 2. Introduction to Step 2 Obstruction Analysis in ATC Room

This analysis will explore the obstruction caused by the monitors in the Air Traffic Control room onto the window. The purpose of the analysis is to investigate if enough of the window is obstructed to the point that operators would have to repeatedly stand to see out the window in order to complete their daily tasks. Repetitive motions cause a large amount of workplace injuries, “the best solution is to ergonomically design workstations to help prevent disorders from occurring in the first place.”<sup>1</sup>

### 2.1 Obstruction Analysis

Below are the steps needed to complete obstruction analysis for the stated problem.

1. Analyze sight limits. Select Analysis -> Vision -> Sightlimits [Fig. 7]
    - a. Center C = Manikin (mid eye is suggested)
    - b. Object O = Object causing the obstruction to the view, in this case, the computer monitors. Select the monitor that the manikin is looking at (manikin line of sight is depicted as a pink line) by clicking on it. Once selected, the monitor should be shaded pink.
    - c. Visual Field V = the view being blocked, in this case, the window. Click anywhere on the window to select the window.
    - d. Select “Surfaces” and “Surface rearward object” boxes.
    - e. Change the base name as needed.
    - f. The length box determines how far the program projects the obstruction view. This can be edited as needed.
    - g. Click “Compute”, once the gold cone appears, click “close”.
  2. Move the manikin’s target point to another screen.
    - a. In the sidebar, use the arrows to extend the view for “Geometry Scene” then “Ramsis\_Task\_Geometry” .
    - b. Click “targetpoint\_screen” then Operations -> Translate. A compass/crosshairs should appear at the target point on the screen. [Fig. 8]
    - c. Using the pointer, click and drag on the specific axis’s to move it to the center of the screen above.
    - d. Select Operations -> Posture Calculation to change the manikin’s view. Click the calculate button as before in step 3.
    - e. Select Operations -> Select to stop translating objects.
  3. Repeat steps 1 and 2 for both monitors. Make sure to select the correct monitor for each vision analysis.
  4. Create an intersection between the wall and the cone of obstruction. This will allow us to approximate the area of the window obscured by the monitors.
-

- a. Select Geometry -> Intersect Objects.
- b. Select object 1 from clicking on the 3D rendering of the sight limit or select the sight limit from the expanded menu on the sidebar. Each sight limit will have it's own intersection with the window.

5. Hide the sight limits. Left click on the rendering or the object name in the side bar -> select hide. For this portion of the analysis, the "back view" is used to make things easier to view. Hide all three sight limits.

6. Calculate approximate distances.

- a. Geometry -> Point then change "Point Type" to "Create on Object", select the object as one of the intersections. Using the cursor, click on the rendering where you want the point to be, then click "Create". Place points in the upper left corner of the top left intersection, lower left corner of the bottom left intersection, and upper right corner of the right intersection. Points will appear as small red \*.

- b. Once the points are created, they will turn from red to teal. To make the points easier to see when not selected, find the points in the sidebar, right click, and select "Object Properties". In that box, there is an option to change the color of the object in question. [Fig. 9]

- c. Select Analysis -> Distance.

- i. Distance across the top: change the distance type to "Y", then select the two highest points. Click "Create". [Fig. 10]

- ii. Height: change the distance type to "Z", then select the two points down the side of the intersection boxes. Click "Create". [Fig. 11]

7. Calculate the approximate area of obstruction by multiplying the two distances together. This is an approximation, although there is no lower right monitor, it can be assumed that the phone placed on the desk to the right will have a significant obstruction of the lower right hand zone and therefore a rectangle can be calculated for an estimation of area.

Perform these steps on tall, short, and medium manikins of each gender and calculate the average area obscured for each gender.

## 2.2 Results in Step 2 Obstruction Analysis

The calculations for approximate area are found in the table below. The equation for calculating the area is

$$(Y\ Distance)*(X\ Distance) = Area \quad (1)$$

The equation for calculating the average area is

$$\frac{(Short+Medium+Tall)}{3} = Average\ Area\ Obstructed \quad (2)$$

**Table 1:** Obstruction Analysis Results.

<b>Male</b>			
<i>Manikin Size</i>	<i>Y Distance (mm)</i>	<i>Z Distance (mm)</i>	<i>Area (mm<sup>2</sup>)</i>
Short	3902.22	2393.27	9,339,066.06
Medium	3845.16	2333.52	8,972,757.76
Tall	3798.75	2310.31	8,776,290.11
<b>Average Area Obstructed (mm<sup>2</sup>)</b>			9,029,371.31
<b>Female</b>			
<i>Manikin Size</i>	<i>Y Distance (mm)</i>	<i>Z Distance (mm)</i>	<i>Area (mm<sup>2</sup>)</i>
Short	4090.94	2499.17	10,223,954.52
Medium	4028.72	2445.96	9,854,087.97
Tall	3977.31	2456.57	9,770,540.43
<b>Average Area Obstructed (mm<sup>2</sup>)</b>			9,949,527.64

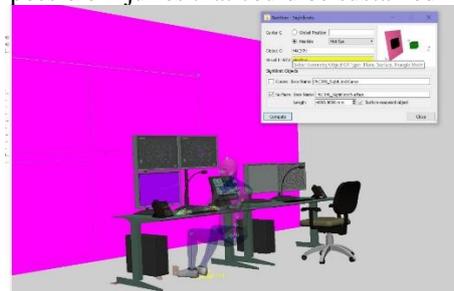
The dimensions of the window are 7084.86mm (width, Y Dimension) by 3396.86 mm (height, Z Dimension), giving it an area of 24,066,277.54 mm<sup>2</sup>. First, the percentage of the window obstructed by each gender should be calculated using equation 3.

$$\frac{\text{Average Area Obstructed}}{\text{Area of the Window}} * 100 = \% \text{ of the window obstructed} \quad (3)$$

**Table 2:** Percent Obstructed

<i>Gender</i>	<i>% Obstructed</i>
Male	37.52%
Female	41.34%

The height of one monitor at the approximate correct ergonomic height is 1658.85 mm. From Table 1, the largest contribution to high percentage of obstruction to window is caused by height of monitors. This height is the largest factor in causing the operator to stand in order to see out the window. In this case, due to the large amount of space obscured by the monitors, the suggestion is to move the monitors to a “three-in-a-row” model. With one monitor, the height of the obstruction would be greatly reduced and therefor decrease the need for the operator to stand repetitively. However, this would extend the width of the obstruction on the window, but not any more than the current desk configuration already does. By decreasing the height of the obstruction to the window, the need for the operator to repetitively stand is decreased, therefore protecting the operator from any possible injuries that could be sustained from that movement.

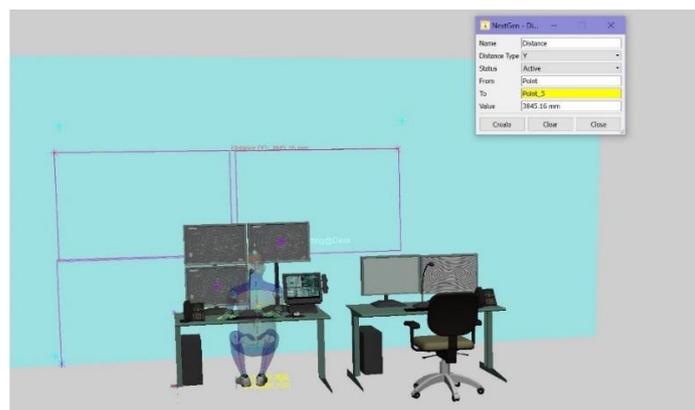
**Fig.7.** Selecting objects to compute Sightlimits.



**Fig.8.** Select targetpoint\_screen from sidebar and Translate function to change location of targetpoint\_screen.. Change test\_manikin's line of sight using Posture Calculation. Workspace view can show all Sightlimit calculations. A view of the intersections can also be shown.



**Fig. 9.** Creating points and Altering visual characteristics of objects.



**Fig. 10.** Finding the Y distance between points.

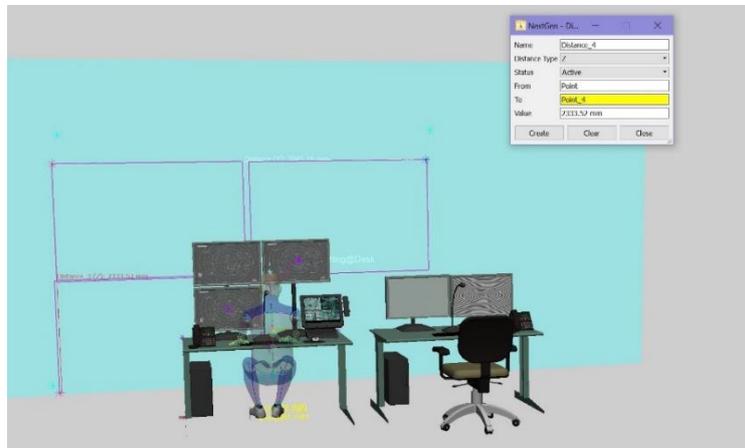


Fig. 11. Finding the Z distance between points.

### 3. Step 3 Forklift Introduction and Problem Statement

#### 3.1 Introduction and Problem Statement

Forklifts are a very popular tool to have when it comes to moving large objects fast and within a short distance. Today, forklifts are used in the warehouses, lumber and grocery stores, loading docks, production factories, construction sites, and any other places where a large amount or large size objects need to be moved on a regular basis. Being such a popular tool forklift poses a great safety threat to the work environments in which it operates in. Per the United States Bureau of Labor Statistics, in the United States, 614 workers, ages 18 to 65, died from traumatic injuries suffered in forklift-related incidents from 2011 to 2017 (US BLS, 2017). Nearly 64% of those fatalities were caused by the forklift operator's failure to clearly see hazards while operating the forklift due to forklift blind spots (US BLS, 2017). Managing forklift blind spots can help to prevent a large number of injuries related to forklift operation. "Warehouses, distribution centers, construction sites – getting rid of forklift blind spots is one of the most important safety mechanisms for any lift driver." (FLC Forklift, 2018)

The purpose of this analysis is to create RAMSIS software model of the forklift blind spots that limit forklift operator field of view and assess the rationale for the use of the forklift wireless camera systems to help the driver see the area beyond the blind spot to ensure safe operation of the forklift machinery. The analysis is simulating the real-world scenario of the operator obstructed the view as he/she is looking forward through the forklift lift bars (see Fig 12).



**Fig. 12.** Real world scenario where forklift operator has obstructed view caused by forward forklift bars. (D2000 Safety, 2014)

### 3.2 RAMSIS Software Simulation Introduction and Procedures

The procedure consists of multiple steps within this section that document the use of the software. Each step is supplemented with the screen capture. Step 1 is to create an appropriate RAMSIS software simulation. Next one would launch “*launchNetGenAutomotive.bat*” file and loading the Forklift session developed by Thorsten (see Fig. 13).



**Fig. 13.** *launchNetGenAutomotive.bat* file.

The “forklift” session has a software model for the forklift simulation with the forklift, a forklift pallet, and loader, who is loading the pallet (see Fig. 14).



**Fig. 14.** Forklift session in RAMSIS.

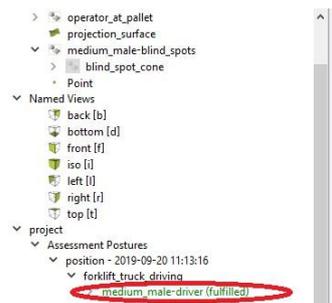
Step 2 (within section 3.2), Next one could create a manikin with an age group of 18-70, USA nationality and add it to the Forklift session. This is accomplished by clicking the “*Create Manikin*” button within the session tab in the toolbar menu. This opens the Manikin parameter window.

Step 3 (within section 3.2), is to apply manikin settings to the manikin by clicking the “Apply” button. As a result, manikin appears within “forklift” session (see Fig. 15).

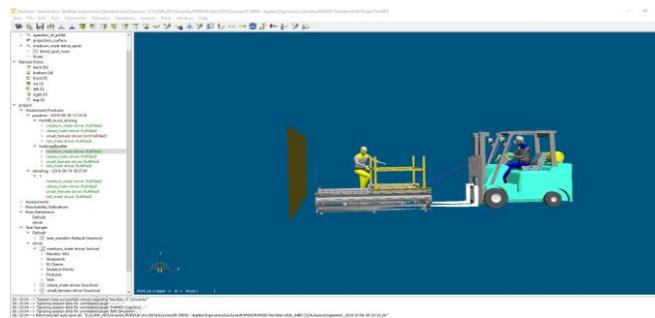


**Fig. 15.** Manikin appeared next to forklift.

Step 4 (within section 3.2) is to move manikin behind the forklift steering wheel. One could open project tabs on the left-hand side of the RAMSIS window: *project* -> *Assessment Postures* -> *position* -> *forklift\_truck\_driving* and select manikin’s name “medium\_male-driver” to assign it to the driver seat of the forklift (see Fig. 16 and 17).

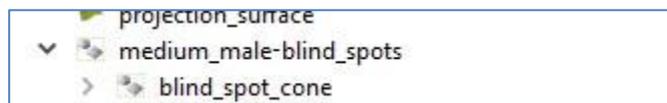


**Fig. 16.** Folder tree on the left-hand side.



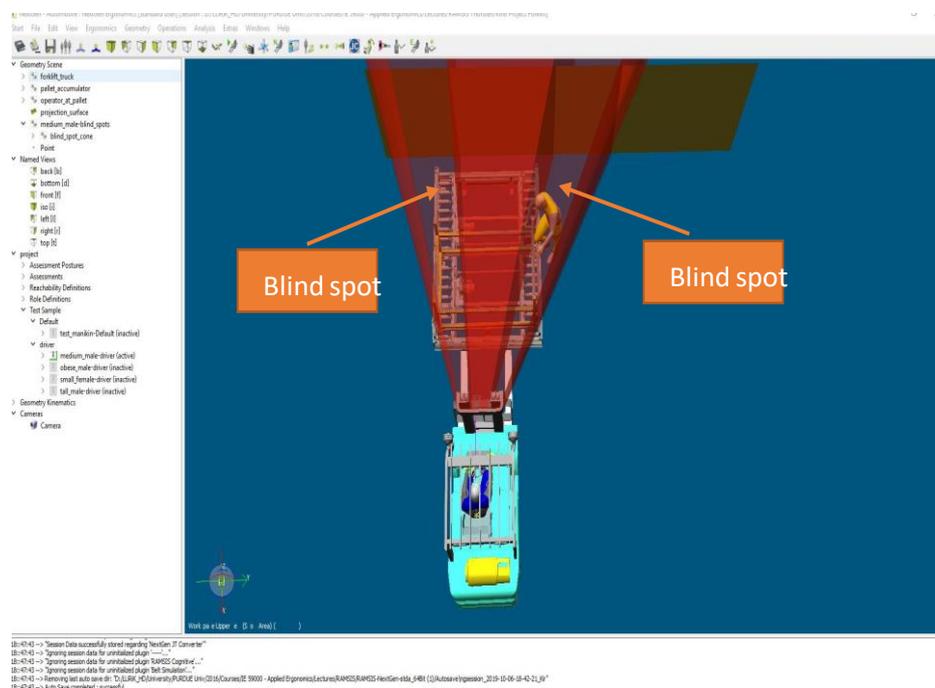
**Fig. 17.** Manikin is moved behind the forklift steering wheel.

Step 4 occurs after moving the manikin behind the forklift steering wheel, One needs to identify and analyze the forklift operator’s blind spots. In order to do so, enable blind spot cone by double-clicking “blind\_spot\_cone” simulation on the right-hand side model panel (see Fig. 18).



**Fig. 18.** Blind-spot-cone model location.

The blind spot cone will appear on the forklift scene, clearly defining the blind spots. Analyzing the scene, it is evident that the loader appears to be within the blind spot (see Fig. 19).



**Fig. 19.** Blind spot cone created by the forklift bars.

Step 5, is to simulate forklift operator eye perspective and analyze his/her obstructed view. To do so, select the *Analysis* tab -> *Vision* -> *Internal View* (see Fig. 20). This will prompt a window that represents the manikin field of view.

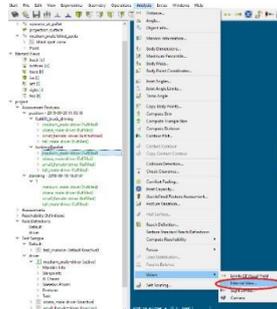


Fig. 20. Operator's view analysis.

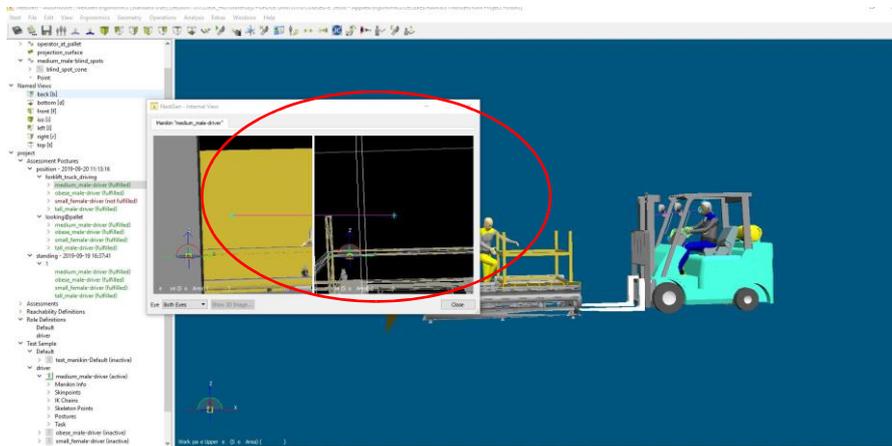


Fig. 21. Operator's view in the window.

Looking at Fig. 21, it is obvious that both eyes of the operator cannot see the loader, who is working within the blind spot area. The view is obstructed by forklift bars. Consequently, this software simulation adequately represents a real-world scenario shown in Fig. 12.

At this point, one is ready to analyze what changes needed for the forklift to eliminate the vision area that goes undetected (blind spot). There several solutions in accordance with Thorsten's presentation. One is to use the mirror and the second is to mount a wireless camera. In this analysis, an analysis is conducted for use of a camera mounted on the forklift to see if it will improve blind spot visibility for the forklift operator.

Step 6 (in section 3.2) is to create a camera in the RAMSIS forklift session. One can click on the menu tab and select *Ergonomics* -> *Camera Definition* (see Fig 22). A Camera definition window will pop-up allowing the user to define the camera parameters (see Fig. 22). Initially, one would want to try default camera parameters: the horizontal opening is set at 60 degrees and a vertical opening at 45 degrees (see Fig. 23). The camera is placed on the overhead guard of the forklift (see Fig. 24).

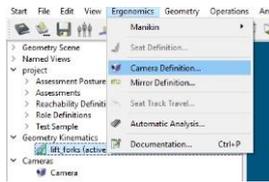


Fig. 22. Creating a camera.

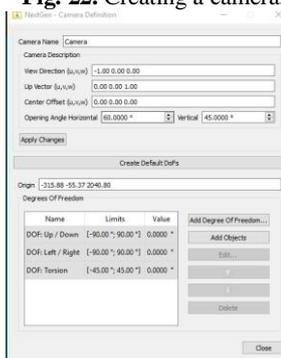


Fig. 23. Camera parameters.

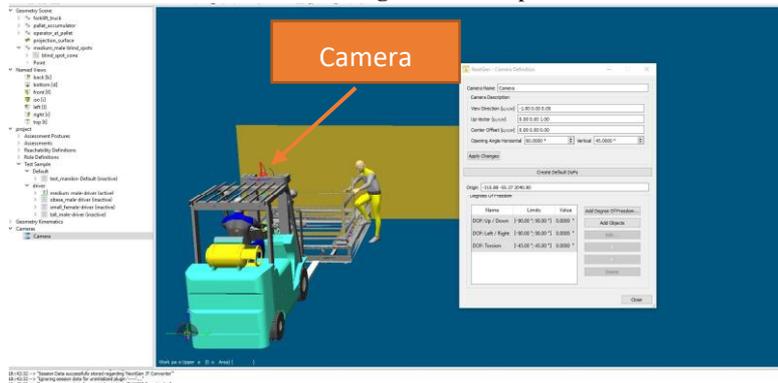


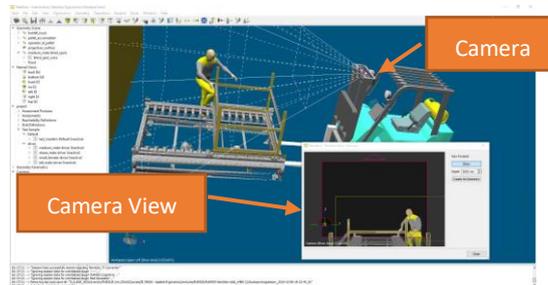
Fig. 24. Camera location and camera parameters window location.

Step 7, having a camera in place, Analyzing its' field of view. This will help one to determine whether the manikin can see beyond the blind spot. To do that, select *Analysis tab -> Vision -> Camera* to create a camera view (see Fig. 25). This function will open a window with a camera view (see Fig. 26).



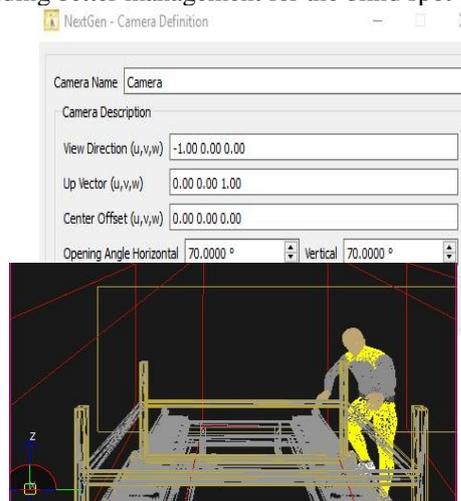
Fig. 25. Selection of the camera field of view.

The analysis of the camera's field of view shows that the camera can see beyond the forklift undetected areas and can detect loader next to the pallet (see Fig. 26).



**Fig. 26.** Camera field of view and visual cone.

Analyzing the picture that is seeing by the camera, one can conclude that the loader can be only seen up to his/her waist and pallet is not visible all the way. As a result, one would like to analyze the effects of the wider camera viewing angles on blind spot management. Step 9 (within section 3.2), double click on camera to activate the Camera definition window. Change both opening horizontal and vertical angle parameters to 70 degrees. As a result, the camera view field allows the operator to see the whole pallet and loader next to it providing better management for the blind spot (see Fig. 27).



**Fig. 27.** Camera field of view and visual cone.

### 3.3 Discussion and Future Work

Forklift driver blind spots were modeled to mitigate them with wireless cameras located on the overhead forklift bar using RAMSIS software. The analysis has considered two different camera view angles at 40 degrees and 70 degrees view angles. Both views were analyzed and compared. It was concluded, that upgrading forklift with the wireless 70-degree view angle camera is the most optimal way to allow forklift drivers to have greater visibility of areas they typically cannot see. The wireless camera can be mounted on the overhead guard so the driver can see where the forks are lining up with the pallet and loaders who are loading the pallet. The analysis makes obvious that the camera

makes it easier for the forklift operator to get a clear and unobstructed view of the forks and rack. The most useful aspects of the forklift video cameras are that they can be attached to any type of forklift. The analysis showed that cameras with wider than 70 degrees view angle had encountered obstruction by the forklift vertical rails.

RAMSIS can overcome limitations of two dimensional human templates, as well as provide methods for predicting driver postures and comfort (Kuebler et al. 2019; EDS Technologies, 2019). However, there are certain limitations that cannot be solved using CAD software at this time but it will be very useful to consider them in the future. For instance, calculation and simulation of expected noise levels from machinery in the workplace is something that currently cannot be modeled in using CAD/CAE software and require the use of the noise databases to predict noise effects (Wasserman, 2014; Federal Highway Administration, 2017; Aviation workers hearing, 2019).

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