Oregon OSHA
Worksite Redesign Program

Durable Ergonomic Seating for Urban Bus Operators

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Introduction

The Tri-County Metropolitan Transportation District of Oregon (Tri-Met) is the largest urban transit authority within the State of Oregon. It is responsible for providing safe, reliable, and efficient bus transit and paratransit service in the urbanized areas of Multnomah, Washington, and Clackamas counties. Tri-Met operates over 700 transit buses to handle ridership demands throughout the urbanized tri-county area. Bus lines operate 24 hours a day, seven days a week. Of its 2,400 employees, approximately 1,200 are bus drivers.

Between 1992 and 1997, approximately 5% of the Tri-Met bus-driver-workforce compensation claims were directly attributed to the design of the bus operator's seat. These claims had a cost of over $204,000, or 23% of the total cost of all compensation claims filed for that five (5) year period.(1) An analysis of bus driver back injuries showed that they were related to prolonged sitting postures and seat malfunction.

Musculoskeletal Disorders

Musculoskeletal disorders are among the leading causes of occupational injury and disability in the United States, with back pain the most common reason for the filing of workers' compensation claims. Back pain accounts for about one fourth of all claims and for about 40 percent of absences from work. In the

United States, in 1990, the cost of back pain was estimated between $50 billion to $100 billion.[2]

There is strong evidence of an association between musculoskeletal disorders, workplace physical factors, and non-work related characteristics.[3] Non-work related characteristics include physical fitness, anthropometric measures, lumbar mobility, physical strength, medical history, and structural abnormalities of the individuals. Workplace physical factors include heavy physical work, lifting and forceful movements, awkward postures, whole-body vibration, and static work postures. Static work postures of prolonged standing, sitting, and sedentary work are isometric positions where very little movement takes place. These postures are typically cramped or inactive and cause static loading on the muscles.[3]

Several studies have investigated back pain among professional drivers. The occupational physical factors of postural stress, muscular effort and long term exposure to whole-body vibration were consistently associated with driving motor vehicles for extended periods of time[4] Studies by Winkledby, Ragland, Fisher, and Syme (1988), found that bus operators are at greater risk for cardiovascular disease, hypertension, gastrointestinal illnesses, and musculoskeletal problems.[5] A study by Anderson found a higher percentage of reported back and cervical pain among bus drivers than among workers in non-driving positions.[6] Kelsey et al found male workers who drove for more than 50 percent of their work time were approximately three times more likely to develop an acute herniated lumbar disc than those who drove less frequently.[3] Other studies indicate that bus drivers experienced an increased risk of injury to the spine as a result of the physical stresses associated with operating buses.[4,7] Magnusson reported higher rates of low back pain (60 percent) and proportionally more work loss among bus drivers than truck drivers.[7] Similarly, Bovenzi, Kompier, and Winkleby confirmed the increased prevalence of low back symptoms among bus drivers.[4,5,7,8] Because of the prolonged sitting postures of transit bus drivers, the seat used by bus operators was examined.

For several years, Tri-Met attempted to identify a durable transit bus operator's seat which met the ergonomic needs of the bus driver workforce. Unable to find an adequate operator's seat, in 1998, Tri-Met was awarded a partial grant by the Oregon Worksite Redesign Program. The grant proposal was to develop and design an ergonomic bus driver's seat that reduced the risk of musculoskeletal injury.

After award of the grant, Tri-Met sought a partnership with a bus operator seat manufacturer to assist in the development of an operator's seat which met the needs of the bus transit industry. USSC Group, Inc. agreed to participate and fund the remaining portion of the seat project. Additionally, Steve Russell of Ergonomic Consulting was retained to assist in the development of the bus operator seat.

This paper describes and discusses the approach, development aspects, and evaluation phases of the production of a prototype, new generation bus operator's seat. A whole-body vibration study is an integral part of the project scope. Dr. Turcic and Dr. Spevlak of Portland State University and Oregon State University, respectively, are conducting this phase of the project. The results of the vibration study are submitted under separate cover.

Methodology

The general objectives of the seat project was to develop a bus operator's seat that would accommodate the extremes of the bus driver population with minimal mechanical adjustment, and was durable enough to withstand daily, prolonged use. However, designing a bus operator's seat presents a unique challenge. Because a particular bus may be driven by as many as six (6) different drivers within a single day, the great variation in driver size within the driver population demands the various adjustments have an adequate range of adjustment to accommodate the wide differences in driver size and shape. Because of the limited amount of time allocated for the preparation and start of transit service, the actions to adjust the seat must be easy, intuitive, understandable, and quick. It is not uncommon for many bus drivers to start their shift away from the bus yard and on the road, relieving drivers from buses already in service. Finally, the seats must fit into the wide variation of urban transit bus workstations available. This lack of uniformity exists not only between bus manufacturers, but also among the bus models themselves. It is not uncommon for bus procurement specifications for operator workstations to vary from one transit system to another transit system for the same model bus.

Ergonomic Bus Operator's Seat Design Considerations

The prevention of musculoskeletal disorders is achieved by interventions which reduce the probability and severity of injuries. It is estimated that through ergonomic design up to one-third of compensable low-back pain in industry can be reduced.(9)

The primary interest in the bus operator's workstation is the relationship between the operator's seat, steering column and wheel, and pedals. Bus operators are required to interact and maintain constant contact with each of these components. It is the use and combination of these components that influence the operator's posture.[10]

Many transit bus manufacturers, however, view the operator's seat as an add-on or afterthought. Typically, the bus interior is designed to optimize the number of passenger seats. The workstation is cramped with instrumentation and a farebox. The operator's seat is fitted within this space. The design of the operator's workstation must not just take into consideration the tasks performed by the bus driver. The design must also consider the physical characteristics of the driver and the accommodations required that permit the full range of seat adjustments.

Seat Placement Reference Point

In conjunction with the bus operator's seat, the position or placement of the seat in the operator's workstation was also a consideration. The heel reference point was used in the placement of the seat within the operator's cab. Placement of the seat should permit the full range of seat adjustments, unobstructed visibility out of the front windshield, and comfortable reach of the controls and foot pedals.

Although the functional design relationships are significantly useful in the bus operator workstation, little work has been done in this area.[10] The Society of Automotive Engineers Handbook (1994) provides several techniques for describing the location of the operator in the workstation. These include the

Seat-Reference-Point (SRP), the Heel-Reference-Point (HRP), Seat-Index-Point (SIP) and the Design-Eye-Point (DEP). Uses of SRP, SIP, and DEP as reference points permit designers to understand where the various body components of the operator are located. However, the reference points provide little information as to the location and required adjustment ranges for the workstation elements.[10] Additionally, the use of SRP, SIP, and DEP do not permit measurements to be made readily in the field without special equipment. For these reasons, the use of SRP, SIP, and DEP as reference points was dismissed. The HRP approach assumes various size operators have a common point for placement of the operator's seat - the accelerator. Although this concept required large adjustment ranges for the seat in order to accommodate the various size and shapes within the driver population, it provided a readily identifiable reference point from which to compare existing seats against the new recommended guidelines.

Anthropometric Data

Anthropometric data are used in design standards for new systems and in the evaluation of existing systems in which there is a human-equipment interface. The purpose of the data is to ensure that the worker is comfortable and efficient in performing work activities and in the use of the equipment.[11]

Traditionally, anthropometric data used by industrial designers has come from military studies. Because no comprehensive and current information on the U.S. civilian population is available, military data sets are the best possible estimate of present anthropometric data on U.S. civilians. However, military personnel do not represent the extremes of height and weight body dimension of the U.S. population.(11) Military males are healthy and young. Because there is some selection in the military population, the anthropometric measurement extremes found in the industrial population differ from those found in the military population.(11) For example, the very overweight or the very small person may be seen more frequently in the industry population, than in the military population.(10,12,)

In the past, males dominated the industrial workforce. The industrial workforce today is comprised of males and females between the age of 17 and 70 who may have chronic illnesses and/or functional capacity losses.(11,12) In addition, the demographics of the industrial population are dramatically changing with significant increases in racial and ethnic diversity in the Unites States general population, and with the increasing number of women entering the workforce. This change is due in large part to the increasing number of immigrants from Asia, and Central and South America.(11) The United States Bureau of Labor Statistics estimates that between 1990 and 2005 an uneven increase in the distribution of racial and ethnic groups in the workforce will occur. The relative percentage of change in the workforce in the United States is predicated to increase 17.4 percent for Whites, compared to an increase of 31.7 percent for Blacks. The relative percentage of change for Asians is predicated to increase 74.5 percent, and for Hispanics, 75.3 percent. Consequently, designing workplaces and jobs for only healthy young white males, results in optimizing workplace design for only about 25 percent of the industrial workforce. Ergonomic designs of workplaces and equipment must take into account the physical capabilities and characteristics of women, and the racially and ethnically diverse industrial population.[11,12]

Where possible, however, anthropometric data for specific populations should be used.[11,12] In a study conducted by Courtney and Evans (1987) of urban transit buses used in Hong Kong, they found several bus operator workstations to be designed and built in the United Kingdom. The workstation design was based on European anthropometric data, but was used for the Cantonese workforce who is a smaller people. The misapplication of anthropometric data resulted in an inappropriate and poor design, with the workforce modifying the workstation to accommodate their needs.[13] Similarly, the increase in women, and racial and ethnic groups in the workforce suggests that the design for commercial vehicles needs to be modified to facilitate operation by drivers of somewhat different physical dimensions.[10] Workstation designs must take into consideration the extremes of the commercial driver population.[11]

In the past, males dominated the commercial driver workforce. As the demographics have changed in the United States, the bus driver has changed in similar ways. The bus driver population is becoming increasingly overweight.[14]

The Society of Automotive Engineers, with the Air Force Engineering Laboratories, is collecting standardized anthropometric data from the United States, Netherlands, and Italy. The study, CAESAR (Civilian American and European Surface Anthropometry Resource), will provide data of anthropometric variability of men and women between the ages of 18 and 65. The sample will be representative of weight, ethnic groups, gender, geographic regions, and socio-economic status. However, the information from this study will not be available until well after 2000. Because, the operator's seat is to accommodate any bus operator between the 5th percentile female to the 95th percentile male, the actual distribution of bus operator sizes within that range, are not relevant. It must be able to accommodate the extremes of the population.

Efforts to Modify the Driver's Workstation

There have been many recent efforts to improve the operator workstation. These efforts began in earnest in 1980's in Montreal and continued into the 1990's. Several studies were conducted by a number of transit organizations and authorities including the Canadian Urban Transit Association (CUTA), Montreal Urban Community Transit Commission (MTCTC), Societe De Transport de la Communaute Urbaine de Montreal (STCUM), Ottawa-Carleton Region Transit Commission (OC Transpo), BC Transit (Vancouver, British Columbia, Canada), King County Department of Transportation Transit Division (Seattle, WA), B.C. Transit (Vancouver, B.C., Canada), and the Transportation Research Board. The studies concluded that the bus driver's seat had several shortcomings. Because of these shortcomings, drivers often modified the workstations through the use of portable seats or cushions to improve their postures and comfort. The findings of the studies concluded that

- insufficient adjustment ranges exist to accommodate a very high percentage of drivers;
- an increase in the number and range of adjustments on the operator's seat should be made;
- the overall dimensional constraints of the operator's workstation itself may be a limiting factor in the optimum use of seat adjustments.

Accordingly, larger operator cab workstations may be required to accommodate the greater range of adjustments recommended for the operator's seats. This requires transit authorities to specify larger operator workstations on new bus procurements and the possible need to retrofit older buses. In many cases, enlarging the operator's workstation will require the loss of some passenger seating and adjustment of the workstation platform.[15,16,17,18,19,20]

Bus Driving Postures

Driving postures used by bus drivers should take into consideration musculoskeletal and biomechanical factors, and ensure that all driving tasks are conducted within a comfortable reach range.

The posture of the seated person is dependent on the design of the seat itself, individual sitting habits and the work to be performed. Seated postures are defined as the body position in which the weight of the body is transferred to a supporting area - the ischial tuberosities of the pelvis and their surrounding soft tissue.[22] The biomechanical considerations of seated postures include the spine, arms, and legs. The muscles at the back of the thighs influence the relative position of the spine and pelvis. The location and slope of the work area influence the position of the neck, shoulders, and upper extremities, when an individual is in a seated posture. Therefore, along with the seat itself, it is essential that the work to be performed be taken into consideration.[10,22]

The static driving position used by bus drivers consists of the individual holding the steering wheel at approximately the 9 and 3 o'clock positions and the right foot resting on the accelerator pedal. The dynamic bus driving posture used by bus operators is defined as the maintenance of the torso in a static position, while reaching to turn the steering wheel, operating controls on the right and left of the instrument panels, and the operator fully depressing the accelerator or brake pedal.(10)

A body position or posture is considered appropriate if the weight of an individual's body is transmitted to the seat with the least amount of stress on the body as possible.(11) The headrest, full-size backrest, and the seat pan should receive the weight of the head, the trunk, and the thighs, while the weight of the lower legs and feet is transmitted to the floor, suitable footrest, or in the case of a bus operator's workstation, the foot pedals. Additionally, the forces exerted toward outside objects, such as the hands and/or feet, should be counteracted at the shortest possible distance by the reaction forces provided on support surfaces. For example, the lower portion of the backrest acts to counteract those forces imposed upon it as a vehicle driver exerts pressure from the foot against the foot pedals.(11)

Because of the factors that influence good posture, there is no single, ideal posture. No posture can be maintained indefinitely. This concept has been widely investigated and stressed by several investigators.[11,12] However, there are several factors which help to minimize musculoskeletal stresses. It is generally accepted that

- the seat should permit shifting or changing of a seated posture;
- a large adjustable back support should be provided;
- seat surfaces should be accommodating, but not spongy, in order to accommodate the forces transmitted on it;
- adjustments in seat height and angles be easy.

All of these features contribute to good seated posture. Additionally, providing a biomechanically improved seated workstation requires consideration of the size variation in the workforce population and that prolonged static muscle exertion be minimized to prevent muscle fatigue. The weight of the human body must be supported without creating high, localized points of pressure.

The height and inclination of the seat pan, combined with the position, shape, and inclination of the backrest influences the resulting seated posture. Low back stresses can be reduced with the use of back supports or seat backs. The most important factor in reducing low back stress is the inclination angle of the seat back itself. Leaning the back against an inclined backrest reduces the physical load on the intervertebral discs and the static strain of the back and shoulder muscles. This is due to the loads on the spine being greater when one is seated, as compared to when one is standing. When one is seated, the posterior elements of the spine place a greater load through the intervertebral discs. Thus, when work is performed while seated, there is a greater risk of damaging the discs. Therefore, it is important to consider the design features of a seat that may influence disc loading. Backrest and lumbar support features have a significant affect on disc pressure. Disc pressure decreases when the backrest angles are increased. Increasing the degree of lumbar support also significantly reduces disc pressure. This is probably due to the fact that as lumbar curvature (lordosis) is reestablished the posterior elements of the spine play more of a role in providing an alternative load path. By the addition of a separate lumbar support, the stress on the back is further reduced. The lumbar support should be placed in the lumbar region to achieve a more normal lordotic curvature when in the seated posture. In order to provide as much comfort as possible, the support should be adjustable in both height and size. The seat back width should allow users to be supported without arm interference. The shape should be convex from top to bottom to conform to the normal lordosis, and concave from side to side to conform to human anatomy and support the occupant in the seat.(22) The tilt angle of the backrest should be adjustable. A backrest inclination of about 110 degrees is considered an appropriate posture, however, greater inclination may be desirable by the user. The backrest tilt angle adjustment should be independent so that there is little or no effect on the front seat height or angle. Seats with high backrests are preferred since they provide both lower back and upper back support. To prevent back strain, it is also recommended that seats have lumbar support, because the lumber region is one of the most highly strained parts of the spine when sitting.

Seat adjustability in terms of height and seat angle help to support the trunk, shoulders, neck, and leg positions to reduce strain on the muscles, tendons, and discs. The postural support and action of the seat should help maintain proper seated posture and encourage good movement patterns. The seat height should be adjustable so that the feet can rest firmly on the floor with minimal pressure beneath the thighs.

Leg support is critical to better distribute and reduce the load on the buttocks and the back of the thighs. The weight of the lower legs should not be supported by the front part of the thighs resting on the seat, with the feet firmly resting on the floor or foot pedals. Pressure applied to the front part of the thighs, the portion close to the knees, can result in swelling of the legs and pressure to the sciatic nerve.(22)

When a seat is too low, the knee flexion angle becomes large and the weight of the trunk is transferred to the seat pan surface over a small area at the ischial tuberosities. The large knee and hip angles soon become uncomfortable, and the spine is flexed as the pelvis rotates backward. Furthermore, the abdominal organs are compressed in this posture when one leans forward.(22)

When a seat is too high, so that the feet do not reach the floor, the pressure on the back of the thighs becomes uncomfortably large. Individuals tend to slide forward to the front part of the seat. This allows the feet to be supported, but the seat back will not be used properly to support the back.(22)

The seat pan, that portion of the seat on which an individual sits, directly supports the weight of the buttocks. The seat pan should be wide enough to permit operators to make slight shifts in posture from side to side. This helps to avoid static postures, and accommodates a large range of individual buttock sizes. The front edge of the seat pan should be well rounded downward to reduce pressure on the underside of the thighs which can affect blood flow to the legs and feet. The seat should be padded to a suitable firmness to ensure an even distribution of pressure on the thighs and buttocks. A properly padded seat should compress about ½ to 1 inches when a person sits on it. Seat pan adjustments should be accessible and easy to use from a seated position.

Armrests may be desirable to support the arms. Armrests, however, can present problems of restricted arm movement for transit bus drivers or irritation of the arms. Well-designed armrests, however, provide support for resting the arms to prevent or reduce arm, shoulder, and neck fatigue. To accommodate individual preferences, armrests that can be moved out of the way should be provided.

Accordingly, it is important the seat adjust to meet the basic anthropometric dimensions of the worker population. In particular, the seat dimensions of seat height, width, length (depth), and slope are critical. Equally important are the shape of the seat, softness of the cushioning materials, frictional properties of the seat fabric, climatic comfort of the seat fabric, and adjustability of the seat dimensions.

The project was divided into six (6) phases. The following is a brief description of each project phase and the design decisions in the development of a prototype bus operator's seat.

Phase I - Literature Review and Development of Operator Seat Survey Questionnaire

This phase of the project consisted of a review of the literature related to musculoskeletal disorders due to occupational driving and of studies to improve the bus operator's workstation. Under the guidance of Ergonomic Consulting, Tri-Met developed a questionnaire and data collection form (Figure 1) to capture critical anthropometric dimensions, driver demographics, and subjective opinions of the seat used by the bus driver populations. The form was distributed to four (4) transit bus authorities – C-Tran (Vancouver, WA), Lane County Transit (Eugene, OR), Seattle Metro (Seattle, WA), and Tri-Met (Portland, OR). The comments were analyzed to determine the operator's main concerns and to assess driver reaction to the different seat models and adjustments currently used at their respective transit systems. Additionally, the questionnaire sought to evaluate the design concept of individual, customized and portable seat cushions. The responses were used to assess driver comfort, and seat functionality.

Figure 1

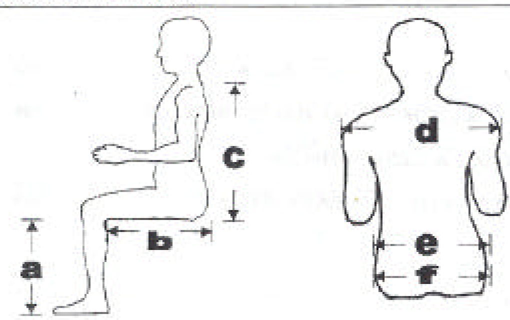
Questionnaire and Data Collection Form

DRIVER'S SEAT QUESTIONNAIRE

Tri-Met has received a grant from the State of Oregon's Worksite Redesign program to develop a prototype for an ergonomically designed bus driver's seat. We would like to utilize your experience as a bus operator to help us research desired and undesired features of driver seats. Please rate the following aspects of driver seats and add your comments and suggestions as you wish.

DRIVER INFORMATION	
EMPLOYER:______________________	LOCATION:______________________
NAME:______________________	YEARS OF DRIVING BUS: ____ Years
CURRENT DRIVING TIME: FULL TIME?_____ PART TIME?_____	
CURRENT RUN TIME (AVERAGE)? ____Hrs.	AVG. RUN TIME IN PAST YEAR? ____Hrs.
WEIGHT: <100 lbs.___; 101-150 lbs.___; 151-200 lbs.___; 201-250 lbs.___; 251-300 lbs.___; 301+lbs.___	

PERTINENT BODY DIMENSIONS	
a) Distance from floor to under thigh with leg vertical and driving shoes on.	______inches
b) Distance from chair backrest to back of knee.	______inches
c) Distance from seat cushion to base of neck.	______inches
d) Width of driver's shoulders.	______inches
e) Width of driver's girth (measured at navel).	______inches
f) Width of driver's buttocks when seated.	______inches



SEAT QUESTIONNAIRE

(MARK THE STATEMENTS THAT MOST REFLECT THE DRIVER'S OPINION)

CURRENT SEAT IDENTIFICATION: Manufacturer:____________________ Model #:________

IF NOT KNOWN, IDENTIFY BUS FLEET #:_____________

AREA OF EVALUATION	CRITERIA		COMMENTS
EVALUATE CURRENT SEAT-BACK CUSHION	Too wide Too narrow	Too high Too short	
EVALUATE CURRENT SEAT-PAN CUSHION	Too wide Too narrow	Too high Too short	
EVALUATE THE UP/DOWN ADJUSTMENT OF CURRENT SEAT	Not high enough Not low enough	Easy to adj. Diff. to adj.	
EVALUATE THE FRONT/BACK ADJUSTMENT OF SEAT	Can't reach pedl. No leg room	Easy to adj. Diff. to adjust	
EVALUATE THE LUMBAR ADJUSTMENT OF CURRENT SEAT	Adequate Inadequate	Too high Too low	
WHAT KIND OF LUMBAR ADJUSTMENT DO YOU PREFER?	Air adjustable Mechanical	None	
EVALUATE CURRENT HEADREST	Adequate Inadequate	Too high Too low	
EVALUATE CURRENT SEAT CUSHION TILT/RAKE ADJUST.	Need more forward tilt Need more backward tilt Difficult to adjust		
EVALUATE CURRENT BACKREST RECLINE ADJUSTMENT	Need more back ward tilt Difficult to adjust		
WHICH TYPE OF UPHOLSTERY DO YOU PREFER?	Woven fabric	Vinyl	

ARE THERE ANY ADDITIONAL FEATURES THAT YOU WOULD LIKE TO SEE ON THE SEAT?

WOULD YOU PREFER TO HAVE YOUR OWN PRIVATE SEAT CUSHION?	Yes		No
WOULD YOU AGREE TO HAVE A CUSHION THAT YOU PUT IN PLACE AT THE START OF YOUR RUN?	Yes		No
WOULD YOU BE WILLING TO USE A CUSHION THAT IS:	≤ 10 lbs.	11-15 lbs.	16-20 lbs.
WOULD YOU BE WILLING TO BRING IT TO WORK EVERY DAY?	Yes		No

ADDITIONAL COMMENTS:

The anthropometric data was used to develop the range of adjustments for the prototype bus operator's seat design. These data points were important in that they represented population-specific data.

Phase II – Preliminary Design Review

The objective of this phase of the project was to develop specific specifications for the prototype seat.

The seat was divided into three primary components – headrest, seat back, and seat pan. Additionally, each component was further divided into dimensional attributes which characterized the design variables: length, width, depth, angle, adjustment range, and travel distance.

Sub-phase A - Determination of Required Adjustments

Ergonomic Consulting, and USSC Group, and Tri-Met reviewed all available adjustments currently available on different seat models, including the USSC Group, Recaro, Bostrom, Grammer, American Seating, Isringhausen, National, and others. In total, twenty-one adjustments were identified. The number of adjustments was determined to be too many, primarily due to the short amount of time typically available to the driver to adjust the seat. In order to simplify the seat adjustment procedure, ten (10) adjustments were identified as being necessary to the safety and comfort of the bus driver. The remaining eleven (11) adjustments were deemed impractical from a user standpoint.

Included within the review of seat adjustments were seat shoulder belts. Although, integrated 3-point seat belts are not required on transit buses, many urban transit bus systems specify them. To accommodate a shoulder belt, a modular seat design with a frame pattern that would accept a shoulder harness, when specified, was selected. Furthermore, the shoulder harness mechanism must be adjustable to accommodate tall and short drivers.

Table 1 summarizes the different adjustments reviewed and the seat component adjustments incorporated into the prototype seat.

Table 1

Seat Adjustments Reviewed

Adjustment Description	Adjustment Required
Height	Yes
Suspension	Yes
Adjustable Suspension Dampening	Yes
Suspension Travel Limiter	No
Fore/Aft Seat Travel	Yes
Seat Pan Rake	Yes
Seat Pan Length	Yes
Seat Pan Air Cushions	No
Backrest Inclination	Yes
Lumbar Support	Yes
Mid-back Articulation	No
Upper Backrest Air Cushions	No
Side Bolsters on Backrest	Optional
Side Bolsters on Seat Cushion	No
Vertical Backrest Height Adjustment	No
Mid-back Air Bladders	No
Headrest Up/Down	Yes
Headrest Forward/Backward	Yes
Armrests Up/Down	Optional
Armrests Angle Adjustment	No
Shoulder Harness – Height Adjustable	If used, yes

Sub-phase B - Determination of Adjustment Mechanisms

After determining which adjustments were needed, the type of adjustment mechanisms were reviewed and specified. Primary emphasis was placed on reliability, user friendliness, intuitive perception of how to make an adjustment, and what people are used to doing. Most seats in the bus market use turning-knobs to actuate a mechanical or air adjustment mechanism. These typically are difficult to operate, and require awkward movement of the driver's arms and/or hands. Simple levers were developed and used, where possible, for the adjustment of the various adjustment mechanisms to allow for quick, minimal effort adjustments. The use of electric adjustments was dismissed due to concerns with durability and cost.

Table 2 summarizes the types of mechanisms currently used and those considered ideal from a user and maintenance viewpoint. The prototype seat was constructed using the ideal mechanisms.

Sub-phase C – Determination of Adjustment Ranges

Adjustment ranges for the driver seat were developed from the driver population data collected and from a review of the literature. The ideal ranges developed are listed in Table 2. The other adjustments were to be fixed with guidelines established. The backrest height was to be fixed at 24 inches above the flat, uncompressed seat cushion. The seat cushion itself was to be 20 inches wide. Cushions any wider may not fit into some cab areas as controls must be accommodated on the sides of the seats. Backrest width was to be 23 inches wide. Frequently, armrests are not specified by urban transit bus systems. However, they should be considered as an option. The armrests should be allowed to move out of the way in order to accommodate bus driver preference in the use of armrests. Adjustment controls should be located on the right side of the seat in logical clusters. Left-sided controls would be hard to reach in many transit buses due to insufficient room between the seat and the instrument control panel located along the driver's left side.

The prototype seat was constructed using the ideal adjustment ranges.

Table 2

Review of Adjustment Mechanisms and Ranges

Sub-phase D – Seat Suspension Designs

The designs of seat suspension systems currently in use were reviewed to evaluate their historical performance in terms of durability and transit system preferences. Suspension system types reviewed included knee tilt suspensions, slide track scissors suspensions, pendulum arm suspensions, parallelogram suspensions, and rear mounted spring suspensions. The use of mechanical versus air suspension systems was also evaluated.

Pendulum arms limit the lateral motion of the suspension seat through its travel and are, in general, proven to provide the most stable seat platform. Additionally, the transit seat industry considers the pendulum arm suspension system as the most reliable, when combined with bilateral adjustments. Bilateral adjustments prevent lateral torsion of the seat when moving up and down. Suspensions with single sided adjustments do not prove to be as reliable. Because of its reliability, a pendulum arm suspension system was chosen for the prototype seat. Due to its ease of use by drivers, a suspension system assisted by air was chosen for the prototype seat over an entirely mechanical system. Electrical systems were discarded due to concerns with service reliability.

Independent versus variable dampened suspensions were also reviewed. With independent suspension systems, the height adjusting system is independent of the seat suspension. The advantage of this system is that the suspension ride does not vary with the height of the seat. This is of particular significance for very short and very tall drivers, who would otherwise bottom out or top out a suspension. With an integrated suspension, the seat cannot offer the same suspension travel in all positions. Thus, the seat designers must accommodate this limitation to prevent bottoming and topping out. Typically, this is done through the use of rubber bumpers that cushion the scissors and prevent suspension “slap”. Despite the intrinsic advantages in providing equal dampening at all heights, independent suspension systems have not proven to be very reliable in field operations.

Because of the desire to provide as much vibration dampening as possible, a variable dampened shock absorber system on an integrated suspension system was specified for the prototype seat. While this type of system would not eliminate the variation in suspension ride at different heights, it would allow the driver to compensate for seat ride quality. Drivers could increase or decrease the dampening coefficient to prevent the scissors from slapping against each other or the seat frame. The seat was also equipped with substantial bumpers to prevent the suspension from bottoming out. The variable dampening suspension system also served to accommodate drivers who opted to adjust the suspension ride quality. Based on the experience of transit systems, some drivers prefer a very "loose" ride with the suspension system providing a floating-like ride, while others prefer a firm ride with little or no seat travel along the vertical axis. Since a bus may be driven by drivers desiring either type of suspension ride quality, the seat must accommodate the extremes of the suspension ride quality spectrum. Additionally, many transit systems have more than one type of bus model in their fleets. Because each bus model has a different ride characteristic, seat ride quality would vary from bus model to bus model, as well. A variable dampening suspension system accommodates driver preference, differences in suspension at different seat heights, and variation in bus model ride characteristics.

Table 3 summarizes the suspension systems reviewed.

Table 3

Review of Suspension Types

	Suspension Description	*Status*	*Reason*
1	Slide Track, Scissors	Rejected	Proven lack of stability and durability
2	Pendulum, Scissors	Accepted	Proven most stable and reliable. Unable to provide equal ride quality at all height levels. Use adjustable damper and rubber stops.
3	Center Moving Linkage	Rejected	Not yet available, potential problems with stability and durability
4	Rear Mounted	Rejected	Primarily for low profile suspensions. Buses require full suspension movement.
5	Knee Action	Rejected	Safety concerns with constant articulation of the back/hip joint
6	Coil Springs	Rejected	Buses require a full suspension movement.
7	Independent, Double System	Rejected	Allows independent adjustments and equal ride quality at all height levels. Lacks stability and durability. Adjustable damper on single suspension systems compensate for changing ride position/suspension.

Other Design Considerations

Removable Seat Cushions – As many different drivers use the same operator's seat in a transit bus throughout the day, the seats are subject to soiling, odor retention, and wear. Consequently, transit authorities change out seat cushions frequently. Removal of cushion assemblies on many seat types requires tools, partial disassembly, and/or removal from the bus. USSC Group developed a hook and loop and mechanical fastener system that facilitated removal of the seat from the seat frame in less than five (5) minutes.

Foam Type and Shape – Different cushion shapes and sizes were evaluated through field test trials. Both heavily contoured and milder contoured cushions were tested. Also, cushions made of different constructions, including memory foam, polyurethane foam, silicone foam, neoprene-based foams, and foam with spring inserts, were evaluated. The drivers preferred full-depth polyurethane foams with a waterfall front edge. The front edge was found to be very important to driver comfort.

Individual Cushion Sets – A concept considered was the use of customized, portable individual seat cushion sets. Under this concept, seat manufacturers would supply the bus operator seats without any upholstered cushions. The operator seats would be equipped to provide only the basic seat adjustments of suspension, height, fore/aft seat travel, backrest inclination, seat pan rake/tilt. Fully upholstered backrest/seat cushion sets, with varying heights, widths, lumbar curvature, and overall shape, would be provided apart from the basic seat unit. Bus drivers would then choose among the various backrests and seat cushions to find the ones that best fit their individual body size and shape. Cushion sets would be issued to each driver who would be responsible for bringing the seat set to work each day. Standard seat sets would be available to those who forgot their individual sets.

This concept has many advantages. First, it eliminates the complaint of having to sit in a seat soiled by the previous driver. Secondly, it simplifies the manufacture and maintenance of the seat. It eliminates adjustment requirements for the lumbar support, bolster, seat pan cushion length, seat pan width, backrest height adjustment, backrest width, and other body dimension variables. Lastly, the concept maximizes the life of upholstery coverings and cushion materials. Less wear would occur to these materials.

The concept, however, has disadvantages. It requires drivers to carry and maintain their seat cushion sets. A survey conducted as part of this study showed little support for the concept. They did not want to carry cushion sets with them. In addition, fixed cushion sets decrease the number of possible adjustments. Drivers should change their seated position frequently. For these reasons, the concept was not pursued.

Upholstery – Upholstery material influences the comfort of drivers. Vinyl is very durable and easily cleaned. Vinyl, however, is sensitive to air temperature and may feel hot or cold to the touch. Additionally, vinyl does not breathe, thus permitting perspiration to collect. Woven cloth is more difficult to clean, but provides a great deal of comfort to the driver and reduces heat transfer problems. For these reasons, woven fabric is the preferable seat covering.

Vinyl seat coverings, however, were used on the prototype seats to ensure durability and maintainability during the testing period.

Back Shroud – The prototype seat is larger than many bus operator seats currently available. Although it is larger in size, it can be readily accommodated in a number of bus operator workstations. However, there are a number of workstations that cannot accommodate the full range of seat adjustments. In workstations that restrict the full range of seat adjustment, the seat backrest often hits the driver's modesty barrier. This results in frequent repairs to the rear seat backrest. The use of thermoform back shrouds protects chaffing of the seat back upholstery. The prototype seat was constructed with a seat back shroud.

Frame Construction – The prototype seat was required to meet Federal Motor Vehicle Safety Standard (FMVSS) 207/210 requirements for integrated 3-point seat belts. Since there could be no tether straps to secure the seat to the workstation platform floor to permit ride quality adjustments, the fore/aft seat travel adjustment slides were located below the seat suspension system. This design change ensured the seat belt system would move with the operator's seat and the orientation of the lap belt would not change as the driver moved the seat forward or backward along the horizontal axis. Placement of the adjustment slides above the suspension system would move the seat upper and the user forward or backward relative the center axis of the suspension system.

Phase III – Development and Construction of the Initial Prototype Seat

Development and construction of the prototype urban bus operator's seat was based on the anthropometric data collected and the concepts of ergonomic design for seated workstations. USSC Group constructed six (6) prototype seats for field evaluation by Tri-Met. The prototype seats were constructed with the specifications previously described.

Rather than develop and construct the seat from new, unproven components all bus operator seat models that were currently in production were reviewed. This approach had two advantages. First, it provided the basis for a design with some proven history. Problems with any new designs are unproven and may not be known for some period of time later, perhaps years. Secondly, the use of currently available seat components reduces the tooling investment required. The transit bus market is relatively small, and a return on the tooling investment may not be realized. This fact would greatly discourage changes to re-design of the bus operator's seat.

Design of the initial prototype seat started with the Model 2100 bus operator's seat, as manufactured by Be-Ge Industrie AB in Oskarshamn, Sweden. Be-Ge is a supplier to many European bus and truck builders. Be-Ge also supplies suspension systems to other seat companies including USSC Group, Recaro, as well as some European seating distributors. While the Model 2100 met some of the features required, it did not meet all the requirements. The Model 2100 met the European testing requirements, but did not meet the FMVSS requirements or Standard Bus Procurement Guidelines as published by the American Public Transportation Association (APTA). In addition, the seat was very European in styling with very thin cushions and was designed to accommodate the smaller European drivers.

Using the Model 2100 as the base, the seat was re-designed to the required specifications. The suspension was modified and strengthened to meet the FMVSS pull test requirements. The mechanisms and frame were modified to increase the adjustment ranges for the individual adjustment mechanisms. Adjustments were re-designed to increase user friendliness. The backrest was re-designed to accommodate air lumbar supports and the 3-point shoulder harness mechanism. The suspension was modified to accommodate a second shock absorber to achieve bilateral adjustments and to change the dampening coefficient. The slide mechanisms and attachments were changed to accommodate the FMVSS 207/210 pull test requirements. Seat risers, the platform on which bus operator seats are placed, were redesigned to meet driver visibility requirements, as defined by the H-point. The seat frames were modified to accommodate the wider, removable seat cushion assemblies.

Phase IV – Continuing Prototype Development

Ergonomic Consulting, USSC Group, and Tri-Met met on a regular basis to review the early prototypes. Improvements were made as the new prototypes emerged from construction. Original Equipment Manufacturers (OEM) were invited to join these meetings to address issues of fit and integration into the bus operator workstations.

Phase V – Factory Testing

The following tests were performed to assure compliance with required regulations and guidelines:

- FMVSS 207/210 – to integrate 3-point seat belt configurations
- APTA Standard Bus Procurement Guidelines
- Shake Table – to determine natural frequencies and transmissibility data (Study still on-going)
- Field Vibration Tests – to determine vibration frequencies bus drivers are subjected to (Study still on-going)

After finalizing the design of the prototype seat, tooling was released and prototype seats constructed. The newly developed seat was once again tested to assure compliance to FMVSS 207/210 and APTA Bus Procurement Guideline requirements.

Phase VI – Field Testing

The six (6) prototype seats was subjected to vibration and durability field-testing, and evaluation by the Tri-Met driver workforce. Installation of the seat was limited to those bus models which could accommodate the full range of adjustments on the prototype bus operator's seat. Three (3) prototype seats were installed in Flyer Low Floor buses and two (2) seats in Gillig Phantom Advance Design buses. One (1) seat was reserved as a replacement seat in the event of a seat malfunction.

An interviewer, familiar with the operation of the prototype seat and bus operations, solicited driver comments and opinions. Evaluations of the prototype seat were conducted while the buses were in actual transit service and from static displays. Under in-service conditions, each operator contacted used the seat for a minimum of one-hour prior to being interviewed. Static evaluations consisted of parking the bus at a garage facility and drivers invited to sit and comment on seat comfort and adjustability. If time permitted, drivers were allowed to evaluate the suspension system by driving the bus about the bus yard. A questionnaire (Figure 2) was used to collect driver opinions. Drivers were asked to evaluate the ease of adjustment, adjustment ranges, and comfort. The evaluation methodology adopted for the evaluation of the prototype seat was patterned after the methodology developed by Drury and Coury.(23) The collected data is summarized in Appendix D, along with a summary of operator opinions regarding the prototype seat.

Figure 2

DRIVER'S SEAT QUESTIONNAIRE

Tri-Met received a grant from the State of Oregon's Worksite Redesign program to develop a prototype for an ergonomically designed bus driver's seat. The project is nearly complete and we would like your feedback on the new seat. Please rate the following aspects of this driver's seat and add your comments and suggestions as you wish.

Driver's Name (optional):

Years of bus driving experience? ____ Current Driving: Full time? ____ Mini-run? ____

Current run time average? ____ Average this year? ____ Height ____

Weight: 100 lbs.____; 101-150 lbs.____; 151-200 lbs.____; 201-250 lbs.____; 251-300 lbs. ____; 301 plus lbs.____

RATE THE FOLLOWING FEATURES OF THE SEAT
(Check the box in the number column that most closely represents your opinion)

FEATURE	LIKE			DISLIKE		COMMENT/SUGGESTIONS
	5	4	3	2	1	
SEAT PAN: Height						
Shape/Contour						
Slope						
Depth						
Comfort						
Fore/Aft Range						
Suspension						
Material						
Ease of Adjustment						
Other:						
BACK: Height						
Shape/Contour						
Lumbar Support						
Kidney Supports						
Recline						
Head Rest						
Ease of Adjustment						
RIDE QUALITY						
Setting Used						MAX ___ MIDDLE ___ LOW ___
Ease of Adjustment						
OTHER:						

Results

Over 90% of the urban bus operator's seats, currently in use today, are represented by the four seat models evaluated. Based on the data collected from the survey of bus operators within four (4) transit systems, none of the seats used by the bus operators could adequately accommodate the greater part of the driver population. Nearly 100% of the drivers surveyed reported dissatisfaction with at least one feature of the seat models evaluated. Approximately 80% of the respondents reported dissatisfaction with multiple features.

Examination of the data shows no relationship between any particular seat model and the bus type in which it was used. However, the survey strongly suggests that the current adjustment ranges of the evaluated bus operator seats were inadequate. Operators consistently reported they could not adjust the seat to accommodate their particular body size and shape. Operators reported insufficient: seat back width and inclination; seat pan width, length, and rake; vertical height adjustment; seat travel; lumbar support adjustment; and headrest adjustment. The collected anthropometric data supports the assessment that the currently available seat adjustment ranges were inadequate. A summary of operator subjective judgments is shown in Table 4.

To assure accommodation of a wide range of body sizes and shapes, the collected anthropometric data was used to determine the adjustment ranges for the prototype bus operator's seat. The anthropometric data collected is shown in Table 5.

Table 4

Summary of Subjective Seat Survey

Driver seat (different manufacturers and models)

	A	B	C	D
Seat back				
OK	70%	50%	8%	58%
Too wide	0%	20%	21%	0%
Too narrow	10%	20%	21%	21%
Too short	20%	10%	58%	16%
Too tall	0%	20%	0%	0%
Seat pan				
OK	55%	30%	8%	62%
Too wide	10%	10%	25%	0%
Too narrow	5%	20%	21%	24%
Too short	5%	20%	21%	8%
Too tall	0%	20%	25%	3%
Too hard	0%	0%	0%	1%
Too long	0%	30%	10%	0%
Up/down adjustment				
Not high enough	5%	10%	4%	11%
Not low enough	25%	20%	29%	17%
Easy to adjust	60%	60%	45%	45%
Difficult to adjust	25%	20%	38%	43%
Front/ back adjustment				
Cannot reach pedal	0%	50%	25%	6%
No leg room	5%	0%	33%	28%
Easy to adjust	95%	50%	38%	58%
Difficult to adjust	5%	10%	29%	18%
Lumbar adjustment				
Adequate	50%	40%	4%	52%
Inadequate	40%	40%	88%	29%
Too high	15%	20%	13%	4%
Too low	10%	10%	25%	16%
Lumbar preference				
Air	50%	70%	75%	71%
Mechanical	5%	10%	21%	8%
None	20%	20%	4%	7%
Both	0%	0%	0%	2%
Headrest				
Adequate	10%	30%	0%	41%
Inadequate	25%	30%	0%	42%
Too high	20%	10%	10%	13%
Too low	5%	10%	0%	20%
Do not use	40%	20%	0%	4%

Table 4 (cont.)

Summary of Subjective Seat Survey

Driver seat (different manufacturers and models)

	A	B	C	D
Tilt/ rake adjustment				
Needs more forward	25%	30%	13%	6%
Needs more backwards	10%	20%	17%	21%
Difficult to adjust	30%	20%	71%	29%
OK	35%	20%	0%	40%
Backrest recline				
Needs more backwards	5%	0%	13%	31%
Difficult to adjust	5%	20%	67%	19%
OK	75%	40%	0%	45%
Upholstery preference				
Woven fabric	95%	80%	100%	82%
Vinyl	5%	0%	0%	8%
Private seat cushions				
Prefer	45%	70%	58%	56%
Not prefer	55%	20%	29%	44%
Agrees to put in place	45%	70%	79%	64%
Will not put in place	40%	20%	8%	32%
Willing to use <10 lbs.	55%	50%	46%	42%
Willing to use 11-15 lbs.	10%	20%	8%	12%
Willing to use 16-20 lbs.	5%	10%	0%	4%
Willing to bring to work	45%	20%	75%	54%
Not willing to bring to work	55%	60%	13%	38%
Sample Size	24	18	87	155

Legend

A – Recaro
B – USSC Group
C – National
D – Isringhausen

Table 5

Summary of Questionnaire/ Data Collection Results

	Description	C- Tran	Lane County	Seattle Metro	Tri-Met	Total Group
A	Distance floor to under thigh					
	Minimum	15.0	16.5	16.0	15.0	15.0
	Maximum	20.0	20.0	19.5	21.0	21.0
	Average	17.7	18.1	18.1	18.5	18.1
B	Distance backrest to back of knee					
	Minimum	16.0	16.0	15.5	12.0	12.0
	Maximum	21.5	22.5	20.0	24.0	24.0
	Average	18.8	19.3	18.3	18.9	18.9
C	Distance cushion to base of neck					
	Minimum	22.5	22.5	25.0	20.0	20.0
	Maximum	31.0	29.0	32.0	33.0	33.0
	Average	27.5	25.8	27.6	26.1	26.8
D	Width at shoulders					
	Minimum	16.5	14.8	15.5	15.0	14.8
	Maximum	26.0	21.8	24.0	31.0	31.0
	Average	19.5	18.0	19.8	20.1	19.4
E	Width at girth					
	Minimum	10.0	10.3	11.5	11.5	10.0
	Maximum	19.0	17.0	22.0	24.0	24.0
	Average	14.5	13.4	16.0	16.0	15.0
F	Width of buttocks when seated					
	Minimum	14.0	14.0	16.5	12.5	12.5
	Maximum	26.5	20.0	28.5	24.0	28.5
	Average	19.0	16.8	19.7	16.9	18.1
G	Weight					
	Minimum	101-150	101-150	101-150	101-150	101-150
	Maximum	251-300	251-300	301+	301+	301+
	Average	151-200	151-200		201-250	
	Sample Size	24	18	87	155	284

The prototype seat significantly increased driver satisfaction with the operator's seat (Table 6, Table 7). At least 98% of the operators using the seat under actual operating conditions reported the seat pan height to be satisfactory to greatly satisfactory. Similarly, the operators reported satisfaction to great satisfaction with the seat pan shape (100%), seat pan slope (98%), seat pan length (100%), seat pan comfort (100%), seat travel (98%), suspension (98%), seat back height (98%), seat back shape (95%), lumbar supports (98%), seat inclination (100%), headrest (95%), and ease of adjustment (100%). The seat covering material, vinyl, was only marginally satisfactory. 47% of the drivers rated the vinyl covering satisfactory to very unsatisfactory.

Drivers evaluating the seat under static conditions reported the features of the prototype seat to be satisfactory to greatly satisfactory: seat pan height (98%), seat pan shape (98%), seat pan slope (98%), seat pan length (100%), seat pan comfort (s), seat pan travel (97%), seat back height (95%), seat back shape (98%), lumbar supports (97%), seat inclination (100%), headrest (95%), and ease of adjustment (100%).

Although not reflected in the data, several drivers reported discomfort in the shoulder blade region of their back. The curvature of the upper portion of the seat back cut into their shoulder blade. Based on these individual comments, the seat back contour is being modified. The curvature of the upper portion of the back is being relaxed to improve comfort in the shoulder blade region.

Some operators reported dissatisfaction with the comfort of the seat in the Gillig buses. They commented an increase in seat travel would be desirable. After further investigation, the seat travel was found to be satisfactory, but the placement of the seat required correction. The bolt pattern of the seat riser was misaligned for the prototype seat. Thus, the seat was installed too close to the accelerator heel point. After this situation was corrected, driver satisfaction with the seat increased. The driver comments received further reinforce the importance of the placement of the operator's seat within the operator's workstation.

At this time no other modifications are being considered. However, in-depth evaluation of the ride quality is required.

Table 6

Driver In-service Questionnaire Results						
	< Like		Rating		Dislike >	
	5	4	3	2	1	Total Responses
Height	53	4	2	2		61
Shape/Contour	48	9	4			61
Slope	50	6	5	1		62
Depth	53	7	3			63
Comfort	51	7	3			61
Fore/Aft Range	51	2	4	1		58
Suspension	51	3	3	1		58
Material	22	11	10	13	6	62
Ease of Adjustment	45	10	4			59
Height	55	5	1	1		62
Shape/Contour	48	5	6	2	1	62
Lumbar Supports	42	5	3	1		51
Kidney Supports	43	5	2	2		52
Recline	53	6	4			63
Head Rest	42	6	8	1		57
Ease of Adjustment	53	5	4			62
	Max	Middle	Low			
Setting Used	15	35	5			55
Ease of Adjustment	48	6	2			56

Table 7

Driver Static Display Questionnaire Results						
		< Like	Rating	Dislike >		
	5	4	3	2	1	Total Responses
Height	44	15	3		1	63
Shape/Contour	48	13	1		1	63
Slope	38	16	5		1	60
Depth	45	12	3			60
Comfort	49	11	1			61
Fore/Aft Range	45	11	2	1	1	60
Suspension	41	13	4			58
Material	22	6	18	5	5	56
Ease of Adjustment	37	13	8		1	59
Height	40	15	4	2		61
Shape/Contour	40	17	3	1		61
Lumbar Supports	41	14	5	1	1	62
Kidney Supports	40	15	4	1		60
Recline	37	18	6			61
Head Rest	35	14	8	2	1	60
Ease of Adjustment	42	16	5			63
	Max	*Middle*	*Low*			
Setting Used	5	13				18
Ease of Adjustment	22	7	2	1		32

Conclusion

The bus operator workstation is the area in which the bus driver directly controls the operation of the bus and interacts with passengers. To understand the casual factors of musculoskeletal injury and discomfort to the driver, the relationship between the operator's seat, steering column and wheel, and pedals in the workstation must be understood. It is the use and relationship of the seat, steering wheel, and pedals that influence the operator's posture. Information from anthropometric data and about human biomechanical capabilities ensures functionality in terms of safety, performance, and ease of use.

Bus manufacturers, however, often ignored the operator's seat as an integral part of the workstation. They used modified truck seats which did not meet the ergonomic needs of the bus driver workforce. Bus drivers often modified the seat to improve their postures and level of comfort. Consequently, the lack of functionality resulted in driver injury and discomfort.

This project used an alternate approach to the way an urban transit bus operator's seat is designed. The seat was designed for specific use in urban transit buses, with bus operations and driver size variation as the principal guiding factors.

To ensure the operator's seat will accommodate the bus driver population extremes, the urban bus operator's seat should have the following minimum seat adjustments and ranges:

Seat Height Adjustment: The seat should ideally adjust 6 inches to 20 inches, as measured from the floor to the uncompressed, flat seat cushion at the front edge. Air or an air driven motor should drive the height adjustment.

Suspension Dampening: The seat should be equipped with a variable dampening shock absorber to allow the driver to adjust the ride from soft to very hard (lockout). Transit industry experience with seats equipped with single shock absorbers seats has been poor. Seats configured with a single shock tend to break down quickly, with the seat pan tilting or leaning toward the non-shocked side. Consequently, a two (2) shock absorber system should be used. Ideally, the shocks should be adjustable. If impractical, a single fixed and single adjustable damper should be used.

Fore/Aft Adjustment: The seat should adjust a minimum of 10 inches. However, 11 inches of adjustment is preferable. The use of an air slide release or similar system facilitates the movement of the seat, providing an infinite number of adjustments. The lock must engage on both sides, and the slides must be located below the suspension to prevent movement of the seat pan when in the locked position.

Seat Pan Angle/Rake: The seat should mechanically adjust 17º, ideally from –5º to + 12º. The adjustment mechanism must engage on both sides to prevent unwanted movement of the seat pan.

Seat Pan Length: As measured from the front of the seat cushion to the backrest at the intersection of the seat cushion, the seat pan should adjust 4 inches, from 16 inches to 20 inches. Furthermore, the seat pan should adjust as one unit, leaving no gaps between sections of the seat pan, in order to fully support the thigh.

Backrest Recline: The backrest should adjust backward to 35º from vertical to permit the user to lean against the backrest. The backrest adjustment should be independent from the seat pan adjustment. The adjustment should be mechanical.

Lumbar Support: The seat should be equipped with air chamber lumbar support system to permit varying degrees of firmness and adjustment. The lumbar support should be large enough to accommodate a wide range of users. In the case of the prototype seat, it was equipped with three (3) air chambers stacked on top of each other.

Headrest Up/Down Adjustment: The headrest should adjust a minimum of 2 inches to up and down from the top of the seat backrest in order to full support the head of the user.

Headrest Forward/Backward Adjustment: The headrest should adjust a minimum of 40º forwards from the vertical.

A critical factor to ensuring the full benefit of the re-designed seat is the fit of the seat within the operator's workstation. Newer buses often have workstation which can accommodate the full range of adjustment of the newly designed operator's seat and will require little or no modification. Older buses, however, typically have smaller operator workstation and may be unable to accommodate the new seat. Consequently, modification of the workstation in older buses may be necessary. Moreover, placement of the operator's seat in new buses must be carefully taken into consideration to ensure the full ranges of adjustments are optimized. Adjustment of the seat riser bolt pattern may be required.

An additional consideration is the covering of the operator's seat. To maximize operator comfort, a woven fabric covering should be used. Although more durable, vinyl coverings should be avoided.

Further study is necessary to determine the effectiveness of the re-designed seat in controlling the frequency and severity of musculoskeletal disorders due to the design of the urban transit bus operator's seat. Additionally, research is needed to validate the anthropometric data for the transit bus operator work population within the United States. Completion of the CAESAR study may provide further insight. Lastly, additional field vibration study may be needed to determine the long term effectiveness of vibration dampening devices.

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