Cost-Effectiveness of Driver Seat Alternatives for King County Metro Buses

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Abstract

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Background: Low back pain (LBP) is a leading cause of occupational disability and a large contributor to worker compensation costs among bus drivers in the transportation sector. In King County Metro, the mass transit provider in Seattle, Washington, LBP in drivers is frequently attributable to whole-body vibration (WBV) exposures that occur when a vehicle encounters bumps in the road. To reduce WBV exposures and mitigate some of the bus driver LBP cases, engineering controls, such as improved seats for drivers, may be used. This predictive cost-utility analysis (CUA) aimed to determine whether alternatives to currently installed, industry-standard, passive air-suspension driver seats could be cost-effective interventions to reduce LBP and neck pain worker compensation claims at the agency. The three strategies evaluated were: installation of an active-suspension driver seat, frequent passive-suspension driver seat replacement, and installation of a static driver seat.

Methods: The CUA was performed from the perspective of the worker compensation payer, King County Metro. A decision-analytic Markov model was developed to simulate the likelihood of a driver filing a LBP or neck pain claim using a 15-year worker compensation claim database from King County Metro. Back and neck claims were classified by their likelihood of WBV-relatedness and severity. Using employee data from King County Metro, rates and costs of back claims and neck claims were determined. Expected reductions in claim rates were determined from the epidemiologic literature on WBV and LBP and previous research on seating interventions. Utilities for back pain and neck pain were taken from relevant health-related quality of life literature. One-way, multi-way, and structural sensitivity analyses were used to test result robustness.

Results: The active-suspension seat was dominant over the existing passive-suspension seat; it was found to improve driver health through reduction in WBV exposures as well as reduce costs to King County Metro. The static seat was found to be cost saving but since it would not reduce WBV exposures, was not predicted to result in quality of life benefits for drivers. Frequent passive-suspension seat replacement did not appear to be cost-effective in comparison to the other seating interventions, with an incremental cost-effectiveness ratio of $1,383,188 per Quality-Adjusted Life Year. In the sensitivity analyses, the results were sensitive to the rate of claim reduction and robust to claims costs and utility inputs.

Conclusion: These findings imply that frequent seat replacement would likely result in a substantial cost increase to King County Metro, while the adoption of active-suspension seats may both improve driver health and reduce claims costs at the agency. The adoption of static suspension seats would likely result in cost-savings from seat cost and seat maintenance costs. However, it is anticipated that these seats would not improve driver health.

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Introduction

Low Back Pain

Low back pain (LBP) can create substantial economic and public health burdens; it is the leading cause of disability globally[1]. Most people will suffer an incidence of LBP at some point in their lives. While there are multiple non-occupational causes for LBP, it is thought that 37% of cases of LBP worldwide involve occupational risk factors[2]. Among the working populations highly affected by LBP are professional vehicle operators, including bus drivers, truck drivers, and off-road vehicle operators ([3];[4];[5]). In the United States, musculoskeletal disorders (MSDs) occur at twice the rate in the transportation sector compared with the total across all private sectors[6]. Among US professional drivers, 81% of bus drivers and 50% of truck drivers suffered from low back pain, as compared with 42% of sedentary workers[4]. In a recent study of Seattle's professional bus drivers, Blood *et al* found that bus drivers at the local transit agency were 1.4 times as likely to submit a worker compensation claim for the back compared with administrative staff at the agency[7].

Worker compensation costs involving the back are among the most common and most costly claims in the US. While LBP accounts for up to 20% of all worker compensation claims, it accounts for up to 41% of worker compensation claim costs[8]. There are several factors that explain the inflated costs associated with LBP claims. Some research suggests that there is over-utilization of healthcare associated with these claims[9]. Treatment for LBP varies around the globe, with the US having one of the highest rates of back surgery, among the most costly treatments for LBP and one that requires a significant recovery time[10]. Additionally, workers with LBP tend to accrue significant amounts of indemnity (timeloss) pay. According to claims data in Washington State, the average number of paid disability days for a work-related musculoskeletal claim for the back is 263 days[11]. Finally, one of the largest predictors of filing a LBP worker compensation claim is having had a previous instance of LBP[12]. Individuals with a recurrent back claim tend to incur longer durations of timeloss and higher medical and indemnity costs[13], inflating the costs of LBP claims overall. Worker compensation costs for back injuries among professional drivers are significant; within King County Metro, the local transit agency in Seattle, bus driver back claims accounted for 12.8% of total costs to the agency.

Whole Body Vibration and Low Back Pain

There are multiple explanations for the high rate and high cost of LBP among professional drivers. Traditional epidemiologic studies have focused on heavy work, lifting and forceful movements, bending and twisting, whole body vibration (WBV), and static work postures as risk factors for LBP. Additionally, psychosocial and work organizational factors are thought to play a role in the development of LBP among drivers. WBV, which occurs when vibrations from driving are transmitted through the driver seat pan to the driver's body, is a well-studied risk factor for lumbar spinal pain.

While the exact mechanism by which WBV affects the back is not entirely elucidated, researchers have discovered several effects WBV has on the spine that could potentially cause damage. WBV elevates spinal loading and causes muscle fatigue[14,15]. There is some evidence that WBV may cause micro-fractures in the bony endplates in the spine, which could potentially lead to disc degeneration[16]. Additionally, WBV is linked to thinning of the intervertebral discs and disc herniations[17]. It is thought that chronic exposure WBV may cause the accumulation of micro-trauma, which can result in LBP after a triggering event such as an impulsive or other acute exposure. The forms of LBP due to WBV exposures appear to be distinct from other more acute forms of LBP related to exposures such as manual materials handling[4].

There is a relatively strong association between WBV exposure and the development of LBP[18-21]. A recent meta-analysis described an increased risk of LBP among workers exposed to WBV with an odds ratio of 2.17 (95% CI: 1.61-2.91)[18]. In addition to affecting the back, researchers have found some evidence that WBV exposures can increase the risk of neck pain in professional drivers[22,23]. Researchers have detected a dose-response relationship between WBV and driving-related LBP[3,24,25]. This dose-response relationship between has not been well characterized and there is no commonly accepted exposure of WBV that will result in LBP[26]. However, there is some indication that daily exposure to WBV for 8 hours per day with an average magnitude greater than 0.5 m/s^2 predisposes to the incidence of low back disorders[27]. Consequently, action limits and exposure limits have been established in the European Union that aim to protect workers exposed to WBV.

Mitigating Whole Body Vibration Exposures

Although the effects of WBV on LBP are widely known, few occupational interventions have succeeded in reducing WBV exposures in professional vehicle operators[28] . While WBV exposures are affected by some non-modifiable variables such as road type[29] and driver posture[30], vehicle design aspects also contribute to the dose of WBV that drivers experience[31] [32,33] . Thus, engineering controls are one potential method to prevent vehicle operator exposure to WBV. Work by the University of Washington Ergonomics Laboratory has quantified exposure differences associated with different vehicle design configurations. It has been found that WBV exposures differed in high-floor coach buses as compared with low-floor city buses[32] and between cab-over vehicles where the cab is over the front axle and vehicles where the cab is situated behind the front axle[33]. In addition to the vehicle type, tire configuration has been found to significantly modify WBV exposures in front-end loaders, a type of heavy equipment vehicle[34].

Driver seats are also a crucial element of vehicle design that determines WBV exposures. In the 1950's, most driver seats were static and most of the vibration shock absorption came from the foam in seat pans. Later, between the mid-1960's and late 1970's, passive-suspension (mechanical and air-suspension) seats were developed. Mechanical-suspension seats have spring suspensions, while air-suspension seats contain an adjustable air bladder that helps absorb shocks that drivers encounter along the road. Air-suspension seats, the most common type of professional driver seat currently on the market, have been found to be superior to mechanical-suspension seats in attenuating WBV exposures among forklift operators[35]. However, despite their relative superiority over mechanical-suspension seats, air-suspension seats generally only attenuate about 10% of vibration exposures and occasionally amplify exposures[32]. With regard to WBV exposures, in on-road vehicles travelling at moderate to high speeds, it has been shown that static, suspension-less seats used in the 1950's are comparable to air-suspension seats[36] [37]**.** Static seats are less complex in their design and tend to be less costly in comparison with air-suspension seats.

While static seats and passive, air-suspension seats have been widely used for decades, recent technological improvements have led to the development of an active-suspension truck driver seat. The active-suspension seat has been found to reduce vibration exposures up to 50%[38]. The seat contains an electro-magnetic force actuator and microprocessor that work to counteract vibration in real-time, reducing its transmission to the driver. Active-suspension seats tend to be more expensive than air-suspension, mechanical-suspension, and static driver seats, but also have the potential to decrease the incidence of work-related LBP in drivers and the costs associated with worker compensation claims.

King County Metro

King County Metro is a large, publicly-funded transit entity in Seattle, Washington, providing over 123 million passenger rides in 2012[39]. Metro offers a variety of services, including bus, electric trolley, vanpool, and water taxi and operates additional routes via bus and light rail under contract with Sound Transit. King County Metro employs approximately 4,400 people, about 60% of whom are bus drivers**.** The agency, like many transportation entities, has a high rate of worker compensation claims, about 150 per 1,000 full-time employees (FTE)[7]. This rate is about 3 times the rate of all employers in Washington, where the rate is 50 claims per 1,000 FTE annually[40]. Among bus drivers at King County Metro, claim rates tend to be especially elevated, with a claim rate of approximately 200 per 1,000 FTE. Of those claims, nearly 25% are for injuries to the back[7].

Metro is a division of King County, which is self-insured for worker compensation claims. When a worker files a claim, Metro pays 100% of the claim unless it is over $2,500,000, in which case the agency has an excess insurance policy. Metro has indicated that addressing back injuries among bus drivers at the agency is a priority, as they are a high cost to the agency and, ultimately, the taxpayers of Washington State. To combat the high rate of injuries, engineering controls, such as improvements in driver seating, may be employed. Current seats in Metro buses are passive, air-suspension seats. Metro is considering modifying the seat installed in its buses if other seats are available that reduce a driver's exposure to WBV. In this analysis, the following seating alternatives were considered: (1) installing an active-suspension seat, which is predicted to reduce a bus driver's exposure to WBV by up to 50%, (2) installing new passive-suspension seats every 5 years over the 15-year life of a bus to mitigate increases in WBV exposures due to seat-related wear-and-tear, and (3) installing a height-adjustable static (suspension-less) seat that would last the 15-year life of a bus and would not increase WBV exposures but would reduce seat maintenance costs. Although currently available only in trucks, the manufacturer of the active-suspension seat is considering adopting it for use in buses.

Cost-Effectiveness Analysis of Metro Bus Seats

To compare among bus driver seating alternatives, a form of cost-effectiveness analysis (CEA), cost-utility analysis (CUA), was used. Cost-utility analysis is a tool for making investment decisions in health in which the analyst evaluates the outcomes and costs of interventions intended to improve health. CUA is widely used in healthcare economics as it represents an alternative to quantifying health benefits in monetary terms. Instead of traditional return-on-investment (ROI) methods that do not consider health outcomes, CUAs consider both health and monetary outcomes; the health the outcome is measured by the quality-adjusted life year (QALY). QALYs typically range from 0 to 1 and include both morbidity and mortality dimensions.

In CUA, alternative treatments or interventions are compared to the existing treatment and to other potential alternatives. An alternative intervention is typically considered cost-effective if it is either: 1) less costly and at least as effective as the existing treatment or 2) more effective and more costly *and* the additional benefit is worth the additional cost. Although there are no universal thresholds for what is considered a reasonable amount to pay for the health benefit of an additional quality-adjusted life year, a commonly used threshold in the United

States is $50,000 per QALY. This means that the value of one year lived in perfect health is $50,000. Though widely used in the pharmaceutical and medical device fields, CUA has been minimally applied in an occupational health setting, but is thought to be a useful method for determining the value of interventions that improve worker health[41].

Specific Aims

This study describes a CUA comparing seating alternatives for King County Metro bus drivers with the goal of reducing work-related low back and neck injuries at the agency. The aims of the study were to:

Aim **(1)**: Create a Markov model to simulate the possibility of a driver filing a back, neck, or back and neck worker compensation claim at King County Metro

Aim **(2)**: Use the Markov model to conduct a CUA comparing existing passive, air-suspension driver seats with the following:

- Installing a more expensive active-suspension, driver seat that lasts 15 years and substantially reduces bus driver exposure to WBV
- Replacing passive, air-suspension driver seats every 5 years over the 15-year life of a bus, which would marginally reduce bus driver exposure to WBV
- Installing a less expensive, static driver seat that lasts 15 years and does not change bus driver exposure to WBV relative to the industry-standard, passive, air-suspension seat

Aim **(3)**: Determine which of the above interventions is the most cost-effective

Aim **(4)**: Test the model for robustness and determine how manipulating model inputs affects model outcomes

Methods

Overall Approach

The cost-effectiveness of the active-suspension driver seat, frequent passive-suspension seat replacement, and static seat strategies were compared against the industry-standard passive-suspension driver seat, which is currently installed in all King County Metro buses. The analysis was undertaken from the payer's/employer's perspective. A Markov chain model was created to simulate a bus driver filing a worker compensation claim affecting the back, neck, or back and neck at King County Metro. Markov models are tools in medical decision analysis to quantify the probability of a person becoming ill or injured. In this study, a Markov model was used to evaluate bus drivers ending up or moving between "well" or "claim" states. The Markov model was appropriate for this analysis, as drivers were likely to file multiple claims and this type of model allows for the recurrence of events. Bus drivers could transition into health states of acute, sub-acute, or chronic severity that affected the back, neck, or back and neck. According to the definition by Frank *et al* [12] acute claims were defined as those lasting 22 calendar days, sub-acute claims were those enduring 22-84 calendar days, and chronic claims were those lasting 85 or more calendar days[12]**.** The Markov model structure is outlined in **Figure 1.** The likelihood of filing a back, neck, or back and neck worker compensation claim was assumed to be related to exposures to WBV. The Markov model had 1-year cycles and was run for 15 cycles to model the claims that may accumulate over the anticipated lifespan of a King County Metro bus.

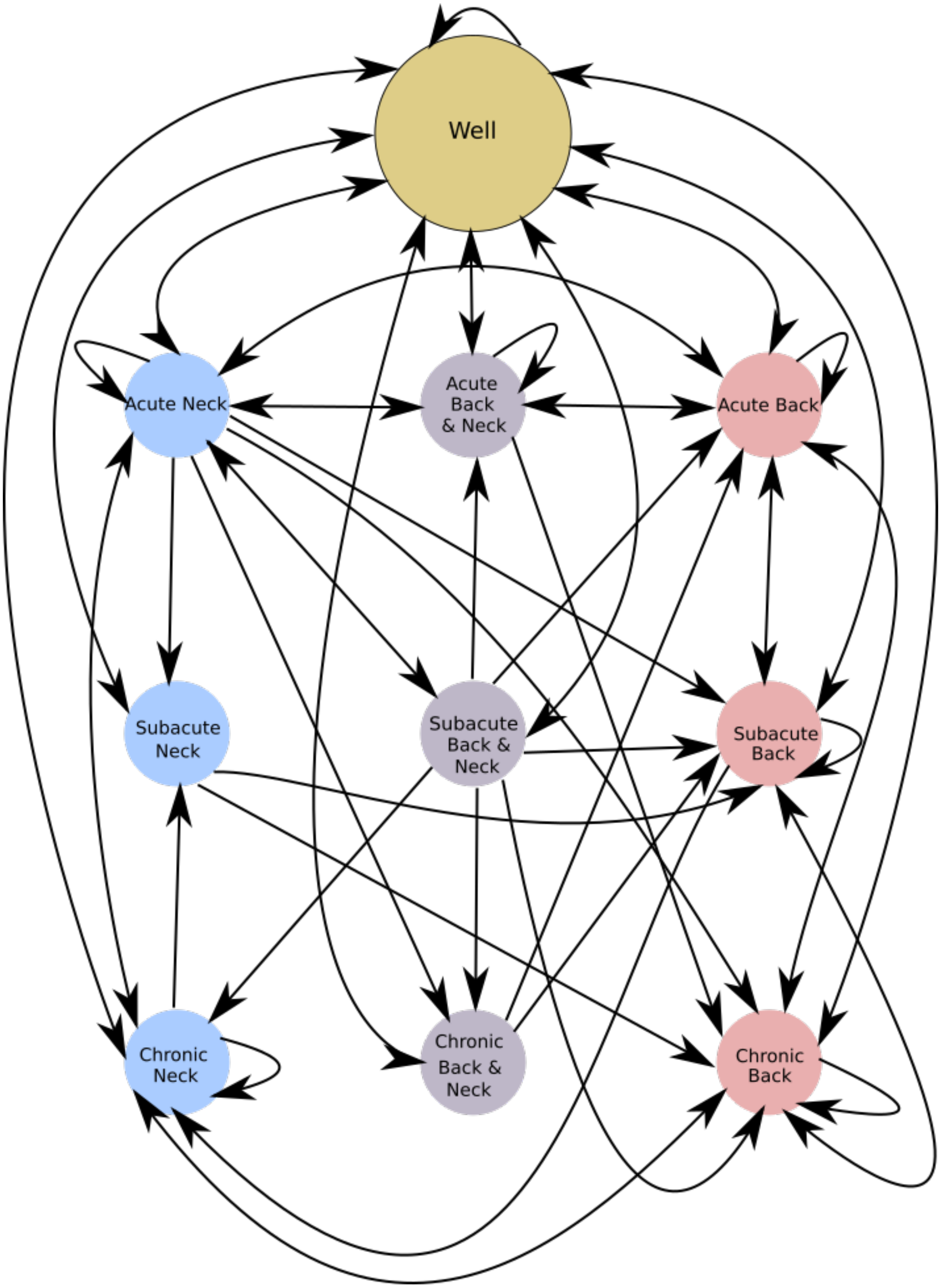


Figure 1. Markov model schematic of likelihood of filing a back, neck, or back and neck worker compensation claim.

Clinical Inputs: Claim Inclusion Criteria

A 15-year Metro worker's compensation claims database from 1999-2013 was obtained from the King County claims department. The database included 10,520 claims. A subset of accepted transit operator claims involving the back, neck, or back and neck were included in the Markov model; if the body part affected was listed as "back," "back-lower," "neck," or "multiple areas," the claim was further evaluated for inclusion. If the body part listed was "multiple areas" in order to be included in the analysis, the claim had to have a mention of the back or neck in the accident description or have an ICD-9 code that was consistent with mechanical low back injury or neck injury. Relevant ICD-9 codes for the back were obtained from work that identified ICD-9 codes for mechanical LBP [42] and relevant ICD-9 codes for the neck were obtained from work investigating work-related musculoskeletal worker compensation claims in Washington State[43]. **Figures 2** and **3** display the list of relevant ICD-9 codes. Additionally, if the ICD-9 codes consistent with mechanical low back injury or neck injury appeared in claims other than those to the back, back- lower, neck, or multiple areas, those claims were included as well. Claims that specified the upper back were not included, as WBV is not suspected to particularly affect the thoracic spine.

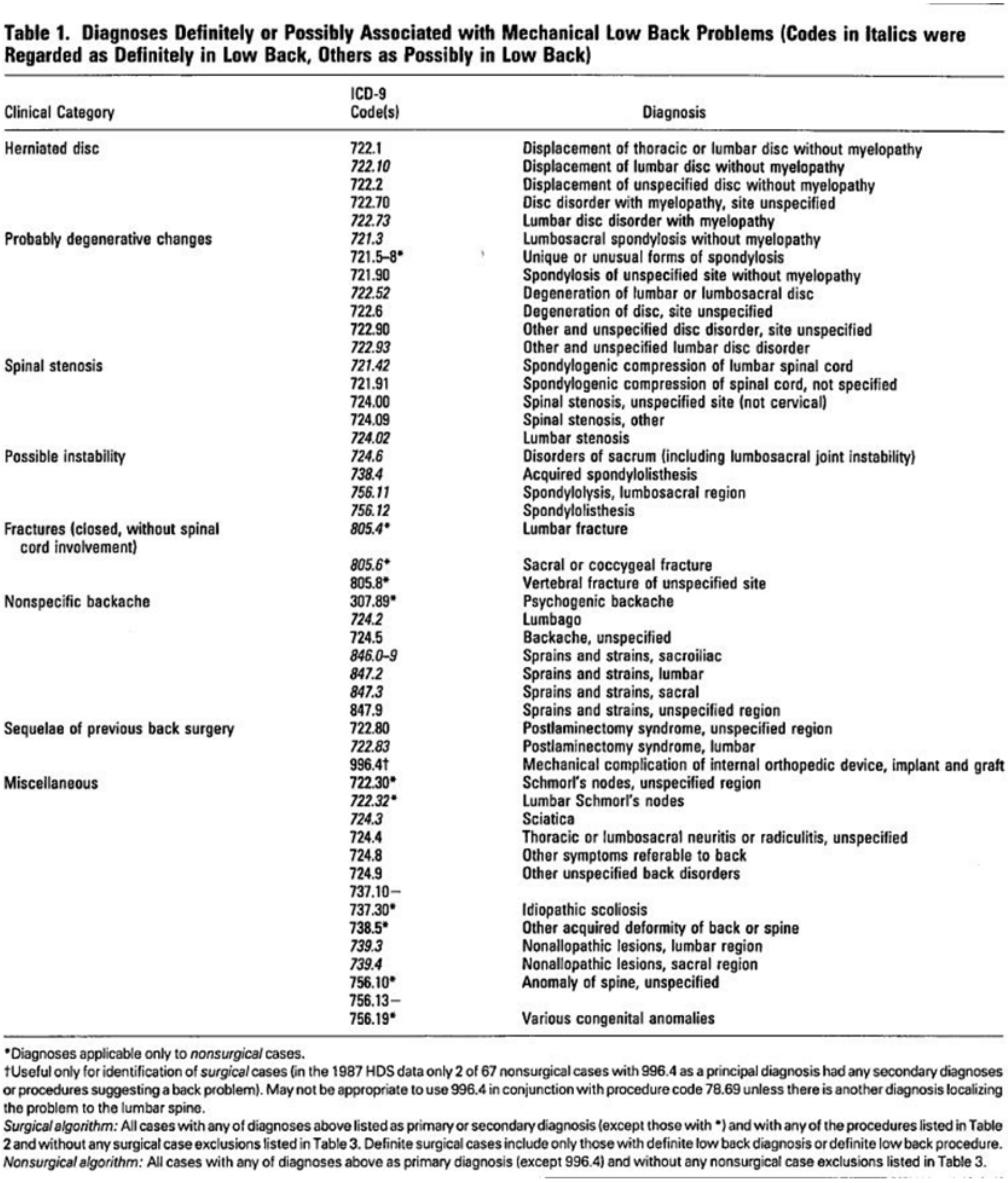


Table 1. Diagnoses Definitely or Possibly Associated with Mechanical Low Back Problems (Codes in Italics were Regarded as Definitely in Low Back, Others as Possibly in Low Back)

Clinical Category	ICD-9 Code(s)	Diagnosis
Herniated disc	722.1	Displacement of thoracic or lumbar disc without myelopathy
	_722.10_	Displacement of lumbar disc without myelopathy
	722.2	Displacement of unspecified disc without myelopathy
	722.70	Disc disorder with myelopathy, site unspecified
	_722.73_	Lumbar disc disorder with myelopathy
Probably degenerative changes	_721.3_	Lumbosacral spondylosis without myelopathy
	721.5–8*	Unique or unusual forms of spondylosis
	721.90	Spondylosis of unspecified site without myelopathy
	_722.52_	Degeneration of lumbar or lumbosacral disc
	722.6	Degeneration of disc, site unspecified
	722.90	Other and unspecified disc disorder, site unspecified
	_722.93_	Other and unspecified lumbar disc disorder
Spinal stenosis	_721.42_	Spondylogenic compression of lumbar spinal cord
	721.91	Spondylogenic compression of spinal cord, not specified
	724.00	Spinal stenosis, unspecified site (not cervical)
	724.09	Spinal stenosis, other
	_724.02_	Lumbar stenosis
Possible instability	_724.6_	Disorders of sacrum (including lumbosacral joint instability)
	_738.4_	Acquired spondylolisthesis
	_756.11_	Spondylolysis, lumbosacral region
	_756.12_	Spondylolisthesis
Fractures (closed, without spinal cord involvement)	_805.4*_	Lumbar fracture
	_805.6*_	Sacral or coccygeal fracture
	805.8*	Vertebral fracture of unspecified site
Nonspecific backache	307.89*	Psychogenic backache
	_724.2_	Lumbago
	724.5	Backache, unspecified
	_846.0–9_	Sprains and strains, sacroiliac
	_847.2_	Sprains and strains, lumbar
	_847.3_	Sprains and strains, sacral
	847.9	Sprains and strains, unspecified region
Sequelae of previous back surgery	722.80	Postlaminectomy syndrome, unspecified region
	_722.83_	Postlaminectomy syndrome, lumbar
	996.4†	Mechanical complication of internal orthopedic device, implant and graft
Miscellaneous	722.30*	Schmorl's nodes, unspecified region
	_722.32*_	Lumbar Schmorl's nodes
	_724.3_	Sciatica
	724.4	Thoracic or lumbosacral neuritis or radiculitis, unspecified
	724.8	Other symptoms referable to back
	724.9	Other unspecified back disorders
	737.10–737.30*	Idiopathic scoliosis
	738.5*	Other acquired deformity of back or spine
	_739.3_	Nonallopathic lesions, lumbar region
	_739.4_	Nonallopathic lesions, sacral region
	756.10*	Anomaly of spine, unspecified
	756.13–756.19*	Various congenital anomalies

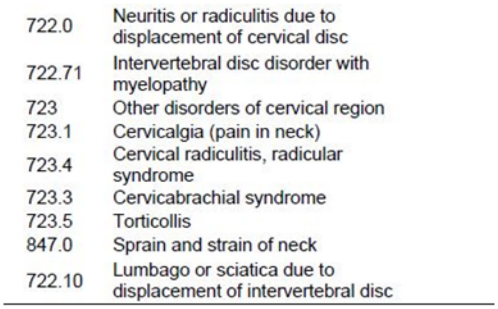
*Diagnoses applicable only to *nonsurgical* cases.

†Useful only for identification of *surgical* cases (in the 1987 HDS data only 2 of 67 nonsurgical cases with 996.4 as a principal diagnosis had any secondary diagnoses or procedures suggesting a back problem). May not be appropriate to use 996.4 in conjunction with procedure code 78.69 unless there is another diagnosis localizing the problem to the lumbar spine.

Surgical algorithm: All cases with any of diagnoses above listed as primary or secondary diagnosis (except those with *) and with any of the procedures listed in Table 2 and without any surgical case exclusions listed in Table 3. Definite surgical cases include only those with definite low back diagnosis or definite low back procedure.

Nonsurgical algorithm: All cases with any of diagnoses above as primary diagnosis (except 996.4) and without any nonsurgical case exclusions listed in Table 3.

Figure 2. ICD-9 Codes for Mechanical LBP from Cherkin *et al* (1992).



722.0	Neuritis or radiculitis due to displacement of cervical disc
722.71	Intervertebral disc disorder with myelopathy
723	Other disorders of cervical region
723.1	Cervicalgia (pain in neck)
723.4	Cervical radiculitis, radicular syndrome
723.3	Cervicabrachial syndrome
723.5	Torticollis
847.0	Sprain and strain of neck
722.10	Lumbago or sciatica due to displacement of intervertebral disc

Figure 3. ICD-9 Codes for Neck Pain from Silverstein and Adams (2007).

Included claims were classified as to their degree of whole body vibration- relatedness A classification scheme was developed to rate each claim's WBV-relatedness as "unlikely," "somewhat likely," or "likely" using the nature, cause, and accident description in the claim database.. 1,239 claims were classified as "likely" or "somewhat likely" to be related to whole body vibration. Of those, 843 (68%) were back claims, 117 (9%) were both back and neck claims, and 279 (23%) were neck claims. Temporary Total Disability (TTD) days were used as a measure for days away from work as the precise number of timeloss days was unavailable for each claim. Light duty days were not factored into the model.

Probability Inputs

Existing Seat (Passive Suspension Seat): To determine the transition probabilities between the "well" and "claim" states in the Markov model, average claim incidences from 1999-2013 were calculated using bus driver count data obtained from King County Metro. To determine transition probabilities between the nine "claim" states in **Figure 1**, claims for each individual claimant were ranked chronologically. Next, it was determined whether a claimant filed a claim in the year following the initial claim and, if so, the type of claim was noted. The health state of the initial claim was known as the “origin health state” and the claim the following year was called the “destination health state,” as shown in **Table 2.**

The transition probabilities were determined by dividing the number of claims bound for a particular destination health state by the total number of claims from the origin health state in each year. Transition probabilities were calculated for each year from 1999-2013 and were averaged to create a single transition probability. If transition probabilities between “claim” states were below 1%, the transition was eliminated as a possibility; transitions were still allowed if they occurred from the “well” to “claim” states if the probabilities were below 1%. The 1% cut-off for “claim” to “claim” transitions was undertaken to make the model more manageable (without this, 100 allowable transitions between the health states could have potentially occurred). Transition probabilities did not vary over time as data was not available to suggest changes in transition probabilities as the seat aged. **Table 2** displays the transition probabilities obtained from this method and used in the model.

<u>Active Suspension Seat Intervention:</u> Transition probabilities for the active suspension seat model were the same as for the previously described passive suspension seat with the exception of transition probabilities for moving from the “well” (healthy) to the “claim” (injured) states. These transition probabilities were reduced by 16%.

To derive the 16% reduction in claim incidence, data on driver WBV exposure with an active-suspension seat[32] was combined with epidemiologic data on the relationship between WBV exposures and the risk of LBP[44]. It has been found that the 8-hour time-weighted vector sum acceleration, or $A(8)_{sum}$, is approximately 0.4 m/s^2 in 26 Metro buses[32]. $A(8)_{sum}$ is a commonly used method of measuring the daily dose of vibration experienced by a driver and is described by the International Standards Organization (ISO) 2631-1 WBV Standard [27]. Based on a 2-year prospective cohort study of 537 drivers, a decreased risk of disability due to LBP was observed as $A(8)_{sum}$ decreased[44].

Disability due to LBP was defined as a score of 12 or above on the Roland Morris Disability Questionnaire (RDQ). The RDQ is a 24-item questionnaire that is valid, reliable, and widely used to track clinical significance of LBP symptoms over time[45-47]. While there is no guarantee that worker compensation claims meet a guaranteed level of disability, in a study of 1,205 Washington State workers with a low back claim with 4 or more days of timeloss, the mean RDQ score was 13.1[48], indicating comparable injury severity between the drivers in the epidemiologic data and workers who file claims.

Researchers have found that workers who had $A(8)_{sum}$ scores similar to those found among King County Metro bus drivers were 2.66 times as likely as those exposed to $A(8)_{sum}$ of <0.30 m/s^2 to have an RDQ score of 12 or above, after adjusting for confounders[44]. Given that the active suspension seat has been found to reduce z-axis $A(8)_{sum}$ approximately 50% in truck drivers[38], it was assumed that with the installation of an active suspension seat, King County Metro drivers would be exposed to <0.30 m/s^2. Using the formula for attributable risk % (AR%): [(RR-1)/RR]*100%, the fraction of drivers with RDQ scores above 12 that were due to elevated WBV exposure was calculated to be 62%. However, a 62% reduction in RDQ scores above 12 would not necessarily predict a 62% drop in worker compensation claims. Rather, researchers have found that only a small portion of workers with work-related injuries proceed to file claims[49]. In a study of unionized workers with work-related musculoskeletal disorders, the authors found that only 25% of workers filed a worker compensation claim[50]. Thus, 62% was multiplied by 0.25, predicting a 16% drop in LBP claims if vibration exposures were reduced with the active suspension seat. Thus, transition probabilities from the “well” state to the nine “claim” states were multiplied by 0.84 to produce the 16% reduction. It was assumed that these reduced transition probabilities between the “well” and “claim” states would remain stable over the 15-year life span of the bus simulated in the Markov model.

Frequent Seat Replacement Intervention: Transition probabilities remained the same as in the passive-suspension seat (existing seat) model, with the exception of transition probabilities for moving from the “well” to the “claim” states. The transition probabilities for moving from the “well” to the “claim” states were reduced by 5% compared with those in the existing seat. Because the rate of vibration reduction expected from the frequent seat replacement strategy was known to be small and reduce A(8) sum by 10% or less[29,32,35], an expected rate of reduction of 5% was chosen, which was slightly less than one-third the rate of reduction for the active-suspension seat.

Static Seat Intervention: Previous research has shown that vibration exposures are nearly identical with passive-suspension seats and static seats[36]. Transition probabilities in the static seat model remained the same as for the passive-suspension (existing seat) model.

Utility (Quality of Life) Inputs

Utilities were obtained from the quality of life literature on LBP, neck pain, and the general population. For LBP, utilities were taken from research [51] in which the authors attempted to compare the validity of direct preferences and SF-36- derived health state preferences for deriving LBP utility. There are multiple ways to derive utilities, including through direct methods such as the standard gamble or time trade-off where subjects are directly asked what they would prefer. Indirect methods typically use algorithms to derive utility values from health-related quality of life questionnaires such as the SF-36. To calculate the utility for LBP used in this analysis, the mean preference values for both the direct and indirect methods were averaged to obtain a single estimate of utility for LBP of 0.668 (SD=0.123).

For neck pain, utilities were taken from a cost-effectiveness analysis on acupuncture for chronic neck pain[52], where the average utility was 0.625. There was a paucity of literature that had utilities for both back and neck pain. Thus, for the health states where a worker had both back and neck claims, a conservative estimate using the utility for neck pain was used. For the "well" health state, nationally representative utilities were taken from Hanmer *et al* [53]. The authors reported utilities by age and sex; using the overall transit operator population, an age and sex weighted utility was calculated to be 0.817. Time weights were applied using severity to determine the utilities of each of the nine "claim" states. For example, for an acute back pain state, the worker was assumed to spend a maximum of 21 days in LBP, such that 21 days away from work out of365 days they would have a utility of 0.668 and 344 days out of 365 days they would have a utility of 0.817, for an overall utility of 0.808. Utility inputs are listed in **Table 3**.

Cost Inputs

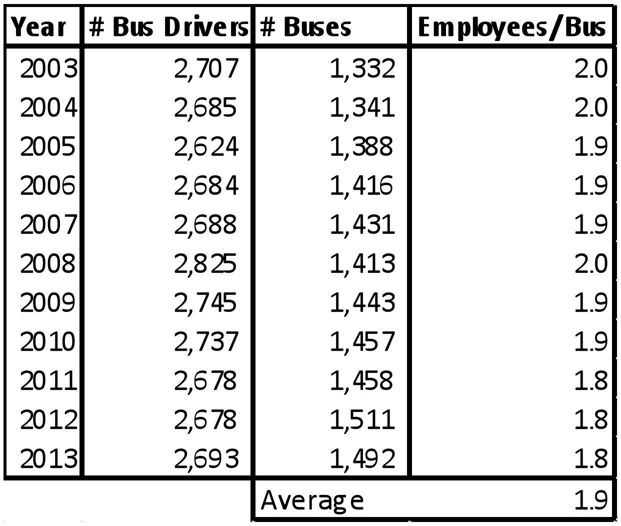
Claim costs were derived from the King County Metro worker compensation database. As the final cost of worker compensation claims tend to be difficult to predict, King County tracks both the total amount paid and the total amount incurred for each claim. The amount incurred incorporates an estimate of how much the claim is likely to cost Metro in the future; total paid and total incurred tend to be equal for older (nearly or fully settled) claims. Mean total paid and mean total incurred for each type of claim for each year from 1999-2013 were adjusted for claim maturity using modifiers supplied by an actuarial company contracted by King County. Mean total costs paid and mean total costs incurred were additionally adjusted for inflation to

2015 dollars using Consumer Price Index (CPI) modifiers from the Bureau of Labor Statistics. Once adjusted for claim maturity and inflation, claim costs derived from the total costs paid and total costs incurred were averaged.

The model additionally incorporated two indirect costs to King County Metro totaling 22%: 10% of the total claim cost paid to King County Administration for administering the claim and a 12% tax on the claim to the Washington State Department of Labor and Industries. Cost of the passive-suspension (existing) driver seat ($2,805) was obtained from the King County Metro vehicle maintenance department. Cost of the active-suspension driver seat ($3,995) and static driver seats ($2,500) were based on current OEM and dealer pricing respectively. Cost of seat maintenance for the existing passive-suspension seat was determined from the King County Metro vehicle maintenance department ($950 every 5 years). The cost of seat maintenance for the active-suspension seat was assumed to be identical to that for the existing, passive, air-suspension seat. The cost of seat maintenance for the static seat was estimated to be $300 every 5 years for the replacement of the foam top of the seat.

Primary Analysis

Claim costs and utility inputs were adjusted to reflect costs and QALYs per bus, as the intervention was to be implemented on the bus level rather than on the employee-level. To determine costs and QALYs per bus, the number of transit operator employees per bus was determined using King County supplied data on the number of driver employees and the number of bus operating hours in each year. It was assumed that each employee worked 40 hours per week. As shown in **Table 1,** the number of employees per bus for each year from 2003-2013 was determined and averaged, yielding a final estimate of 1.9 employees/bus. To determine claims costs and QALYs per bus, claim costs and QALYs were multiplied by 1.9. All costs and QALYs were discounted at a rate of 3% using the following formula: $DPV = FV/(1+r)^n$, where DPV is the discounted present value, FV is the nominal future value, r is the discount rate, and n is the number of years before the future cash flow occurs. Costs and QALYs were summed over the 15-year life of a bus.



Year	# Bus Drivers	# Buses	Employees/Bus
2003	2,707	1,332	2.0
2004	2,685	1,341	2.0
2005	2,624	1,388	1.9
2006	2,684	1,416	1.9
2007	2,688	1,431	1.9
2008	2,825	1,413	2.0
2009	2,745	1,443	1.9
2010	2,737	1,457	1.9
2011	2,678	1,458	1.8
2012	2,678	1,511	1.8
2013	2,693	1,492	1.8
		Average	1.9

Table 1. Determination of # of employees per bus. Data was obtained from King County Metro staff and publicly available data on the King County Metro website. Data was unavailable before the year 2003.

Incremental cost-effectiveness ratios (ICERs) were calculated. Over the 15-year life of the bus, the existing, passive, air-suspension seat was compared with: 1) the installation of an active-suspension driver seat, 2) replacing passive-suspension seats every 5 years, and 3) the static seat. ICERs were calculated using the following equation: $ICER = \Delta C/\Delta E$, where ΔC = incremental cost in 2015 dollars and ΔE = incremental benefit in QALYs.

Net Monetary Benefit (NMB) was calculated using the following equation: $NMB = \lambda \times \Delta E - \Delta C$, where λ = maximal willingness-to-pay (WTP), ΔE = incremental benefit in QALYs, and ΔC = incremental costs. WTP refers to the maximum amount a decision-maker or stakeholder believes is reasonable to pay for each additional QALY gained. While there is no universal cut-point for WTP (or what is cost-effective) in the United States, \$50,000/QALY is commonly used[54] and some researchers have noted values over \$400,000/QALY[55]. WTP must be defined by the decision-maker, as they are aware of their budget and the alternative uses of that budget[54]. In this case, King County Metro's WTP was unknown; a conservative estimate of \$50,000/QALY was selected as the WTP threshold for the NMB.

Return-on-investment (ROI) was calculated using the following equation: [(benefits – costs)/costs] x 100%. Benefits were defined as difference in monetized outcome measures between the seat intervention and the existing seat. Costs were defined as costs associated with the seat, including the cost of the seat itself as well as periodic seat maintenance, if applicable.

Sensitivity Analyses

One-way sensitivity analyses were conducted using the base case transition probabilities in **Table 2** and those described above. Other model inputs for the sensitivity analyses are listed in **Table 3**. Tornado diagrams were constructed using Net Monetary Benefit (NMB), as the interpretation of negative ICERs is ambiguous[56]. Tornado diagrams serve to visually represent how parameter uncertainty affects model estimates.

To determine how multiple parameter changes would affect the cost-effectiveness of the different seat interventions, three scenarios were created to simulate other potential input combinations. **Table 3** displays inputs for the various scenarios. Scenario 1 simulated a situation in which claim costs were lower, intervention seat costs were higher, and claim state utilities were higher, which would potentially make alternative seats less cost-effective. Scenario 2 simulated a situation in which claim costs were higher and intervention seat costs were lower, potentially making alternative seats more cost-effective. Scenario 3 simulated a situation in which the rate of claim reduction was more modest (5% reduction in claims for the active-suspension seat) than predicted by the epidemiologic data (16% reduction in claims for the active-suspension seat).

Because there was some uncertainty about whether the "somewhat likely" claims were likely to be affected by changes in bus driver seating, a structural sensitivity analysis was performed in which only claims that were classified as "likely" to be related to WBV were included. This analysis included 659 claims. A revised Markov model was created for this sensitivity analysis with the same claim states, but different allowed transitions. Probabilities of transitioning between the "well" and nine "claim" states (acute back, acute back and neck, acute neck, sub-acute back, sub-acute back and neck, sub-acute neck, chronic back, chronic back and neck, chronic neck) were determined. As in the primary model, if the probabilities of transitioning from a "claim" state to another "claim" state were below 1%, the transitions were not allowed. If probabilities of transitioning from the "well" state to a "claim" state were below 1%, these transitions were allowed.

Table 2 displays the transition probabilities for the existing seat in the structural sensitivity analysis. Transition probabilities were derived as described in the section on "Probability Inputs." Transition probabilities for the active-suspension seat, frequent seat replacement, and static seat interventions were modified as described above in the "Probability Inputs." Mean claim costs for the "likely" only claims were determined using the methods described above in "Cost Inputs." All other inputs remained the same as the base case analysis. **Table 3** shows the inputs for the structural sensitivity analysis.

Table 2. Transition probabilities between “well” and “claim” states for the existing seat. Base case transition probabilities were derived including claims that were both “somewhat likely” and “likely to be related to WBV. The structural sensitivity analysis included only claims that were deemed “likely” to be related to WBV.

Origin Health State	Destination Health State	Existing Seat Transition Probabilities (Base Case)	Existing Seat Transition Probabilities (Structural Sensitivity)
Well	Well	0.9689	0.9835
Well	Acute Neck	0.0037	0.0021
Well	Acute Back & Neck	0.0014	0.0009
Well	Acute Back	0.0117	0.0056
Well	Sub-acute Neck	0.0017	0.0008
Well	Sub-acute Back & Neck	0.0009	0.0005
Well	Sub-acute Back	0.0057	0.0029
Well	Chronic Neck	0.0015	0.0009
Well	Chronic Back & Neck	0.0006	0.0004
Well	Chronic Back	0.0038	0.0023
Acute Neck	Well	0.8235	0.7785
Acute Neck	Acute Neck	0.0122	0.0000
Acute Neck	Acute Back & Neck	0.0172	0.0291
Acute Neck	Acute Back	0.0450	0.0558
Acute Neck	Sub-acute Neck	0.0125	0.0207
Acute Neck	Sub-acute Back & Neck	0.0112	0.0157
Acute Neck	Sub-acute Back	0.0316	0.0290
Acute Neck	Chronic Neck	0.0192	0.0467
Acute Neck	Chronic Back & Neck	0.0118	0.0000
Acute Neck	Chronic Back	0.0157	0.0244
Acute Back & Neck	Well	0.8615	0.9139
Acute Back & Neck	Acute Neck	0.0410	0.0278
Acute Back & Neck	Acute Back & Neck	0.0667	0.0375
Acute Back & Neck	Acute Back	0.0154	0.0000
Acute Back & Neck	Chronic Back	0.0154	0.0208
Acute Back	Well	0.8905	0.9162
Acute Back	Acute Neck	0.0141	0.0212
Acute Back	Acute Back & Neck	0.0104	0.0000
Acute Back	Acute Back	0.0379	0.0356
Acute Back	Sub-acute Back	0.0276	0.0271
Acute Back	Chronic Back	0.0196	0.0000
Sub-acute Neck	Well	0.9556	0.9038
Sub-acute Neck	Acute Neck	0.0000	0.0192
Sub-acute Neck	Acute Back & Neck	0.0000	0.0385
Sub-acute Neck	Sub-acute Back	0.0278	0.0000
Sub-acute Neck	Chronic Back	0.0167	0.0385
Sub-acute Back & Neck	Well	0.7359	0.7583
Sub-acute Back & Neck	Acute Neck	0.0410	0.0250
Sub-acute Back & Neck	Acute Back & Neck	0.0128	0.0333
Sub-acute Back & Neck	Acute Back	0.0128	0.0000
Sub-acute Back & Neck	Sub-acute Back	0.0410	0.0833
Sub-acute Back & Neck	Chronic Neck	0.0256	0.0000
Sub-acute Back & Neck	Chronic Back & Neck	0.1154	0.1000
Sub-acute Back & Neck	Chronic Back	0.0154	0.0000
Sub-acute Back	Well	0.8819	0.8363
Sub-acute Back	Acute Neck	0.0000	0.0111
Sub-acute Back	Acute Back	0.0423	0.0445
Sub-acute Back	Sub-acute Neck	0.0000	0.0133
Sub-acute Back	Sub-acute Back	0.0468	0.0631
Sub-acute Back	Chronic Neck	0.0178	0.0111
Sub-acute Back	Chronic Back	0.0112	0.0206
Chronic Neck	Well	0.9133	0.9143
Chronic Neck	Acute Neck	0.0333	0.0357
Chronic Neck	Acute Back	0.0000	0.0143
Chronic Neck	Sub-acute Neck	0.0133	0.0357
Chronic Neck	Chronic Neck	0.0133	0.0000
Chronic Neck	Chronic Back	0.0267	0.0000
Chronic Back & Neck	Well	0.9394	0.9688
Chronic Back & Neck	Acute Back	0.0455	0.0000
Chronic Back & Neck	Sub-acute Back	0.0152	0.0313
Chronic Back	Well	0.9258	0.8696
Chronic Back	Acute Back	0.0139	0.0296
Chronic Back	Sub-acute Neck	0.0000	0.0111
Chronic Back	Sub-acute Back	0.0283	0.0380
Chronic Back	Chronic Neck	0.0112	0.0172
Chronic Back	Chronic Back	0.0209	0.0345

Parameter	**Base Case Input**	**Range (95% CI or estimates thereof)**		**Scenario 1**	**Scenario 2**	**Scenario 3**	**Structural Sensitivity**
Rate of Claim Reduction							
Active-Suspension Seats	**16%**	2%	30%	**5%**	**10%**	**5%**	16%
Frequent Seat Replacement	**5%**	0%	20%	**1%**	**5%**	**3%**	5%
Static Seat	**0%**	-10%	10%	0%	0%	**-2%**	0%
Claim Costs							
Acute Neck Claim	**$3,804**	$ 2,292	$4,854	**$ 2,292**	**$4,854**	$3,804	**$4,079**
Acute Back & Neck Claim	**$5,591**	$ 4,313	$6,728	**$ 4,313**	**$6,728**	$5,591	**$6,216**
Acute Back Claim	**$3,892**	$ 2,532	$4,676	**$ 2,532**	**$4,676**	$3,892	**$4,436**
Subacute Neck Claim	**$21,172**	$ 17,996	$27,965	**$ 17,996**	**$27,965**	$21,172	**$19,662**
Subacute Back & Neck Claim	**$17,724**	$ 15,019	$22,980	**$ 15,019**	**$22,980**	$17,724	**$17,835**
Subacute Back Claim	**$15,722**	$ 12,399	$17,754	**$ 12,399**	**$17,754**	$15,722	**$15,982**
Chronic Neck Claim	**$116,728**	$ 102,777	$156,367	**$ 102,777**	**$156,367**	$116,728	**$113,666**
Chronic Back & Neck Claim	**$141,600**	$ 128,090	$198,465	**$ 128,090**	**$198,465**	$141,600	**$186,195**
Chronic Back Claim	**$107,431**	$ 69,425	$123,988	**$ 69,425**	**$123,988**	$107,431	**$95,008**
Seat Costs							
Active-Suspension	**$3,995**	$3,500	$5,995	**$4,500**	**$3,500**	$3,995	$3,995
Passive-Suspension (Existing)	**$2,805**	$2,000	$3,000	**$3,000**	$2,805	$2,805	$2,805
Passive-Suspension (Replacement)	**$2,805**	$2,000	$3,000	**$3,000**	**$2,500**	**$2,500**	$2,805
Static Seat	**$2,500**	$2,000	$3,000	$2,500	**$2,000**	**$2,200**	$2,500
Indirect Costs Multiplier	**1.22**	1	2.5	1.22	**2**	1.5	$1
Seat Maintenance Costs							
Passive-Suspension (existing)	**$950 every 5 years**	$800 every 5 years	$1100 every 5 years	$950 every 5 years	$950 every 5 years	$950 every 5 years	$950 every 5 years
Active-Suspension	**$950 every 5 years**	$500 every 5 years	$1100 every 5 years	$950 every 5 years	**$500 every 5 years**	**$800 every 5 years**	$950 every 5 years
Static Seat	**$300 every 5 years**	$0	$500 every 5 years	**$500 every 5 years**	**$0**	**$200 every 5 years**	$300 every 5 years
Employees/Bus	**1.9**	1.5	2.5	1.9	**2**	1.9	1.9
Utility Inputs							
Neck Claim	**0.625**	0.55	0.75	**0.7**	0.625	**0.65**	0.625
Back Claim	**0.668**	0.55	0.75	**0.7**	0.668	**0.65**	0.668
Back & Neck Claim	**0.625**	0.55	0.75	**0.7**	0.625	**0.62**	0.625
No Claim	**0.817**	0.78	0.95	0.817	**0.9**	**0.85**	0.817

Table 3. Inputs for Base Case and Sensitivity Analyses. Bolded inputs in the Scenario columns and structural sensitivity column indicate departures from the base case inputs.

Results

Base Case Analysis

The passive-suspension (existing) seat, active-suspension seat, static seat, and frequent passive-suspension seat replacement strategies were compared in terms of the total costs and total QALYs they would incur over the 15 year life of 1,500 buses. . **Figure 4** displays a graphical representation of the cost-effectiveness of the four strategies. It was found that the active-suspension seat was the dominant intervention; it both increased QALYs by 5 and decreased costs by $4.8 million over the 15-year time horizon of King County Metro's 1,500 bus fleet relative to continuing to use the existing, passive-suspension seat. The static seat neither increased nor decreased QALYs compared with the existing seat, but decreased costs by $2.0 million over the 15-year life of 1,500 buses.

Two incremental cost-effectiveness ratios (ICERs) were calculated for the frequent seat replacement intervention; replacing the passive-suspension seats every 5 years had an ICER of $1.38 million/QALY when compared with the existing, passive-suspension seat and $2.54 million/QALY when compared with the static seat. Although the frequent seat replacement intervention would typically be compared with the lower cost intervention, in this case there was some uncertainty surrounding the effectiveness of the static seat, which was the lower cost intervention. Thus, the frequent seat replacement intervention was compared to both the static seat and the existing, passive-suspension seat and two ICERs were calculated. For all other incremental calculations, the existing, passive-suspension seat was used as the comparator due to the uncertainty in the effectiveness estimate for the passive-suspension seat.

Table 4 displays the results of the base case analysis, including costs and QALYs per bus and overall. Overall costs and QALYs were calculated by multiplying costs and QALYs per bus by 1,500 buses. Assuming that King County Metro has approximately 1,500 buses and that the buses have a lifecycle of 15 years, the installation of an active-suspension seat would result in about a $4.8 million savings, the static seat would result in a $2.0 million savings, and the replacement of passive-suspension seats every 5 years would cost $2.4 million over the 15 year period. At a willingness-to-pay of $50,000 per QALY, the active-suspension seat and static seats had positive NMBs (net monetary benefits) of $3,387 and $1,349 per bus respectively. A positive NMB signals that the investment would be an acceptable investment in a health-improving intervention if the payer is willing to spend $50,000 for every additional quality-adjusted life year.

The ROIs were negative for all seating interventions (**Table 4).** However, the ROI was the least negative (-42%) for the active-suspension seat. The ROI for the static seat was -55%. The frequent seat replacement had the most negative ROI at -122%.

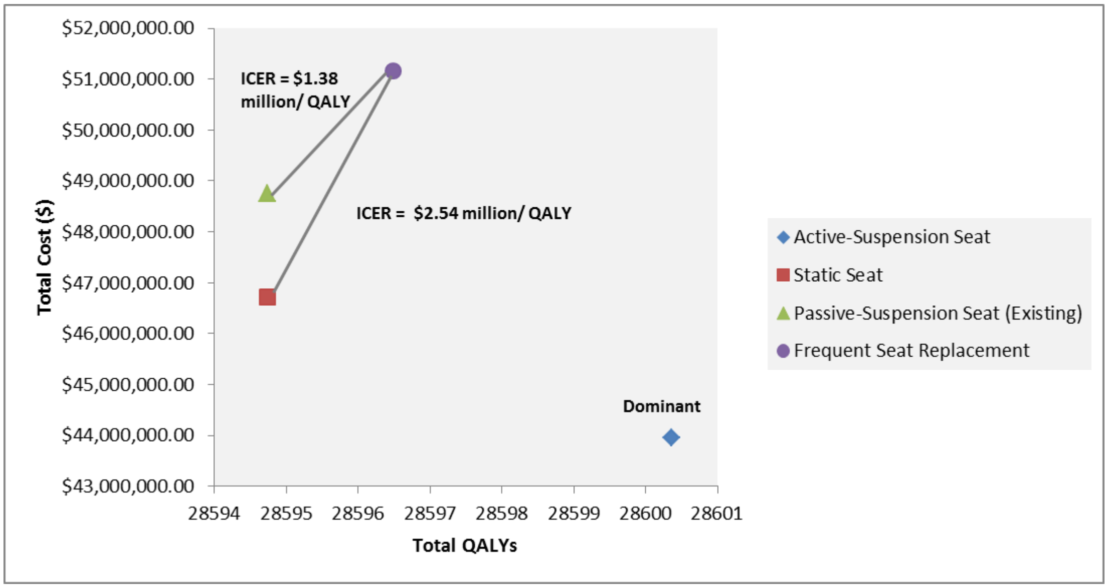


Figure 4. Base Case Cost-Effectiveness. This plot compares total costs for 1,500 buses over the 15-year life of a bus with total QALYs for 1,500 buses over the 15-year life of a bus for each intervention. . The active-suspension seat is dominant (both health saving and cost saving) over the other 3 seating alternatives.

Intervention	Cost per Bus	QALY per bus	Overall Cost	Overall QALYs	ICER	ICER: Relative to Static Seat	ICER: Seat Relative to Existing Seat	Cost Relative to Existing Seat	NMB	ROI
Active-Suspension Seat	$29,300	19.0669	$43,950,639	28600.4	Dominant			-$4,799,127	$3,387	-42%
Static Seat	$31,150	19.0632	$46,725,731	28594.7	Dominated			-$2,024,035	$1,349	-55%
Passive-Suspension Seat (Existing)	$32,500	19.0632	$48,749,766	28594.7	Dominated					-100%
Frequent Seat Replacement	$34,113	19.0643	$51,169,881	28596.5	Dominated	$2,540,001	$1,383,188	$2,420,115	-$1,555	-122%

Table 4. **Results of the base case analysis, presented in 2015 dollars**. Interventions are ranked by cost from lowest to highest. Overall costs and overall QALYs are costs and QALYs per bus multiplied by 1,500 buses. The NMB per bus uses the existing, passive-suspension seat as the comparator.

One-Way Sensitivity Analyses

Active Suspension Seat: In the one-way sensitivity analysis for the active-suspension seat intervention, the variable with the largest impact on cost-effectiveness was the rate of claim reduction. **Figure 5** displays a tornado diagram showing the relative contributions of different parameters in affecting the cost-effectiveness of the intervention. The rate of claim reduction, indirect costs multiplier, cost of the active-suspension seat, and the number of employees per bus appear to be key parameters in determining NMB. The model appeared robust to claims costs, seat maintenance costs, and utility inputs.

Figures 6 and **7** show the threshold sensitivity analysis for the rate of claim reduction, the variable that could cause the NMB to fall below $0 with a WTP of $50,000 per QALY. The ICER-based threshold sensitivity analysis shows that low rates of claim reduction would render the active-suspension seat a poor investment with ICERs above $1,000,000 per QALY. Using the lower bound of the estimated 95% confidence interval of the rate of claim reduction increased the ICER to over $500,000 per QALY. Using base case inputs, the active-suspension seat intervention appears to be cost saving if the rate of claim reduction is approximately 4.4% or above. At a WTP of $50,000 per QALY, a NMB-based sensitivity analysis shows that the intervention appears to be cost-effective compared with the existing, passive-suspension seat if the rate of claim reduction is 4.2% or higher.

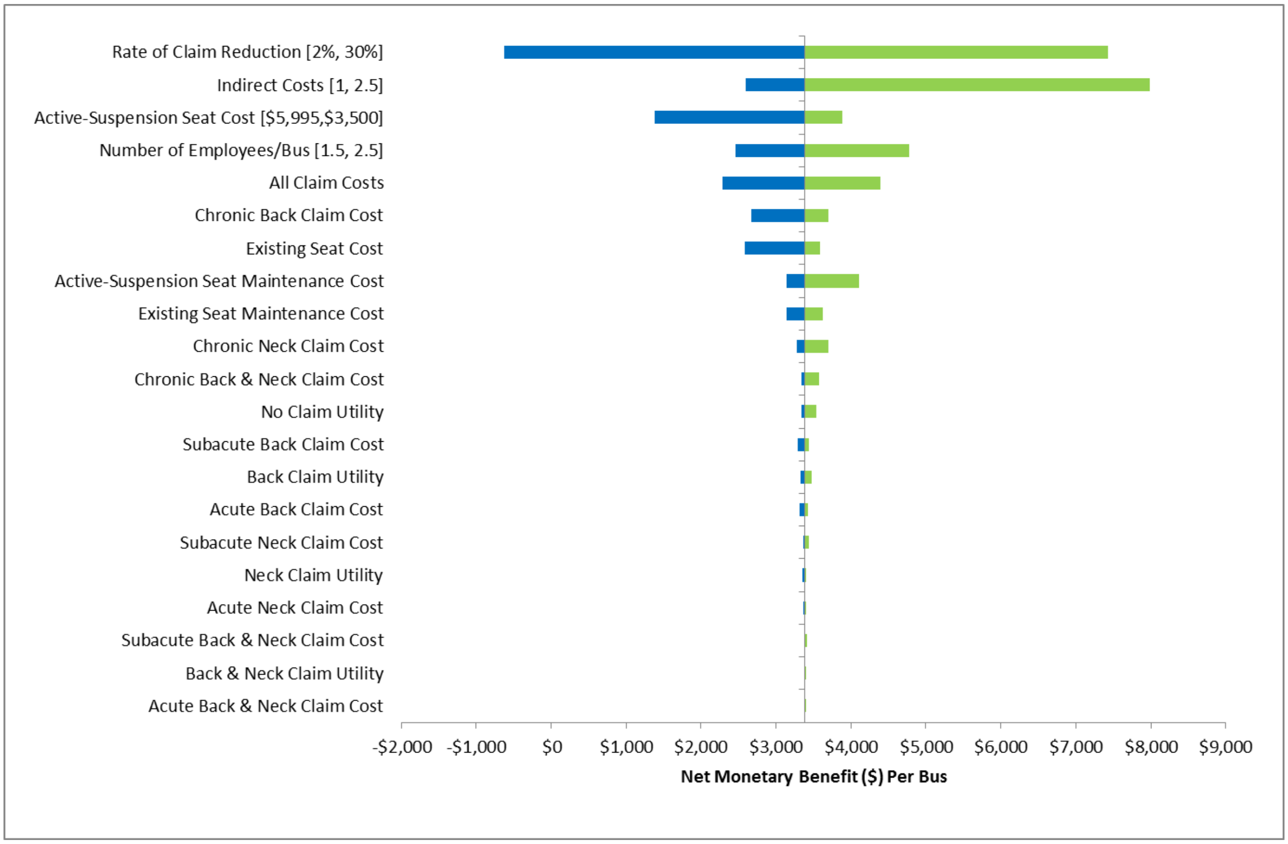


Figure 5. Tornado Diagram of Model Parameters for Active-Suspension Seat Intervention. The tornado diagram is centered around $3,387 per bus as that is the base case NMB.

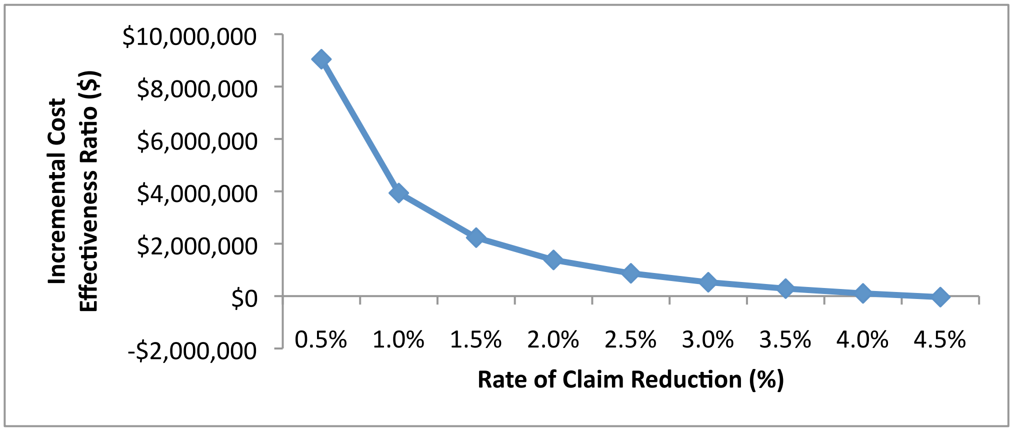


Figure 6. Threshold Sensitivity Analysis: Rate of Claim Reduction (ICER). The active-suspension seat intervention appears to result in cost-savings when the rate of claim reduction approaches 4.4%.

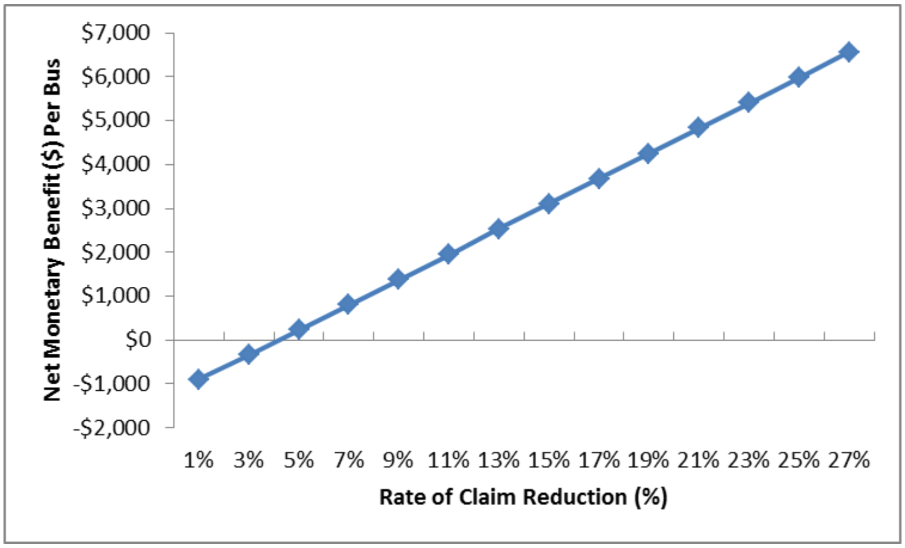


Figure 7. Threshold Sensitivity Analysis: Rate of Claim Reduction (NMB). If the rate of claim reduction is 4.2% or higher, the NMB per bus is above $0, indicating cost-effectiveness at a WTP of $50,000.

Frequent Seat Replacement: In the one-way sensitivity analysis for the frequent passive-suspension seat replacement intervention, the variable with the largest impact on cost-effectiveness and the only variable that appeared capable of elevating the NMB above $0 was the rate of claim reduction. **Figure 8** displays the results of the one-way sensitivity analysis. The rate of claim reduction, the indirect costs multiplier, the rate of claim increase per year, the cost of the replacement seats, and the number of employees per bus appear to have a large impact on the NMB. NMB appeared robust to claims costs and utility inputs.

Threshold analysis was performed to determine what rate of claim reduction, indirect cost multiplier, and replacement seat cost would make the frequent passive-suspension seat replacement more health and cost-effective (dominant) over the existing seat intervention. **Figures 9-14** display the threshold analyses. In **Figure 9**, the ICER-based threshold sensitivity analysis shows that if the rate of claim reduction is approximately 11% or higher the frequent seat replacement intervention is cost saving compared with the existing seating strategy. Similarly, in **Figure 10** the NMB-based threshold sensitivity analysis shows that if the rate of claim reduction is about 11% or higher, the frequent seat replacement intervention would be cost-effective compared with the existing driver seats at a WTP of $50,000 per QALY. In **Figure 11**, the ICER-based threshold sensitivity analysis shows that if the indirect cost multiplier is 2.7 or higher, the frequent seat replacement intervention is cost saving compared with using the existing seats for 15 years. Similarly, in **Figure 12,** NMB-based threshold sensitivity analysis shows that if the indirect cost multiplier is 2.6 or higher, the frequent seat replacement is cost-effective using a WTP of $50,000/QALY. In **Figure 13,** the ICER-based threshold sensitivity analysis shows that if the replacement seat cost is lower than $1,800 the frequent seat replacement intervention is cost saving compared with the existing seat. Finally, the NMB-based threshold sensitivity analysis in **Figure 14** shows that if the replacement seat is $1,830 or less, the frequent seat replacement intervention is cost-effective at a WTP of $50,000/QALY.

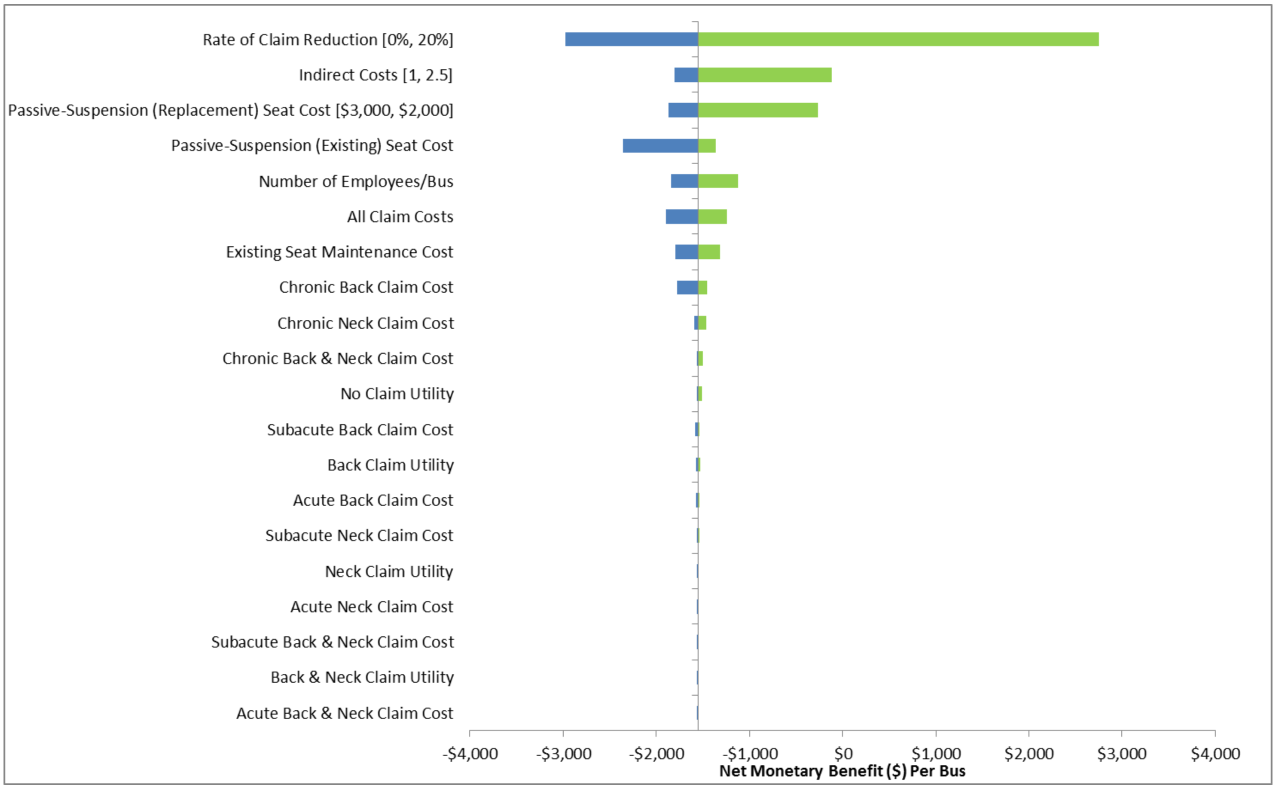


Figure 8. Tornado Diagram of Model Parameters for Frequent Seat Replacement Intervention. The tornado diagram is centered around $1,155 per bus as that is the base case NMB for the frequent seat replacement intervention.

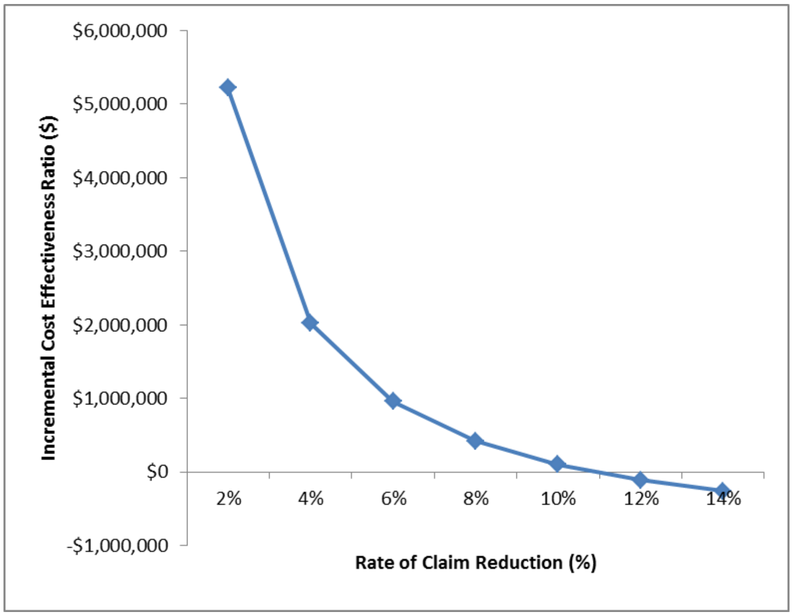


Figure 9. Threshold Sensitivity Analysis: Rate of Claim Reduction (ICER). The ICER drops below $0 per QALY when the rate of claim reduction is approximately 11%; the frequent passive-suspension seat replacement strategy would be cost saving at this point.

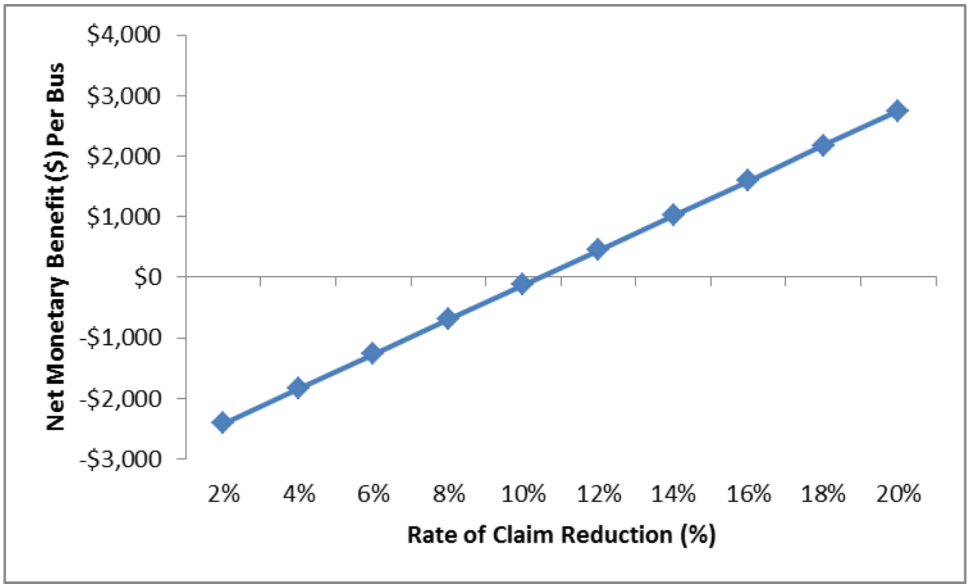


Figure 10. Threshold Sensitivity Analysis: Rate of Claim Reduction (NMB). The NMB rises above $0 when the rate of claim reduction is approximately 11% or higher. Compared to the existing, passive-suspension seat, the frequent passive-suspension seat replacement strategy is cost-effective when the rate of claim reduction is 11% or above.

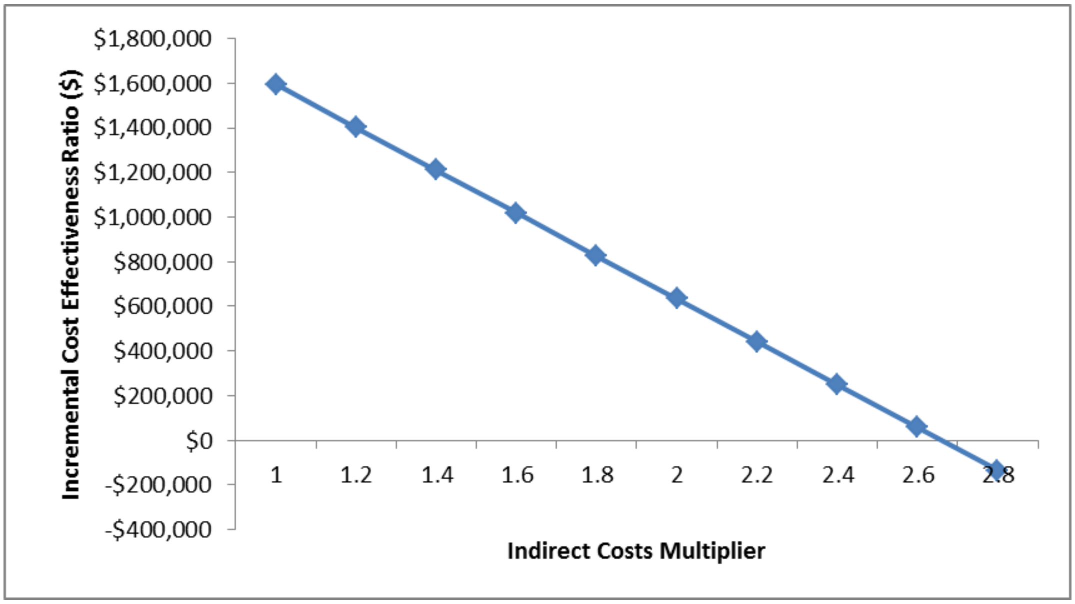


Figure 11. Threshold Sensitivity Analysis: Indirect Cost Multiplier (ICER). The frequent passive-suspension seat replacement intervention is cost saving compared with the existing seat strategy if the indirect cost multiplier is 2.7 or above.

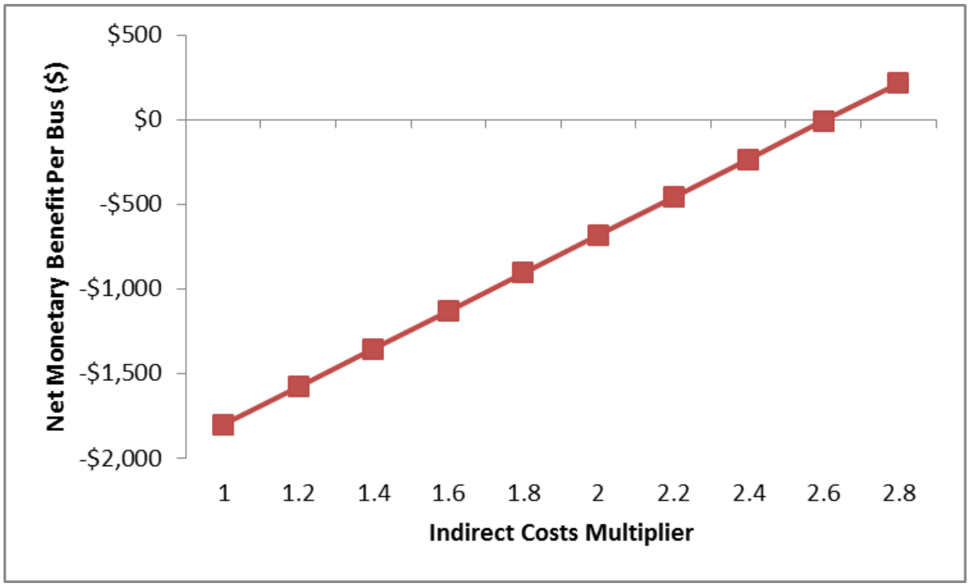


Figure 12. Threshold Sensitivity Analysis: Indirect Cost Multiplier (NMB). The NMB rises above $0 if the indirect cost multiplier is 2.6 or above.

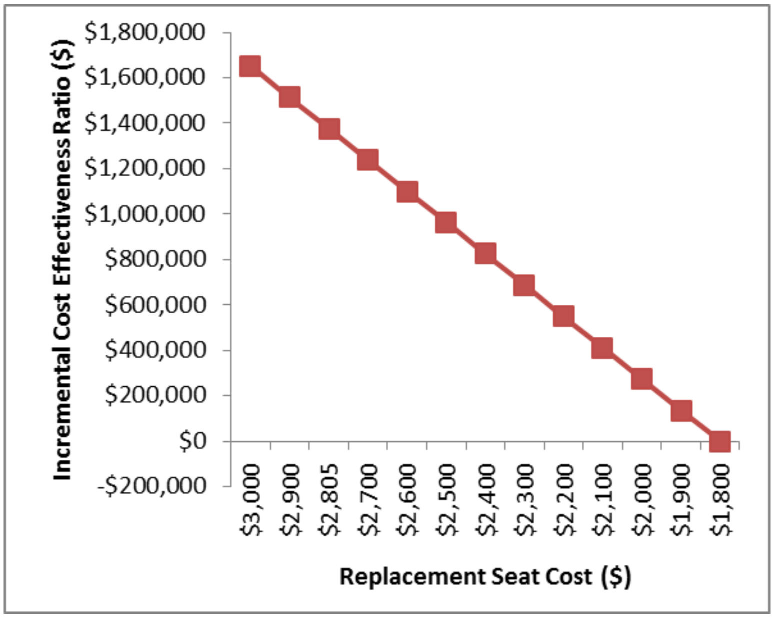


Figure 13. Threshold Sensitivity Analysis: Replacement Seat Cost (ICER). The frequent seat replacement is cost saving compared with the existing seat if the replacement seat cost is $1,800 or below.

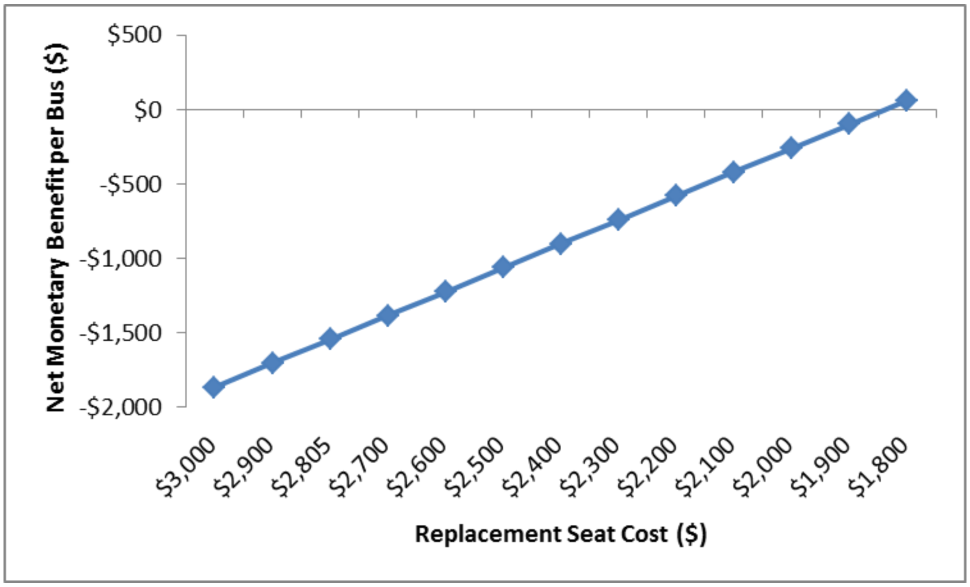


Figure 14. Threshold Sensitivity Analysis: Replacement Seat Cost (NMB). At a WTP of $50,000 per QALY, the seat replacement intervention would be cost-effective if the price of the replacement seat were less than $1,830.

<u>Static Seat</u>: As the static seat was not predicted to impact the rate of claims relative to the existing seat strategy, few parameters affected its cost-effectiveness. **Figure 15** displays a tornado diagram showing the results of the one-way sensitivity analysis. If the installation of the static seat increased the rate of claims, NMB could drop below $0. As an increase in the rate of claims could reduce cost-effectiveness of the static seat, a threshold analysis was conducted to determine what rate of claim reduction would drop the NMB below $0. At a WTP of $50,000/QALY, a rate of claim reduction of -4.5% or below would make the static seat intervention not cost-effective, as shown in **Figure 16.**

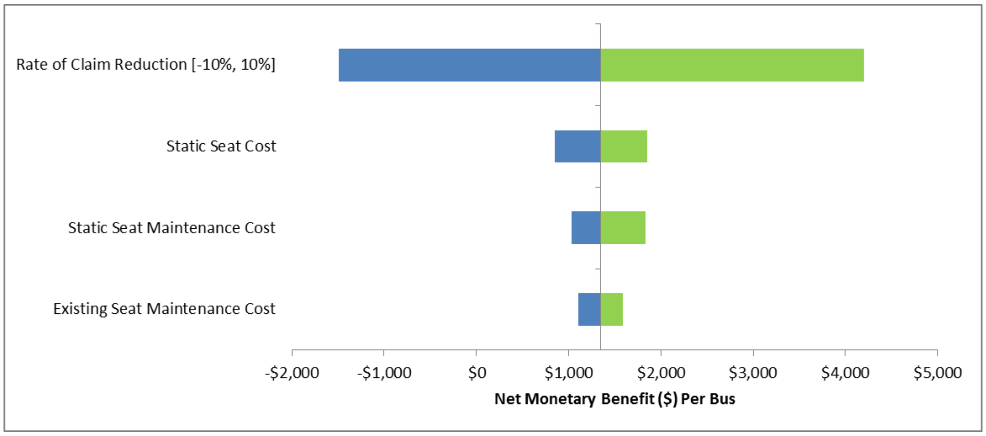


Figure 15. Tornado Diagram of Model Parameters for Static Seat Intervention.

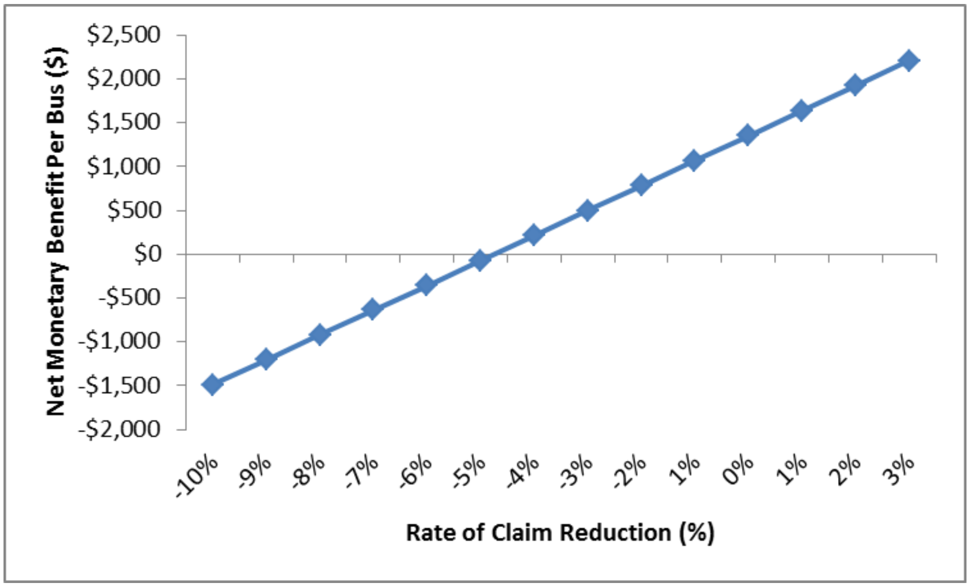


Figure 16. Threshold Sensitivity Analysis: Rate of Claim Reduction (NMB). At a WTP of $50,000 per QALY, the static seat intervention would be cost-effective if the rate of claim reduction were -4.5% or higher would make the intervention cost-effective.

Multi-way Sensitivity Analyses

Scenario 1: Scenario 1 simulated a situation in which the existing seat strategy might be expected to be more cost-effective than the seating alternatives: claims costs were lower, rate of claim reduction for the active-suspension and frequent seat replacement interventions were lower, and alternative seat costs were higher. **Figure 17** displays the results of the cost-effectiveness analysis using the inputs from **Table 3**. Compared with the base case, the ICERs are quite different. **Table 5** displays the results of Scenario 1 compared with the base case.

In Scenario 1, the active-suspension seat is no longer cost saving and health saving (dominant) over the existing seat, with an ICER of $0.6 million/QALY. The ICER of the frequent seat replacement strategy is approximately $17 million. Using a WTP of $50,000 in this scenario, the static seat is the most cost-effective option and the only intervention that has a positive NMB. The ROIs were negative for all interventions in this scenario; however, unlike the base case, the ROI for the static seat was the least negative (-63%) and the active-suspension seat had an ROI that was more negative than the existing, passive-suspension seat (-109%).

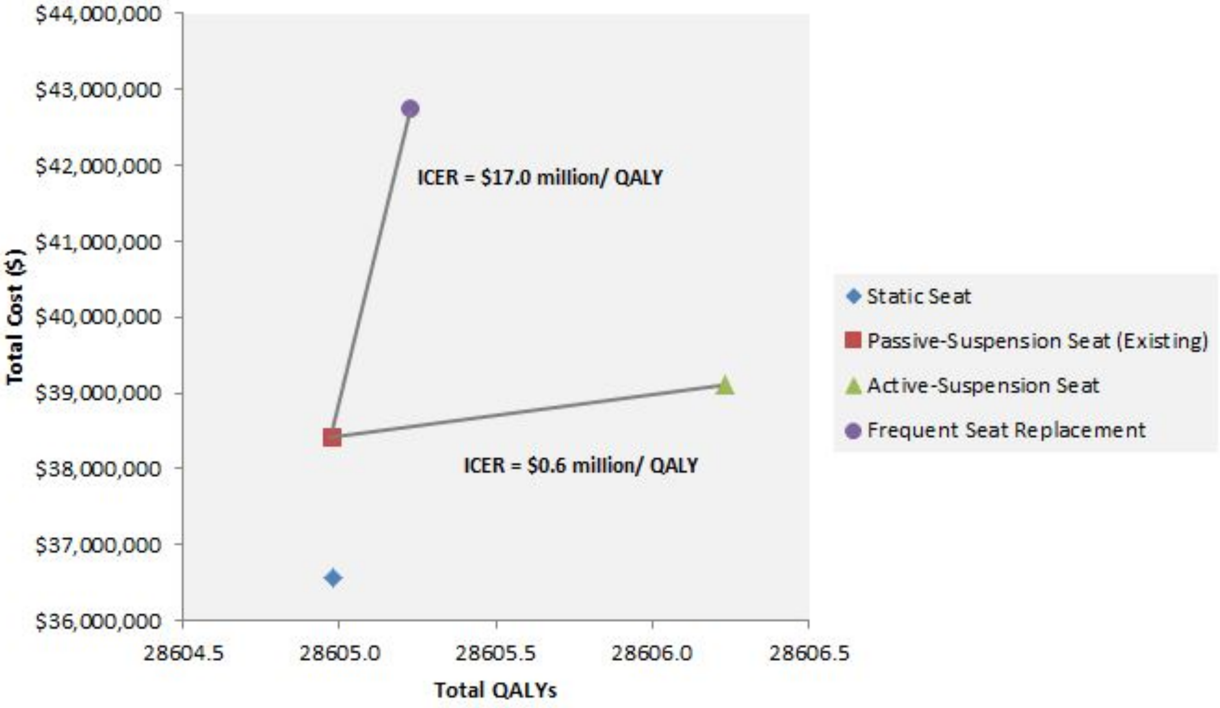


Figure 17. Cost-Effectiveness of Seating Alternatives in Scenario 1. This plot compares the total costs for 1,500 buses over the 15-year life of a bus with total QALYs for 1,500 buses over the 15-year life of a bus for each intervention. Using the existing, passive-suspension seat as a comparator, the ICER of the frequent seat replacement strategy is $17.0 million/ QALY and the ICER of the active-suspension seat is $0.6 million/ QALY.

<u>Scenario 2</u>: Scenario 2 simulated a situation in which the alternative seats might be expected to dominate over the existing seat strategy: claim costs were higher, alternative seat costs were lower, and indirect costs were higher. **Figure 18** displays the results of the analysis in this scenario using the inputs from **Table 3**. The active-suspension seat continues to dominate over the existing seat, as in the base case. However, the active-suspension seat does not dominate over the static seat in this scenario; the overall costs of the static seat are lower. Compared with the base case, the ICER is reduced for the frequent seat replacement intervention, at $0.4

million/QALY. **Table 5** displays the results of Scenario 2 compared with the base case. The NMB of the active-suspension seat intervention and the static seat intervention are both positive: $3,747and $4,154 respectively. In this scenario, the static seat had a positive ROI in this scenario (108%) and the active-suspension seat had a slightly negative ROI (-29%).

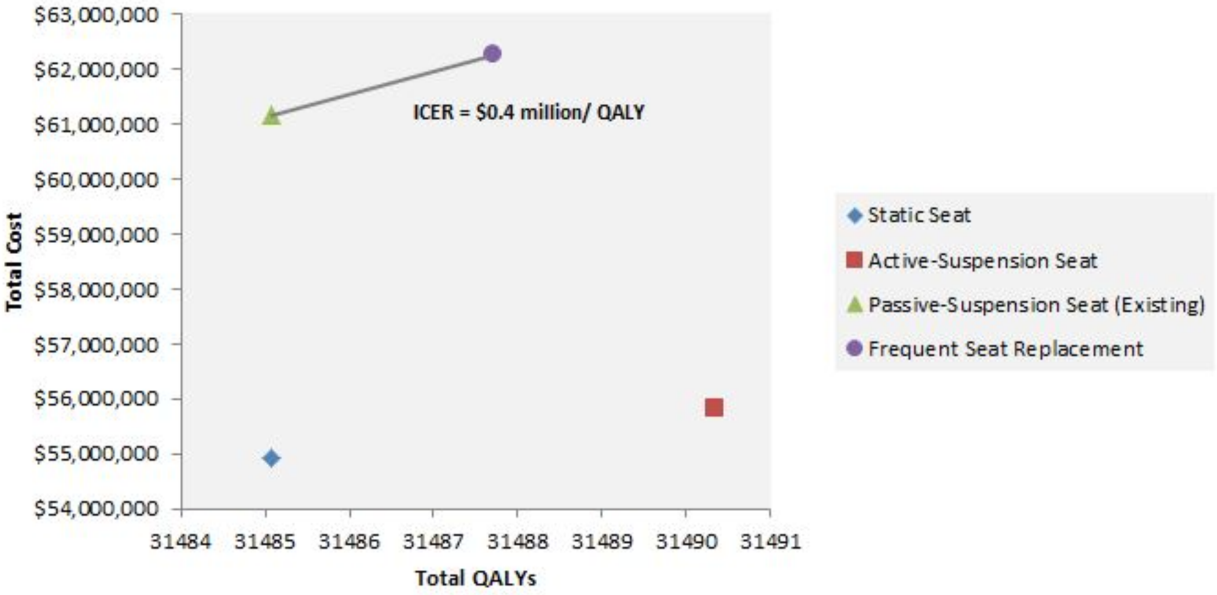


Figure 18. **Cost-Effectiveness of Seating Alternatives in Scenario 2**. This plot compares total costs for 1,500 buses over the 15-year life of a bus with total QALYs for 1,500 buses over the 15-year life of a bus for each intervention. Using the existing, passive-suspension seat as a comparator, the ICER of the frequent seat replacement strategy is $0.4 million/ QALY.

Scenario 3: Scenario 3 simulated a situation in which the rate of claims reduction was slightly lower than predicted from epidemiologic data, expected rates of claim reduction were altered, and seat maintenance costs were slightly lower for the active-suspension and static seats. **Figure 19** displays the results of Scenario 3 using the inputs from **Table 2**. In Scenario 3, the active-suspension seat dominates over the existing seat and the frequent passive-suspension seat replacement strategy. However, the static seat is slightly less expensive than the active-suspension seat. **Table 5** displays the results of Scenario 3 compared with the base case. The static seats and active-suspension seats have NMBs that are similar, approximately $800. In this scenario, the ROIs were negative for all interventions; the static seat had the least negative ROI (-70%), followed by the active-suspension seat (-85%).

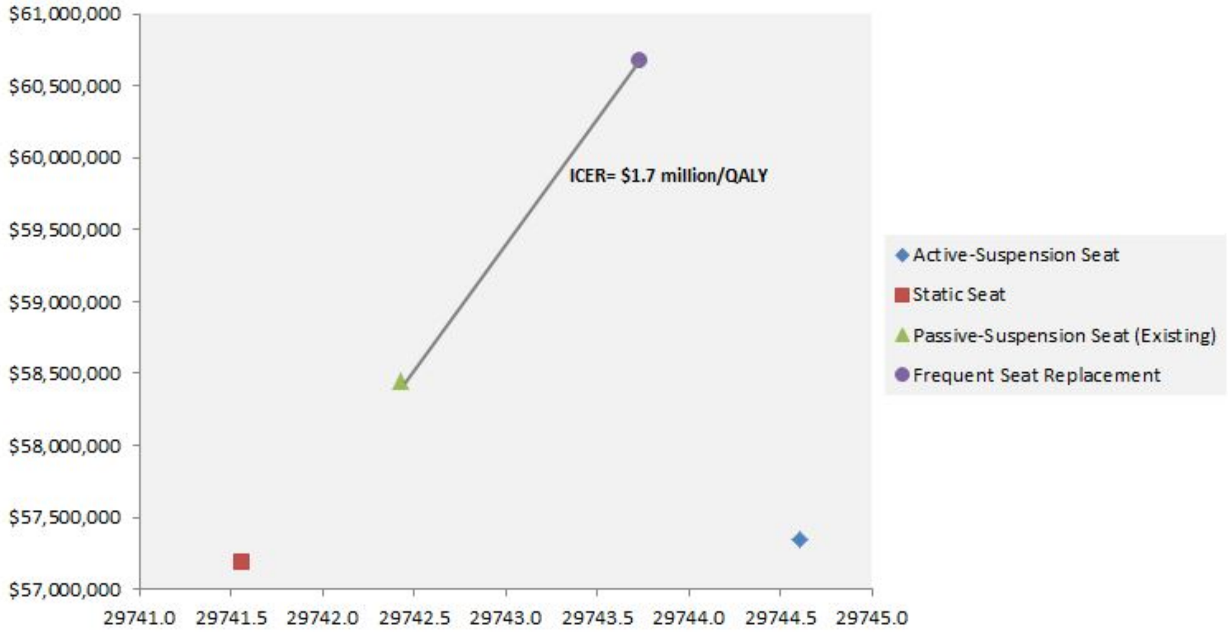


Figure 19: Cost-Effectiveness of Seating Alternatives in Scenario 3. This plot compares total costs for 1,500 buses over the 15-year life of a bus with total QALYs for 1,500 buses over the 15-year life of a bus for each intervention. Using the existing, passive-suspension seat as a comparator, the ICER of the frequent seat replacement strategy is $1.7 million/ QALY.

Structural Sensitivity Analysis

A structural sensitivity analysis was conducted to determine the sensitivity of the model to inclusion of claims that were classified as “somewhat likely” to be related to WBV exposure; the base case included claims that were both “somewhat likely” and “likely” to be related to WBV whereas this structural sensitivity analysis included only “likely” claims in the analysis **Figure 20** shows the cost-effectiveness of the seating alternatives in the structural sensitivity analysis. **Table 5** displays the results of the structural sensitivity analysis compared with the base case. The active-suspension seat dominates over the other seating alternatives. The frequent seat replacement strategy is similarly not cost effective, with an ICER of $3.2 million/QALY. The NMB for the active-suspension seat and the static seat are both positive, at $1,465 and $1,349 respectively. The ROIs were negative for all interventions using these inputs; the ROI was -55% for the static seat and -75% for the active-suspension seat.

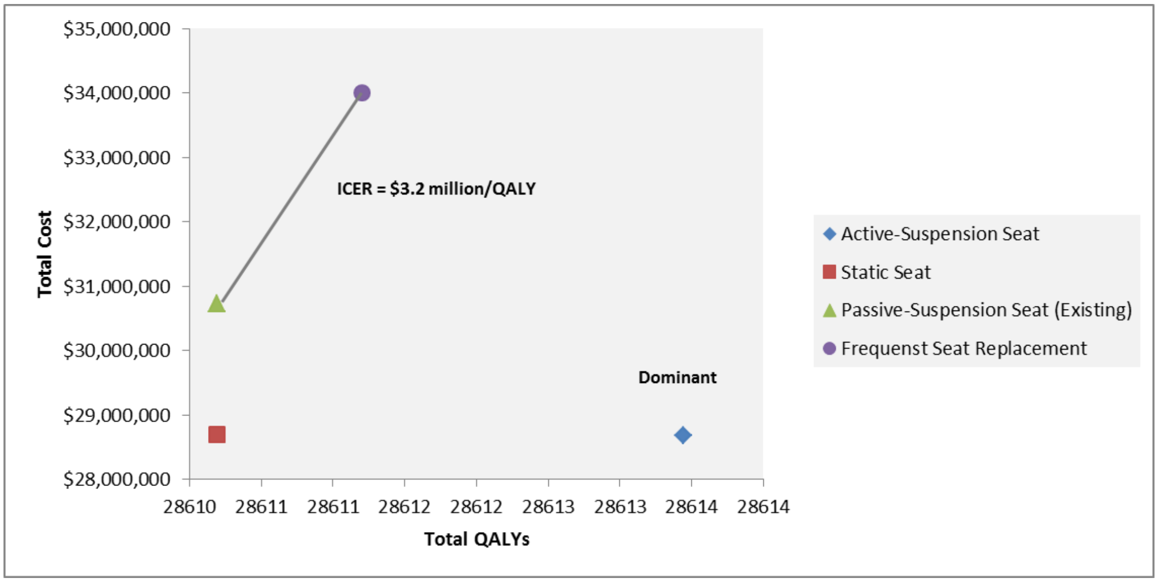


Figure 20. Cost-Effectiveness of Seating Alternatives: Structural Sensitivity Analysis. This plot compares total costs for 1,500 buses over the 15-year life of a bus with total QALYs for 1,500 buses over the 15-year life of a bus for each intervention. Using the existing, passive-suspension seat as a comparator, the ICER of the frequent seat replacement strategy is $3.2 million/ QALY.

Description	Scenario	Intervention	Cost per Bus	QALY per bus	Overall Cost	Overall QALYs	ICER	ICER: Relative to Static Seat	ICER: Seat Relative to Existing Seat	Cost Relative to Existing Seat	NMB	ROI
	Base Case	Active-Suspension Seat	$29,300	19.0669	$43,950,639	28600.4	Dominant			-$4,799,127	$3,387	-42%
	Base Case	Static Seat	$31,150	19.0632	$46,725,731	28594.7	Dominated			-$2,024,035	$1,349	-55%
	Base Case	Passive-Suspension Seat (Existing)	$32,500	19.0632	$48,749,766	28594.7	Dominated					-100%
	Base Case	Frequent Seat Replacement	$34,113	19.0643	$51,169,881	28596.5	Dominated	$2,540,001	$1,383,188	$2,420,115	-$1,555	-122%
Lower Rate of Claim Reduction	Scenario 1	Static Seat	$24,375	19.0700	$36,562,446	28605.0				-$1,834,524	$1,223	-63%
Lower Claims Costs	Scenario 1	Passive-Suspension Seat (Existing)	$25,598	19.0700	$38,396,970	28605.0						-100%
Higher Seat Costs	Scenario 1	Active-Suspension Seat	$26,075	19.0708	$39,113,053	28606.2		$2,036,180	$571,657	$716,083	-$436	-109%
	Scenario 1	Frequent Seat Replacement	$28,492	19.0702	$42,738,677	28605.2		$24,683,312	$17,351,634	$3,625,624	-$2,886	-140%
Lower Rate of Claim Reduction	Scenario 2	Static Seat	$36,626	20.9900	$54,939,629	31485.1				-$6,230,716	$4,154	108%
Higher Claims Costs	Scenario 2	Active-Suspension Seat	$37,209	20.9936	$55,813,477	31490.3		$165,352		-$5,356,868	$3,747	-29%
Lower Seat Costs	Scenario 2	Passive-Suspension Seat (Existing)	$40,780	20.9900	$61,170,345	31485.1						-100%
	Scenario 2	Frequent Seat Replacement	$41,502	20.9918	$62,252,619	31487.7		$2,771,866	$410,218	$1,082,274	-$634	-111%
Lower Rate of Claim Reduction	Scenario 3	Static Seat	$38,126	19.8277	$57,188,350	29741.6				-$1,258,760	$810	-70%
Claim Increase: Static Seat	Scenario 3	Active-Suspension Seat	$38,233	19.8297	$57,349,452	29744.6				-$1,097,658	$804	-85%
Lower Seat Maint. Cost: Active Seat	Scenario 3	Passive-Suspension Seat (Existing)	$38,965	19.8283	$58,447,110	29742.4		$1,450,261				-100%
Higher Seat Maint Cost: Static Seat	Scenario 3	Frequent Seat Replacement	$40,447	19.8292	$60,670,940	29743.7		$1,603,477	$1,705,463	$2,223,829	-$1,439	-122%
	Structural	Active-Suspension Seat	$19,124	19.0756	$28,686,645	28613.4	Dominant			-$2,036,001	$1,466	-75%
Only "likely" claims	Structural	Static Seat	$19,132	19.0735	$28,698,611	28610.2	Dominated			-$2,024,035	$1,349	-55%
	Structural	Passive-Suspension Seat (Existing)	$20,482	19.0735	$30,722,646	28610.2	Dominated					-100%
	Structural	Frequent Seat Replacement	$22,668	19.0741	$34,001,452	28611.2	Dominated	$5,232,273	$3,235,173	$3,278,806	-$2,152	-130%

Table 5. Results of Base Case Compared with Multi-Way Sensitivity Analyses. Results are presented in 2015 dollars. Total savings are savings per bus x 1,500 buses x 15 years. NMB calculations assumed a WTP of $50,000 per QALY.

Discussion & Limitations

This analysis presents data on the cost-effectiveness of 3 alternatives to existing passive-suspension seats in King County Metro buses. Active-suspension seats, frequent passive-suspension seat replacement, and static seats were all evaluated for cost-effectiveness. In the base case analysis, it was found that the active-suspension seat was dominant over the other interventions. While the static seat reduced costs, it was not predicted to improve driver health-related quality of life. Replacing passive-suspension seats every 5 years was not predicted to be cost-effective, with an ICER of $1,383,188. This ICER implies that King County Metro would have to pay over $1.3 million for each additional quality-adjusted life year among bus drivers. Spending $1.3/QALY is not typically considered cost-effective in the United States. With the base case inputs, it was found that if King County Metro were to install active-suspension seats in their buses, they would save approximately $4.8 million dollars over a 15 year period. If Metro were to install a static seat, they would save approximately $2.0 million dollars over that same time period; however, no health benefits would be anticipated from a static seat. Replacing passive-suspension seats every five years would cost the agency about $2.4 million dollars over a 15-year period.

To our knowledge, this is the first analysis to investigate the cost-effectiveness of driver seat alternatives in buses taking into account that some seating alternatives have the potential to reduce rates of LBP claims, neck pain claims, and costs. An advantage of the analysis is its use of detailed worker compensation data from a large, metropolitan transportation entity from which rate of claims, type of claims, and costs were derived. Furthermore, seat costs and maintenance costs were also actual costs, derived from King County Metro records or experts in the field. Sensitivity analyses revealed that while the model was robust to claims cost inputs and utility inputs, it was sensitive to the rate of claim reduction, indirect costs, and seat costs for the active-suspension and frequent seat replacement interventions. Sensitivity analyses for the static seat were limited as the seat was not predicted to affect the rate of driver claims.

Rate of Claim Reduction Sensitivity analyses revealed that the model was sensitive to the rate of claim reduction. For the frequent-seat replacement intervention, threshold analyses revealed that claims would have to be reduced by 11% for the frequent seat replacement intervention to dominate over existing seats. In this analysis, it was predicted that the frequent seat replacement strategy would reduce claims by 5%, which makes the strategy neither cost-effective nor cost saving. The 5% rate of claims reduction was not derived from epidemiologic research, as there was minimal evidence to indicate that replacing seats reduces WBV exposures. Kim *et al* [57] found that newer air-suspension seats only attenuated about 7% more vibration than existing air-suspension seats. However, it was predicted that installing a new, passive-suspension seat every few years would improve driver comfort and thus reduce claim rates by 5%.

For the active-suspension seat, threshold analyses of the base case showed that the active-suspension seat would only remain dominant if the claims rate were reduced by 4.4% or more. Based on preliminary results of a randomized controlled trial comparing active-suspension and passive-suspension truck seats, it was hypothesized that the rate of claim reduction would be higher than 4.4% if these seats were to be installed in buses; Kim *et al*[57] found that drivers who received an active-suspension seat reported back pain score decreases of approximately 30% compared with no such decrease among those drivers who had received a new, passive-suspension driver seat. Although these results were not statistically significant due to a small sample size, they served as an indication that an active-suspension seat could improve pain and, potentially, reduce associated worker compensation claims.

The appropriate rate of reduction in worker compensation claims associated with the installation of active-suspension seats presented a challenge. Despite extensive epidemiologic research on the relationship between WBV and LBP, the true rate of claim reduction to be expected from a WBV-reducing driver seat is unclear for several reasons. There are multiple ways to measure the dose of WBV, with some measurements based off average exposures, others taking into account cumulative yearly exposures, and others prioritizing shocks over continuous steady state vibrations. Some epidemiologic studies have found that the low back is more sensitive to shocks than to continual vibration exposures[58]. The exposure metric in this research was $A(8)_{sum}$, which is a metric of average daily vibration

In addition to the existence of multiple methods of WBV exposure measurement, the presence of LBP does not necessarily mean that a worker will file a worker compensation claim for LBP. The rate of worker compensation claims is workplace-specific and varies depending on the type of workplace[49]. Many workers who could file MSD-related worker compensation claims do not or may see a general physician, leading to an under-reporting of the true rate of MSDs[49,50,59]. Researchers have found that in some workplaces up to 90% of workers do not file worker compensation claims for work-related injuries[60]. For this analysis, it was assumed that approximately 25% of workers with LBP would file claims, based on research on the rate of filing of unionized auto workers who had WMSDs[50]. Researchers have observed a slight tendency for unionized workers to file more claims than non-unionized workers[59,61]. As King County Metro workers are unionized, it would be expected that they are more likely to file claims than other classes of workers. Additionally, injury severity has been correlated with claim filing[59], which strengthens the rationale behind using the Roland-Morris Disability Questionnaire score of 12 or above to correlate with claim filing.

To our knowledge, no studies have examined worker compensation back claims as an outcome after interventions targeting a reduction in WBV exposures. However, in a study examining a seating intervention to reduce WBV among forklift drivers, researchers found that LBP prevalence, defined as a visit to the physician due to LBP, fell 33% when forklifts were equipped with a suspended seat and pneumatic tires[62]. While the study was conducted in Japan among 27 workers, the 33% decline in LBP prevalence after the vehicle modification strengthens the rationale behind the potentially conservative 16%% reduction predicted from epidemiologic data for the active-suspension seats.

The rate of claim reduction would not only be affected by the dose of WBV received by Metro drivers, but also by other variables that impact claim filing. Research has found that employees have lower rates of absenteeism in workplaces that they rate as healthy[63]**.** Worker perception of investment in employee health is thus an important factor in claim filing. It is possible that driver worker compensation claims would drop, independently of WBV exposure reductions, due to the perception that King County would be investing in driver health with the installation of a newer seat such as the active-suspension seat, or by installing new passive-suspension seats more frequently. It is unlikely that employees would have such a response to the static seat, as these seats are less technologically advanced than current air-suspension seats and they could be perceived as a decrement in the occupational health environment.

Claims Costs

Although sensitivity analyses revealed that the model was fairly robust to claims costs, it is possible that the claims costs might be over-estimates or under-estimates of the true claim costs. Claims costs included all the costs for that claim, even if there were multiple body parts affected in the injury. Thus, claims costs might be over-estimates because costs unrelated to the back and/or neck are included in the model. Furthermore, as claims costs tend to be skewed by a small percentage (5-20%) of very costly claims[12,64] mean claim costs may be overestimates of the true costs. Although the sensitivity analysis incorporated median claims costs, as the active-suspension seat and frequent passive-suspension seat replacement have never been tested in a controlled setting using worker compensation claims as an outcome, it is unknown what type of reduction they would have on back and neck claims. These interventions might help reduce those ~10% of costly claims or they might reduce the less expensive, typical claims. If the interventions targeted the most expensive claims, they would be more likely to be cost-effective. Using the mean cost estimate in the analysis it was assumed that the interventions would target a portion of the high-cost claims.

It is unclear what determines high claims costs, although some risk factors for high back claim cost include advanced age, male gender, and previous back injury[12,65]. Recurrent back claims typically incur longer durations of timeloss and higher medical and indemnity costs[13]. Unfortunately, claim recurrence data was not available for this analysis and stratification by this variable was infeasible. Surprisingly, medical diagnosis is not a good predictor of the development of LBP disability, which results in high costs[66]. This may be due to the fact that treatments for LBP vary widely; oftentimes medically unnecessary diagnostic procedures are undertaken with occupational back pain, increasing the cost[9]. Additionally, patients frequently undergo surgery for occupational LBP, even though only 5% to 10% of LBP cases will respond to costly surgical intervention[67]. Due to the treatment anomalies related to occupational low back pain, it can be quite difficult to predict the cost and outcome of a particular claim.

Because of the difficulty predicting outcomes for LBP, some researchers have posited that disability resulting from occupational LBP may be as much a social phenomenon as a medical phenomenon[66]. Psychosocial factors have been found to correlate with the chronicity of LBP: a study in Sweden found that depression was a predictor of chronic, but not acute, LBP in men[68]. Others have found that the duration of LBP correlated with a sensation of "being sick all the time"[69]. If risk factors such as age, gender, treatment anomalies, and psychosocial functioning explain the high costs of certain low back pain claims, then one would expect seating interventions to do relatively little to combat those claims with high costs at King County Metro.

Additionally, financial compensation may play a role in the duration of worker's compensation claims. In many cases, the time-loss compensation that workers receive in the event of a workplace injury is lower than their standard pay. Returning to work is thereby incentivized. However, ATU 587, the union to which King County Metro drivers belong, has negotiated their contract with Metro such that drivers receive full pay in the event of a workplace injury. Returning to work thus carries no financial incentive for injured drivers and it is plausible that some workers stretch out their periods of disability out longer than they would under other conditions. Improvements in seating alternatives would not affect those claims that are elongated due to this type of claim behavior.

Seat Costs

Sensitivity analyses revealed that the frequent seat replacement intervention was especially sensitive to seat costs. Existing seat costs are known, but it is unknown whether the purchase of a greater number of seats would reduce or possibly even increase the marginal cost of the seats. Currently, seats are installed by the bus manufacturer. If King County Metro decided to purchase additional seats from the seat manufacturer directly, the total costs might be slightly higher due to the time to remove the old seats and install the new passive-suspension seats.

Although the model appeared to be fairly robust to the price of the active-suspension seats, it is unknown what the exact cost of the active-suspension seats would be. Prices for these seats in the trucking industry range from $3,995-$5,995, with a list price of $5,995. It was assumed that in this model, under contract, Metro would pay $3,995 for the seats. However, the truck market and the bus market are distinct and it remains unclear whether this would be the actual price if the manufacturer decided to market the active-suspension seat to public transit entities.

Indirect Costs

Sensitivity analyses revealed that the models were sensitive to the indirect costs multiplier selected. The multiplier 1.22 is most likely an under-estimate of indirect costs. Though indirect cost multipliers vary depending on what costs are included[70], estimates of indirect to direct costs range anywhere from 1:1 to 30:1[71], with 4:1 being an oft-referenced estimate. The 1.22 multiplier (or 0.22:1 ratio) utilized in this model is derived from known indirect costs: Metro pays an additional 10% of claim costs to the King County Administration to administer the claim and an additional 12% tax to Washington State Labor and Industries. The indirect cost multiplier does not include estimates of absenteeism; as Metro expects a certain number of drivers to be out on a worker compensation claim at any given time, they hire compensatory workers. The indirect cost multiplier does not include the cost of the benefits for these compensatory workers, and hence is conservative.

Claim Inclusion

Results from the structural sensitivity analysis revealed that the active-suspension seat and static seat interventions would continue to be cost-effective even if a smaller subset of claims were affected by the interventions. Including only claims that were "likely" to be related to WBV exposures eliminated those claims "somewhat likely" to be related to WBV that were due to incidents such as twisting, bending, and over-exertion. Because LBP is multifactorial in origin[3], claims that were not specifically due to bouncing and jarring during driving were also included in the analysis. Researchers have found that the development of WBV-related LBP tends to gradually develop over time, which is markedly different from the acute presentation of LBP from lifting or other manual materials handling (MMH) tasks[4].

It is possible that some of the "somewhat likely" claims included in the base case analysis had little to do with WBV exposures. Drivers with MMH tasks have a higher prevalence of LBP even though they often have shorter WBV exposure durations than drivers who don't encounter MMH tasks on a daily basis[72]. As bus drivers at King County Metro encounter a variety of MMH tasks, such as wheelchair assistance, it is challenging to know for a particular claim which exposure was most crucial for LBP development.

Employees Per Bus Input

The model used a multiplier of 1.9 to convert costs and QALYs per employee into costs and QALYs per bus. This multiplier assumed that there are 1.9 employees per bus. However, while this calculation was made based on data from King County Metro, there is a level of uncertainty surrounding it, as the number of hours worked by an average driver varies widely; it was assumed the drivers worked an average of about 40 hours/week. Similarly, the number of bus operating hours also varies. The variation in the number of bus operating hours would likely have an effect on the validity of the frequent seat replacement intervention; if some buses are used more than others, they would likely wear out more quickly and hence the rate of claims associated with that bus would rise.

Future Work

A future model might also take into account health improvements and cost savings from sources other than back claims. In particular, a reduction in vibration exposure might reduce the rate of motor vehicle accidents (MVAs) at Metro. WBV has been found to affect the nervous system[73] and slow reaction times when combined with strained postures and correlates with increased fatigue[74,75]. It has been found to negatively affect work performance, specifically disrupting perceptual ability[76]. The manufacturer of the active-suspension seat suspects that the reduction in vibration would reduce driver fatigue, improve reaction times, and lead to a decrease in MVAs. While worker compensation claims resulting from MVAs were excluded from the analysis due to inadequate data on the relationship between WBV and MVAs, a future analysis might include a reduction in the rate of MVAs at the agency to determine cost-effectiveness.

Conclusion

In this predictive CUA, it was found that two seating alternatives would dominate over existing passive-suspension bus driver seats in King County Metro buses. The installation of an active-suspension seat would likely result in cost-savings to King County Metro and health-related quality of life improvements among Metro drivers. The installation of a static seat would result in cost-savings to the agency, but would not likely improve driver health. Frequent replacement of passive-suspension seats does not appear to be a cost-effective strategy to reduce LBP and neck pain claims at King County Metro.

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