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# An Ergonomic Case Study of Scale-Pits in Transportation

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# Abstract

In the transportation industry, human technicians are involved in weighing loads that are being transported. The procedure to weigh such loads requires the human operator to maintain the scales which are located in confined spaces, known as scale pits. Unfortunately, these scale pits were not designed with considerable attention to ergonomics or safety issues that may impact the technician. This paper examines the ergonomic concerns associated with the design of Scale-pits. Specifically, in this research, two case studies were used to assess the risk of falling due to loss of balance, as well as the perceived level of exertion and body discomfort experienced as a result of moving around in the small pit area. The studies conducted in this paper and previous research findings indicate that scale technicians are negatively impacted by the awkward posture positions that they have to assume when moving around and performing work in the restricted space of a scale pit. Also, the case studies analyzed in this paper indicate that scale technicians are likely to experience a decrease in their balance or stability as the work task parameters change which influences an increase in body discomfort due to the awkward postures that they have to assume when moving around and working in the restricted areas within the pit.

Keywords: Scales; Pit-scales; Ergonomic concerns; Hazardous working conditions

# Introduction

The The purpose of this research is to assess and suggest solutions for the ergonomic problems associated with having human technicians working in scale pits. Other than the materials used to construct them and their size, pits have not changed significantly since the time of Thaddeus Fairbanks. Even under the best of circumstances they are dirty, unpleasant, difficult to maintain, and many times dangerous. A number of these dangers and/or concerns are due to poor ergonomic design found in the scale pit environment. Pits are designed to house levers, load cells, and other components of the scale system, but with no thought for the technicians who have to work inside of these areas.

Scale pits are plagued with a number of ergonomic concerns such as maneuvering, pushing and pulling within this confined space [1]. Each year an unspecified number of scale technicians are injured in a variety of ways related to working in scale pits. Among these are injuries due to falling into pits, slips and falls while climbing into pits, various cuts and bruises due to the confined spaces and poor lighting, rat bites, spider bites, snake bites, electrical accidents, and back injuries. While there are no official numbers on these injuries they contribute to the number of lost workdays and the costs in lost time and medical experiences caused each year by hazardous working conditions.

## **Research Goals and Objectives**

This paper presents a discussion of ergonomic concerns associated with working in a confined space in the unique environment of platform scale pits for use in weighting trucks. The goal of this paper is to assess aspects of pit design and suggest redesign improvements that can be made to improve the conditions of the pit for the men who work in them. Specifically, the objective of this research is to assess two of the primary ergonomic concerns associated with Scale pits: (1) Getting the technician and his equipment safely into the pit; and (2) the ability to move around safely in the pit.

# Literature Review

## **Platform scales**

Since weight is the truest measure devised for buying, selling,

and taxing commodities it can be claimed that the platform scale changed the world (Fairbanks Scales) [2]. This scale has seen minimal modification since its development in 1830. However, the technical capabilities and occupational expectations have changed considerably since 1830.

In the time of the development of the platform scale, the wagon was the major method of transporting goods over land, and the ability to determine the true weight of whole wagon loads both rapidly and accurately, made commercial transactions more equitable. The primary thing that has changed in the almost 200 years regarding the use of these scales is that now trucks and railroad cars are the major means of transporting goods over land. What has not changed, however, is the value of the platform scale. The platform scale still serves the same purpose it has since its development.

The platform scale has not changed from its basic design and purpose since its creation. Today's scales, like those of the 1800's, consist of a platform onto which the vehicle being weighed drives or is pulled. The vehicle is stopped and then weighed. What have changed are the size, materials, and complexity of the system itself. Today's scales have pits poured of concrete, with levers make of cast-iron and fabricated steel girders, and either concrete or metal platforms. In addition, not all of them are mechanical in design. Some of the latest are completely electronic.

The size of scales has also changed due to the differences in the

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means of transport. An example of the variety of the sizes of today's platform scales is shown in table 1 along with their capacity, dual axle capacity, and the number of sections. Axle capacity is the true maximum amount of weight that the scale is designed to weigh accurately and should never be exceeded. The number of axles bearing the weight specifies axle capacity. There are three types of axles. Using a tractor-trailer rig as an example, single axle refers to the front wheels on the tractor, two wheels and one axle. The dual wheels on the end of the tractor where the trailer hitch is located is an example of a dual axle. Finally, the three sets of wheels located on the back of the trailer are an example of a tandem axle. Thus, a scale with tandem axle capacity of 55,000 pounds, for example, means that a 55,000 pound weight with a footprint approximately that of a typical tandem axle can be accurately weighed in any location along the length of the scale [3].

As can be seen in table 1, there is little consistency is across scales. The size and capacity of the scale depend on the needs of the customer and size of what will be weighed. For example, if the scale will only be weighing heavy capacity forklifts then a smaller scale with a lighter capacity would be more appropriate than a 10 foot by 60 foot truck scale. The largest scales are designed to weigh rail cars and are called railroad track scales.

The first scales were classified as mechanical. These scales use a series of levers and an elaborate suspension system to concentrate numerous massive forces into a single mechanical indicator that shows the total weight. The lever system consists of a main lever, which runs down the center of the pit for its entire length and a series of transverse levers that extend from the main lever at right angles. The number and location of the transverse levers depend on the type of scale and its size. A full truck scale has eight transverse levers [3].

A second type of scale is the Full Analog Load Cell scale. A load cell is basically a piece of metal that changes its shape as a force (weight)

Platform Size	Scale Capacity	Dual-Tandem Axle Capacity	Number of Sec- tions	
9'×22'	15 tons	30,000 pounds	2	
10'×24'	25 tons	50,000 pounds	2	
10'×24'	30 tons	60,000 pounds	2	
10'×30'	30 tons	60,000 pounds	2	
10'× 10'	40 tons	70,000 pounds	2	
10'×20'	40 tons	70,000 pounds	2	
10'×34'	50 tons	60,000 pounds	4	
10'×60'	60 tons	60,000 pounds	4	
10'×70'	60 tons	80,000 pounds	5	
10'×60'	80 tons	80,000 pounds	5	
10'×70'	80tons	80,000 pounds	5	
10'×30'	85 tons	70,000 pounds	3	
10'×40'	85 tons	70,000 pounds	3	
10'×50'	100 tons	70,000 pounds	3	
10'×60'	100 tons	70,000 pounds	4	
10'×70'	100 tons	70,000 pounds	5	
10'×80'	100 tons	70,000 pounds	5	
10'×90'	100 tons	70,000 pounds	6	
10'×100'	100 tons	70,000 pounds	6	
10'×110'	100 tons	70,000 pounds	6	
10'×120'	100 tons	70,000 pounds	7	
12'×60'	120 tons	120,000 pounds	4	
12'×70'	120 tons	120,000 pounds	5	
14'×60'	120 tons	120,000 pounds	4	
14'×70'	120 tons	120,000 pounds	5	

Table 1: Specifications of Platform Scales.

is applied. The change is monitored by electrical strain gages that generate an analog signal that varies with the load. The signals from the load cells are summed in one or more junction boxes at the scale. The combined signal is then transmitted to the scale house where it is measured and equated with a weight. Like a mechanical scale, these scales require multiple-component suspension systems to isolate the load cell from damaging horizontal forces. Depending on the type and size of scale, there may be as many as 12 load cells in the pit [3].

There are also two types of hybrid scales being used. The first of these is the Combination or Electromechanical Scale. This scale is simply a mechanical scale that concentrates the weight into a single force that is applied to a single analog load cell. The second hybrid is the Hydraulic Load Cell scale. In this scale multiple hydraulic load cells support the platform. From each cell a line is run to a slave cylinder in an accumulator. The slave cylinders are placed one on top of the other in series so that the forces from the load cells under the platform are added together. The total force then acts on an analog load cell. These scales are favorable for hazardous areas where a stray spark or an overheated electrical component could ignite a fire or explosion [3].

Finally, there are fully electronic scales. An example of these is the DigiTOL Power Cell Scale built by Mettler-Toledo and the Rodan RC Series built by Fairbanks. In these scales, the load cell generates an analog signal that is immediately converted to a digital signal within the load cell enclosure. A section of the scale has a minimum of four of these load cells. The cells send their signal to the main instrument that then adds the individual readings to arrive at the total weight. Unlike the first four scales described, this scale does not require a mechanical suspension system because the cells are self-centering and self-righting by virtue of their design. There for this scale does not need a pit [2,3].

Scales are also classified as either pitless or pit-type scales. At one time all scales required pits because they were mechanical and needed the pit to house the lever system. Today, pits are still required for mechanical scales, but are optional for scales employing load cells. Pitless scales are for the most part superior to pit-type scales. The platform is built up approximately 1.5 feet above the ground, sits on the load cells, and the scale is open-sided. Because of this cleaning, maintenance, service and calibration can all be done from the side of the scale which makes it safer and easier for the technician [3].

Although superior, pitless scales have one problem, they require an approach ramp because the scales basically sit on top of the ground. These ramps must be approximately one-third of the length of the scale to meet the standards set by the National Institute of Standard and Technology (NIST) in their Handbook 44 [4]. In many cases the company does not have the room for both scale, and entry and exit ramps. For example, if a company purchases a 100-foot long truck scale it needs another 66 feet for the entry and exit ramps, and all of this in a straight-line. One more point must be made about the use of pit-type scales. Because of the cost, once a scale is installed it is often cheaper to maintain the scale, replacing and updating the instrument, than it is replacing the whole scale. Because of this, and the fact that pit-scales have been in use since the time of Thaddeus Fairbanks, there are still a huge number of pit-type scales in service today.

## **Confined** spaces

Confined spaces are present in a many industries including space operations, research in the Arctic or under water, mining, tanking operations and weighing industries. The kind of long-term isolation and confinement that humans will undergo in the space station, on the moon, or en route to mars is typically experienced only by groups such as submarine crew, Antarctic researchers and the mountain climbers [5]. Basic human factors principles that have been applied to the space environment include anthropometry, biomechanics, and ergonomics. Additionally, work design, workload, and task analysis currently receive much attention as do habitability and other aspects of confined environments [5]. Mining is among the most hazardous occupations in terms of ergonomic hazards per year, although the consequences of these hazards have been documented, there has been little systematic study of the mining environment and factors that may affect miners [6].

It is interesting to note that OSHA deems the previously discussed areas as a confined space and they are being studied to optimize human performance. In contrast, industries in general do not consider human performance in confined spaces. The issue that physical, physiological and psychological factors all have a direct relationship with human performance shows that there is a significant amount of research and developments required to create and optimize a model for performance and accommodate limitations of workers in confined spaces.

On January 14, 1993, The U.S. Occupational Safety and Health Administration (OSHA) adopted the Final Rule for Permit-Required Confined Spaces for General Industry (29 CFR 1910.146) with an effective implementation date of April 15, 1993. This regulation requires employers to set up a comprehensive confined space program that includes, but is not limited to: identification, permitting, testing, training, emergency response, and rescue. The limitation of this standard is the lack of a complete assessment of factors that affect human performance and in turn designing the task to fit the human.

The regulation requires that employers initially evaluate the work place to determine when confined space permits are required [7]. The problem with identification is the ambiguous definition of a confined space and knowing how this applies industry wide.

What constitutes a confined space? "The nature of a confined space may vary considerably, and typically includes trenches, silos, tanks, vats, boiler, compartments, ducts, sewers, pipelines, utility manholes, vaults, bins tubs, pits, degreasers, tunnels, crawl spaces, incinerators, scrubbers, air exhaust plenums, rooms with improper size openings with or without natural or mechanical ventilation and other areas in which space from a hazardous element is limited [8]. The definition of a confined space is the simultaneous occurrence of three criteria [7].

- 1. The space is not designed for continuous employee occupancy.
- 2. The human body can fit entirely within the space.
- 3. Access to the space is limited.

Once a space is determined to be 'confined', it must be determined whether the confined space is permitted or non-permitted. If any of the following criteria apply, it is a permitted space:

- 1. The space could contain a hazardous atmosphere.
- 2. The space could contain a material that could engulf a person.
- 3. The space has a configuration that could trap or asphyxiate a person.
- 4. The space contains any other recognized serious safety hazardous.

For a non-permitted space, the criteria is reduced from the 4 permitted space criteria items to 3:

- 1. It is mechanically ventilated.
- 2. The space could contain a hazardous atmosphere.
- 3. The space has been reclassified as a non-permitted space after the elimination of other hazards.

Once the area is deemed a confined space, the next step is to perform testing of the environment. The following categories cover the major hazard groups found in confined spaces: atmospheric, content issues, potential energy, environment, configuration, nature of the work, external hazards, and miscellaneous Schroll. There is a definite tangible effect on workers operating in confined spaces as indicated by Sharit et al. [9]. As the postural deviations needed increased, the discomfort in the operator's corresponding body parts also saw a sharp increase [9]. Delleman [10] estimated this tangible relationship in military settings. It was found that regardless of compensation method for the confined space, the health and performance of the military personnel decreased. The overall health decreased by 10 percent on an hourly basis, while the observation performance dropped by 30 percent per hour. There are several system safety analysis techniques that have been developed to aid the worker in testing the environment and subsequently preparing to work in a confined space as described by Utley [11].

### Entering the pit

While scales and scale pits have been in existence for over 100 years there is limited research that has been done on the hazards related to entering and bringing equipment into this confined space. Nevertheless, a study by Safety Sciences reported that out of 276 cases of accident in confined spaces, 33 occurred at the entrance or exit Campbell [12]. In the case of scale pits these accidents are more likely due to slips while entering the pit.

Surprisingly, the actual means of entry in the pit, the manhole, has no bearing on the problem. The manhole in a pit is actually no smaller than other similar hatch type entries and provides more than enough room to accommodate the average bi-deltoid shoulder breadth of American males which is 19.37 inches [13].

As described previously, scale technicians enter pits by first stepping onto the center lever and then stepping onto the pit floor. For pits 6 feet to 8 feet deep, most scale technicians usually insert a folding ladder into the pit, setting it up beside the lever to aid them getting in and out. Depending of the depth the ladder is typically, 4 to 5 feet high.

Although the lever is 4 inches wide, it can be slippery and may have other trash on it that may make balance precarious. The risk of losing one's balance is further increased by the act of bringing tools and equipment into the pit. Parsons and Pizatella [14] conducted a safety analysis of the roofing industry and determined that transporting materials and equipment while ascending and descending ladders were one of the major causes of injuries to roofers. In these cases there are a number of factors that must be taken into consideration beyond just climbing the ladder. For example, the object might shift as it is being moved. These kinds of "surprises" while carrying objects lead to radical shifts in the stress being placed on various parts of the spine. Thus, any sudden change necessitating stretching or reaching can have extremely hazardous effects. Beals and Hickman [15], as cited in Hollenbeck Ilgen [16] supported this conclusion in a study of 46 workers with back injuries. After reviewing each case, they found that 85% reported that their injuries occurred in a situation where something unexpected happened.

Unexpected happenings can take many forms. In tasks involving

lifting and carrying for example, being surprised by the weight of the item being lifted can result in a loss of balance that can in turn result in stresses, strains, and falls. The loss of balance of is intriguing phenomena which requires an understanding of the dynamics of the task performed. Wu et al. [17] estimates the minimum step length necessary for recovery of forward balance with a minimum number of steps (i.e. one). They prove that an increase in forward velocity and shift in Center of Mass Motion (COM) requires a larger increase in the step length needed to recover balance. Additionally, the minimum step length has an inverse relationship with muscle strength of the muscles around the ankle. Waters et al. [18] determines the Spinal Loading Exposure estimates for manual material handling. It basically estimates the risk of spinal injuries by obtaining personal data, estimating spinal loads. Two studies have specifically examined the effect that lifting heavy loads has on balance. While neither of these was conducted while the subjects were precariously balanced on a ladder or a 4-inch beam, they did examine the effect that lifting a surprise has on balance. In the first study by Commissaris and Toussaint [19] two experiments were conducted. In the first, 8 male subjects lifted a heavy load (22% of their body mass) using a leg lift and a back lift. In this experiment the subjects were told how much the object weighed. In the second experiment, 25 male subjects lifted a 6-kilogram box that they expected to weigh 16 kilograms. The combined results of these two experiments showed how a lifter prepared himself to counteract the threat to losing balance that is imposed by picking up a rather heavy load in front of the body.

Lifting such a load induces a risk of toppling forward because the body's center of gravity (CoG) quickly shifts forward and the counterclockwise angular momentum of the body towards an erect posture is halted. Subjects countered this adverse effect of the forward CoG shift by changing the CoG momentum. During leg lifting, a profound backward momentum was created prior to the lift to break the forward shift. The adverse effect of the halted counter-clockwise angular body momentum was reduced by a preparatory increase in momentum in the counter-clockwise direction. In a backlift, the forward CoG shift is even more threatening than when leg lifting. The reversal of this was an increase in backward momentum that was all that was required to maintain balance during the lift.

The results also showed that when a lifter overestimated the weight of the object being lifted, an overshoot in the linear and angular momentum of the body occurred leading to a disturbed balance. To counter this subjects used a series of twisting or jerking actions to regain balance that either resulted in their regaining their balance or falling.

In the second study, 9 healthy males were asked to lift a box rapidly from the floor. The weight of the box varied from 5 to 10 kilograms. The results showed that when subjects lifted an object which was heavier than they expected there was a burst of activity in the abdominal muscles which was associated with the rapid repositioning of the hips to regain balance [20].

Both studies concluded that the loss of balance and the subsequent efforts to regain balance so as not to fall were potentially hazardous to the musculoskeletal system of the lower back. These conclusions are consistent with those of other researchers. For example, Oddsson and Thorstensson [21] as cited in [19] in a similar study concluded that postural reactions required to regain balance while lifting could be hazardous to the low-back muscoskeletal system. Manning and Shannon [22] found that falls that occur while lifting an unexpectedly heavy object are associated with lower back injuries. They also concluded that the high mechanical stress on the lower back caused by Page 4 of 10

lifting the unexpectedly heavy object, along with falls, slips, and trips that resulted from the loss of balance, was a major cause of lower-back injuries.

A parallel can be drawn from lifting an unexpectedly heavy object and lifting a heavy object of a known weight while precariously balanced. The act of lifting a known weight while balanced say on a ladder would resemble the back lift described by Commissaris and Toussaint [19] and should involve the same corrections required to maintain balance. The question then becomes are these corrective actions sufficient to cause the person to lose their balance, and if so, could they regain their balance and keep from falling?

To answer this question and assess the similarity between lifting an item of a surprising weight and lifting an item of a known weight while precariously balanced the first experiment in this study examined how balance was affected by lifting an object while standing on a step ladder. Based on the studies described above it is believed that a pattern of movements similar to those described by Commissaris and Toussaint [19] in their second experiment and by van der Burg et al. [20] in their study will be observed. The major difference is that for this experiment the subject will know the weight of the object, but will have to lift it and maneuver down the ladder. It is expected that any loss of balance will be due to over correction for the added weight while on the ladder and the actions of moving down the ladder with the weight in hand.

Li and Liu [23] provided the first estimation of the maximum acceptable weight in all manual material handling tasks. This study showed that frequency of manual material handling also has a significant contribution to the acceptable weight determination.

## Moving around in the pit

Many occupations require individuals to work in restricted spaces. One such group of individuals that have been the target of such research is mechanics and maintenance people. For example, many aircraft maintenance tasks require the maintenance staff to perform inspection and diagnostic activities within the narrow confines of aircraft structures, [9] like airplane mechanics and others, scale technicians are also forced to work in a confined or restricted space.

Mozrall et al. [9] examined the effects of restricted body position on task performance. In their study, the subjects were asked to perform an inspection task in an experimentally constructed restricted space. Subjects were restricted laterally, sagittally, vertically, or in some combination of the three. A series of physiological measures, such as heart rate and respiration rate, physical and cognitive stress measures, fatigue measures, and task performance measures were taken.

Their results show that the subjects' responses and physical stress were directly related to the degree of restriction. The vertically restricted groups were required to adopt the most physically demanding postures. To counter this, the subjects in this group changed posture more times in the lateral and sagittal planes than subjects in the lateral and sagittal groups did in the vertical plane. This contrasted with the multiple-restricted groups (vertically and sagittally restricted, and vertically, laterally, and sagittally restricted) who were forced to adopt physically demanding postures but did not have as much chance to change postures. These groups were less able to cope with the physical stress and showed higher levels of discomfort. The fact that this group was restricted in the number of postures that they adopted meant that they had to retain those postures longer. This replicated the findings of a similar study conducted by Boussenna et al. [24]. The overall pattern of responses indicates that body part discomfort increased in the functional body areas in which postural deviations were forced by the space (e.g. vertically restricted groups experienced more discomfort in the neck and trunk). It was also found that body part discomfort increased more rapidly in subjects in the multiplerestriction groups. It appears that subjects restricted in only one plain took advantage of the freedom in other planes to adjust their posture. The results also showed that the groups under the most physical stress also experienced increases in heart rate and respiration rate.

Cognitive stress and fatigue appeared to play no role in this study supposedly because of the short task duration. The lack of a cognitive effect fits with the findings of Zhang et al. [25] who found that workers required to stand in one spot were able to maintain performance on an inspection task for an hour before any performance effects were found. This depended on the subjects being able to make slight postural shifts during the task.

The topic of manual material handling while in non-standard postures has been examined by a number of researchers. Smith et al. [26] conducted a series of four experiments which looked at the manual material handling capabilities of subjects in 99 lifting and carrying tasks while in non-standard postures. Among those particularly relevant to this analysis are those where the subjects where kneeling on one or both knees, sitting, squatting, and lying on their backs. The study also examined horizontal transfers while the subjects were kneeling and sitting, lifting a toolbox with one hand from the floor to 76 meters, lifting and carrying an item 3 meters under ceilings 40%, 60%, and 80% of the subjects' height, lifting weights to 85% of the subjects' stature, and one hand carries while crawling.

The results of this study showed that the amount of weight lifted decreased as the height of the lift increased for all of the postures used. The amount of weight also decreased as the subject went from twohanded lifts to one-handed lifts. Finally, the amount of weight lifted decreased as the ceiling height became lower. When combined the results suggested that the more awkward the posture assumed, the greater the decrease in weight that could be handled safely.

Awkward postures also include those that involve twisting the body. Twisted postures may be due to having to work in areas where people have to reach over barriers and around objects. Another hazardous situation occurs when people have to work overhead. In an effort to examine the effects these postures have on strength Haselgrave et al. [27], collected isometric strength data on four awkward work situations that are often imposed by workplace constraints in industries such as repair and maintenance. The tasks used were identical to those used by Warwick and are outlined in table 2.

The results of this study showed that when compared with tasks carried out standing, lying on the back and working overhead was not significantly different when exerting horizontal forces. However, when the exertions were vertical, the force exerted while standing was 16% to 82% greater depending on the distance of the reach and the direction. The results also showed that overhead force exertion in either the horizontal or vertical planes are likely to be weak when space is restricted. However, when lying down, pushing force capability increased some as the reach distance was decreased.

In another study conducted along the same line of investigation [28] measured the isometric strength that can be exerted single-handed when people are kneeling on one or both knees, and the effect that the direction and height of the exertion took place. The maximum forces exerted by kneeling subjects were measured in six directions, at three

Task	Location of the point at which the force was exerted		
Standing, facing forward (Standard Condition)	0 rotation, height at subject's shoulder level, right foot at maximum reach distance.		
Standing, twisted sideways	90 rotation to the right, height at 142 cm (ap- proximately shoulder level, right foot 45.7 cm from test handle. 135 rotation to the right, height at 142 cm, right foot 53.9 cm from test handle.		
Standing, working overhead	Test handle mounted on at 4 locations above the right foot position set to be at maximum reach distance from the subject's right shoulder at angles of 15 degrees forward, 15 degrees rearward, and 15 degrees to each side.		
Lying supine on the floor, working overhead.	Test handle mounted at 3 locations above the right shoulder position and set to be at maximum reach distance at angles of 0 and 15 degrees to each side.		

Table 2: Task Situations Tested by Haselgrave et al. [27].

work heights (shoulder height while kneeling, waist height while kneeling, and 100mm above the floor), and at three reach distances (maximum reach, 75% and 50% of maximum).

The findings showed that subjects were able to exert more force while kneeling on one knee than they could while kneeling of both knees. This was most marked for pulling forces, but the difference was slightest when pressing down. The difference in force exerted may have been due to the fact that when kneeling of one knee a person can use the other leg to brace the body and supply additional force.

The findings also served to confirm that exertion of strength in real tasks is a very complex situation. It is affected considerably by task layout factors such as reach distance and the direction of the exertion. For example, in regards to the distance from the body, the results depended a great deal on the subjects' posture. When kneeling on one knee, subjects could exert more force close to their bodies. When kneeling on two knees, the reach effect was significant for pulling and for lateral forces exerted to the side but not for those exerted across the body. For lateral forces, the most advantageous reach distance was at 50% maximum reach when kneeling on one knee and 75% reach when kneeling on two knees. It was apparent that lifting forces were strongly affected by reach distance, so that much higher forces can be exerted close to the body. The height the work took place had no significant effect on the amount of exertion.

These studies all looked at subjects in a specific posture performing one specific act. In the real world however, maintenance and repair people are often required to perform a variety of actions while maintaining the same awkward posture. Furthermore, while these studies all provide performance measures, none of them attempt to measure the levels of discomfort and exertion experienced by the subjects while doing these activities. It is possible that people find working in awkward postures comfortable or that exertion does not change as posture changes.

In an attempt to address these questions [29] compared the risks assessed in a single MMH task with those of a combination task (pull, lift, carry, push and lower) using the ratings of discomfort, exertion, and heart rate from 9 male and 9 female students. The discomfort measures was developed by Visser and Straker [30] and incorporates a body map with 13 body parts each associated with discomfort scale ranging from "no discomfort" to "extreme discomfort" [29]. The individual body parts discomfort ratings were then summed to get a

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measure of total discomfort. Exertion was rated using Borg's exertion scale developed in 1985 [31].

The results showed that tasks involving awkward postures tended to have higher discomfort ratings than tasks with less awkward positions. Discomfort was also found to be greater for the combination tasks than for the single tasks. It seems that discomfort is sensitive to task differences such as posture and sequencing as well as being sensitive to the complex interactions between these factors.

The exertion ratings showed a similar pattern of results. Exertion ratings were higher for combination tasks than they were for the component tasks on most occasions. They also increased as the postures experienced by the subjects became more and more awkward. This was also reflected by changes in heart rate. Heart rates tended to be higher for tasks requiring crouching or stooping and for high frequency tasks. They also tended to be higher for combination tasks than single component tasks. Magnitude was similar to that of the exertion ratings.

Taken together these studies demonstrate that having to work in situations where the body is restricted in one or more directions where the worker must assume awkward positions to do the job constrains not only physical performance but also increases the levels of exertion and discomfort experienced. In addition, having to work in these circumstances reduces the amount of force that the worker can apply. As a result, a worker who is restricted by his work environment may not be able to generate the force necessary to due parts of his job without suffering some form of injury.

In the real world, where tasks must be performed in some combination to accomplish the job, the risk of injuries to workers is increased. That risk is further increased by requiring the worker to perform them in a restricted environment. In the study by Safety Sciences that Campbell [20] reported, insufficient maneuverability was cited as the cause of 15 injuries out of the 276 examined and another 12 died of stress related injuries. As Straker et al. [29] showed heart rate does increase as the complexity of the combination of actions increases and as the perceived level of exertion increases. Thus, it can be said that working in restricted spaces can be fatal under certain conditions.

The parallels between these studies and the conditions that scale technicians work in while in scale pits are quite clear. The standard 4 foot deep truck scale pit requires the technician to work either stooped over, kneeling, squatting, or sitting, and in some cases, depending where they are, they may even have to work lying on their backs. For example, as shown in figure 1, there is a transverse lever that runs the length of the neck of a mechanical scale. To work around this lever requires the technician to lie on his back to get around it. Mozrall et al. study showed that having to work in such condition interferes with task performance, and the studies by Haselgrave et al. [27,28] showed that non-standard postures such as kneeling reduces the amount of force that can be exerted. These studies also showed that the complexity associated with the effects of a non-standard posture makes predicting outcomes in terms of risk of injury difficult. Finally, Smith et al. [26] and Straker et al. [29] demonstrated that manual material handling capabilities are affected by awkward postures resulting in a limited ability to move materials. Straker et al. [29] also showed that when combination task must be performed the perceived level of discomfort and exertion are increase, as is heart rate which is often used as a physiological measure of exertion.

## Case Study 1

Ergonomic review of lifting and carrying.

## Rationale

This study is of particular relevance to scale technicians because one of their jobs is the inspection of the pit and scale. To do this they must walk or crawl throughout the entire pit. For the standard, 4-foot deep truck scale pit, this directly parallels the study by Mozrall et al. [9]. In addition, when it comes to maneuvering under and around the levers, the scale technician may face multiple levels of restriction.

The problem is further complicate by the fact that when a repair needs to be made scale technicians often have to bring equipment with them such as toolboxes. The act of doing this requires the technician and any other mechanic or maintenance worker to push, pull, lift, and carry using some very awkward postures and improper lifting techniques. It must be noted that although less stressful than lifting, pushing and pulling objects has been cited as a cause of back injuries, and carrying objects entails many of the same risks as lifting them, but with the added consideration of movement, Hollenbeck and Ilgen [16].

## Subject

One male subject 72 inches tall, weighing 256 pounds was used for this case study.

## Apparatus

Two different twenty-pound weights were used in this case study. The first was a twenty-pound toolbox measuring 18.5 inches long by 9.5 inches wide by 10.5 inches high. The second was a twenty-pound barbell measuring 14 inches long by 7 inches high by 7 inches wide.

Also a stepladder with two steps was used. The ladder was 39 inches high and 14 inches wide. The top step was 21 inches above ground level,



12 inches wide, and 6 inches deep. The next step was 11 inches above ground level, 12 inches wide, and 3.25 inches deep.

## Survey instruments

Two scales were used in this case study. The first is the Borg-RPE (Rating of Perceived Exertion). The scale is constructed so that the ratings, 6 to 20, are linearly related to the heart rate associated with that level of exertion Borg Sanders and McCormick [30,32] (See Appendix A).

The second rating scale is a standard five-point Likert scale designed to assess balance. The scale was used by an observer to assess the subject's balance. Table 3 shows the rating scale and explains the corresponding rating values.

# Procedure

For the first trial the toolbox was placed on the floor in front of the shelf and next to the ladder. The ladder was placed in front of the shelf, facing it so when the subject stood on the ladder he was facing the shelf. In this trial the subject lifted the tool box in his right hand and climbed to the top step of the ladder. He then placed the toolbox on the shelf. The pattern of climbing and the perceived stability of the subject were recorded.

For the second trial, the subject climbed the ladder, picked up the toolbox, and brought it back down to the floor.

For the third and fourth trials the subject repeated the same procedure except that this time the ladder was turned at a 90-degree angle to the shelf. This required the subject to climb the ladder and then rotate 90 degrees to pick up or set down the toolbox.

For trials 5 through 8, the ladder was set on top of two blocks: Block A was 2 inches high, and Block B was 1.5 inches high. The purpose of this was to simulate the effect of working on an uneven floor which, because a large amount of debris buildup inside the pit is not uncommon. The same task procedure used in trials 1 through 4 was repeated with the ladder in this uneven position.

Trials 9 through 16 were carried out identically to trials 1 through 8 using the twenty-pound barbell instead of the toolbox.

Following each trial, the subject was asked to provide a rating of exertion using Borg's Rating of Perceived Exertion. Also, the observer rated the subject's stability.

## Results

Table 4 shows the exertion rating and balance rating for each trial.

Numerical Rating	Qualitative Rating	Explanation of Rating
1	Fall	The subject has lost his balance and either fallen, has been forced to grab something to keep from falling.
2	Poor	The subject is very unsteady and must perform sudden radical movements of the body to maintain balance.
3	Fair	The subject is unsteady and moves very deliberately to maintain balance.
4	Good	The subject moves smoothly and confidently, but still shows awareness of his surroundings.
5	Very Good	The subject is very confident and moves normally without over due thought about his movements, like when walking.

Table 3: Perceived Rating of Subject Balance Scale.

A Pearson's r was calculated correlating the exertion ratings with the ratings of balance. The correlation analysis showed that there was a significantly negative relationship between the perceived level of exertion and the observer's rating of stability (r=-.9396, p=.0000). Thus showing that as the perceived level of exertion increased the participant's balance decreased.

Multiple two-sample t-test were computed to compare the following scenarios: 1) the effect of using the tool box versus the barbell; 2) the effect of having the ladder flat on the floor versus putting the ladder on the blocks; 3) the effect of positioning the ladder at 90 degrees versus having the ladder face the shelf; and 3) the effect of climbing up versus climbing down the ladder. For all t-test analysis, the probability of making a Type I error (alpha) was set at .01 to counter the inflation of the case study error rate. Table 5 shows the results of the t- tests.

#### Discussion

During the case study, the trials where the subject had the most problems balancing were also the ones where the observer rated the subject as being the most unstable. For example, on trial 5 and trial 7, the subject experienced a great deal of instability, it was noted that he was rocking and shifting his weight in order to keep his balance. These were also the two trials that he rated as the highest on the perceived level of exertion. Thus, supporting the data results that indicated a negative correlation between perceived level of exertion and balance.

## Case Study 2

Manual materials handling in a restricted environment

#### Rationale

Scale technicians are often required to do all of the things outlined in these studies daily. In a single job, they may be required to crawl through a pit while carrying one or more pieces of equipment. They then must sit or kneel while working of the scale. Sometimes the job they are doing may require great force such as when they have to remove a frozen pivot or bearing and replace it. They then must make the same trip back to get out of the pit and hope everything works.

One thing that none of the previous studies did was measure the

Trial	Exertion	Balance	Trial	Exertion	Balance
1	9	4	9	11	3
2	11	3	10	11	3
3	10	4	11	9	4
4	11	3	12	9	4
5	13	2	13	10	4
6	12	3	14	12	3
7	14	2	15	10	4
8	9	4	16	10	4

 Table 4: Rating Results for Exertion and Balance.

	Comparison	t	р
Exertion	Ladder facing shelf vs. Ladder at 90 degrees	.3	.7710
Exertion	Climbing up the ladder vs. Climbing down	.16	.8737
Exertion	Ladder flat on Floor vs. Ladder on blocks	.68	.5000
Exertion	Carrying tool box vs. Carrying Barbell	-1.19	.8727
Balance	Ladder facing shelf vs. Ladder at 90 degrees	-1.44	.1718
Balance	Climbing up the ladder vs. Climbing down	0.00	1.000
Balance	Ladder flat on Floor vs. Ladder on blocks	-1.58	.1363
Balance	Carrying tool box vs. Carrying Barbell	1.44	.1718

Table 5: Table of Two Sample T-Test Results (df = 14 for all tests).

Citation: Mortimer C, McCauley-Bush P, Crumpton-Young L, Kordestani R (2012) An Ergonomic Case Study of Scale-Pits in Transportation. Ind Eng Manage 1:104. doi:10.4172/2169-0316.1000104

variables of combined manual materials handling with a restricted area and awkward postures over a long distance. The greatest distance covered in any of these studies was 3 meters. Scale technicians, however, must move around in a restricted environment for distances of 60 feet and in some cases more. In order to evaluate the effect that this has on exertion and discomfort the second experiment in this study required subjects to maneuver a twenty-pound weight along a 40-foot path. The height of the ceiling was set at 4 feet for most of the length, but was lowered in some places, In addition, several obstacles were included along the route. Exertion was measured using Borg's Sanders and McCormick [31] scale of exertion and discomfort was measured using the [29,30] scale of body discomfort. The goal is to determine the stress that is experienced by a technician as he is moving through a pit without his tools, with his tools, and with his tools facing obstacles. It is believed that the levels of discomfort and exertion will increase as the load increases. It is also believed that discomfort will be greatest in the lower back, neck, and knees due to the restricted posture.

#### **Subjects**

Two male subjects participated in this case study. Subject 1 was 75 inches tall, weighed 238 pounds and was 75 years old at the time of the case study. Subject 2 was 72 inches tall and weighed 256 pounds and was 34 years old at the time of the case study.

### Apparatus

The same 20 pound toolbox used in case study 1 was used in this case study. The box measures 18.5 inches long by 9.5 inches wide by 10.5 inches high.

#### Setting

An experimental path measuring 40 feet in length was used. The width of the path was 48 inches except for a stretch of 6 feet where it narrowed to 30 inches. The height of the path was set at 41 inches except in two places where the height dropped to 24 inches. One of these places was also where the path narrowed. The path includes two right turns and two left turns.

#### Survey instruments

As in case study 1, the Borg Rating Scale of Perceived Exertion was used. Also the Visser and Straker's Scale of Discomfort was used, Straker et al. [29]. This survey instrument incorporates an image of the body with 13 body parts; head, neck, lower back, hip, left and right shoulder and arm, elbow, forearm, wrist and had, thigh and knee and leg and foot. Each body part is associated with an analog discomfort scale that has a 100mm horizontal line with "no discomfort" marked at the left and "extreme discomfort" at the right end. Subjects were asked to mark along the line to indicate the intensity of their discomfort level for each region of the body where they were experiencing some discomfort. For this analysis, the level of discomfort for separate body parts was combined to represent a whole body discomfort rating, Straker et al. [29]. The survey instrument used is shown in Appendix B.

## Procedure

A series of anthropometric measures were taken on both subjects using a standard 8-foot tape measure.

Each subject was required to travel the course three times. In trial one, the subjects traveled the course without carrying anything. On trial two, they traveled the course while carrying the tool box. On trial three, the subjects once again traveled the course with the toolbox, but this time two obstacles were placed in the path. The first obstacle required the subject to go around it, while the second required the subject to go over it.

Subjects were asked to rate their level of exertion after each trial. They were also asked to rate the discomfort they felt in each body part.

## Results

Table 6 shows the anthropometric measures of interest for this study taken of the two subjects. These measurements were compared first to those of the experimental course and then to some of the known measurements of a scale pit. Of particular interest is the measurement of both subjects from their wrist to their shoulder (23.5 and 25 inches respectively) which was an approximation of the length of their upper body.

Based on these measurements it is understandable why both subjects had to crawl on their stomachs to get through the lowest part of the course (Table 6).

In regards to completing the experimental task, both subjects used the same method to move through the course. At the outset they dropped to their knees and crawled through the course except where the ceiling dropped to two feet where both had to crawl on their stomachs. In trials 2 and 3, both subjects alternated between pushing the toolbox in front of them and using a carry with a one-handed crawl on their knees method. Table 7 shows the perceived exertion ratings for both subjects and the average perceived exertion value for each trial.

Both subjects reported increased levels of perceived exertion on each trial. This data trend was expected because in each trial additional task factors were added that made the completion of the course more difficult.

Table 8 shows the data on discomfort over the three trials and the sum for each subject and each trial.

According to the data, the knees, lower back, and shoulders were the areas where both persons reported the greatest amounts of discomfort were reported. Neither subject reported any discomfort in the forearms, wrists, hands, thighs, legs, or feet during any of the trials.

The average level of perceived exertion per trial and the total discomfort per trial were tested using Pearson's Correlation Coefficient. The test showed a significant positive correlation between the subject's ratings of exertion and the total level of discomfort experienced (r=.9978, p=.0421) when using an alpha value of .05.

## Discussion

These results support the contention that working in a restricted

Body Part	Subject 1	Subject 2
Height	75.0	72.0
Floor to Hip	39.875	40
Knee to Hip	17	19
Wrist to Shoulder	23.5	25
Elbow to Shoulder	12	13
Shoulder Width (Bideltoid)	19	22
Elbow to Shoulder	12	13

 Table 6: Subject's Anthropometric Measurements (in inches).

Trial	Subject 1	Subject 2	Average
1	13	10	11.5
2	15	13	14
3	18	16	17

**Table 7:** Exertion Ratings on Experimental Course.

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Body Part Subject 1	Trial 1		Trial 2		Trial 3	
	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2
Head and Neck	20	0	20	0	35	30
Lower Back	60	25	80	25	85	50
Hips	20	0	25	0	40	0
Shoulders	30	25	45	40	70	55
Arms	0	0	0	30	40	35
Elbows	10	10	10	15	10	15
Forearms	0	0	0	0	0	0
Wrists	0	0	0	0	0	0
Hands	0	0	0	0	0	0
Thighs	0	0	0	0	0	0
Knees	60	30	65	50	80	60
Legs	0	0	0	0	0	0
Feet	0	0	0	0	0	0
Total Discomfort	200	90	255	160	360	245
Total per Trial	290		4	15	6	05

#### Table 8: Discomfort Ratings

area affects the comfort levels of the people involved. Both subjects reported increased levels of discomfort as the space became more confining (Trial 1 vs. Trail 3). Thus, each time an individual is forced to twist himself into an awkward posture to accomplish a task it increased his perceived level of exertion and body discomfort.

Also, each time that a new task was added, subjects reported greater levels of discomfort and higher levels of perceived exertion. Adding a new task required an increase in the exertion of more force, and/ or required the individual to assume more awkward postures, which caused increases in exertion and discomfort.

## **Conclusions and Suggestions**

The case studies analyzed in this paper and the research reviewed indicate that scale technicians are likely to experience a decrease in their balance or stability as the work task parameters change which influences an increase in their perceived level of exertion. Also, these technicians may experience a higher perceived level of exertion and an increase in body discomfort due to the awkward postures that they have to assume when moving around and working in the restricted areas within the pit.

To travel the length of a pit requires the technician to crawl over 60 feet, often on their knees or stomachs. The results of this study suggest that this can be a very taxing job that affects some parts of the body more than others. The parts of the body most likely to be affected are the shoulders, knees, and lower back. This is understandable because these are the areas that must support the weight of the body when it is in a crawling position. These findings indicate that maneuvering in a scale pit is a potentially hazardous task for technicians.

Redesign recommendations for scale-pits.

The following is a brief discussion of two proposed changes to the design of Scale-pits that will help to reduce the awkward posture, perceived level of exertion and body discomfort experienced by technicians.

 Scale-pits should have a uniform depth that accommodates the anthropometrics of the ninety-fifth percentile male worker. This is because there are already scales out there that use this depth so the design and engineering technology is already available. Secondly, at this depth there is still plenty of clearance for even the tallest technician, and there is nearly 4 feet of clearance under the levers making moving about in the pit much easier.

2) All pits should have a staircase that leads down into the pit. The staircase should be designed using ergonomic and anthropometric guidelines so that it is wide enough for technicians to get down into the pit while carrying their tools. The stairs should also be deep enough so that technicians do not have to worry about balance. Additionally, proper maintenance and housekeeping should be employed to keep the stairs safe for use.

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