

Left r/head: Pushing trolleys: weight/handle height limits

Right r/head: Culvenor

## **Initial force and desirable handle height range when pushing a trolley**

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\*\*\*precedent for disclaimer is on p 67 Vol 21(1)\*\*\*

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### **Abstract to come**

#### **KEYWORDS**

TROLLEYS

MANUAL HANDLING

ERGONOMIC DESIGN

PUSH FORCE

#### **1%Introduction**

Trolleys are often used in workplaces to move things, including food, laundry, materials, supplies, parts, and even people. Since lifting and carrying present a known hazard in the workplace, pushing and pulling trolleys is often used as a solution. However, it has been suggested that these activities are not as well researched as lifting and carrying.<sup>1</sup> This article concentrates on the design of trolleys in an automotive assembly setting. Due to the need to remove forklifts from the assembly environment, it was necessary to deliver parts using

electric buggies. The buggies are used to tow a series of trolleys which have been joined together to form a short train. Crates of parts would then sometimes be transferred by hand from the trolleys to racking. For some other parts, the entire trolley would be disengaged and pushed into the required place. The actual processes of automotive assembly involve considerable manual work. Like other automotive assembly operations<sup>2</sup>, in the setting where the data for this article were collected, there is a systematic analysis of workplace hazards (such as manual handling risks) that extends to all tasks, including the delivery of parts. The intended outcome is that jobs should be designed to fit the person.

Force is one of the risk factors identified in manual handling regulations throughout Australia. However, suggested values are uncommon as it is recognised that many factors interact with the force and these must be considered together. Contemporary Australian material, such as the *Draft National Code of Practice for the Prevention of Musculoskeletal Disorders (MSD) from Manual Handling at Work*, is similar in this regard.<sup>3</sup> However, some regulatory material does include force guidelines for push and pull activities (*guidelines* — not strict limits). One example is the Swedish equivalent of the manual handling code of practice.<sup>4</sup> The Swedish approach is to use a “traffic light” design tool. For initial pushing forces, the Swedish guideline is as follows:

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- acceptable “green” zone: < 150 N;
- evaluate more closely (yellow): 150–300 N; and
- unsuitable (red): > 300 N.

The draft national code of practice<sup>3</sup> also uses the “traffic light” approach to categorising manual handling risks:

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- green: indicates good practice and good design principles;
- yellow: indicates factors that require action in the near future; and
- red: indicates factors that pose a high risk and require immediate action.

The Swedish material offers a broad guide to push force limits. In order to obtain more specific data, guidance on acceptable push and pull force for various population percentiles is available. Biomechanical modelling, using tools such as the University of Michigan 3DSSPP, is one way in which given loads can be compared with strength data. The tables devised by Snook and Ciriello are another way, with the tables providing a more direct way to define acceptable push and pull forces.<sup>5</sup> For example, considering a short push (7.6 m) every five minutes, with handle heights of 144 cm (male) and 135 cm (female), the acceptable figures from the Snook and Ciriello data for 90% of the male and female populations are 22 kg and 18 kg, respectively.

By whatever guidance source is chosen, once the guidance for acceptable forces is established, then the task needs to be designed to fit within this limit. The question is then, what load is demanded by the use of a trolley? The force required to move a trolley can be influenced by many factors, including the weight of the trolley and load, the slope of the surface, acceleration and deceleration, the turning forces, the friction in the wheel bearings, the wheel diameter in relation to bumps/lips on the floor surface that might be encountered, and so on. Further, the design of the trolley handle (particularly the height) then dictates the load on various body joints (particularly the shoulder) created by the required force. The principles of physics indicate that the torque in a joint is proportional to the magnitude of the force and the distance of the joint from the line of action of the force. Therefore, a line of action through a joint generates no torque. For a horizontal push or pull, the torque in the shoulder and elbow can therefore be minimised (theoretically eliminated) by pushing or pulling at shoulder height with the arms outstretched so that the elbows are also at this height.<sup>6</sup> Consequently, some authors have recommended shoulder height handles.<sup>6</sup>

While the force can be influenced by many factors, in some industrial settings many of the relevant factors can be standardised so that the variables are limited. For instance, in the automotive assembly facility in which this study was undertaken, the floors are essentially

horizontal and generally of a smooth concrete surface, trolley wheels were large (200 mm), their bearings were of a kind that allowed free movement, and a vertical handle design was standardised to offer all users a free choice of trolley handle height.

On observation, under these circumstances the constant speed rolling friction of a trolley was very low. Pulling a trolley with a force gauge indicated a force of around 1% of the mass. That is, for a 300 kg trolley the sustained force to move the trolley would be about 3 kg. Jansen et al reported constant speed forces of 1.7% and 2.5% of the mass.<sup>7</sup> For their study, wheel diameters were 185 mm and 200 mm, respectively, and the floor was linoleum. In contrast, for a trolley with smaller wheels (120 mm) which was being moved on soft carpet, the sustained force was 12% of the mass. Whether the constant speed value is one or two per cent of mass, it is clear that for tasks that involve short movements using a trolley with large wheels, good bearings and a hard surface, the force at constant speed is not particularly relevant. It is the force required to accelerate the trolley that will be critical. It was clear from preliminary investigations that acceleration forces were much more than 1% and this has been noted in previous research.<sup>6,7</sup> In lifting tasks, it is not uncommon to ignore acceleration of the load in the analysis — usually the actual weight of the object is taken as being the force. In lifting, this is not likely to be a particularly large error; however, in the case of a trolley being pushed on a smooth, level floor for short distances, it is the acceleration force that is most critical. What acceleration can be expected in these circumstances? If a reasonable figure for acceleration of a trolley when repeatedly delivering parts in a factory was known, then the weight of the trolley could be set to meet the force guidelines.

Al-Eisawi et al addressed this problem to some degree.<sup>8</sup> They investigated experimentally the initial forces applied to a trolley. The subjects (five male and five female university students) pushed and pulled a trolley on a carpet surface to determine initial forces. The trolley weights tested were 73 kg and 181 kg. The handle was horizontal and set at three heights for each subject (that is, knuckle, elbow, and shoulder height). The most directly horizontal push occurred when handle heights were set at elbow height. This contrasted with

forces somewhat downward when the handle was at knuckle height and upward when the handle was at shoulder height.<sup>8</sup> For the varying handle heights, the mean forces applied to initiate movement are set out below (data are shown for men and women but, under the conditions examined, the forces applied by men and women were not statistically different).

To initiate movement of the 73 kg trolley, the forces applied were:

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- 15–16 kg (20–22% of the trolley weight) by men; and
- 12–15 kg (17–21% of the trolley weight) by women.

To initiate movement of the 181 kg trolley, the forces applied were:

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- 22–29 kg (12–16% of trolley weight) by men; and
- 20–25 kg (11–14% of trolley weight) by women.

As a proportion of the trolley weight, lower forces were applied to the heavier trolley. Users were therefore accepting a lower acceleration of the heavier trolley. Perhaps this indicates that the figure of about 20–25 kg represents a value which is close to the maximum of what is comfortable.

Jansen et al measured forces to push 58.5 kg catering trolleys.<sup>7</sup> They investigated three kinds of trolley and two surfaces, linoleum and carpet. The subjects were four women working in a catering service. The handle heights were between 94 cm and 101 cm. The values for the initial pushing efforts were very similar on linoleum and carpet and between the three trolley types. The forces applied were:

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- 15–16 kg (26–27% of trolley weight) on linoleum; and
- 17 kg (29% of trolley weight) on carpet (same value for each trolley type).

Lawson and Potiki measured forces to initiate the movement of trolleys of up to about 300 kg.<sup>9</sup> The trolleys were linen trolleys. The surfaces were vinyl and two carpets, one synthetic and one wool (without underlay). The forces measured were just sufficient to initiate movement and were found to be 2–3% of the total weight. These forces were not, therefore, the forces that might actually be applied — just the minimum required. The acceleration of the trolley would be very low. To move the trolleys around with “normal” speed of movement would require greater force. As such, although the weights tested are greater, the data only tell us the minimum — not what would be required to allow a typical pace of movement.

Donders et al measured push and pull forces to initiate, sustain and stop trolleys of 130 kg, 350 kg and 400 kg.<sup>10</sup> The article was written in Dutch and the results were reported by van der Beek et al, a number of whom authored the original report.<sup>1</sup> The subjects were seven males who moved the trolleys 12 m. The handle height and other details were not noted. The mean initial figures for pushing were 22 kg, 29 kg and 32 kg for the three trolleys (130 kg, 350 kg and 400 kg). These equate to 17%, 8% and 8% for the three trolleys, respectively.

The studies of Al-Eisawi et al and Jansen et al give an indication of the initial forces applied to trolleys of weights below 200 kg.<sup>7,8</sup> The trolleys in these studies also used handle heights of about 1 m. The study of Lawson and Potiki gives values for trolleys of greater weight but they are only the minimum forces required to initiate movement, not the forces that users would typically apply.<sup>9</sup>

### **%1%Aim**

The aim of this study was to determine the initial force required (acceleration) when pushing 150–400 kg trolleys at preferred handle height. Preferred handle height was therefore also to be determined.

## **%1%Method**

The study was carried out in an automotive assembly setting. The methodology was developed within the circumstances of the workplace — including the requirement of not interrupting production.

The subjects were seven employees who normally worked on parts delivery, including pushing trolleys by hand. All of the subjects were male. No women worked in this job at the time.

The same sort of trolley used in the workplace was used in this study (\*\*Figure 1\*\*). Typically, these trolleys were loaded with a pallet which carried plastic crates containing parts. The trolley had two vertical handles which extended from near the floor up to a height of 140 cm. The handles were 3.5 cm in diameter. For cylinder handles, Humanscale lists the minimum diameter as 2.5 cm, the maximum as 4.4 cm, and the optimum in the range of 2.5–3.8 cm.<sup>11</sup> Pheasant's text, *BodySpace*, suggests a range of 3.0–5.0 cm.<sup>12</sup> The Standards Australia ergonomics handbook lists the maximum grip diameter of small females (5<sup>th</sup> percentile) as 4.3 cm.<sup>13</sup> In the present workplace, grip diameter had been the subject of some trial and error on force applications (such as trolley pushing with a preferred value at the time of 3.5 cm). Compared with typically smaller handles, this grip size seemed to allow a powerful grip and spread the load in the hand. The spacing of the vertical handles was 45 cm. The handle width corresponds to the elbow–elbow width of the average male (50<sup>th</sup> percentile)<sup>13</sup> The width of the handle was fixed and was therefore a compromise. Potentially, the handle could be duplicated at different widths to offer a choice of grip width. Although the trolleys had fixed front wheels and swivel rear wheels, in order to eliminate a confounding variable, the rear wheels were locked in the straight position for the trials.

The trolley handle was fitted with a force gauge to record peak force when pushed (Mecmesin AFG 1000). The force gauge and handles matching the trolley handles were fitted with clamps in such a way as to be adjustable for the subject's preferred hand height.

Subjects were asked to demonstrate the height that they would place their hands on another trolley of the same design. The force gauge on the trial trolley was then adjusted to that height.

The trials were undertaken on a horizontal, smooth concrete floor of the type found elsewhere in the factory. Six different trolley weights were tested. These weights were approximately 160 kg, 200 kg, 250 kg, 300 kg, 350 kg and 400 kg (the actual weights are shown in \*\*\*Table 1\*\*\*). The weight was increased by consecutively adding a wooden pallet and some additional parts.

Subjects were asked to push the trolley about 4 m in the way that they would normally push a parts trolley. The peak force for each trial was recorded. Each subject completed three trials at each weight. Each subject completed the entire test before the next subject began (this was the only practical way to perform the experiment, given that it was occurring in work time). Subjects began with the lightest weight and progressed to the heaviest weight.

## **%1%Results**

### **%2%Initial force**

The results are shown in Table 1. \*\*\*Figure 2\*\*\* shows the mean results graphically, with a linear trend line that approximates the experimental results. The linear equation of the line shown is  $F = 6.5 + TW/20$ , where  $F$  = initial force and  $TW$  = trolley weight. This equation is a good fit with the data over the range measured. Theoretically, a trolley of no weight should require zero initial force. An alternative quadratic equation ( $F = TW/10 + TW^2/11111$ ) set to pass through zero push force for a zero weight trolley also fits the data well. This equation is perhaps theoretically more realistic but, over the range measured (150–400 kg), there is little difference.



## **%2%Preferred hand height**

The design of the trolley used in this study allows for users to adopt a handgrip height of up to 140 cm. Subjects were allowed to choose their preferred height. \*\*\*Table 2\*\*\* shows the preferred hand height of the seven subjects. Generally, the subjects grasped the handle slightly above elbow height. The preferred hand heights were between 120 cm and 135 cm. The heights of the subjects ranged from 167–189 cm (in shoes).

As a proportion of overall stature (in shoes), the preferred hand height ranged between 66% and 77%. Data shown in the Standards Australia ergonomics handbook indicate that the 5<sup>th</sup> percentile female stature is 150 cm and the 95<sup>th</sup> percentile male is 186 cm.<sup>13</sup> Allowing 3 cm for shoes, these figures are 153 cm and 189 cm. Taking 66% of the 5<sup>th</sup> percentile female stature and 77% of the 95<sup>th</sup> percentile male stature gives a handle range of 101–145 cm. Allowing some scope either side of these for error and for handbreadth, a suggested vertical range for the handles might be 90–155 cm. This range is perhaps larger than necessary, given that the low value is based on a small stature (153 cm) multiplied by the lowest hand height/stature proportion (66%), which was recorded by one of the taller subjects (189 cm). Conversely, the upper figure is based on a large stature (189 cm) multiplied by the greatest hand height/stature ratio (77%), which was recorded for one of the shorter subjects (168 cm).

## **%1%Discussion**

### **%2%Using the data to develop a simple “traffic light” design tool**

As discussed, acceptable forces can be determined in a number of ways. Snook and Ciriello’s data are only one example. Using these data as an example, for a short push (7.6 m) every five minutes with handle heights of 144 cm (male) and 135 cm (female), the acceptable figures for 90% of the male and female populations are 22 kg and 18 kg, respectively.

Allowing a conservative limit of 16 kg (greater than 90% of females would be capable), the trials conducted here predict that male workers in this setting would apply a 16 kg force to a 200 kg trolley (using the formula  $F = 6 + TW/20$ ). This could then provide a design limit for the trolley.

The traffic light model in the draft national code of practice (like the Swedish approach) uses three levels: acceptable (green), not acceptable (red), and a range in between (yellow). To fit in with this approach, an upper guide for the force is needed. For the example considered (7.6 m push every five minutes), 75% of the female population would be capable of a 22 kg force according to the Snook and Ciriello data. Using the data collected, this would correspond to a 300 kg trolley.

\*\*\*Table 3\*\*\* provides a guide as to what would be acceptable (green), what is not acceptable (red), and when further advice should be sought (yellow) for these particular circumstances.

Manual handling regulatory regimes in Australia and elsewhere generally recognise that many factors are relevant in determining the acceptability of a task. This model provides an abundance of flexibility, which is appropriate as manual handling tasks are many and varied. Where, though, does this leave designers of activities in workplaces? Designers of tasks must theoretically apply ergonomics knowledge in order to determine a design limit for the relevant circumstances. The designer may become knowledgeable in ergonomics and apply this knowledge to the task. Alternatively, the designer may be frustrated at the lack of specific advice. What the designer probably seeks is an acceptable value for the circumstances. Guidance is needed to fill the gap between the flexibility of the regulatory models and the specific needs of the people who make decisions about the set-up of workplaces. This principle would apply not only to trolleys, but also to many manual handling activities.

## **%2%Further work**

This study was conducted in a manufacturing setting in order to provide data that would enable the development of trolley weight guidelines. The study was defined by the circumstances that were relevant to the needs of the business concerned. These circumstances included the type of floor (level concrete), the handle design, the wheel configuration, etc. The fitting of the force gauge involved a custom-designed fitting that was clamped to the trolley handles. A more stable arrangement could be devised. The study used the resources available, including the subjects — which was a strength in that the subjects were used to this kind of work, were used to the trolley design, and could push the test trolley in the same way that they normally worked. However, the study was limited for a number of reasons, including: only a small number of subjects were available; only male subjects were available; only one type of trolley handle was used; the trolley weights were limited to the 160–400 kg range; and the study was only conducted on a level surface. The study could be expanded with more subjects, including women, to enable greater certainty in the results. A focus on the parameters that are relevant to industrial needs remains worthwhile but the conduct of additional trials in an experimental setting as opposed to an industrial setting would allow better control and manipulation of the variables — and the introduction of other variables of interest to some industrial settings (such as floor slope).

## **%1%Conclusion**

Trolleys are used in many workplaces. Guidelines are available to set limits on the force that can be reasonably applied in a workplace setting. In some circumstances, the level of acceleration and the weight of the trolleys will be the most significant factors in governing the force that is applied. Hence, determining a weight limit in order to meet the force limits requires knowledge of the acceleration. Some research data about initial forces exist but the available data were not necessarily comparable with the circumstances of the workplace studied, such as the trolley weight and handle type. Previous studies give indications of the initial forces applied to trolleys of weights below 200 kg and some others provide data about heavier trolleys but not exactly what was sought in the present workplace.

This study was undertaken to determine the initial force applied to trolleys in a manufacturing setting. The wheel and floor configuration was such that rolling friction was small. The floor surfaces were essentially level. Seven male subjects participated in the study. Trolley weights were between 160 kg and 400 kg.

The results show that the preferred handle height was in the range of 120–135 cm for people who are between 167 cm and 189 cm tall. With regard to the force applied, for six trolley weights (between 160 kg and 400 kg), the *average* results fall closely along a linear equation,  $F = 6.5 + TW/20$  (where  $F$  = initial force and  $TW$  = trolley weight). However, variations in the results were substantial and only a limited range of circumstances were examined. Data about the *applied force* can be combined with data about the *acceptable force* in order to set design limits for the trolley weight. An example of this kind is included (Table 3).

Previous studies have included small numbers of subjects (usually 10 or fewer) and, like earlier studies, this research involved a small number of subjects (seven participants). Future research should include a more comprehensive set of trials with a greater number of subjects (including both men and women). These trials should be cognizant of the needs of industry but would probably be best if they were undertaken in a controlled experimental setting.

## **Acknowledgment**

Data reported in this article were collected at the Material Planning & Logistics (MP&L) Department of the Ford Motor Company of Australia, Campbellfield Plant, Victoria. Special thanks go to Alison Scoullar, MP&L Manager, Paul Bramich, MP&L Process Improvement Engineer, and Gabrielle Edwards, MP&L Process Improvement Specialist, for their support of the data collection.

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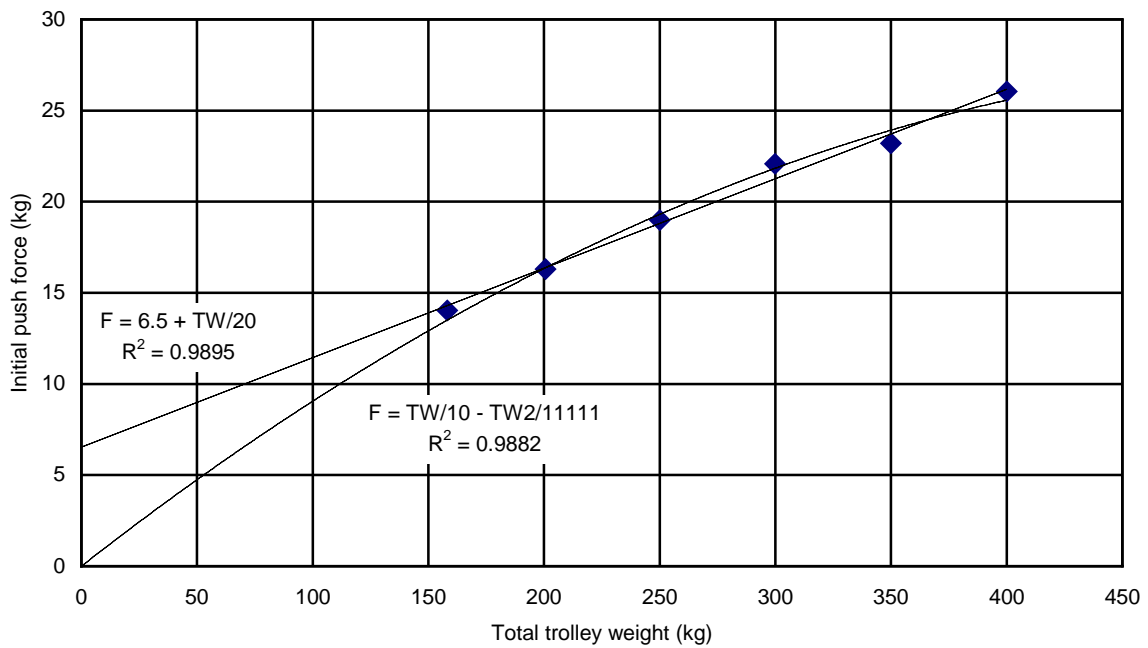
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**FIGURE 1**  
**Type of trolley used in the study**



**TABLE 1**  
**Initial force (kg) to push different weight trolleys**  
 Subject

<i>Trolley weight (kg)</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>Mean</i>	<i>SD</i>
158.16	18.2	10.8	10.7	5.8	7.1	19.5	26.1	14.0	7.4
200.66	17.8	13.7	14.7	9.1	10.4	22.7	25.7	16.3	6.1
250.05	20.5	15.7	18.2	10.9	13.1	28.1	26.4	19.0	6.5
299.80	21.9	21.1	23.3	12.5	15.0	27.0	33.6	22.1	7.1
350.00	21.3	22.0	24.9	15.4	18.3	26.6	33.9	23.2	6.0
400.00	23.0	21.2	28.9	19.5	21.4	28.0	40.4	26.1	7.3



**FIGURE 2**  
**Mean initial force (kg) to push different weight trolleys**

**TABLE 2**

**Preferred hand height of subjects**

	Subject						
	1	2	3	4	5	6	7
Height (cm)	169	189	176	167	188	173	168
Preferred hand height (cm)	125	125	120	120	135	120	130
Preferred hand height as % of the subject's height	74%	66%	68%	72%	72%	69%	77%

**TABLE 3**

**Example of trolley weight guidance limits**

<i>Trolley weight* (kg)</i>	<i>Code</i>	<i>Designer action</i>	<i>Push force</i>	<i>Acceptability of Applied Force</i>
< 200 kg	Green (acceptable)	Proceed with design	16 kg	> 90% of females



200–300 kg	Yellow (moderate)	Evaluate	16–22 kg	75–90% of females
> 300 kg	Red (unsuitable)	Improve design	22 kg	< 75% of females

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**\* Caution: These guidance limits are based on the circumstances described and the chosen push force values and percentiles capable. These will NOT be applicable to all situations.**

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