HUMAN FACTORS CASE HISTORY

ERGONOMIC DESIGN FOR FORKLIFT TRUCKS

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No matter how hard do you prevent the misuse of a product. People will always find another use you did not think about.

Fig. 1 (One man's blog, 2010)

1. Introduction

- **Definition of forklift:**

“A forklift (also called a lift truck, a high/low, a stacker-truck, trailer loader, sideloader, fork truck, tow-motor or a fork hoist) is a powered industrial truck used to lift and transport materials” (WIKIPEDIA, 2010).

- **Objetive:**

The purpose of this case history is to study the different human factors involved in the design of forklifts. It will be tried to emphasize which are the main problems and how they are solved. In some cases, there would not be a clear solution to the problem.

A correct design of a forklift can increase efficiency, reduce fatigue and minimize healthy risks, etc…; while a poor design could lead to fatalities, injuries, health problems, etc…

Because there are different classes of forklifts, this case history will focus on counterbalanced, sit-down, pneumatic tire forklifts. An image of this type is found on the title page (Mitsubishi forklift trucks, 2010).

2. Human factors involved

- **Definition of human factors :**

"Human factors is the discipline that tries to optimize the relationship between technology and the human." (Kantowitz, 1983)

- The next list resume the principal human factors that must be solved when designing a forklift truck:

1. Whole body vibration (WBV): can cause lower back pain (LBP).
2. Visibility requirements: more that 80% of forklift truck-related accidents are caused by poor visibility (Collins el al., 1999 citeed in Chin-Bong et al., 2008)
3. The sitting posture: is also involved in LBP and neck problems
4. Dimensional requirements: related with the anthropometrics of the human body.
5. Design for hand/foot operation: driving system
6. Controls and display design: driving and fork controls systems
7. Fatigue: as a result of a good design in the previous factors, the fatigue can be minimized.

One of the problems that every designer encounters is that these factors are interrelated, what makes it more difficult to study.

3. Whole body vibration I

- **The problem:**

  ➢ Whole body vibration (WBV) is recognized as an important risk factor for occupational low back pain (LBP) in a variety of occupational groups (Bogadi-Sare, 1993; Brendstrup and Biering-Sorensen, 1987; Futatsuka et al., 1998; Malchaire et al., 1996; Pope and Novotny, 1993; Pope et al., 1987; Riihimaki et al., 1989; Wikstrom, 1993; Wilder et al., 1996 cited in Joubert & London, 2007).

  ➢ Low back pain (LBP) occurs frequently and is one of the most costly health problems affecting industry and society in all countries (Dillingham, 1998 cited in Shinozaki et al., 2001).

- **The risks:**

  Joubert & London (2007) and Barriera et al. (2008) state that operators exposed to driving forklifts are greater than twice the risk of those not exposed to driving forklifts to experience LBP.

- **Other factors involed:**

  WBV could be the principal factor to cause LBP, but not the only. Posture is also quite important. All the factors can be seen in Fig. 1

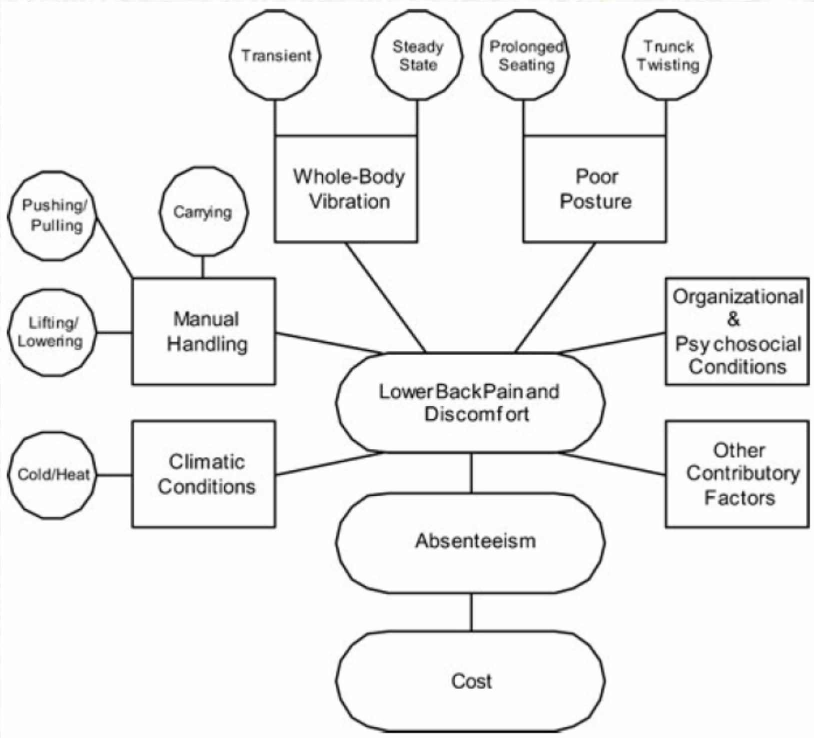


Fig.2 Contributory factors to LBP (Barriera el al.,2008)

3. Whole body vibration II

- **The analysis:**

➢ To study the vibration in the operators, acceleration should be measured in three orthogonal axis (x-fore and aft, y-lateral, z-vertical) under working conditions according to the recommendations of ISO 2631-1.

➢ The position of the driver also should be studied. To evaluate ride comfort the proposed indices could be used: mean personal rating (MPR), vibration number (VN) and k-value (Smith (1976), Kozawa et al. (1986), and Cucuz (1994) cited in Han-Kee & Du-Yoon, 2004)

➢ The most common research method used to study WBV is the cross-sectional type.

➢ To know the limit values for WBV the legislation where the forklift is going to be used must be taken into account. For example, in the UK, the exposure limit values and action values (legislation.gov.uk, 2010) for whole body vibration are :

(a) The daily exposure limit value (ELV*) is **1.15 m/s^2** A(8)

(b) The daily exposure action value (EAV**) is **0.5 m/s^2** A(8)

* ELV: is the maximum amount of vibration an employee may be exposed to on any single day (Health and Safety Executive, 2010).

** EAV: The exposure action value is the amount of daily exposure to whole-body vibration above which you are required to take action to reduce risk (Health and Safety Executive, 2010).

3. Whole body vibration III

- **The results:**

Because there are many cross-sectional studies about WBV in forklifts, here will see the results of two of them, each one studying a different issue related with WBV.

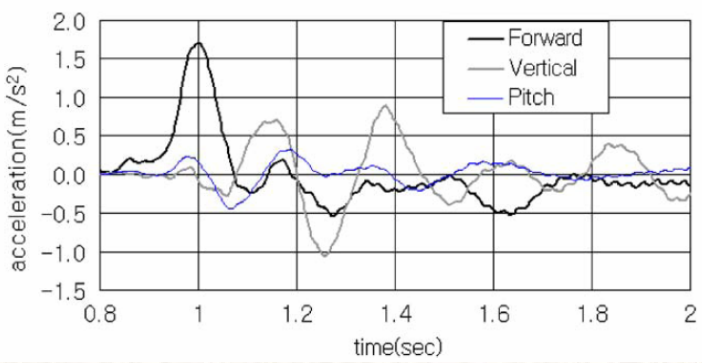


Fig. 3 Time histories of accelerations meassured in the three axes on the seat of the vehicle (Han-Kee & Du-Yoon, 2004)

- Fig. 3 shows the results Han-Kee & Du-Yoon (2004) obtained when they studied the start-motion quality in a forklift to create a procedure for developing the objective index for the estimation of subjective feeling of ride quality.

- Hoy et al. (2005) conducted a cross-sectional study to investigate the risk from WBV and posture demands for LBP among forklift drivers (Fig.4).

The results showed acceptable levels of vibration in the x- and y-directions(i.e., below the EU Physical Agents Directive on Vibration Exposure recommended action level—0.5 m/s^2), but not in the z-direction.

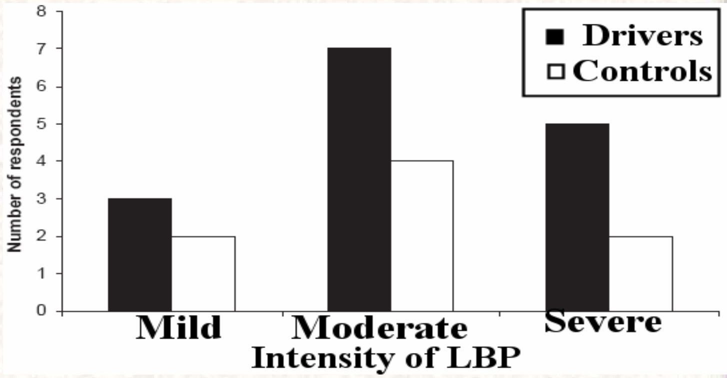


Fig. 4 Intensity of LBP for the controls (N=8) and the forklift drivers(N=15) (Hoy et al., 2005).

3. Whole body vibration IV

- **Ergonomic recommendations (Barriera et al., 2008) :**

Two different kind of solutions can be achieved to minimize the effect of WBV. The first one would be from the point of view of the design of the forklift. The second one are a list of the recommendations forklift drivers should follow.

- **Design recommendations:**

1. Use suspension seats
2. Use pneumatic tyres (may reduce the floor-induced vibration by up to 50%)
3. Electric trucks preferable than diesel
4. Smooth ground surfaces
5. >110° back rest, with a height between 29-35 cm from the Seat Index Point (SIP*)
6. Seat cushion front side at least 47cm, length more than 42 cm from the back rest, cushion angle between 8° and 13°, cushion softness with a depression of more than 2.7cm by 1.5 cm
7. Front seat rounded and with 30-50mm of clearance between it and the operator's knees

- **Forklift driver recommendations:**

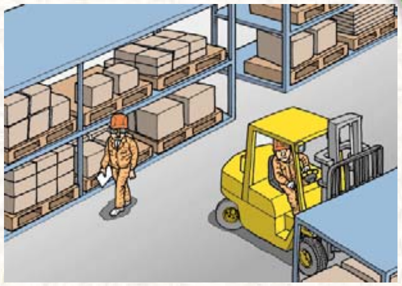
1. Avoid heavy lifting after driving
2. Walk for five minutes after WBV exposure
3. Variable posture

* SIP: intersection on the central vertical plane through the seat centerline of the threoretical pivot axis between a human torso and thights

4. Visibility I

- **The problem:**

➢ A forklift truck that has insufficient visibility can cause serious accidents. More than 80% of forklift truck-related accidents such as striking pedestrians or other vehicles,falling of ramp or a loading dock are caused by visibility problems (Collins et al., 1999 citied in Chin-Bong et al., 2008).



➢ Forklifts are design for forward driving. However, operators have to drive backwards usuallyWhen driving forklifts, the backwards driving is as important as the forward driving, however, they are design mainly for forward driving. Driving backwards for long periods of time can cause neck problems. The design must minimize this posiblity.

Fig. 4 (JORPOR, 2010)

- **The risks:**

➢ The principal risk would be a fatality. To illustrate the problem, nearly 100 workers are killed in forklift-related accidents every year in the United States (Bureau of Labor Statistics, 1998 cited in Horberry et al., 2004). In other cases they cause severe injuries, like a broken hip (Miller, 1988). Not all the accident are caused by visibility problems, but in many cases its a contributing factor.

Fig. 5 (Driving Lessons, 2010)

4. Visibility II

- **The analisys:**

➢ There are several techniques for measuring visibility (Cartesian reference frame, light beam capture, light beam emision…). Chin-Bong et al. (2008) applied and compared three different methods:

1. Light bulb shadow test, Fig. 6 (following standard of ISO/DIS13564-1 for traveling and maneuvering tests)
2. A manikin vision assessment test, Fig.7 (using CATIA V5R13 human modeling solutions).
3. An individual test, Fig. 8 (with six participants).

Fig. 6 Set up of the light bulb shadow test (Chin-Bong et al., 2008)

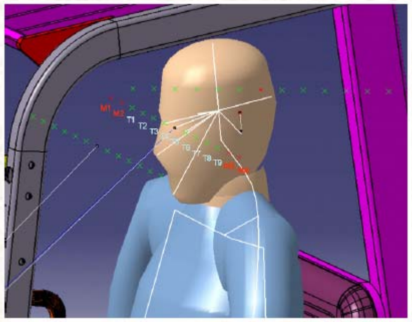


Fig. 7 Human and forklift models (Chin-Bong et al., 2008)

Fig. 8 Individual test (Chin-Bong et al., 2008)

➢ It was found that the design factors of load backrest extension, lift chain, hose, dashboard, and steering wheel should be the first factors considered to improve visibility, especially when a forklift truck mainly performs a forward traveling task in an open area

4. Visibility III

- **Recommendations:**

➢ To avoid neck problems, the operator should not rotate the head more than 20º to either side and tilted more than 5º up and 30º down (Barriera et al., 2008), Fig. 9.

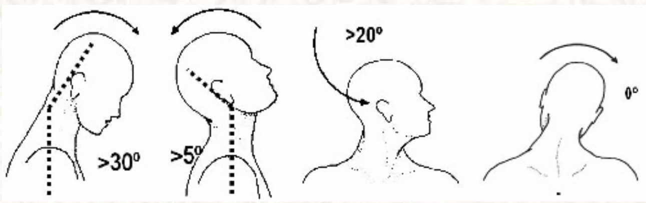


Fig. 9 Rotating angles to cause injuries (Vallejo, 2009)

A neck support system (Fig. 11) reduces neck strain caused by looking up for prolonged periods of time (Forklift Training Systems, 2010)

Fig. 11 Nek-Sav Neck Support System (Forklift Training Systems, 2010)

➢ A back-up handle to drive backwards can reduce back strain (Fig.13). The diver can activate the horn of the forklift without releasing the steering wheel. Operators who are required to travel in reverse often grab the overhead guard. This dangerous practice has resulted in serious injuries (Forklift Training Systems, 2010).

Fig. 13 Back-Up Handle (Forklift Training Systems, 2010)

➢ To facilitate backwards driving it is useful to allow the seat rotate between 15º and 20º. Other possibility is the rotation of the whole cabin, Fig. 10.

This measures decrease visibility problems and also incorrect neck and back postures.

Fig. 10 Rotating seat and cabin (Vallejo, 2009)

➢ Some mirrors, like the one in Fig. 12, can give 220º of vision and allows the operator to see everything around before backing up. This mirrors are useful, but they do not prevent looking backwards.

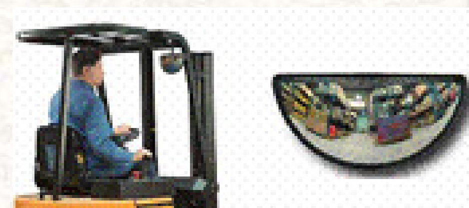


Fig. 12 Blind spot mirror (Forklift Training Systems, 2010)

➢ Studies in Holland have proven that Camera Systems (Fig.14) contribute to reductions in lost time and sick leave from neck and back injuries and they improve significantly the visibility of the forklift driver (Forklift Action, 2005)

Fig. 14. Forklift camera (Forklift Action, 2005)

5. Safety I

- **The problem:**

  - As it has been showed in previous sections the use of forklifts can cause fatalities, severe injuries, health problems, etc… This section will try to cover those aspects that are related with the safety of drivers and pedestrians which were not covered yet.

  - It can be differentiated between two different types of measures: external and internal.

- **Recommendations:**

  - **External measures:** can be defined as those safety measures that are not situated inside the forklift truck. The following measures are defined by Horberry et al. (2004).

❖ The best solution to avoid pedestrian accidents is design an environment where forklifts can never come into contact with pedestrians (Fig. 15).

Fig. 15 Computer generated image of a possible environment for forklift pedestrian separation (Horberry et al., 2004)

Because the previous situation is very difficult to create in existing factories other measures can be used to reduce the risk of an accident.

❖ Place barriers (physical or temporal) between forklift and pedestrians.

❖ Improve warning/markings, visibility and effective traffic rules, where forklifts and pedestrians traffic intersect.

❖ Use commercial safety products like the Mirror Alert (Alert Safety Products, 2002).

Fig. 16 Mirror alert (Alert Safety Products, 2002)

5. Safety II

➢ **Internal measures:** can be defined as those safety measures that are situated inside the forklift truck.

❖ The overhead guard (Fig. 17) prevents objects to fall on the driver.

Fig. 17 Overhead guard (Forklift Action, 2005)

❖ Sirens (Fig. 18) emit an optic and acustic to signal the position of the forklift.

Fig. 18 Siren (Perales, 2010)

❖ Forklifts are often used outside the factory. To protect from the sun light or the rain it is necessary the use of weatherguards or sunshades. (Fig. 19).

Fig. 19 Wheatherguards (UK BMB, 2010)

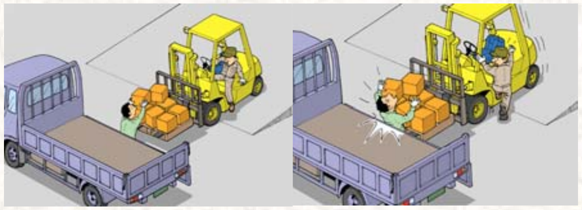


Fig. 20 (JORPOR, 2010)

❖ To prevent accidents like the one in Fig. 20. a dead man's switch system can be implemented in the seatbelt of the forklift. The function is showed in Fig. 21.

Fig. 21 Schematic view of the seatbelt system operation (Horberry et al., 2004)

❖ The seatbelt, used with lateral protections on the seat (Fig.22) can protect the driver if the forklift tips over.

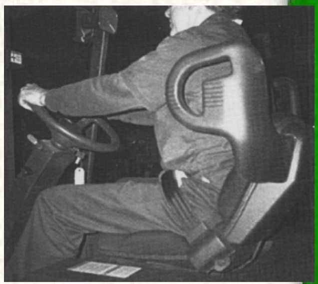


Fig. 22 Safeguards (Swartz, 1998)

6. Dimensional requirements I

- **The problem:**

➢ This section will deal with a combination of human factors. The different measurements of the operators (anthropometry), with dimensional requirements and the sitting posture. These factors operate together directly on the driver when he’s operating the forklift.

❖ Anthropometry: the space in the forklift has to fit different operators that would have different measures.

❖ Dimensional requirements: the forklift needs to have easy access to get in and out, so the driver does not twist himself.

❖ The sitting posture: needs to be comfortable for all the drivers, allowing easy reach of the controls.

A good combination of the previous factors can lead to more efficiency, less fatigue on the driver, less healthy risks and less risk of an accident.

- **Recommendations:**

➢ To ensure the best operation possible, the driver should be able to adjust the seat, the armrest and the steering wheel.

➢ On the right there is a video of how can be implemented the adjustment of the components. To begin the video just click on it.

Vid. 1 (YOUTUBE, 2010)

6. Dimensional requirements II

➢ The adequate access to the forklift is also important. A bad design could lead to ankle or knee sprain. It also could force the drivers to twist themselves when getting in the forklift. The following recommendations are needed for a good design (Vallejo, 2009):

❖ The step's height should not be more than 500 mm from the ground.

❖ The space for the foot in the step should be at least 200 mm.

❖ The step should have an angle of about 80º to help the position and balance of the driver.

Fig. 23 Forklift access (Vallejo, 2009)

➢ The method for getting in and out of the forklift is also important. Operator should be taught in this aspects when they receive the forklift formation.

Fig. 24 shows the proper method to get in and out of the forklift.

Fig. 24 Getting in and out of the forklift (Vallejo, 2009)

➢ The handrail is positioned in the front of the overhead guard (not confuse with the back-up handle to drive backwards, positioned on the back) to help the operator access the forklift:

Fig. 25 Handrail (Vallejo, 2009)

❖ They should not be position over a height of 1450 mm.

❖ The diameter of the handrail should be between 20 – 40 mm.

❖ The space around the handrail should be at least 75 mm.

7. Controls and displays I

- **The problem:**

  ➢ The operator of the forklift has to control the fork and drive the forklift; usually at the same time.

  The driving of the forklift involves many changes of direction, needs precision to control the fork and requires many controls to operate the forklift.

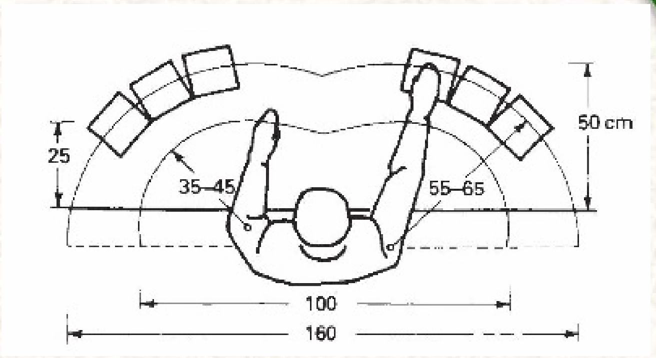


Fig. 26 Controls ubication (Vallejo, 2009)

- **Recommendations:**

  ➢ The display should inform about:


Fig. 27 Display (HYSTER, 2010)

  - ❖ Battery State of Charge Indicator
  - ❖ Low Battery Lift Interrupt Program
  - ❖ Hour Meter
  - ❖ Performance Mode Indicator
  - ❖ Fault Indicator

  ➢ The design of the display should be:

  - ❖ Easily reachable
  - ❖ Provide information at a glance
  - ❖ Easy to operate
  - ❖ Do not interrupt visibility

➢ At the sides of the steering wheel the shift lever and the light switch can be position.

This controls are similar to the ones used in the car. They can be operated just with one finger.

To design this controls, the location, mode of operation and size encoding methods should be used.


Fig. 28 Electric shift lever & Automotive style light switch (Toyota Lift of Minnesota, 2010)

7. Controls and displays II

- **Recommendations:**

  - The steering wheel:

    The diameter is smaller than a car's steering wheel, about 30 cm, to facilitate the large number of operations needed. Because the operator has to control the fork while driving and only can use one hand, it is quite useful the use of a steer assist knob.

Fig. 29 Steering wheel (FLEX Logistics, 2006)

Fig. 30 Forklift controls (FLEX Logistics, 2006)

Fig. 31 Forklift controls (Toyota Lift of Minnesota, 2010)

  - The controls for the fork:

    Traditionally, the control of the fork needs four levels, Fig. 30, (raise & low the mast, tilt the mast, move load left or right…) which are operated with one hand. New designs use mini levers or joystick hydraulic controls positioned in an armrest to easy operation, requiring less effort.

    The arm is always placed on the armrest while controlling the fork what can be translated into less fatigue, more productivity and more comfort. Other controls, like the horn, can also be position next to the levers/joystick.

  - The pedals:

    New forklift designs have a single pedal (Fig. 32) to quickly, easy and smooth change travel direction and control speed without removing hands from steering wheel or hydraulic controls.

Fig. 32 Monotrol pedal (HYSTER, 2010)

8. Other considerations

- **Local vibration:**

➢ In a previous section it was studied the whole body vibration. However, the operator is also subjected to local modes of vibration:

- ❖ Hand-arm vibration from the steering wheel
- ❖ Feet vibration from the pedals
- ❖ Head vibration from the seat

During the research done, it was not found any information about local vibration in forklifts. It could mean two different things:

1. Local vibration is not a problem in forklifts
2. More research in this field is needed.

Fig. 33 Local vibration (HYSTER, 2010)

- **Working environment:**

Fig. 34 Versaile operator convenience station (HYSTER, 2010)

➢ The operator's working environment is going to be the forklift, so they need some add-ons to perform their work more comfortable like cup holders or compartments for documents.

Air conditioning, heaters or sunshades can also improve the comfort of the operator.

Fig. 4 Overhead compartment

(Forklift Action, 2005)

9. Conclusions

- **Essentials vs luxuries:**

  - The design of a forklift involves many human factors. In some cases, there are not many studies about a particular issue so there are not much information about how it can be improved. However, in other cases, the designer has all the information he needs; so, why not all the forklifts follow the same standards?

  - The principal problem is which cabin features constituted essentials and which ones are luxuries. In whole body vibration, for example, there are many studies done that gives ergonomic solutions to minimize the problem. A good seat is obviously going to be better than a poor design seat; the problem is that the price of the good one is also going to be three or four times the poor one. Here we have another important issue: money. The are human factors that can be improved, but spend money is needed.

  - In other cases, is more difficult to differentiate what is an essential and what is a luxury. In some cases air conditioning and heaters could be consider as luxuries; but if the operator has to work in extreme weather conditions this features are going to be essentials.

  - The study of all the human factors involved is quite difficult. They are usually interrelated. Some of the factors are also difficult to study. In some cases, although it is know how to solve the problem, the solution could be expensive or in other cases very difficult to implement in the machine.

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