EVALUATION AND REDESIGN OF A PARTICULAR SELECTED ENVIRONMENT OR SET OF EQUIPMENT FROM AN ERGONOMIC POINT OF VIEW

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ABSTRACT
This research evaluated and proposed a redesign a pallet refurbishment company from an ergonomic point of view. Ergonomics is: “the science of fitting jobs to the people who work in them.” The aim of the project was to incorporate ergonomics into the system design and as a result, optimise the human well-being as well as the overall system performance. Various ergonomic assessments were performed. Passive and active surveillance was undertaken as well as obtaining information from group discussions and evaluating the training and awareness of the workers. The full system was evaluated, identifying ergonomic hazards, for example: lack of workstations, which formed the basis for the ergonomic redesigns. A final concept was chosen using a weighted evaluation methodology. The final design was fully specified and costed. The expected benefits were quantified and conservatively calculated to be: ±30 extra pallets could be refurbished in a day, leading to an increased profit of R10 362.60 a month. The return on investment was calculated to be 1604.8%, with a payback period of 2 months. The net present value was calculated to be R240 726.48 over a 3 year investment period. The utilisation of the entire plant could potentially increase from 66.25% to 91.25%.

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1 INTRODUCTION

Ergonomics is ‘the science of fitting jobs to the people who work in them’ [1]. Ergonomics traditionally focuses on creating and ensuring a safe work environment with easy to use equipment, and thus improving the efficiency of employees. The field focuses on items such as; design of workstations, controls, displays, tools etc. to meet the physical requirements, capabilities and limitations of employees [1]. It is a science that relies on continuous improvement of the work system and interaction between humans and their environment.

Company X is a family owned, pallet refurbishment company situated in Alberton, Gauteng. There were 8 employees working for the company at the time of the project. Company X operate on tight margins, in a competitive market with low barriers to entry. Company X experience both operating and capital constraints.

The objective was to create a work environment that catered for the employees’ safety and well-being as well as to improve the efficiency and performance of the organisation. The anticipated benefits driving the business case included:

- Lesson chance of injuries,
- Increase productivity through higher throughput,
- Decrease non-value adding activities such as: handling, searching for components, walking to material supply locations etc.
- Decrease lead times by evaluating the design of work organisation and shop floor layout,
- Lower cost,
- Increase accuracy,
- Increase employee morale,
- Improve employee engagement.

Therefore, the purpose of the project was to test whether ergonomics, a field of science traditionally used in high technology, capital intensive environments, could be meaningfully applied to a labour intensive, low technology and capital sensitive environment and be commercially viable.

2 LITERATURE REVIEW

Ergonomics focuses on three key areas, namely: person/people, job/task, environment. [2] The first focus area is the person/people performing the task(s). This area is divided into the physical and mental components of the employees, as well as evaluating factors such as the anatomical, biomechanical, psychological and physiological properties of the employees. The next focus area is the job/task. In this area, ergonomics assesses what the worker is doing, how frequently the worker is performing a task, the duration and intensity of the task, the objects involved as well as the required movements performed on the object. For example: is the object pushed, pulled, lifted? Physical attributes of the object, such as the shape, size and couplings are also evaluated. [2] The last focus area is the environment which is divided into two parts, namely the external and internal environment. The external environment looks at where the employee is working. For example, is the worker exposed to cold, direct sunlight, vibrations etc.? The internal environment is comprised of the work organisation, team work, safety culture etc.

Ergonomics is a unique discipline as it combines three fundamental characteristics [3]:

1. It has a systems approach,
2. It is design driven,
3. It focuses on two closely related outcomes; performance and well-being.

**Ergonomics takes a systems approach** - Ergonomics considers different aspects of the person and environment (as mentioned above), as a result of this, issues on multiple levels within the system can be identified and addressed [3].

**Ergonomics is design driven** - Ergonomics can be used in stages such as: planning, implementation, evaluation, maintenance, continuous improvement of systems, redesign and design etc [3]. Ergonomics is differentiated from other disciplines such as sociology and anthropology because of the design aspect [3].

**Ergonomics focuses on two closely related outcomes: performance and well-being** - The two mentioned outcomes influence each other. In order to ensure the success of both, they should be understood to be strongly connected and dependant on each other [3].

### 3 METHODOLOGY

The methodology used in this paper focused on the integration of ergonomics with lean principles. The focus was on incorporating ergonomic risk assessments with prioritization methods such as process mapping in order to select areas or processes for analyses. The ergonomic assessments were used to identify potential ergonomic and productivity problems and areas for improvement. By applying ergonomic design concepts to workstations and understanding how workers interact with their environment, tools, material etc. productivity can be improved and costs due to error, sick leave will be reduced.

“**Every system is perfectly designed to get the results it gets.**” [4] (1994) explains that the system design is often the aspect that needs changing; therefore a holistic view was taken when performing the analysis.

Initially, a set of criteria were established for the investigation and redesign and were as follows:

- Safety of the workers needs to be improved. The new designs should consider safety in more depth than the current state.
- Cost of the new design should be minimised as much as possible.
- The new design should improve aspects such as employee morale, employee engagement etc.
- Time spent by workers looking for raw material should be decreased.
- Reduce chances or likelihood of injuries.
- Design of workstations should minimise the time spent lifting, rotating or turning pallets (manual material handling).
- Design of workstations should minimise the likelihood of back, shoulder or ankle injuries or pain.
- Design of work organisation should allow for the ease of pallet transportation within the factory.
- Design of work organisation and work stations should minimise the time spent workers lift their hands above their crown (head) or shoulders while lifting pallets.
- The new design should facilitate an improvement in productivity by increasing the efficiency.
There were also some key constraints to the possible redesign:

- Company X operates under financial constraints.
- Capital constraints are present in the form of equipment and machinery.
- Labour intensive operations are required in the pallet industry.
- Lack of technology available to solve the problem of handling pallets by hand.

The investigation and evaluation of the company environment was done using the following techniques:

- **Passive surveillance** in the form of injury records, such as first aid reports, accident reports, workers’ compensation etc. [5] The goal was to assess whether such records existed, whether an awareness regarding a safe and healthy work environment existed, as well as to identify where the highest incidences of injuries were occurring, as well as the types of injuries.
- **Consultation** with employees and management staff, for example, informal discussions, group discussions etc.
- **Active surveillance**: Area inspections, walk through surveys, direct observations of workers.
  Techniques and tools such as: Body Part Discomfort Survey (BPDS) [5], Ergonomic Risk Awareness Assessment [5], Musculoskeletal Disorder (MSD) Hazard Identification Tool [6], Rapid Entire Body Assessment (REBA) [7], Hazard [8] and Caution [9] Zone Checklists and an Ergonomics suggestion box to involve all employees in the process and improve employee engagement.

4 EVALUATION OF ENVIRONMENT

4.1 Caution Zone Checklist

The first tool used was the WISHA Caution Zone Checklist [9]. This is used as a screening tool to determine if an activity has ergonomic stressors present for a sufficient duration of time to become a problem. The tool focuses on specific ergonomic stressors which included the following: awkward posture, high hand force, highly repetitive motion and repeated impacts. Workers were observed on various days, at different times while performing their tasks. (Please note: all assessments were done with the help of an ergonomist and an occupational therapist who specialised in ergonomics.) In this project, the caution zone checklist assessed the movements or posture required to perform tasks in the different work stations of the company.

The caution zone checklist identified that five out of six areas evaluated can be classified as “caution zones”.

4.2 Hazard Zone Checklist

After analysing the above mentioned checklist results, particular problem areas were identified. These were identified by using the Hazard Zone Checklist. This tool focuses on the detailed aspects of the actual tasks being performed, which included: gripping (pinch and power), force (lifting, lowering, pushing, and pulling), awkward/ fixed postures, repetition, as well as other hazards for e.g.: repeated impacts, contact stress, hand-arm vibration, whole body vibration, cold/ hot temperatures. The duration of the ergonomic stressors were taken into account. The problematic areas included:

- The current workstations. Workers have to put themselves in awkward postures in order to perform the tasks of the job. For example, workers have to work with their backs bent forward more than 45 degrees without any support or ability to vary posture.
It was identified that fine motor skills of the hands are not required for the job; however, high hand force in the form of gripping an unsupported object weighing more than 4.5kg occurs. The duration is more than 3 hours a day.

4.3 Musculoskeletal Disorder (MSD) Hazard Identification Tool

In order to validate the results from the Caution and Hazard Zone Checklists, a MSD Hazard Identification Tool [6] was used.

A simple equation can be used to explain what causes MSDs [6]:

\[
\text{Force + Awkward Position + Repetition + Long Duration} = \text{Increased MSD Risk}
\]

Similar results were seen from this investigation. The results showed that workers are required to lift and lower loads in such a manner that have a high possibility of causing work related MSDs.

4.4 Rapid Entire Body Assessment (REBA)

REBA focused on the postural analyses of the workers, both static and dynamic. REBA allowed for the objective measure of the MSD risk caused by tasks. Tasks that involved the whole body could be assessed, therefore making it applicable to the pallet industry. The MSD hazards considered included: force, posture, repetition and duration.

Different ergonomic stressors are given different scores, for each part of the body. While observing the workers, the scores are allocated according to a predetermined table and set of rules, giving an outcome of a “REBA score”. The REBA score gives an indication of the severity of the current state/work environment. The REBA score was 15, thus placing it in the category of “11 and above”, making it a very high risk environment - where change needs to be implemented.

4.5 Body Part Discomfort Survey (BPDS)

Different workers from the three different workstations completed the survey. The workstations were: pallet stripping, pallet repairs and pallet spraying. Workers were asked to give each body part a discomfort score as well a score indicating how often the discomfort was experienced. This was done at the end of the work day. The survey focused on fine detail, including scoring the left and right hand side of the body separately for each body part where applicable.

This tool involved the workers in the process, therefore aimed at improving worker engagement. All surveys reflected similar results, showing workers experienced discomfort at the end of the work day in three major muscle groups, namely: back (lower and upper), shoulders and neck.

Discomfort can be a precursor to injuries, therefore the BPDS allowed for the ergonomic hazards to be addressed before injuries occurred. The advantage of the BPDS was that it revealed discomfort that may not lead to specific injuries or cause workers to take sick leave. For example; standing for prolonged periods of time causes discomfort to the knees and legs but may not appear in injury statistics. Although they do not appear in injury statistics, they need to be addressed as they could potentially affect work performance.

Other assessments were conducted which included: group discussions, assessing the workers’ ergonomic risk awareness knowledge as well as direct observations in the different work stations. The observations identified factors such as: no work rotation, lack of workstations, debris filled walkways, constant bending, twisting and working off ground level, poor ventilation and insulation, noise pollution, poor lighting, close proximity of workstations, slip, trip and fall dangers, ineffective use of personal protective equipment (PPE) etc. These assessments indicated similar results and thus a trend of ergonomic hazards and work-
related MSDS were identified, leading to a further investigation incorporating different tools. These tools included (please note these are select examples of tools used):

4.6 Value Added and Non Value Added Activities

The avoidable non-value adding activities included:

- Workers walking from one workstation to the next (±12m), located on opposite sides of the factory, to fetch raw materials.
- Transporting the pallets from the back of the factory to the truck parked 10-15m outside the factory, and ±37m from spraying department.
- Unnecessary manual material handling at repair and stripping work stations. This leads to fatigue, increased risk of developing work related MSDs and time wasting due to inefficiencies.

Figure 1 shows a spaghetti diagram of the flow of products in the factory. Please note the diagram is not to scale.

![Spaghetti diagram showing current state](image)
4.7 Process Mapping

Figure 1 shows the movement of the pallets within the factory. One can see there was not a systematic flow as pallets moved from one side of the factory to the other, on various occasions (positions: 1-2; 4-5 and 5-6 as seen in Figure 1) leading to the waste of unnecessary movement. Figure 2 shows the processes that each pallet went through. As seen in Figure 1 and Figure 2, activities leading to inefficiencies and time wasting included:

- Finished goods travelling from the back of the factory from the spraying department to the truck parked outside ±37m away,
- Excessive Manual Material Handling,
- Repairers looking for and walking to the raw material location,
- Nail gun constantly jamming due to insufficient training,
4.7 Cause and Effect Diagram

The cause and effect diagram in Figure 3 shows the likely causes of MSD hazards present identified using the MSD Hazard Identification Tool, consultation with workers and management staff as well as direct observations of the shop floor.

![Cause and Effect Diagram of Possible MSD Hazards](image)

**Figure 3: Cause and effect diagram of possible MSD hazards.**

The ‘Human’ elements were aspects such as insufficient training. Insufficient supervision allowed the workers to not always wear their PPE, and thus sustaining injuries as a result. Production pressures placed upon the company by their customers, made the workers work longer days and take fewer breaks. The lack of action once a worker reports a work related MSD decreases employee morale and engagement as well as demotivates the workers from reporting in the future.

Under ‘Equipment’: it was seen that there was no set area for the workers to rest while on their tea or lunch breaks. Workers either sat on the floor or on the finished goods waiting to be delivered. The maintenance of the hammers and PPE needs to be improved with the hammer having lost the entire rubber lining on the handle.

As stated above these are select examples, other tools used to complete the investigation included:

- **5S** - the tool was used to achieve the goals of:
  - Reduction in waste and variation,
  - Improved productivity.

- **Ohno’s 7 wastes** - the following wastes were identified:
  - Waste of Waiting,
  - Waste of Unnecessary Motions,
  - Waste of Unnecessary Inventory.

- **Matheson Scale of Physical Demand and Work Classification** - this provided a guide as to how much the workers should be lifting, according to the characteristics and classification of the work. It was seen that workers should not lift loads of ±9.1 - 22.73kg, 34 - 66% of the day. Observations indicated that this does occur. (Pallets weigh roughly 20 - 22kg)
Time and Motion Study - factors such as the following were identified as contributors to time wasting:

- Moving stack of broken pallets,
- Clearing walkways,
- No supervision,
- No seating,
- Twisting, lifting and turning of pallets etc.

5 FINAL DESIGN

Three possible solutions were developed to address the problems identified. When developing the design concepts, the DuPont model was referred to. The DuPont model states that any business can do three things in order to make more money, namely: (1) increase the revenue, (2) decrease the costs, (3) improve the asset optimisation. For this project, the third case will most likely be the most applicable. All concepts were fully specified and costed. Each made use of different strategies to determine the best design for the company. The concepts were compared with the requirements and constraints initially formulated. Once the concepts conformed to these, they were compared using the criteria gathered from the initial investigation. A weighted evaluation system was then used to determine the most appropriate design that catered for the majority of the company’s constraints and requirements. This ensured the final design was aligned with the customer’s needs. The final design aimed at combining ergonomic principles as well as industrial engineering tools and techniques.

Examples of general recommendations included:

- Replace all worn out personal protective equipment (PPE) and supply earplugs, goggles etc.
- General resting area. Comfortable chairs and tables should be available when workers are on their break. Workers sat on the floor or broken pallets which added to the discomfort identified through the assessments.
- Replace burnt out lights. (Two lights were currently working in the factory at the time of the project.)

Further softer side of the analyses recognised the need for:

- Job rotation. This would increase the stimulation of workers as well as distribute the physical labour in a more fair way. By rotating the jobs, the possibility of developing work related MSDs decreases as workers are exposed to different tasks, and thus the frequency of the potential hazards decrease per person.
- Developing a safety culture. Includes the increase in supervision as well as PPE usage.
- Training of the workers in the correct method of lifting heavy weights without the aid of couplings as well as the correct stretches in order to warm the muscles up, especially in winter. The work requires a jerky motion, stretching would alleviate muscle pain as well as the possibility of pulling a muscle. The training would be conducted by an occupational therapist specialising in ergonomics.
- Incentives and appraisals. In order to motivate the workers, incentives and appraisals are suggested. On average, the workers earn between R96 to R100 a day. Therefore, if they achieve their target set by quantifying the benefits of the final concept, they will get 15% of their daily rate (±R15) as bonus. If they achieve more than this target, each worker will earn R1.50 a pallet.
Leadership rotational program. This aims to improve employee engagement and promote self-directed workstations as well as increase the accountability of the workers.

Examples of suggestions regarding the workstations included:

- A rack step for the sprayer in order to reach the top pallets. Currently the worker would stand on old paint cans which were dangerous and unstable.
- Rotation tables. A variety of MSDs would be addressed and reduced by introducing a rotating table. Strain placed on workers' backs, necks and shoulders would be alleviated. Research shows that forward functional reaching should be kept to within roughly 43cm from the front of the body [10]. As soon as the reach exceeds this amount, the shoulder and back muscles are stressed. The use of a rotating table allows the workers to rotate the pallet to the area that needs repair, reducing the reach distance. [10]
- Standing workstations were recommended in the stripping department. Sitting workplace is suggested for the stripping department and sit/stand workstations and rotation tables for the repair department. Please see Figure 4 for an example. The respective heights relating to Figure 4 (as seen in the figure marked A - H), are further detailed in table 1.

![Figure 4: Sit/stand workstations (left) and sit workstations (right). [11]](image)

Table 1: Height ranges relating to workstations. [11]

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<tbody>
<tr>
<td>A</td>
<td>45 - 91cm</td>
<td>E</td>
<td>86 - 91cm</td>
</tr>
<tr>
<td>B</td>
<td>45cm</td>
<td>F</td>
<td>213cm</td>
</tr>
<tr>
<td>C</td>
<td>15 - 23cm</td>
<td>G</td>
<td>45 - 60cm</td>
</tr>
<tr>
<td>D</td>
<td>17 - 23cm</td>
<td>H</td>
<td>74 - 76cm</td>
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To improve the flow of products in the factory, some of the following suggestions were made:
- **Demarcate walkways and aisles** according to the NIOSH standards. The minimum clearance for aisles and corridors for two persons passing should be: 137cm and for a two-wheeled hand truck such as the pallet jack: 76cm. [12]

- **Process layout** of workstations. The principle of process layout is to minimise the distance between the departments, avoiding long distance movement of materials, as well as arranging the departments in sequence of operations. [13]

![Diagram of process layout](image)

**Figure 5: Process layout for final concept.**

As seen in Figure 5, the new proposed process layout includes the truck coming into the factory, using the available ramp. The pallets will then be offloaded; one by one they will be stripped, then moved to the repair department, and finished in the spraying department, where they could either be loaded immediately, or wait in the area to the left of the truck.

The advantage of the new layout is: the spraying department is close to the entrance, therefore increasing the ventilation of the factory. The stripping department, where the most dust occurs, is situated near the other entrance of the factory (at the back), thus adding to the ventilation. The proximity of workstations is also addressed, as the spraying department is removed from the other departments. The compressor cord will not need to span the entire factory floor thus reducing slip, trip and fall dangers. The repairers will be given a box, so they can fill it up with slats of wood, bearers etc. that they will keep close to their workbench. This will eliminate the majority of movement occurring in and around this work area. Currently, they have no means to carry more wood or bearers than what they can physically carry.

6 **BENEFITS CASE - QUANTIFYING THE BENEFITS**

In order to build the benefits case, the expected benefits should be quantified. A conservative factor of 25% was applied in order to increase the validity of the results and ensure that the cost benefits case will materialise.

From the expected time savings due to the increased efficiencies of the final concept, it was seen that 1296 minutes will be saved in a day. This value is the sum of all the time savings for all 8 workers. No double benefits were added to this figure. Therefore, in order to express it in terms of plant capacity: this translated to roughly 30 extra pallets to be refurbished in a day.

6.1 **Utilisation**
Referring to the utilisation of the total plant, one will look at both the availability and the utilisation thereof.

The utilisation of the plant was negatively impacted by a number of inefficiencies ranging from: insufficient training, undue fatigue, lack of flow of products, wasteful micro-movements, excess manual material handling etc. and on average reduced available plant capacity by 2 hours per day. The current utilisation of the plant was ± 66.25%.

The chosen design would potentially increase the utilisation to ±91.25%

6.2 Feasibility Study

In order to ensure the financial validity of the design, the net present value, return on investment (ROI) as well as payback period were calculated and are seen in Table 2:

<table>
<thead>
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<th>Table 2: Feasibility Study.</th>
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<tr>
<td>Net Present Value</td>
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<tr>
<td>Return on Investment</td>
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<td>Payback Period</td>
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7 PROJECT SCHEDULE

Change management is important when many different aspects of the business are changed or modified. Effectively, all three aspects of the company, namely: people, process and technology were adapted or changed to a certain degree. People don’t always accept change, which is why all attempts were made to include the workers in the process. For this reason, the changes will be implemented on a staggered basis using the concept of change management.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusion

- The chosen environment was the pallet refurbishment company - Company X. Before the investigation, it was understood that small companies operating on tight margins struggle to identify ergonomic hazards and maintain safe work environments. Currently, there is a lack of available technology to make the pallet refurbishment sector a safer sector of industry.

- Various ergonomic assessments were performed.

- From the assessments, ergonomic hazards were identified, therefore warranting the need for ergonomic designs as well as a further investigation into the environment, using industrial engineering techniques and tools.

- The expected benefits of the final concept were quantified and found to be: ±30 extra pallets would be refurbished in a day, leading to an increased profit of R10 362.60 a month. The ROI was calculated to be 1604.8%, with a payback period of 2 months. The NPV was calculated to be R240 726.48 over the 3 year investment period.

- The utilisation of the entire plant could potentially increase from 66.25% to 91.25%.

- A Pareto analysis was undertaken when dealing with the two products - major and general repairs. It was identified that the general repairs are the more profitable product, where the major repairs are currently running at a loss. More money can be made with the general repairs, therefore the focus should be on this product.
• The chosen concept shall be introduced on a staggered basis, using the concept of Change Management.

In conclusion, “A clean and safe environment is a productive environment.” (Anonymous)

8.2 Recommendations for Future Work

• The last S in the 5S is for Sustain. It is crucial to sustain the principle of 5S on an ongoing basis. This also follows the principle of continuous improvement by Dr. E. Deming. Therefore, planned maintenance every Friday afternoon is suggested. The workers finish at 2pm on Fridays, therefore, if 15 minutes to half an hour is spent tidying up, making sure slats of wood are in the correct bins or positions, nails have been picked up etc. the new week can begin with a tidy workplace.

• To evaluate the success of the leadership program. If the workers respond well to the program, it should continue. However, if the workers do not respond well and the aim of increasing employee morale and engagement fails, the second option is to get the workers to appoint a leader who will act as the foreman. The communication channel will work through the foreman as a result.

• The competitive analyses showed that companies that refurbish pallets are able to do it at a cheaper rate than Company X. The reason being: they repair on the client’s premises. This idea should perhaps be further investigated by Company X. It is a viable option as Company X only serves a single customer. This would eliminate overhead costs such as rent as less space would be needed. Transportation costs to and from the factory would also be reduced. The alternative of this option is also worth investigating. Company X can look to acquire customers who have space constraints, and don’t have premises available for companies to use to repair their pallets.

• Exploring the option of working two Saturdays a month. It was discussed with the owner, that if more pallets can be repaired in a day, the client is able to send more pallets. (The client’s reserves of broken pallets is vast) Therefore, if the workers come in for two Saturdays a month, working 4 hours, a profit of R2 866.60 can be made.

9 Acknowledgments

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10 References


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