Journal of Engineering Science and Applications (JESA)

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2. Authors should submit three (3) copies of each manuscript, neatly typed double spaced on one side of a good quality paper (A4 – 210x297mm) with at least 3cm margin, on the left hand side and top and 2cm for the other sides. Tables should be typed with double spacing and should be provided with appropriate headings. Figures should be drawn in black and photographs should be of good quality. The system international (SI) units should be used for all scientific data. Captions for Tables shall be at the top but captions for Figures and photographs shall be placed at the bottom. When the paper is accepted, a C.D. of the paper in Microsoft word should be submitted along with a printed copy of the revised version of the paper.

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4. In the text, references should be cited by consecutive numbers in square brackets []. References should include the author’s name, (surname precedes initials), year of publication (in parenthesis), title of article, name of publication (abbreviated in accordance with the fourth edition of the world list of scientific periodicals), volume number, first and last paper page numbers. References to books should include in addition, the editor’s (editors’) name(s), where applicable, the edition number, the publisher name and place of publication. Where there are more than three authors, only the first author’s name followed by et al. should appear in the text. The page(s) referred to should be indicated after the year.

5. Submission of manuscript with a non-refundable processing fee of ₦3,000 per manuscript should be directed to:

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An Imperative Ergonomic Evaluation of the Nigeria Banking Operations and Analysis for Identifying Cumulative Trauma Exposures in the Office Man Machine Interaction

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Abstract—The use of computers has resulted to physical disorder by operators ranging from simple fatigue through musculoskeletal disorder to permanent disabilities. The most common office-related physical disorders are: lower back strain, Carpal Tunnel Syndrome, tennis elbow, waist pain. The purpose of this study is to identify office-type ergonomic risk factors facing certain employees in the banking operation, and to develop a problem evaluation and analysis to be used in reducing Cumulative Trauma Disorder symptoms and lower back pain experienced by these employees while the goals are to: (1) identify the risk factors facing bank employees by the continued usage of computers and other equipment in the office environment, and (2) to administer an employee symptom survey, along with a job station analysis. Decision-making information was gathered by administering symptom surveys from the ailing employees, as well as collecting measurements of the workstation design/layout. The input given from the employee filling out the survey showed the type, location, nature, and severity of the strain or sprain. The risk factors gathered from complaints identified focus areas needed to prevent and control loss-producing exposures/risks. With the consistent and thorough identification of CTD exposures in the office setting, it is anticipated that the company’s employees will be able to develop an action plan to reduce or minimize the identified exposures.

Keywords: Cumulative trauma disorder, Disability, Lower back pain, Musculoskeletal disorder, Operations

1. Introduction

In today’s contemporary society and workforce, the use of computers has resulted to physical disorder by operators ranging from simple fatigue through musculoskeletal disorder to permanent disabilities (Pasher, 1997). The most common office-related physical disorders are: lower back strain, Carpal
Tunnel Syndrome, tennis elbow, waist pain etc. The aggravation of such disorders further increases with the constant utility of the office desk/chair set-up and the man machine interaction arrangement and design. Ergonomics as a discipline is designed to address and mitigate such issues by examining the relationship between man and their workstations.

The banks are a finance office and business system with over 20 employees. In the various positions, associated employees are required to spend a large amount of time interacting with computers, as well as on the telephone, while seated in their respective cubicles. As a result of these activities, there have been a growing number of complaints, especially from one employee, concerning the occurrence of pain in her lower back area, wrists and neck.

Claims of musculoskeletal injuries now often include those that involve repetitive hand and wrist injuries from working at computer workstations - such as the highly publicized carpal tunnel syndrome, and neck, arm, shoulder and back injuries (Pasher, 1997). Cumulative trauma injuries, stress/strain injuries and associated disorders are a prevalent force in the world of work today. For employees and their firms, this area is remembered in two words only: pain and cost. Claims of eye injuries that may be caused by work at visual terminals, such as eye-strain, are becoming more prevalent as well (Pasher, 1997). This type of loss that results in a worker compensation claim represents a "sunk" cost, where there is little or no utility value for the company on this type of cost. Productivity loss, morale, and humanitarian issues come into play if proactive measures are not taken to prevent this static loss.

1.1 Overview of Cumulative Trauma Disorders and Lower Back Strain

Work-related musculoskeletal disorders (WRMD’s) are now recognized as a major occupational health problem and are linked to jobs that are repetitive, require high focus, and require continuous or repeated extreme or awkward postures (Jones, 1998). The Labour Statistics reports that upper extremity CTDs accounted for almost 60% of the 332,000 new cases of occupational illnesses reported in 1990 (LeBar, 1992). The number of office ergonomic-related claims and their associated costs had doubled between fiscal years 1994 and 1995 (Conway, 1998). These claims included repetitive motion, cumulative trauma disorders and injuries caused by improper workplace ergonomics, as well as improper lifting techniques. The bulk of worker compensation payments (75-85% in many companies) are spent for CTD lost time, medical, and disability costs. This does not take into account low-back pain, which is often a symptom found in conjunction with CTD’s.

A significant reason for the large increase in CTD’s is the increased pace of work, along with the growing interaction with computers. This type of movement may be performed as many as 25,000 times in a workday, despite fatigue (Luopajarvi, et. all, 1979). Many people interact daily with computer keyboards and until the late 1800’s, office work assumed a very small role for most businesses (Lueder, 1991). Workers in the 1980’s witnessed the onslaught of the personal computer into the workplace. In the last ten years, no other form of technology has come close to matching the impact that computers have had on the Nigerian labour force. By the end of 1990, nearly 10 million people will conduct their work using personal computers (Wallin, 1994). Not surprisingly, the increase in computer usage has led to an increase in reports of operator stress problems related to keyboard entry.

The first hazard Ramazinni mentioned could be explained today as exposure to hazardous materials in the field of industrial hygiene and environmental control technology (Putz-Anderson, 1988). The second hazard Ramazinni describes as “irregular motions and unnatural postures” is
equivalent to the current problem of cumulative trauma disorders (CTD’s). Until recently, CTD’s attracted very little (if any) attention from the public or employees, much less any regulatory interest (Courtney, 1998). However, there is sufficient documentation from early medical records that indicate that CTD’s were present.

Recognition that work may adversely affect health was recorded more than 200 years ago by an Italian physician, Bernardo Ramazinni (Putz-Anderson). He identified two types of workplace hazards: the “harmful character of the materials handled” and the “certain violent and irregular motions and unnatural postures of the body, by reason of which the natural structure of the vital machine is so impaired that serious diseases gradually develop therefrom” (Putz-Anderson, 1988).

The review of past medical records show that experienced tradesmen suffered from a variety of musculoskeletal disorders (Putz-Anderson, 1988). Often ailments were named after the profession or trade; i.e., “bricklayers shoulder”, “carpenter’s elbow”, “stitcher wrist”, and “game keepers thumb” (Hunter, 1978). The primary obstacle that contributed to the lack of awareness or concern by the public (or employers) in the past was the lack of reliable measurement and proper documentation of these disorders (Putz-Anderson, 1988). These types of disorders are tracked far more efficiently today than in the past, which were drawn from data bases not designed for this type of information, and consequently provided only limited insight into the CTD problem. These reports combined with the findings from the individual work sites, office work sites, clinics, etc., do suggest that the hazards described in Ramazinni’s work as “irregular work motion or unnatural postures of the body” account for an increasing amount to lost work time (Putz-Anderson, 1988).

One may ask what this leading cause of human suffering and loss of productivity is on our compensation systems. Cumulative trauma, or repetitive motion disorders are diseases of the musculoskeletal and nervous system which may be caused or aggravated by repetitive motions, forceful exertions, vibration, mechanical compression (hard and sharp edges), sustained or awkward postures or by exposure to noise over extended periods of time.

CTD’s can affect nearly all tissues including the nerves, tendons, tendon sheaths, and muscles, with the upper extremities being the most frequently affected. These painful and sometimes crippling injuries develop gradually over a period of weeks, months, and years, and result from repeated actions such as twisting and bending the hands, arms, and wrists (Putz-Anderson, 1988). A common risk factor among these disorders is the use of force combined with repetitive motion over time. The most common occupational illnesses associated with CTD’s are tendon disorders such as tendinitis, tenosynovitis, DeQuervain’s disease, trigger finger, Raynaud’s syndrome and carpal tunnel syndrome (Putz-Anderson, 1988).

The total number of recorded cases of repetitive motion injury has increased from 34,700 cases in 1984 to 332,000 cases in 1994 and represents nearly two-thirds of all workplace illnesses. These disorders include tenosynovitis, carpal tunnel syndrome, tendinitis, epicondylitis, and others. Currently, cumulative trauma disorders are considered the most costly and severe disorders occurring in the office work environment (Gerard, 1996). Because office workers may spend several hours at their work station, poorly designed equipment and workstations can create fatigue, discomfort, musculoskeletal stress and/or mental stress.

Occupational back injuries are a major problem in Nigeria (Imaekhai, 2010). Aching backs area medical providers’ Valhalla. As much as N100 billion each year is spent treating low back pain.
Medical experts believe that while low back pain may manifest itself suddenly, it actually develops slowly over time for the vast majority of sufferers. Some 80 percent of Nigerians will experience at least one bout of low back pain before the age of 65 (Imaekhai, 2010). Researchers like Stover Snook, Ph.D., Assistant Vice President and Director of Laboratories at Liberty Mutual Research Centre for Safety and Health, admits that they cannot pinpoint the cause of back pain. They do not know if it originates in the muscles, vertebrae, ligaments, or discs of the back. They do not know that the effects are cumulative, becoming more apparent as we age (Smith, 1996). Thus, while low back pain might be an inevitable condition for most of us, low back disability is not.

Low back pain can be triggered by jobs which involve repetitive motion and tasks such as lifting, bending, and stretching. Redesign of the job or workstation when repetitive motion is a problem can greatly reduce strain on the lower back. Employees who fall out of that range could potentially have a problem. Another mistake that is quite common for low back pain is when companies buy the same chair for all employees, even though people come in all heights and sizes.

2. Methods

The purpose of this section of the study is to evaluate banking operations with regard to the potential risk factors associated with the development of office employee cumulative trauma disorder related injuries. Although there is a fair number of assessment tools on the market intended to identify, address, and correct repetitive motion injuries, many are time-consuming in nature and are not designed specifically for evaluating the ergonomic safety of the office workplace design. Despite the increase in CTD injuries in office employees, little attention has been given to addressing office safety in a swift and efficient manner that meets the customer’s needs. Using the symptom survey feedback form as an independent standard, comparative analysis was performed between the reported ailments and the desktop design and layout. Banks were evaluated and utilized for this study. This business was selected due to the fact that two employees have been experiencing physical ailments, ranging from neck strain/eye strain, to lumbar and wrist discomfort. The workstations located there are all standard issue, generic in design, and easily accessible through any office product catalogue. Because of their limited ability to be adjusted, accommodating all sizes of people can be difficult.

2.1 Data collection

The methods used to obtain the data are: task analysis, symptom survey (ANSI, 1994), diagram of original workstation, and Boise-Cascade Product Catalogue. Decision-making information was gathered by administering symptom surveys from the ailing employees, as well as collecting measurements of the workstation design/layout. The input given from the employee filling out the survey showed the type, location, nature, and severity of the strain or sprain. This study has attempted to design an evaluation and analysis using the following procedures.

(a) Reviewed loss control data to determine the nature and extent of past ergonomic-related losses (if any) and current complaints voiced by employees.
(b) Review OSHA 200 logs (if applicable)
(c) Determine associated injury/illness costs
(d) Consulted with employees
(e) Identified CTD and lower back strain as a source of employee complaints.
(f) Obtained management support
(g) Define evaluation guide goals
(h) Review CTD costs
(i) Review evaluation and analysis program goals
(j) Develop an evaluation and recommendations for banking operations
(k) Reviewed related literature critical to evaluation development
(l) Cumulative trauma disorders
(m) University of Wisconsin-Stout Library
(n) Analysed collected data to determine whether or not realistic recommendations could be made for improving the design/activities of the office from an ergonomic standpoint.

3. Results and Discussion

This section describes the result of data that was gathered in order to administer recommendations and arriving at conclusions for banking operations.

3.1 Task Analysis

A task analysis was implemented for this particular employee. A task analysis (or worksite analysis) is used to make determinations of whether or not there are problems. Various tasks were identified that were found to be repetitive or adverse as far as posture and reach were concerned. Table 1 shows the breakdown of the daily tasks and risk factors associated with a typical day for the employees during the week. It was found that many times, employee 1 would be making more than 25 outgoing calls and receiving over 25 incoming calls a day. This, in conjunction with spending approximately 85-90% of her time working on her computer, helped us identify reasons for her various plans and discomforts.

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<tr>
<th>Daily Task</th>
<th>Risk Factors</th>
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<td>Pick up phone and check messages</td>
<td>None</td>
</tr>
<tr>
<td>Start-up computer and check daily planner</td>
<td>None</td>
</tr>
<tr>
<td>Attend any morning meetings</td>
<td>None</td>
</tr>
<tr>
<td>Start placing outgoing calls (20-25 a day)</td>
<td>Repetitive motion, posture</td>
</tr>
<tr>
<td>Mail marketing correspondence</td>
<td>Repetitive motion, posture</td>
</tr>
<tr>
<td>Fax any marketing correspondence</td>
<td>None</td>
</tr>
<tr>
<td>Receiving calls (15-20 a day)</td>
<td>Repetitive motion</td>
</tr>
<tr>
<td>Assembling marketing follow-up folders</td>
<td>None</td>
</tr>
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3.2 Symptom Survey

Employee 1 was asked to fill out a very thorough symptom survey. The survey was borrowed from the ANSI Z- 365 Standard on Cumulative Trauma Disorders. It was determined from the feedback on the survey that there was a range discomfort. It was important to note on the survey the various shaded areas on the human body where the employee was feeling pain and the frequency of said pain/strains. Based on the overall responses, the results indicated that employee 1 not only felt physically exhausted after work, but often felt pain and discomfort that the employee believes is related to work. The symptoms of pain have been apparent for over a year, according to the feedback on the survey.
3.3 Organised workstation
Measurements were taken at various points to assist in identifying areas with a potential for adverse ergonomic concerns. Some measurements taken that are of issue were the distance of the mouse in relation to the user’s reach, the height of the monitor, and the distance between the employee and the computer printer and paper trays.

3.4 Boise-Cascade Product Catalogue
As for costing resources, the Boise Cascade Office Products catalogue was referenced. It is a 1999 publication that furnishes ergonomic products that are very comprehensive in terms of content. A basic listing of the equipment includes: multi-functional chairs, articulating/ergonomic keyboards and mouse drawers, foot turtles, copy stands/glare reducers, monitor risers and adjustable desks. Everything that would be recommended with respect to equipment specifications and selections were concerned. Price, warranty, and quality were all factors considered when choosing this reference guide.

4. Conclusion
The symptom survey developed by ANSI was administered. The survey is thorough, practical and easy to put into practice. The survey divided the human body into various body part areas; each with its own column. The risk factors gathered from complaints identified focus areas needed to prevent and control loss-producing exposures/risks. With the consistent and thorough identification of CTD exposures in the office setting, it is anticipated that the company’s employees will be able to develop an action plan to reduce or minimize the identified exposures. With this in place, it is expected that the proper identification of office CTD's and the follow-up plan to address these exposures will be reflected in a reduction in the client's yearly Workers' Compensation claims.

References


The Imperativeness of Production Ergonomics in Development and Operation of Production Systems

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Abstract—Elimination of ergonomics in production systems can cause musculoskeletal disorders (MSDs), and man machine conflicts in the interaction between man and machine. This conflict has over the years not favoured man as machine is always had undue advantages putting man’s life in total risk. This paper presents an action research project that was initiated, with the same engine manufacturer, to integrate ergonomics into regular development work. The change process was slow and marked by setbacks, caused by both individual factors (e.g. disinterest, changing jobs, illness), and organisational factors such as intergroup communication barriers and short project timelines that limited uptake of new approaches. Despite these setbacks the resolute production manager, acting as a “political reflective navigator”, was able to establish credibility, overcome resistance, and begin to integrate ergonomics into regular developmental processes. The process remains slow and is vulnerable so long as the manager is navigating alone. Workplace risk factors can be precisely and accurately quantified. These risks are embedded in strategic choices in the design process. Load amplitudes were determined by workstation layout and the material supply sub-system. Risk related to the pattern and duration of loading are determined more by flow and work organisation elements. Psychosocial risk factors appear to be affected by a combination of system design elements. Managing the emergence of these risks proactively requires attention to ergonomics throughout the design process, especially in strategic choices. Integrating ergonomics into early development stages implies changing roles for groups and individuals in the organisation. This approach appears feasible but is difficult and remains an under-utilised strategy for sustainable competitive advantage.

Keywords: Ergonomics, Man machine conflict, Manufacturing, Musculoskeletal disorders, Organisational.

1. Introduction

The problem under study in this paper is the occupational source of work related musculoskeletal disorders (MSDs). The opportunity under study is the ability of an organisation to apply knowledge about humans, ‘Human Factors’ or ‘Ergonomics’ (IEA Council, 2000), to create high performance work systems that are effective, profitable, and healthy workplaces. These two aspects – the human
health, and the system performance – are central to the research approach of the ‘Production Ergonomics’ group at the National Institute for Working Life West in Gothenburg Sweden, from which this thesis emerges. It is through the joint optimisation of these two aspects that sustainable development can be achieved.

This paper presents a ‘systems’ framework and new data for understanding how MSDs can emerge as an unintended result from the design of a work system. Four research papers are used to study the following problems: how can an organisation best integrate ergonomic considerations into their daily development processes? “Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance”

1.1 System Model

A ‘system’ model is proposed to help understand how ergonomics is handled in production system development and what consequences this has for MSDs and productivity.

Skyttner (2001) defined a system as ‘a set of interacting units or elements that form an integrated whole intended to perform some function.’ The Skyttner’s model builds on previous work, which identified relevant factors for ergonomic intervention at the level of the community, the company, and the individual worker (Hagberg et al., 1995; Mathiassen and Winkel, 2000; Westgaard and Winkel, 1997; Winkel, 1992). The model presented here focuses more explicitly on the chain of events that ultimately result in MSDs, viz. Production Strategy, System Design, Production System, Risk Factors and Productivity, and Quality, Economy.

A simplified systems’ model for analysing the development of musculoskeletal disorder in a work system is described in this paper. The company’s development process can be seen to begin with conceptual choices of production strategy (5), followed by the design stage (4) to the eventual implementation of the production system (3). Production system operators are then exposed to the physical loads and psychosocial working conditions within the system that determine risk for MSD (2). The system outputs (1) include, for example, productivity and quality and also, as a side effect, MSDs. This paper describes the model from the bottom (outputs, 1) to the top (strategy, 5) and then briefly also discuss the contextual issues related to the individual, company and society levels which can both affect MSD outputs (at 1) but can also affect how the system might react to intervention attempts.

System Outputs: Oxenburgh (1991; 2004) described in detail how health and safety in general can contribute to a firm’s financial performance. For the purposes of this thesis system outputs are assigned two categories: Musculoskeletal disorders, and Productivity.

Musculoskeletal Disorders: Musculoskeletal disorders (MSDs) at work are a persistent problem in industrial nations costing a lot of money and causing much suffering. MSDs are an unintended output of many work systems.

In 2013 Nigerian’s total costs for work related sickness and absence were over 110 million– an increase of almost 50% in just 4 years. The economic costs alone for work related ill health have been estimated by some African nations at between 2.6% and 3.8% of gross national product with about half of this cost being attributed to MSDs (EASHW, 2000b).
Poor ergonomics in manufacturing not only results in direct costs associated with injury treatment and compensation, but also in indirect costs related to factors such as absenteeism, costs of administration, employee turnover and training, poor employee morale, as well as reduced productivity and quality (Alexander and Albin, 1999; Oxenburgh et al., 2004; WSIB, 2001). Indirect costs may be several times greater than direct costs and are often not measured by companies (Hagberg et al., 1995), which may lead them to underestimate the scope of the problem. For the afflicted workers the consequences of injury are much more personal and include reduced physical, psychological and economic well-being (Pransky et al., 2000; Tarasek and Eakin, 1995). While much research has been done on intervening to reduce MSDs in the workplace (Westgaard and Winkel, 1997) the problem appears to be continuing, arguably, unabated.

Work related musculoskeletal disorders are a heterogeneous group of disorders that, by definition, have a work-related cause and can include a broad range of body parts and tissues (Hagberg et al., 1995). MSDs are also difficult to diagnose with precision (Van Tulder et al., 1997). In the model presented (Fig. 1) MSDs form the final outcome of a chain of events over the course of the development of the production system. These disorders can be seen as unintended side effects of the production system that have negative consequences both for the operator and for system performance. This thesis focuses specifically on musculoskeletal disorders which form the single most expensive work related ill health category (WHO, 1999). The solution pathway for MSDs deals with many of the same issues that must be handled when trying to solve other work-related health problems. Thus we use MSDs as a kind of ‘model’ that might be applied more generally to other problems as well.

**Productivity and Quality:** Production systems are designed to maximise profits through productivity or quality outputs. This focus often excludes human factors. There is increasing awareness of the strategic value of ergonomics for companies (Dul, 2003b). Konningsveld (2003) has described how ergonomics can be integrated with core business performance such as productivity, lead-time, and reliability of delivery, quality, and flexibility. Recent research in the quality field suggests that around 30-50% of quality deficits are related to poor ergonomics (Axelsson, 2000; Drury, 2000; Eklund, 1995; Lin et al., 2001).

The high rate of failure of manufacturing initiatives (Clegg et al., 2002) has also been associated with failures to accommodate human factors (Nadin et al., 2001). Under these circumstances it should be easy to justify ergonomics since multiple objectives are achieved simultaneously. The case for productivity can be more difficult since the most obvious way to increase productivity is to simply make the production system operators work faster, thereby increasing MSD risk. Nevertheless economic analysis can demonstrate how profitability can be enhanced through better health and safety (Aaras, 1994; Hendrick, 1996; Oxenburgh et al., 2004).

In this paper, the author argued for a joint optimisation approach whereby humans and other key system elements are simultaneously considered so that globally optimal solutions to the production problem can be developed. Achieving this in practice is, proverbially, easier said than done.

### 1.2 The Challenge of Intervention in a Complex System

To be most effective ergonomic considerations should be a natural part of the development process focussed on improving total system performance. This is easier said than done. While the system under study is complex (Backström et al., 2002; Guastello, 2003), research tends to be conducted along traditional academic lines. The problem, as Rasmussen (1997) points out, is that there is very little
research that spans the problem domain. Since there are non-linear and dynamic connections between system elements, the models generated by different academic disciplines cannot be simply stuck together. Greenwood, from the social sciences, rails against this problem: “The world does not deliver social problems in neat disciplinary packages, despite the pathetic insistence of most academic social scientists in defending their academic turfs against all other forms of knowledge” (Greenwood, 2002).

What is needed, according to Rasmussen (1997), are ‘vertical’ studies of the system behaviour that engage a broad range of skills and perspectives. This is proving difficult as there is almost no attention to ergonomics, for example, in the management literature (Dul, 2003a) and the incorporation of management science perspectives in ergonomics may be similarly absent. Despite many successful ergonomics case studies (Aaras, 1994; Abrahamsson, 2000; EASHW, 2000a; GAO, 1997; Hendrick, 1996; Kemmelert, 1996; US Federal Register, 2000) researchers have generally had difficulty demonstrating consistent effects when trying to intervene in businesses for better ergonomics (Westgaard and Winkel, 1997). Karsh et al. (2001) have expressed the problem thus: “…effective risk management strategies cannot be developed by the integration of the results of horizontally oriented research within the various disciplines… Instead vertical studies of the control structure are required.” - Rasmussen (1997).

“A pressing problem that has plagued ergonomic intervention research is the lack of understanding as to why seemingly identical interventions work in some instances but not in others... We propose that research pay special attention to various implementation approaches to ergonomic interventions (Karsh et al., 2001).” From an organisational change perspective this is a classic problem, and from a systems perspective this is hardly surprising. Growing evidence (Burnes, 2004; Clegg et al., 2002) indicates that 50-75% of organisational change efforts and attempts to implement advanced manufacturing processes are not successful. Researchers are suggesting that these failures relate less to technical failures than to failures to accommodate people (Badham et al., 1995; Das, 1999; Nadin et al., 2001) – an example of how poor ergonomics can undermine system effectiveness. Researchers in both organisational development and ergonomics communities point out that “ergonomic” intervention engaging a broad range of organisational actors who own the process show most promise for success (Gustavsen et al., 1996; Westgaard and Winkel, 1997). Similarly Bamford and Foster (2003) point out that: “In today’s business environment, one dimensional change interventions are likely to generate only short term results and heighten instability rather than reduce it (Bamford and Forrester, 2003).” Considering the time dimensions of change Bateman and Rich (2003) claim that: “Point Changes’ without sufficient infrastructure to support improvements, at the business level, are unlikely to yield real and sustainable change.” Considering this evidence we see a need to integrate ergonomics into the development process to avoid the expense and delay of retrofitting processes.

In order to avoid ‘one dimensional change’ it may be helpful to emphasise the performance benefits along with the health benefits of good ergonomics (Dul, 2003b; 2004) provides an illustration of how design may lead to a double-win, or synergy effect, if productivity and ergonomics goals are optimised jointly for increased total system performance (Gustavsen et al., 1996; Huzzard, 2003). If increasing the engagement of personnel in human factors is not to be a ‘point change’ then an evolutionary seems appropriate to accommodate the time needed to change organisational practice.

In order to support better management of human factors throughout the development process, particularly in the early stages of development, we see a need to improve utilisation of leading indicators of MSDs, such as risk factors, in the design process. Achieving this will require 1) tools by
which risk can be identified and quantified, 2) an understanding of how and where risk emerges in the design process, and 3) development of the design process itself so that ergonomic issues are actively managed and integrated with technology concerns throughout the process.

The aim of this paper is to investigate how ergonomics might be integrated into a company’s regular development process, with special focus on barriers and assists to achieving such integration. This study focuses on the organisational level and includes the entire development process.

2. Methods

2.1 Integrating Ergonomics into Development Work

In this longitudinal case study, a carry-on from the study in Production Strategy Change from Long-cycle Cellular Manufacturing to Short-cycle Serial Line Assembly. A Categorical Imperative in Ergonomics (Imaekhai, 2017), we adopted an ‘action research’ stance (Badham et al., 1995; Reason and Bradbury, 2001) as we participated cooperatively with the company in their efforts to integrate ergonomics into their business processes. This provides a close insider perspective on the organisational change process as it evolves over time (Toulmin and Gustavsen, 1996) allowing greater insight into the complexity of company processes (Ottosson, 2003). Throughout the process we participated in meetings and discussions providing advice and information to the best of our abilities. We also strove to avoid an overbearing “relationship of dependance” (Westlander, 1995) where the process became too dependent on the researchers which might lead it to collapse once we left the company (Siemieniuch and Sinclair, 2002). Our role therefore was more like a coach or advisor than a consultant or contractor. Field notes were made during and after site visits and meetings were tape recorded for review or sharing amongst the research team.

Organisational change is incredibly complex (Ottosson, 2003). It is not possible to represent the ‘whole’ reality of this change in a linear narrative of limited length (such as this thesis)(Sørensen et al., 1996). It is important therefore, to acknowledge the ‘filtering’ process which necessarily occurs in presenting such a project (Palshaugen, 1996). In this case we attempt to reflect on the case in terms of the theoretical base described in our introduction opening a kind of dialectic between theory and observation (Greenwood, 2002; Pettigrew et al., 2001; Vicente, 2000; Yin, 1994). Some researchers have argued that, since theory is created to reflect an evolved practice, action research is ‘beyond’ theory as it focuses on advancing current practice (Toulmin and Gustavsen, 1996). Here we also take the opportunity to advance current theory. In reporting this study we attempt to identify those aspects of the case which might, in a coherent fashion, be useful to other practitioners and researchers who are faced with their own organisational change ‘mess’ (Saka, 2001). According to Badham et al. (1995) “Standardised questionnaires, structured interviews, and statistical analyses cannot begin to grasp the complex fabric of organisational change.”

2.2 A Paradigm Shift in Methodology

The methodology adopted in this paper marks a departure from classical positivistic research. I will refrain from an extended discourse on research paradigms but agree generally that the use of numbers and statistics must always come back to the world of language to become meaningful and, through this transition, enter the social domain of language mediated reality (Collins, 1984). With this in mind, I don’t really understand the positivist hostility to social constructivism or what Ottosson refers to as the quantum (as opposed to the classical ‘Newtonian’) paradigm (Ottosson, 2003). With tongue in cheek I
would say that positivists are simply social constructivists who tend to operate in a state of denial. More fruitfully I can say that we are moving into what Gibbons and colleagues have dubbed “Mode 2” knowledge generation in which knowledge regarding solutions to complex problems are studied in situ, trans disciplinarily, with a focus on solution efficacy, and embedded knowledge exchange mechanisms that go beyond the usual peer review oversight (Gibbons, 1994). ‘Mode 2’ is seen as a response to societal needs for solutions to complex problems and diffusion of research occurring as a natural part of the process rather than the narrow communications channels institutionalised in the traditional disciplinary research (Mode 1) model. The ‘action research’ approach applied in paper 4 is one method for achieving this.

3. Results

3.1 Integrating Ergonomics into Development Work

The change process was slow with inhibitors coming from both individual and organisational factors. The production manager, using internal knowledge to act as a ‘political reflective navigator’, was able to steer the process forward.

3.2 The Case Story

Initiation: When the results from “Production Strategy Change from Long-cycle Cellular Manufacturing to Short-cycle Serial Line Assembly. A Categorical Imperative in Ergonomics (Imaekhai, 2017) was presented to the project steering group, the production manager (PM) emphasised his vision statement that “operators should be able to continue to work in these systems up to retirement”. Having seen the systems comparison in the paper he wished to see action to capitalise on the new knowledge. Realising that the steering group was too large to analyse the problem effectively he created an ‘Analysis group’ charged with identifying opportunities for improvement as part of a ‘Production Ergonomics’ (ProErg) initiative. The analysis group included union, health & safety service, line supervision, engineering and research representatives. After a series of discussions the group returned suggesting the creation of three working groups: 1) ‘Return to Work’ for rehabilitation issues, 2) ‘Future’ group for line development, and 3) ‘Measurement’ group to improve information gathering and utilisation. These groups began to form and, as needed, created sub-groups to deal with specific tasks or activities such as making improvements based on an ergonomics audit. Initiation of activity was fastest when it involved persons already engaged in the process and took some time when persons new to the process needed to be recruited. This period was marked by considerable activity surrounding ‘ergonomics’ in the company and many small improvements were implemented. The group could not deal with improvements related to more central system features such as the material supply system as they were too expensive.

Reflection: The group structure chosen initially made sense to the company. The researchers had entered the company through the production department via the PM who provided strong support and a clear vision. The structure created appeared to reinforce the position of ergonomics as a ‘production’ issue with little engagement of system developers from engineering. For those not previously involved in the ProErg initiative the new tasks appeared to pose additional work – not integrated with regular duties. Ergonomic problems relating to core system features appear to be “locked in” once built.
**Problems Emerge:** A dramatic slowdown in activities was observed immediately after summer holidays with many meetings cancelled or postponed. It emerged that each of the three group leaders was being transferred to new positions in the company. Problems also emerged as some of the sub-group’s activities began to intersect with other activities. Individuals with heavy workload were not sure how the ‘new’ ergonomics tasks should be prioritised, particularly when their supervisor from another department was not fully supportive of the initiative. Toward the end of this stage the company’s safety engineer, who had been coordinating and driving the process, left work on sick leave and, sadly, died in January 2004 marking a low point in the project.

**Reflection:** Individual factors, including normal life events such as promotion, retirement, marriage, and cancer, all appeared to influence individuals’ ability and/or willingness, to engage in the change effort. Organisationally engineering groups responsible for system development remained distanced from the process, which thus remained a ‘production’ issue. The process was insufficiently anchored in daily work routines to survive the turbulences of ordinary life.

**New opportunities:** The production manager (PM) and researchers reflected upon the situation in the fall of 2013. The PM decided to lift the issue up to the site management group to inform and engage senior managers from other departments. At this meeting it became clear that developing the new system, not retrofitting the old system, was the primary focus of the engineering groups. The site manager called for a workshop so that knowledge gained from the system evaluation (Production Strategy Change from Long-cycle Cellular Manufacturing to Short-cycle Serial Line Assembly. A Categorical Imperative in Ergonomics (Imaekhai 2017)) could be spread to the new system’s design team. Having reviewed the system comparison data in the workshop, engineering management decided that developing ergonomics capabilities needed to be done outside the current development project which had tight budget and time constraints. Following the workshop a number of discussions were initiated engaging both engineering and the health and safety service. For example, the consideration of ergonomics through computer simulation technologies (Medbo and Neumann, 2004; Neumann et al., 1999b) was demonstrated and discussed in connection with development being made by the engineering groups. Upon further reflection of how to better anchor ergonomics into the development process, the PM arranged for the company Ergonomist and Safety engineer to join the ‘Assembly steering group’, which was responsible for managing all assembly development via the company’s product development gate system, the ‘Global Development Process’ (GDP). The PM saw the integration of ergonomics into the GDP as a strategy for locking in ergonomics considerations throughout the development process. Another tactic pursued by the PM was to establish an ergonomics training program for leadership, design teams, and assembly personnel to help improve knowledge and communications surrounding the management of MSD risk.

**Reflection:** Here we see the PM acting politically to gain support for his vision. Having researchers present ‘hard’ data on both technical and human factors appeared to establish credibility for ergonomics concepts and created a forum for further development of ergonomics capability in design. By integrating health and safety personnel into the steering group the PM signalled the importance of this issue in development. Targeting the GDP as an area for ergonomic improvement sets the stage for the PM to ‘lock-in’ ergonomics and provides a practical opening to engage the H&S personnel in early stages of process development.
4. Conclusion

With regards to integrating ergonomics into an organisations’ development work, the following conclusions are made:

(a) Integrating ergonomics into the organisation, even with strong support from production management, is a slow process marked by setbacks; developmental barriers may be at organisational (e.g. inter-group barriers, communication gaps), or at individual levels (e.g. work overload, pending retirement, life events).

(b) ‘Ergonomics’ groups that are outside of regular development processes are vulnerable to disruption from, for example, reorganization; lack of engineering engagement in the initial process development can lead to barriers when engineering personnel became involved in the change effort.

(c) A deliberate process of ‘political reflective navigation’, taken on here by an internal stakeholder, supports the identification of new avenues for the integration of ergonomics into regular development practice.

(d) Workshops appear to be a good method to provide information, solicit support, and initiate dialogue with the engineering design team; tools such as computer simulation appear to have good potential in providing designers with quantified or unambiguous indicators they can use to consider ergonomics simultaneously with other production concerns.

(e) The stakeholder map was a useful ‘navigational aid’ and helped us understand that not all design groups with relevant control over ergonomics have yet been reached by the process.

(f) Engineering teams work to the mandate given by senior managers – if innovative designs are to be developed senior managers must sanction them; introducing innovations after key strategic choices may be too late to be taken up into the design process.

References


Voltage Profile Improvement of the Nigerian 330-kV Transmission Network using STATCOM

Okakwu, I. K., Olabode, E. O. and Okundamiya, M. S.

Abstract—This paper aims to investigate the effect of STATCOM on the Nigerian 330kV transmission network. The Newton-Raphson iteration algorithm was used to solve the non-linear problem, which was modelled using MATLAB Software. The result shows that some of the buses fell outside the statutory limit of $0.95pu \leq V \leq 1.05pu$, which includes: 16 (Kano, 0.8721pu), 17 (Kaduna, 0.9046pu), 18 (Jos, 0.8731pu), 19 (Gombe, 0.8735pu), 20 (Yola, 0.8580) and 21 (Katampe, 0.9167pu). On incorporating STATCOM on these weak buses, the voltage magnitude was improved as follows: 16 (Kano, 1.0000pu), 17 (Kaduna, 0.9678), 18 (Jos, 1.0000pu), 19 (Gombe, 1.0188pu), 20 (Yola, 1.0106pu) and 21 (Katampe, 1.0000pu). The improvement of the bus voltage profiles, ranging from 7% at Kaduna (bus 17) to 17.8% at Yola (bus 20), with the proposed STATCOM enables the voltage profiles to fall within the acceptable statutory limits. The result of this simulation shows the effectiveness of the STATCOM in improving the bus voltages of the Nigerian 330kV transmission grid.

Keywords: Newton-Raphson algorithm, Nigerian 330-kV network, Power flow, STATCOM, Transmission network, Voltage magnitude.

1 Introduction

Power system network in many third world countries including Nigeria suffered voltage instability, voltage insecurity, appreciable real power losses and insufficient reactive power compensation (Bharat and Umesh, 2016). Anumaka (2012) and Makoju (2002) reported that both the distribution and transmission system in Nigeria account for about 40% of the total system losses with transmission lines losses alone incurring an estimated value of 9.2% (PHCN National Control Centre Oshogbo, 2004; PHCN National Control Centre Oshogbo, 2005). The need to address these problems is a unique area of interest to the power system researchers (Luis, 2015). Transmission system serves as intermediary between the generation stations and distribution systems, its roles in transporting electricity cannot be...
over-emphasised. However, its integrity in doing this assigned task is being enormously affected by steady-state and dynamic limitations. Consequently, transmission line power transfer capability and system stability are brought under great threat (Obulesu et al., 2011). Imbalance of reactive power on network system exists when fault occurred, lines are heavily loaded or voltage fluctuation exists within the system (Kamarposhti and Lesani, 2011).

Effective and efficient distribution of reactive power plays a leading role in mitigating losses on transmission lines as well as in enhancement of system voltage profile (Musa and Mustapha, 2015). Modern approach to supply of reactive power boiled down to the use of power electronic devices; which are the foundational building block pivoting the advent of Flexible Alternating Current Transmission System (FACTS) (Okundamiya, 2016). FACTS devices are endowed with fast speed response in controlling electrical signal, space reduction and over time, found to be highly reliable in increasing the transmission line efficiency (Musa and Mustapha, 2015). They are generally categorised into four major classes, which are series compensators, shunt compensators, series–shunt compensators and series-series compensators (Eseosa and Odiase, 2012). A member of shunt-connected FACTS device found versatile in raising defective voltage buses coupled with adequate means of supplying reactive power compensation is Static Synchronous Compensators (STATCOM). This inherent ability of STATCOM is largely due to its attractive steady state performance and operating characteristics (Amarnath and Manohar, 2012; Nwohu, 2011).

The STATCOM, as a voltage source converter, is connected in shunt with the transmission line via a shunt transformer (Canizares, 2000). Its uses gate turn off thyristors and DC capacitor to produce a three-phase synchronous voltage at fundamental frequency (Claudio et al., 1997). As a reactive power source and a voltage controller, it regulates the voltage at midpoint of transmission line by absorbing/generating the reactive power at the point of common coupling (Maturu and Shenov, 2010). Principally, if the output voltage of the STATCOM is higher than the AC system voltage at the point of connection, then it produces reactive current. Conversely, it absorbs reactive power when the voltage amplitude of the STATCOM is lower (Aggarwal et al., 2010). The identified benefits of STATCOM so far include oscillation damping in power system, transient stability margin enhancement, steady-state power transfer capability improvement, and ability to diminish temporary over-voltage as well as enhanced voltages control and regulation among others (Aggarwal et al., 2010; Adebisi et al., 2015).

Application of STATCOM to enhance Nigerian longitudinal transmission system has been attempted by several researchers (Eseosa and Odiase, 2012; Ambafi et al., 2013; Aborisade et al., 2014; Adebisi et al., 2015) using different bus systems. Eseosa and Odiase (2012), Aborisade et al. (2014) and Adebisi et al. (2015) used the Nigerian 28-bus system while Ambafi et al. (2013) used the Nigerian North-East 330kV as test case system. This paper employed the Nigerian 330kV, 32-bus system as test case system to validate the proposed efficiency of the STATCOM in combating real power losses and enhancement of system voltage profile.

2. Methods

2.1 Description of the Test Case System

The Nigerian 330kV, 32-bus grid system spans through 5,523.8km and consists of eleven generating stations, twenty-one loads buses, twenty-seven transmission lines and seven transformers. It is a mix of hydro-thermal power stations with total generating installed capacity of 7461MW (Nwohu and Sadiq, 2013). The single one-line diagram of the Nigerian 330kV, 32 bus system is shown Figure 1.
Figure 1: One-line diagram of the Nigerian 330-kV, 32-bus transmission network.

2.2 Mathematical Modelling of the Test Case System

The Newton-Raphson iterative algorithm was used to model the test case system as this algorithm is an efficient iterative tool found to be superior to other load flow techniques due to its excellent quadratic convergence with little iteration among others. With this technique, a set of non-linear simultaneous equations are approximated to a set of linear simultaneous equations by means of Taylor’s series expansion with the terms limited to the first approximation (Obanisola et al., 2017). For a typical two bus power system represented by bus \( i \) and bus \( k \); current \( I_i \) injected into bus \( i \) is given as follows:

\[
I_i = V_i \sum_{j=1}^{n} y_{ij} V_j,
\]

(1)

where \( y \) is line admittance and \( V \) is bus voltage.

In polar form, (1) can be expressed as:

\[
I_i = \sum_{j=1}^{n} |Y_{ij}| |V_i| \angle \theta_{ij} + \delta_j,
\]

(2)

\( Y \) is bus admittance and \( \theta \) is bus phase angle. The complex power at bus \( i \) is written as follows:

\[
P_i - jQ_i = V_i^* I_i = |V_i| \angle -\delta_i \sum_{j=1}^{n} |Y_{ij}| |V_j| \angle \theta_{ij} + \delta_j,
\]

(3)

where \( P \) is real power and \( Q \) is reactive power.
The real and imaginary parts of (3) can be expressed as (4) and (5) respectively.

\[ P_i = \sum_{j=1}^{n} |V_iV_j| \cos(\theta_{ij} - \delta_i + \delta_j). \]  

\[ Q_i = -\sum_{j=1}^{n} |V_iV_j| \sin(\theta_{ij} - \delta_i + \delta_j). \]  

In compact matrix form, applying Taylor’s series to expand (4) and (5), the initial estimate gives (6).

\[
\begin{pmatrix}
\Delta P_2^{(r)} \\
\vdots \\
\Delta P_n^{(r)} \\
\end{pmatrix}
= 
\begin{pmatrix}
\frac{\partial p_2^{(r)}}{\partial \delta_2} & \cdots & \frac{\partial p_2^{(r)}}{\partial \delta_n} \\
\vdots & \ddots & \vdots \\
\frac{\partial p_n^{(r)}}{\partial \delta_2} & \cdots & \frac{\partial p_n^{(r)}}{\partial \delta_n}
\end{pmatrix}
\begin{pmatrix}
\Delta \delta_2^{(r)} \\
\vdots \\
\Delta \delta_n^{(r)} \\
\end{pmatrix}
\]

\[
\begin{pmatrix}
\Delta Q_2^{(r)} \\
\vdots \\
\Delta Q_n^{(r)} \\
\end{pmatrix}
= 
\begin{pmatrix}
\frac{\partial q_2^{(r)}}{\partial \delta_2} & \cdots & \frac{\partial q_2^{(r)}}{\partial \delta_n} \\
\vdots & \ddots & \vdots \\
\frac{\partial q_n^{(r)}}{\partial \delta_2} & \cdots & \frac{\partial q_n^{(r)}}{\partial \delta_n}
\end{pmatrix}
\begin{pmatrix}
\Delta \delta_2^{(r)} \\
\vdots \\
\Delta \delta_n^{(r)} \\
\end{pmatrix}
\]

The diagonal and off diagonal elements of the Jacobian matrix (6) is given in (Obanisola et al., 2017), the power mismatches are as expressed by (7) and (8) while the updated voltage magnitudes and angles are given by (9) and (10).

\[ \Delta P_i^{(k)} = P_{i,spec} - P_{i,cat}. \]  

\[ \Delta Q_i^{(k)} = Q_{i,spec} - Q_{i,cat}. \]  

\[ |V_i^{(k+1)}| = |V_i^{(k)}| + \Delta |V_i^{(k)}|. \]  

\[ \delta_i^{(k+1)} = \delta_i^{(k)} + \Delta \delta_i^{(k)}. \]  

Where \( \delta \) is voltage phase angle.

### 2.3 Mathematical Modelling of the STATCOM Power Flow

Generally, the bus at which the STATCOM is connected is represented as a PV (generator) bus and in the event of limits being violated it changes to a PQ (load) bus (Gholami et al., 2010). The mathematical modelling of STATCOM incorporated into load flow algorithms is obtained using its equivalent circuit as shown in Figure 2.

**Figure 2: Equivalent Circuit for STATCOM (Gholami et al., 2010)**
The STATCOM power flow equations can be obtained as follows:

$$E_{VR} = V_{VR}(\cos \delta_{VR} + j \sin \delta_{VR})$$  \hspace{1cm} (11)

The complex power based on shunt connection as shown Figure 1 above is given as;

$$S_{VR} = V_{VR}^* (V_{VR} - V^*)$$  \hspace{1cm} (12)

The active power obtained for the converter and the bus $k$ is given as;

$$P_{VR} = V_{VR}^2 G_{VR} + V_{VR} V_K [G_{VR} \cos (\delta_{VR} - \theta_K) + B_{VR} \sin (\delta_{VR} - \theta_K)]$$  \hspace{1cm} (13)

$$P_K = V_{VR}^2 G_{VR} + V_{VR} V_K [G_{VR} \cos (\theta_K - \delta_{VR}) + B_{VR} (\theta_K - \delta_{VR})]$$  \hspace{1cm} (14)

The reactive power obtained for the converter and the bus $k$ is given as;

$$Q_{VR} = -V_{VR}^2 B_{VR} + V_{VR} V_K [G_{VR} \sin (\delta_{VR} - \theta_K) + B_{VR} \cos (\delta_{VR} - \theta_K)]$$  \hspace{1cm} (15)

$$Q_K = -V_{VR}^2 B_{VR} + V_{VR} V_K [G_{VR} \sin (\theta_K - \delta_{VR}) - B_{VR} \cos (\theta_K - \delta_{VR})]$$  \hspace{1cm} (16)

The linearized model for STATCOM using these power flow equations (11) – (16) is as:

The developed linearized model (17) was tested on the Nigerian 330kV, 32-bus grid system and the results are presented and discussed in the following section.

3. Results and Discussion

The results of the power flow simulation of the Nigerian 330kV, 32-bus network using Newton-Raphson algorithm are presented in Tables 1 and 2. Table 1 presents the bus no, bus name, bus voltage profile without STATCOM and bus voltage profile with STATCOM, while Table 2 shows the percentage voltage profile improvement. Figures 3 and 4 depict the bar chart and graphical illustration of the voltage profile with and without STATCOM respectively.
### Table 1: Summary of bus voltage magnitude of the Nigerian 330kV, 32-bus network before and after compensation

<table>
<thead>
<tr>
<th>Bus No.</th>
<th>Bus Name</th>
<th>Voltage Profile Before Compensation</th>
<th>Voltage Profile After Compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Voltage Magnitude (per unit)</td>
<td>Voltage Angle (Degrees)</td>
</tr>
<tr>
<td>1</td>
<td>Egbin G.S</td>
<td>1.0400</td>
<td>0.0000</td>
</tr>
<tr>
<td>2</td>
<td>Benin</td>
<td>1.0063</td>
<td>6.9193</td>
</tr>
<tr>
<td>3</td>
<td>Ikeja West</td>
<td>0.9811</td>
<td>-4.7260</td>
</tr>
<tr>
<td>4</td>
<td>Akangba</td>
<td>0.9735</td>
<td>-5.4148</td>
</tr>
<tr>
<td>5</td>
<td>Sakete</td>
<td>0.9623</td>
<td>-7.1567</td>
</tr>
<tr>
<td>6</td>
<td>Aiyede</td>
<td>0.9471</td>
<td>-13.6748</td>
</tr>
<tr>
<td>7</td>
<td>Olorunshogo G.S</td>
<td>0.9800</td>
<td>-6.4793</td>
</tr>
<tr>
<td>8</td>
<td>Omotosho G.S</td>
<td>1.0200</td>
<td>6.8160</td>
</tr>
<tr>
<td>9</td>
<td>Oshogbo</td>
<td>0.9578</td>
<td>-22.0787</td>
</tr>
<tr>
<td>10</td>
<td>Gamo</td>
<td>0.9603</td>
<td>-27.6345</td>
</tr>
<tr>
<td>11</td>
<td>Shiroro G.S</td>
<td>0.9700</td>
<td>-55.7140</td>
</tr>
<tr>
<td>12</td>
<td>Jebba T.S</td>
<td>1.0026</td>
<td>-29.5556</td>
</tr>
<tr>
<td>13</td>
<td>Jebba G.S</td>
<td>1.0100</td>
<td>-29.2973</td>
</tr>
<tr>
<td>14</td>
<td>Birnin Kebbi</td>
<td>1.0302</td>
<td>-29.1309</td>
</tr>
<tr>
<td>15</td>
<td>Kainji G.S</td>
<td>1.0200</td>
<td>-26.1358</td>
</tr>
<tr>
<td>16</td>
<td>Kano</td>
<td>0.8721</td>
<td>-76.2603</td>
</tr>
<tr>
<td>17</td>
<td>Kaduna</td>
<td>0.9046</td>
<td>-67.3781</td>
</tr>
<tr>
<td>18</td>
<td>Jos</td>
<td>0.8731</td>
<td>-78.0406</td>
</tr>
<tr>
<td>19</td>
<td>Gombe</td>
<td>0.8735</td>
<td>-87.1135</td>
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<tr>
<td>20</td>
<td>Yola</td>
<td>0.8580</td>
<td>-90.1711</td>
</tr>
<tr>
<td>21</td>
<td>Katampe</td>
<td>0.9167</td>
<td>-61.3107</td>
</tr>
<tr>
<td>22</td>
<td>Ajaokuta</td>
<td>1.0199</td>
<td>12.0747</td>
</tr>
<tr>
<td>23</td>
<td>Geregu G.S</td>
<td>1.0200</td>
<td>12.1056</td>
</tr>
<tr>
<td>24</td>
<td>Onitsha</td>
<td>1.0099</td>
<td>9.0862</td>
</tr>
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<td>Alaoji</td>
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<td>New Haven</td>
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<td>5.2336</td>
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<td>27</td>
<td>Sapele G.s</td>
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<td>9.0861</td>
</tr>
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<td>Delta G.S</td>
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<td>10.2525</td>
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<td>29</td>
<td>Okpai G.S</td>
<td>1.0200</td>
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</tr>
<tr>
<td>30</td>
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<td>31</td>
<td>Aja</td>
<td>1.0376</td>
<td>-0.2139</td>
</tr>
<tr>
<td>32</td>
<td>Aja</td>
<td>1.0147</td>
<td>9.2895</td>
</tr>
</tbody>
</table>

### Table 2: Percentage improvement of the voltage profile of the Nigerian 330kV, 32-bus network

<table>
<thead>
<tr>
<th>Bus No.</th>
<th>Voltage before Compensation</th>
<th>Voltage after Compensation</th>
<th>% Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.9471</td>
<td>1.0000</td>
<td>5.6</td>
</tr>
<tr>
<td>16</td>
<td>0.8721</td>
<td>1.0000</td>
<td>14.7</td>
</tr>
<tr>
<td>17</td>
<td>0.9046</td>
<td>0.9678</td>
<td>7.0</td>
</tr>
<tr>
<td>18</td>
<td>0.8731</td>
<td>1.0000</td>
<td>14.5</td>
</tr>
<tr>
<td>19</td>
<td>0.8735</td>
<td>1.0188</td>
<td>16.6</td>
</tr>
<tr>
<td>20</td>
<td>0.8580</td>
<td>1.0106</td>
<td>17.8</td>
</tr>
<tr>
<td>21</td>
<td>0.9167</td>
<td>1.0000</td>
<td>9.1</td>
</tr>
</tbody>
</table>
**Figure 3:** Voltage profile magnitude of the Nigerian 330kV, 32-bus network before and after compensation

**Figure 4:** Graphical illustration of voltage profile magnitude of the Nigerian 330kV, 32-bus network before and after compensation
The results obtained from the simulation also identified buses whose voltages fell outside the statutory limit within the range of 313.5kV (0.95pu) to 346.5kV (1.05pu), which includes: buses 16 (Kano, 0.8721pu), 17 (Kaduna, 0.9046pu), 18 (Jos, 0.8731pu), 19 (Gombe, 0.8735pu), 20 (Yola, 0.8580pu) and 21 (Katampe, 0.9167). On incorporating the network with STATCOM due to these buses that violate the voltage magnitude, their voltage magnitudes were now improved within the acceptable limit of 0.95pu ≤ V ≤ 1.05.

4. Conclusion

In this paper, a load flow analysis was carried out using Newton-Naphson iteration technique modelled using MATLAB Software. The test case was the Nigerian 330kV transmission network. The result obtained shows that some buses violate the required voltage magnitude of 0.95pu ≤ V ≤ 1.05pu. The effect of the application of STATCOM for enhancing these voltage magnitude was demonstrated satisfactorily by raising the voltage magnitude where they were applied; thereby, reinforcing the network. Conclusively, the result confirmed that STATCOM is an effective tool to improve the voltage stability of power system networks.

References


Risk Management in the Design of High Performance Man Machine Interaction: Ergonomic Tendencies and Implications

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Abstract—The absence of ergonomics in production systems compromises performance and leads to musculoskeletal disorders (MSDs), and this has a high financial implication on companies, individuals and the general society. This paper identifies and quantifies workplace risk factors for MSDs, An electronic device for tool analysis to quantify postures while working was developed. The tools’ reliability, accuracy, and ability to identify risks for MSD were evaluated. The tool was adequately accurate and good to moderate reliability. Low back MSDs were strongly associated with working trunk postures. Operators with high exposure to peak flexion level had 4.6 times higher MSD risk than the unexposed operators. Similarly high peak extension velocity increased risk by 3.0 times. In a workplace, man machine interaction risk factors can be adequately quantified. These risks are embedded in strategic choices in the design process.

Load amplitudes were determined by workstation layout and the material supply sub-system. Risk related to the pattern and duration of loading are determined more by flow and work organisation elements. Psychosocial risk factors appear to be affected by a combination of system design elements. Managing the emergence of these risks proactively requires attention to ergonomics throughout the design process, especially in strategic choices. Integrating ergonomics into early development stages implies changing roles for groups and individuals in the organisation. This approach appears feasible but is difficult and remains an under-utilised strategy for sustainable competitive advantage.

Keywords: Ergonomics, Man machine conflict, Manufacturing, Musculoskeletal disorders, Risk measurement.

1. Introduction

Many risk factors for MSDs, including physical and psychosocial factors, have been identified. Being able to measure risk factors is important as these act as leading indicators – allowing potential intervention before MSDs occur.
The exposure of production operators to risk factors (level 2 in the model in Figure 1) is an inescapable part of work. If ergonomic conditions are good risk will be low. That working postures and forces can cause musculoskeletal disorders has been known for over 300 years (Ramazzini, 1700). Nevertheless the last quarter of the 20th century saw a tremendous amount of research on the physical and psychosocial risk factors for MSDs and a number of excellent reviews exist (Ariens et al., 2000; Bernard, 1997; Bongers et al., 1993; Buckle and Deveraux, 1999; Buckle and Deveraux, 2002; de Beek and Hermans, 2000; Hoogendoorn et al., 2000b; Malchaire et al., 2001a; Netherlands, 2000).

More epidemiological studies continue to corroborate these reports and enhance our understanding of the relationship between workplace demands and MSDs to the back (Hoogendoorn et al., 2000a; Hoogendoorn et al., 2001; Kerr et al., 2001), neck (Ariens et al., 2001a; Ariens et al., 2001b), neck & shoulder (Fredriksson et al., 2000; Östergren et al., 2001) and hand-wrist (Malchaire et al., 2001b). Conceptual models of MSD onset mechanisms have been developed (Armstrong et al., 1993; Kumar, 2001; McGill, 1997; NAC et al., 2001) that generally account for risk from high peak loads (Neumann et al., 1999c) as well as the accumulation of load or prolonged loading (Kumar, 1990; Kumar, 2001; McGill, 1997; Norman et al., 1998). Long exposure to very low amplitude load, or low variation repetitive movements, have also been associated with MSDs (Hagberg et al., 1995; Hägg, 1991; Westgaard, 1999; 2000; Winkel, 1985). These low level risks can be aggravated by poor psychosocial conditions, themselves an independent class of risk factor (Bongers et al., 1993; Karasek and Theorell, 1990; Kerr, 1997).

Identifying and quantifying risk factors may help understand how to prevent the emergence of these factors when production systems are created. Quantification of the factors associated with MSD is a useful approach to identifying potential problems before injury occurs – they present leading indicators of MSDs (Cole et al., 2003). Precise quantification can be used to provide specific design criteria to designers of the production system (Wulff et al., 1999a) as well as to help find solution pathways for problems identified in existing systems (Norman et al., 1998). Quantification of hazards can also act to build credibility in the negotiation of constraints for new designs (Perrow, 1983) and has potential to support the integration of ergonomics with other performance elements in the production system design process.

Measuring postural related MSD risk factors poses an important measurement challenge (Burdorf, 1992; Burdorf and Laan, 1991). A number of approaches to risk factor quantification have been proposed including self-report questionnaires, observational techniques and direct technical measurements (Mathiassen and Winkel, 2000; Neumann et al., 1999c; Van Der Beek and Frings-Dresen, 1998; Wells et al., 1997). Questionnaire approaches have not proven to be reliable (Burdorf and Laan, 1991). Observational techniques often try to account for the amount of time spent in particular posture categories (Neumann et al., 2001a; Punnet et al., 1991) but rarely capture the time-history of movement. Instrumented measurement approaches have identified movement velocities as a risk factor (e.g. Hansson et al., 2003; Marras et al., 1995), but are relatively expensive and require specialised training to operate.

An approach is needed that can be used without special electronic equipment or educational requirements. Recently, video approaches have been developed to help workers identify and communicate specific physical workload related tasks (Kadefors and Forsman, 2000) and psychosocially problematic aspects of work (Johansson Hanse and Forsman, 2001). While helpful, these approaches do not provide data on specific physical load demands, nor the dynamic or time
aspects of working postures. Video analysis has potential for this kind of analysis although reliability, accuracy, and the indicators with best risk-predictive capability would need to be determined.

2. The Production System

Risk factors for MSD are related to the design of the production system and the nature of the work performed. By production system I refer primarily to an operating system that manufactures a product (Wild, 1995) although many aspects of this discussion could also apply to other kinds of operating systems such as service provision. Risk factors emerge from the interactions between the individual operators and other elements (machines, materials) in the production system (Peterson, 1997). The production system has been described as a sociotechnical system with technical and social subsystems (Eijnatten et al., 1993).

It is the nature of the work itself that will primarily determine the operators’ mechanical exposure profile (Allread et al., 2000; Kerr, 1997; Wells et al., 1999). The design of the system therefore will provide a number of performance constraints for the worker who must perform within the assigned parameters. From this perspective the design of the work becomes a critical element in determining the loading pattern, and hence injury risk. Many risk factor studies have focussed on operator aspects, such as posture or lifting activities (Bernard, 1997), fewer studies have identified risk associated directly with production system performance features such as cycle time (Silverstein et al., 1987).

Mathiassen and Winkel (1996) found that reductions in work pace, controlled using the engineering methods-time-measurement (MTM) system, were associated with similar reductions in muscle activity, heart rate, perceived effort, and muscle tenderness. Bao et al. (1997) have shown that well balanced production lines with fewer production irregularities result in higher movement rates, increased time-density of muscle activation, and hence decreased tissue recovery time than less well balanced systems. These few studies suggest that risk factors in the realised production system are related to the design of the system itself. Where in the design process risk emerges does not appear to be well understood.

The aim of the paper is to develop and evaluate a video based tool for quantifying postural factors at work in terms of inter-observer reliability, accuracy, and association with risk of reporting low back pain at work. This paper illustrates the relationship between risk factors and MSDs illustrated at the bottom of the theoretical model.

3. Methods

The relationship of postural indicators to risk was quantified by comparing workers with and without low back pain. The measurement tool uses videotapes that can be recorded in the field without interfering with the operator.

The section of video to be analysed is first digitised and stored on the computer. The analyst then controls playback speed while recording trunk flexion-extension and lateral bending position on continuous scales using a joystick. Twisting postures were recorded using a binary on-off scale and was considered present whenever the line between the shoulders was angled more than 20 degrees from the line between the hips. During analysis the computer would sample the joystick (or keyboard) input device once for every frame of video while providing feedback to the analyst with a mannequin image. The system provides a continuous time-history of posture, visually synchronised to video, from which
exposure parameters relating to flexion amplitude, duration of flexed postures, and flexion velocity can be extracted.

The inter-observer reliability of the system was assessed by having seven (8) trained observers analyse video from the same ten (10) production jobs. The jobs were selected from the epidemiological study database to include the variety of work observed in the field. The inter observer reliability data were analysed using intra-class correlation coefficients (ICC) to provide indexes of similarity between observers relative to the range of job exposures observed (Shrout & Fleiss, 1979). System accuracy was determined by comparison to a laboratory based opto-electric reference system that was considered a ‘gold-standard’. Eight (8) trained analysts each analysed the same 1 minute video which had been recorded synchronously with the referent system.

Comparisons between the video and referent systems were made for both the time series data and for the amplitude probability distribution function (APDF) data. The accuracy assessment included the calculation of RMS differences between the APDF data from reference and new systems, and average differences for selected variables of interest, and Pearson correlations between observer results and those of the reference system for both time-series and APDF data. The risk association of exposure variables quantified by the system to the reporting of low back pain was determined with a case-control study of low back pain in the automotive industry. Incident low back pain cases (105), defined as workers who reported low back pain to the company nursing stations, were recruited. Controls (129) were selected randomly from the company rosters synchronously with incident cases. No subjects had reported pain in the previous 90 days. The relationships between kinematic indicators and case-status were explored in a series of bi-variable comparisons as well as through multivariable logistic regression modelling.

4. Results

The tool appeared to have generally good performance characteristics for flexion/extension postures. Operators reporting low back pain bent their trunks more, further, and faster than operators not reporting low back pain. The results of the reliability study showed that the ICC for peak flexion and time-in-posture categories exceeded 0.8. Dynamic indicators such as peak velocity, average velocity, and flexion movement variables tended to have somewhat lower reliability coefficients. Inter-observer reliability was not good for variables relating to twisting and lateral bending.

The accuracy assessment showed that flexion-extension time series data was highly correlated (r = 0.92) to data from the criterion opto-electric imaging system. The amplitude probability distribution function (APDF) data had, on average, an RMS difference of 5.80 from the criterion system’s APDF. The risk relationship study confirmed the importance of trunk kinematics as risk factors for low back pain reporting. In bi-variable logistic regression comparisons peak flexion accounted for the most variability in case status and had the highest odds ratio. Other significant predictors included peak and average velocities as well as the ‘percent of time spent in flexion’ category indicators. Multivariable modelling resulted in a final model with peak flexion level and average lateral velocity as risk factors. This model also included percent time in laterally bent postures, which was not significant in bi-variable comparisons, as a protective factor in the multivariable model.
5. Conclusion

With regards to risk identification, it is possible to obtain reliable and accurate quantification of work related risk factors for MSD from video recordings. In this case posture and movements related to low back pain. MSD risk factors can be measured in existing systems and, by implication, could be predicted in planned systems to provide leading indicators of MSDs. With regards to sources of risk in production system design, the early selection of technological solutions tended to lock in risk factors and could not be overcome by adjustments to the workstation layout. This highlights the ergonomic impact of early strategic decisions made by senior managers. Conversely, workstation layout (in conjunction with the material supply subsystem) determines operators’ physical load amplitudes, the flow strategy and work organisation influence the pattern of physical loading. Psychosocial factors appear to be influenced by a combination of flow strategy, work organisation and, to a lesser extent, layout.

References


Development of a Low Cost Printed Circuit Board Exposure Unit

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Abstract—This research is aimed at developing a low cost Printed Circuit Board (PCB) Exposure Unit that can be used for circuit implementation in educational facilities. The design of the exposure unit is based on the principle of photolithography and a good knowledge of embedded programming. The exposure unit was constructed using Energy saver lamps as a source of ultraviolet radiation because it is relatively inexpensive, not bulky and has low power consumption. In order to make the system semi-automated, the operation was determined by a control circuit which was implemented using PIC16F628A microcontroller. The predetermined time of operation was selected by control push button while the time operation was displayed on a liquid crystal display screen. The design was simulated using Proteus v8.0 before construction. Test result of the exposure unit showed that it can be efficiently deployed in both single layer and double layer PCB production and eliminate rough estimates with the exposure time.

Keywords: Exposure, Photolithography, Printed circuit board, Prototype.

1. Introduction

Despite the fact that printed circuit boards are widely deployed in electronic devices which range from cell phones, alarm systems, dishwashers, and radios to ultra-sophisticated radar and computer systems, there is still no technological breakthrough in PCB fabrication process (Kiran and Prasad, 2015; Koric, 2012). Currently, the various PCB fabrication process still needs significant improvements and innovations. The various methods employed in the production of printed circuit board could be categorized as either manual or automated. The manual methods involve the use of crude techniques such as the use of heat, ink etc. to produce the printed circuit.

The PCB can be produced manually by using the direct draw approach, photo-resist spray or heat transfer method (Asuni, 2011). The Direct Draw Approach uses either a resist pen to draw the circuit or by using specialty tapes (dry transfer) the circuit is traced out directly on the copper board. However, the ink does not apply uniformly, thus there is the risk that the traces will be etched away. For this
reason, this method can only be used on very easy, low-definition PCBs. Also, photo-resist spray method is cumbersome because the spray photo sensitive resist is very hard to use, as it always gets dust settling on the wet resist. Lastly, the heat transfer method which is a widely used method requires expertise while applying heat and is more time consuming.

The stress involved and time implication of the manual processes and the resultant poor quality of PCB as a result of exposure mismatch gave birth to the automated method which uses sophisticated approach in drilling, milling or cutting operations to produce PCB with the aid of machine tools and sensors. The fully automated PCB production machines are normally complex, bulky, rugged and very expensive (Mody et al., 2015).

From the above stated methods, manual methods are highly stressful and more time consuming while the automated PCB making machine is very expensive, complex and are not readily available in educational facilities like universities, technical school etc. for quick and cheap production of prototypes and small scale production. Thus, there is need to develop a semi-automated unit for educational facilities especially in universities and technical schools where a lot of design and prototyping are carried out. The exposure unit provides a controlled source of ultraviolet radiation on the photo-resist board, thus the name “exposure unit”.

2. Methodology

Photolithography which is a standard method of fabricating printed circuit board (PCB) is the concept applied for the development of the unit (Kiran and Prasad, 2015). The procedure of PCB fabrication using photolithography is discussed in (Koric, 2012). The process uses light to make the conductive paths of a PCB layer. It involves using light exposure through a mask to project the image of a circuit, much like negative image in standard photography. This process hardens a photo-resistive layer on the PCB which is imprinted in the form of circuit paths on the PCB. This process is facilitated by a controlled source of ultraviolet radiation, usually from an exposure unit. The source of ultraviolet radiation can either be from UV florescent lamp, metal halide lamp or LED. Fluorescent lamps are frequently used in smaller exposure systems for commercial purpose but have a main challenge of been expensive and bulky due to the need for ballast in its operation. Metal-halide lamps are used in large exposure systems intended for industrial production and may also require special fixtures with ballasts. LEDs on the other hand, have many advantages over these light sources and they are suitable for installation in smaller systems (Koric, 2012). However, the PCB industry possibly does not use LED panels because of the need for larger work areas. Hence, in this work energy saver lamps were chosen as the source of UV radiation because they are relatively cheap, not bulky and have low power consumption. Also, it can be used for single and double layer production of printed circuit boards.

2.1 Design Analysis

This work is implemented in two parts: hardware and software. For the software implementation, it involves writing code and programming the microcontroller. While hardware implementation involves designing the circuit of the project on Proteus electronics software and Printed Circuit Board PCB development. The block diagram of the PCB exposure unit is shown in Fig. 1.
The exposure unit consists of a box, a lamp system and a control (timer) system. The box is made of wood which houses both the lamp system and the control circuit. The timer circuit helps to control the lighting from the exposure unit. The most important part of this exposure unit is the lamp system because it is the source of ultraviolet radiation which creates the photolithography process for making printed circuits.

\[ N = \frac{E_p}{E_s} = \frac{N_p}{N_s} = \frac{I_p}{I_s}, \]

(1)

where, \( N \) is the turn ratio, \( E_p (= 220\text{Vac}) \) is the primary voltage, \( E_s (= 12\text{Vac}) \) is the secondary voltage, \( N_p \) is the primary turn, \( N_s \) is the secondary turn, and \( I_s \) is the secondary current. The primary current is deduced as follows:

\[ I_p = \frac{E_{p,\text{peak}}}{E_s} = \frac{220\times 1}{12} = 18.33\text{A}. \]

(2)

The peak primary and secondary voltages are deduced using the following equation respectively:

\[ E_{p,\text{peak}} = E_p \sqrt{2} \]

(3)

\[ E_{p,\text{peak}} = 220\sqrt{2} = 311.13\text{Vac} \]

\[ E_{s,\text{peak}} = E_{p,\text{peak}} \times \left( \frac{E_s}{E_p} \right) \]

(4)

**Figure 1:** Block diagram of the conceptual design phase
\[ E_{\text{peak}} = 311.13 \times (\frac{12}{220}) = 13.67 \text{ Vac} \]

**Choice of Bridge Rectifier**

The bridge rectifier IC, 2WGS (Composed of four IN4007 diodes) used for the design, has the following specification: forward voltage drops of (0.7V x 2 =) 1.4V, maximum current of the rectifier of 1A. Since a voltage of 12Vrms ac is supplied by the transformer, the equivalent dc Voltage in R.M.S is given by the equation:

\[ V_{\text{rms (dc)}} = V_{\text{rms (ac)}} - \text{Forward Voltage Drop of Diode} \]
\[ = 12\text{V} - 1.4\text{V} \]
\[ = 10.6\text{Vdc} \]

Therefore,

\[ V_p = V_{\text{rms (dc)}} \times \sqrt{2} \]
\[ = 10.6\text{V} \times \sqrt{2} \]
\[ = 14.998\text{V} \]

In this design 15Volts approximate value was used in subsequent calculations

**Choice of Smoothing Capacitor**

In order to minimize ripple, an electrolytic capacitor was used for the filtering of the output voltage and its value was calculated using the formula. The ripple voltage for a given capacitance is given by:

\[ V_R = \frac{l_{dc}}{2f_c} \]

Which becomes equation (8) by making Capacitance (C) the subject of the equation

\[ C = \frac{l_{dc}}{2fV_R} \]

given the specifications: rectifier output current, \(l_{dc} (= 200\text{mA})\), supply frequency, \(F (= 50\text{Hz})\), ripple voltage, \(V_R\) and Capacitance, \(C\) deduced as follows:

\[ C = \frac{200 \times 10^{-3}}{2 \times 50 \times \sqrt{2}} = 1000\mu\text{F} \]

A capacitor of 1000\(\mu\text{F}\), 50V was chosen and used for the construction of the filtering circuit.

**Choice of Voltage Regulator**

The function of the voltage regulator is to produce fixed positive voltage to a load. The voltage regulators chosen is the 7805 and 7812 voltage regulators. The 7805 voltage regulator was chosen since the microcontroller requires 5V for its operation. The 7812 voltage regulator is used to provide 12V supply which is connected to the relay coil for the relay operation. Their characteristics are shown in Table 1.

<table>
<thead>
<tr>
<th>IC</th>
<th>Output Voltage (V)</th>
<th>Minimum Input Voltage (V)</th>
<th>Maximum Output Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7805</td>
<td>+5</td>
<td>7.3</td>
<td>1.5</td>
</tr>
<tr>
<td>7812</td>
<td>+12</td>
<td>14.6</td>
<td>2</td>
</tr>
</tbody>
</table>
Choice of Push Button
A set/reset switch having two terminals was used, because it can be easily interface with microcontroller, so that only at the instances when the pushbutton is depressed a signal is sent.

2.3 Processing Unit

Choice of Microcontroller
The PCB Exposure unit is designed around PIC16F628A microcontroller (Fig. 2), which acts as the brain of the entire system, where all arithmetic, logical and decision making operations are being carried out on the system. The PIC16F628A microcontroller was chosen for this work because it is a powerful (200 nanosecond instruction execution) yet easy-to-program (only 35 single word instructions) CMOS FLASH-based 8-bit microcontroller. The PIC16F628A features 256 bytes of EEPROM data memory, self-programming, an ICD, 2 Comparators, 5 channels of 10-bit Analog-to-Digital (A/D) converter, 1 capture/compare/PWM functions.

The synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI™) or the 2-wire Inter-Integrated Circuit (I²C™) bus and a Universal Asynchronous Receiver Transmitter (USART). All of these features make it ideal for more advanced level A/D applications in automotive, industrial, appliances and consumer applications.

![Figure 2: Diagram of a 16F628A micro-controller](image)

Choice of Crystal Oscillator and Capacitor
The crystal oscillator used for the control circuit is 8MHz. From the microcontroller’s datasheet, it is the required external oscillator used to provide frequency stability during the operation of the microcontroller. 22pF capacitor was connected in parallel with the terminals of the crystal oscillator. According to the datasheet of the PIC16f628A microcontroller, the 22pF capacitor connected with an 8MHz crystal oscillator would help to stabilize the clock cycle of the microcontroller.

2.4 Output Unit
This unit is made up of relays (12 Volts) and transistors driver which switches the appropriate relay (and eventually the connected load) based on the microcontroller trigger.
**Choice of Electromechanical Relay**

The JQX-30F (T91) relay is used to switch: the 220Vac supply to the lamp and the 12Vdc supply to the buzzer. It has the following specifications: coil voltage of 12 Vdc, coil resistance of 155 ohm, switching capability of 30 A, and power consumption of 0.9 W. The coil current is calculated using the equation:

\[ I_c = \frac{V_c}{R} \]

\[ I_c = \frac{12}{155} = 0.077 \text{ A} = 77\text{mA} \]

where \( V_c \) is the coil voltage and \( R \) is the resistance of the coil. The \( I_c \) is the collector current of the transistor used to drive the relay.

**Choice of Diode**

Following the fact that a relay is an inductive load, a diode is used to prevent back EMF from the coils. The 1N4007 is employed in this case since it has a peak inverse voltage of 1000 volts, far greater than the relay coil voltage of 12 volts.

**Choice of Transistor as a Switch**

A 2N2222 bipolar junction transistor is used as a switch to drive the relay in this design. It receives its biasing voltage from the microcontroller through a biasing resistor. The characteristics of the 2N2222 Transistor is shown in Table 2.

<table>
<thead>
<tr>
<th>Type</th>
<th>Material</th>
<th>( P_T ) (W)</th>
<th>( I_c ) (A)</th>
<th>( V_{CEO} ) (V)</th>
<th>( V_{CBO} ) (V)</th>
<th>( h_{FE} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2N2222</td>
<td>NPN</td>
<td>0.5</td>
<td>0.8</td>
<td>30.0</td>
<td>60.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Equation (10) shows the relationship between the gain, collector current and base current of the transistor, where \( \beta \) is the transistor gain, \( I_c \) is the collector current and \( I_b \) is the base current.

\[ \beta = \frac{I_c}{I_b} \] \[ I_b = \frac{0.077}{30} = 2.57 \times 10^{-3} = 2.57\text{mA} \]

The value of the resistor that will limit the base current with respect to the supply voltage from the microcontroller to the base of the transistor can thus be derived with (11) as:

\[ R = \frac{V_{cc} - V_{be}}{I_b} \]

\[ R = \frac{5 - 0.7}{2.57 \times 10^{-3}} = 1173\Omega \]

For availability sake, a 1 k\( \Omega \) resistor is used.
Choice of Display
A 16 x 2 LCD display was chosen for displaying information on the time of exposure to the user. From the manufacturer’s specification datasheet the required power supply is +5V (+3V optional), with supply current typically is in the range 1.2mA-3.0mA.

Choice of Buzzer
The buzzer used is a DC 3-24V Piezo Electronic tone buzzer alarm. It has a continuous beep of 95dB and a maximum current rating of 10mA. The buzzer was trigger with a 12V supply. The operation of the buzzer is such that whenever the relay stops the operation of the lamps, the buzzer comes on as an alarm to alert the user of the exposure process.

2.5 Design of Exposure Box
The housing for the unit is made of wooden materials because it is cheap and easily workable. The box constructed has an upper and lower layer so that it can be used for single and double layer production. 5mm thick clear glass are fitted around the top edge of each layer and the working area dimension is 62cm × 21cm. The glass at the upper and lower layer serves to protect the lamps and hold the photoresist board during production. The inner part of the box is sprayed white to act as a reflector and provide good and even illumination for the board. The housing is constructed such that it can conveniently accommodate the lamps and control circuit. To ensure the mask is in good contact with the copper board, the lid of the box have foam tape pads so that when it is closed it applies gentle pressure to the covers. The overall external dimension of the unit is 66cm × 25cm × 40 cm as shown in in Fig. 3.

Choice of Lamp
The energy saver bulbs were chosen as the source of UV radiation because they are relatively cheap, not bulky and have low power consumption. The following are the specifications of the energy saver bulb chosen in this design: electrical power, 36W; voltage, 220 – 240Vac; frequency, 50 - 60Hz; light output, 1800lm; and current, 245mA. Therefore, the luminous efficiency is deduced as follows:

\[
\text{Luminous efficiency} = \frac{\text{light output, } \text{lm}}{\text{electrical power, } \text{W}} = \frac{1800}{36} = 50 \text{ lm/W}
\]  

(12)
Calculating the Lumen Covered in the Exposure Unit

No. of bulbs used = 4 (i.e. 2 bulbs per layer), Lumen capacity for one lamp = 1800 lm, hence, the total Lumen illuminated and the total area covered by Lumen are derived respectively as follow:

\[
\text{Total Lumen illuminated} = \text{No. of bulbs} \times \text{Lumen capacity (lm)} = 4 \times 1800 = 7200 \text{ lm}
\]

\[
\text{Area covered by Lumen} = \text{Total Lumen illuminated} \times \text{Square meters} = 7200\text{lm} \times 0.124\text{sqmeter} = 892.8\text{m}^2
\]

2.6 Design Implementation of the Exposure Unit

The working algorithm of the microcontroller based PCB machine exposure unit control system is depicted with the program flow chart shown in Fig. 4. The program for the PIC16F628A was written in C language and compiled with the MikroC Pro v.6.61 for PIC compiler. The designed circuit was simulated using Proteus 8.0 so as to determine whether the circuit would work in the desired manner if bread boarded and subsequently soldered. It was discovered that it functioned perfectly when simulated in this environment. The circuit was bread boarded and later implemented on a Vero board as shown in Fig. 5. The complete circuit diagram of the exposure unit is shown in Fig. 6 while the pictorial view of complete cased unit is shown in Fig. 7.

![Program flow chart for PCB Exposure unit](image-url)
Figure 5: Design implementation of exposure unit (a) Bread boarding of circuit and (b) Implementation on Vero Board

Figure 6: Circuit Diagram of PCB Exposure Unit
3. **Results and Analysis**

Tests were carried out initially during construction to determine the right height of the box in relation to the distance between the lamp and glass in order to achieve proper illumination of PCB as shown in Table 3.

<table>
<thead>
<tr>
<th>Test Height (cm)</th>
<th>Observation</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0</td>
<td>Layout and lines are unclear i.e. the PCB was under-exposed</td>
<td>Height not suitable for PCB production</td>
</tr>
<tr>
<td>20.0</td>
<td>Layout and lines are unclear i.e. the PCB was under-exposed</td>
<td>Height not suitable for PCB production</td>
</tr>
<tr>
<td>15.0</td>
<td>Some portions are visible i.e. PCB is still under-exposed</td>
<td>Height not suitable for PCB production</td>
</tr>
<tr>
<td>12.5</td>
<td>Layout and lines are visible and unbroken</td>
<td>Optimal Height for PCB production</td>
</tr>
<tr>
<td>10.0</td>
<td>Most portion turns black i.e. PCB is over-exposed</td>
<td>Not suitable for PCB production</td>
</tr>
</tbody>
</table>

Also, test on different time of exposure to determine the optimum time of exposure for getting efficient PCB was carried out as shown in Table 4. Tracing paper were used for printing the circuit before exposure and it proved to be better because it has better adhesion of the toner. It was observed that excellent PCB was realised at an exposure time of 3 minutes as shown in Figure 8.

<table>
<thead>
<tr>
<th>Exposure time (min)</th>
<th>Observation</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Photoresist traces remains due to insufficient illumination.</td>
<td>Under-exposed: Time is too short for PCB production</td>
</tr>
<tr>
<td>2</td>
<td>Photoresist traces remains due to insufficient illumination.</td>
<td>Under-exposed: Time is insufficient for PCB production</td>
</tr>
<tr>
<td>3</td>
<td>Excellent PCB as layout and lines are visible, clear and unbroken.</td>
<td>Optimum time for PCB production</td>
</tr>
<tr>
<td>4</td>
<td>Layout and lines are visible but broken</td>
<td>Exposure time is too much</td>
</tr>
<tr>
<td>5</td>
<td>Layout and lines are totally invisible.</td>
<td>Exposure time is too much</td>
</tr>
</tbody>
</table>
4. Conclusion

The expensive nature of PCB making machines which has led to its unavailability in most educational facilities where numerous prototyping and circuit implementation activities should take place has been the motivating factor in the development of this work. Hence, in this work the development of a PCB Exposure unit to produce printed circuit board based on photolithographic process using ultraviolet radiation has been implemented. This low cost semi-automated unit will help in inculcating the practice of PCB production in students and encourage small scale production of PCB which can eventually help in solving unemployment in society.

References


Obstacle Detection and Avoidance for Mobile Robotic and Autonomous Tricycle

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Abstract—In this paper a real-time and high performance system of obstacle detection and avoidance for mobile robotic and autonomous tricycle based on ultrasound has been proposed, designed, and implemented. This was achieved with the aid of ultrasonic sensors, GPS and Bluetooth technology. The system uses ultrasonic sensors to detect obstacles and obtain measurements which are transferred to ATmega328P microcontroller for control and coordination. The system is also designed with the ability to receive coordinates of a desired location and autonomously navigate to that location. The concept was implemented using reactive control algorithm for detection/avoidance of obstacles instead of pre-computation of an obstacle-free path in which a robot is programmed or trained to navigate through. Performance evaluation of the system from test results showed that given a number of obstacles, the tricycle showed great accurate movement and navigated successfully to any desired destination.

Keywords: Actuator, Autonomous, Microcontroller, Obstacle detection.

1. Introduction

Despite the fact that printed circuit boards are widely deployed in electronic devices which range from In recent times, there has been a proliferation of tricycles in Nigeria as they are used as a means of transportation. The rise in industrialization and urbanisation has led to this great challenge which has resulted in numerous accidents in our society. Also the need to access any location without human guide, e.g., a visitor to a new city or an elderly person who cannot drive still remains a huge challenge. In transportation systems, a vehicle is the first place where safety starts and it is imperative that it should be equipped with necessary technologies and measures to make it a safe machine which can detect obstacles and avoid collision with them (Ramya et al., 2012). Hence, there is the need for the development of an obstacle detector robotic vehicle which will have the ability to autonomously get to its destination by detecting obstacles within a given range and avoid collision with these obstacles on
its path. This will make it possible for prevention of accidents, surveillance, monitoring and accessibility of any desired location.

There are essentially two approaches for obstacle detection. Passive methods try to detect obstacles based on passive measurements of the scene, e.g., in camera images. They have the advantage that they work over a wide range of weather and lighting conditions, offer a high resolution, and that cameras are cheap. On the other hand, Active methods use sensors such as laser scanners, time-of-flight, structured light or ultrasound to search for obstacles (Christian et al., 2015). Several works has been done on obstacle detection and avoidance systems for autonomous or robotic vehicles using active method but these systems have their own disadvantages as a result of the method of sensing employed. In Jorge (2004) and Ramya et al. (2012) the designed systems used infrared emitters and receivers to sense its environment and detect obstacles. Vasavi and Praveen (2014) proposed an Obstacle Avoidance and Detection Autonomous Car based on IR sensor and uses energy from solar panel. However, these method of obstacle detection is susceptible to dust and fogs, hence is inaccurate in dusty environments. A Sentry Wizard which is an autonomous, FPGA powered motion tracking robot that is designed to patrol an area that is supposed to be empty and engage unauthorized targets by identifying movement with a response time under one third of one second was done in Jeremy (2010). The robot combines four independent subsystems to accomplish this task—navigation, vision, turret and wireless control—all of which are mounted on a mobile platform. All of these subsystems are interfaced through an Arduino microcontroller. However, the work turned out to be cramped for space in the end and provided limitations in part placement.

Saravanan and Kavitha (2012) in their work concentrated on vehicle navigation and obstacle detection using RFID technology and GSM. The RFID which consist of reader and tags were placed in autonomous vehicle and the post respectively. The tag details were predefined in a microcontroller. This was then used to navigate the vehicle from source to destination. The obstacle detection is carried out using ultrasonic sensor. However, this system lacked the use of GPS and neural network concept but was only suitable for industrial goods transportation in a pre-defined path arrangement system. Gildas et al. (2002) in their work proposed a Motion-based Obstacle Detection and Tracking for Car Driving Assistance using a camera mounted on it. A technique entirely based on image motion analysis was design and tested and proved accurate, reliable and efficient on numerous real situations.

Jaiswal (2014) in his work proposed a Mobile Robot that can detect and avoid obstacle by using LED and LDR. The implementation of the artificial intelligence (AI) logic of the system was done and was able to successfully run on an obstacle free course after being able to detect obstacles and take appropriate actions with an accuracy of 86.62%. According to Christian et al. (2015) relying on only monocular cameras and wheel odometry for self-driving cars for obstacle detection is a veritable way. Their experimental results demonstrated that this method is capable of achieving a detection accuracy that is sufficient for practical applications while running in real time. However, the proposed system could not detect dynamic obstacles such as other cars because it would require them to associate obstacle detections over time.

Vidhi et al. (2016) in their work designed an obstacle detection technique based on dynamic cameras and moving objects for vehicles in a transportation system. The aim of the proposed system was to prevent accidents, and make driving fully automated. However, the approach was pre-planned because it used a number of images for training for the obstacle and these parameters were known to
the system. Medha et al. (2013) proposed the navigation of an autonomous vehicle in real-world environments by using ultrasonic sensors mounted on the chassis to determine the distance in three different direction. However, this complex decision based mechanism required for path tracking based on sensing the environment did not incorporate GPRS for real-time navigation.

In this paper, a real-time obstacle detection and collision avoidance system for mobile robotic and autonomous tricycle based on ultrasound is proposed. This was achieved with the aid of ultrasonic sensors, GPS and Bluetooth technology. These sensors provide the means for the robot to acquire information about itself and understand the world around it. This is then used in detecting static objects, determining the amount of free space around them and measuring the distance between these obstacles as it navigates to a given location. The concept used in this work is unique since it uses reactive control algorithm for detection/avoidance of obstacles instead of the concept of path planning which involves pre-computation of an obstacle-free path in which a robot is programmed or trained to navigate through.

2. Methodology and System Design

In this section, the methodology used in the design of the Obstacle Detection and Avoidance for mobile robotic and autonomous tricycle is described. The top to bottom design approach was used in the implementation of this system. This approach entails splitting the system into smaller units hence aiding the designer get more detailed insight into the various compartments of the system. Considerations were made on the type of platform, software component, hardware component and mode of operation of the obstacle detector robotic vehicle. Also, low cost of component, availability, reliability, flexibility and simplicity were considered in the selection of components for the design.

2.1 System Overview

The system block diagram of the various units that make up the obstacle detector robotic vehicle is shown in Figure 1. It consist of the following units: communication unit, control unit, drive unit, data acquisition unit, feedback unit, power supply unit.

![Figure 1: Block diagram of the Developed Obstacle Detector Vehicle](image-url)
2.2 Hardware Design Considerations

Drive Unit
The drive unit is responsible for the mobility and navigation of the obstacle detector robotic vehicle autonomously. The drive unit consists of a motor driver and dc gear motors. The L293D motor driver was chosen for this work and it is used to maintain an accurate movement and control of the dc gear motors. The L293D motor driver implemented here uses the H bridge circuit principle because it contains four switching element, with the load at the centre, in an H-like configuration. Its specifications are as followings in Table 1.

The actuators for the obstacle detector robotic vehicle is extremely important for the adequate movement of the robot. For this purpose Direct current motors (DC Motors) are employed. The SKU: 03-01-0-003-00 Micro DC Gear Motor with Shaft (Fig. 2) is used for this work. It has a unique design to accommodate ease and to easily incorporate the controller and wheels. Also, they are inexpensive, small, easy to install, and ideally suited for use in a mobile robot car. The specifications are as follows: gear ratio of 1:48, no-load speed (5V) of about 208RPM, rated torque of 0.8 Kg.cm @ 5V, no-load current (6V) of $\leq$ 350mA, dimension of 71mm x 27.4mm x 22.4mm, and weight of 28g.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>-</td>
<td>36</td>
<td>V</td>
</tr>
<tr>
<td>Input voltage</td>
<td>-</td>
<td>7</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage</td>
<td>-3</td>
<td>+3</td>
<td>V</td>
</tr>
<tr>
<td>Peak output current, $I_O$ (non-repetitive, $t \leq 100$ $\mu$s)</td>
<td>-1.2</td>
<td>+1.2</td>
<td>A</td>
</tr>
<tr>
<td>Continuous output current, $I_O$</td>
<td>-600</td>
<td>+600</td>
<td>A</td>
</tr>
</tbody>
</table>

Figure 2: SKU: 03-01-0-003-00 Micro Geared DC Motors

Feedback Unit
The feedback unit is designed in such a way that it accommodates the obstacle sensor and Micro Servo Motor. The basic functionality of this unit involves the measurement of the distance to an obstacle by
the ultrasonic sensor, comparing the measured distance with a reference input (20cm) and carrying out some predefined instructions by the microcontroller based on the acquired data. The block diagram of the control loop for obstacle detection is shown in Figure 3.

The Ultrasonic ranging module HC-SR04 as shown in Figure 4 was used for obstacle detection in the design. It has the ability to provide 2cm – 400cm non-contact measurement function, the ranging accuracy can reach to 3mm and it is very compact and has a very high performance. This Ultrasonic sensor transmits the ultrasonic waves from its sensor head and again receives the ultrasonic waves reflected from an object.

By measuring the length of time from the transmission to reception of the sonic wave, it detects the position of the object. The specifications are as follows: power supply, +5Vdc; quiescent current, < 2mA, working current: 15mA; effectual angle: < 15degrees; ranging distance: 2cm – 400cm/1’’-13ft, resolution: 0.3cm, measuring angle: 30 degree, input pulse width: 10uS, VCC = +5VDC, Trig is the trigger input of sensor and echo is the echo output of sensor.

In a bid to improve the flexibility of the obstacle detector Robot, the Ultrasonic sensor is placed on a servo motor. The servo motor chosen for this task is the SG90 model servo motor. The SG90 has the ability to control and rotate the sonar to three predetermined positions and at these positions, the reading of the ultrasonic is obtained and compared while the microcontroller decides its next line of action. The SG90 servo motor offers great torque and power characteristics. It comes in a small size, and because it has a built-in circuitry to control its movement, it can be connected directly to the microcontroller. The SG90 servo motor has the following specifications: torque: 25.0 oz-in (1.80 kg-cm) at 4.8V, speed: 0.1 sec/60° (4.8V), voltage: 4.0V to 7.2V, 46V-5.2V nominal, weight: 9g, running current with 5V supply: 220 +/- 50mA.
Data Acquisition Unit

The data acquisition unit which consist of the Global Position System (GPS) module and the magnetometer is dedicated to the acquisition of information with regards to the current location and coordinates of the obstacle detector robotic vehicle. These two modules are required for the navigation of the obstacle detector vehicle through any given environment to any given location and they are interfaced using the Atmega328p microcontroller. The GPS receiver used for this work is the VK2828U7G5LF GPS receiver which has an industry standard GPS antenna of 25 * 25 * 4mm, high sensitivity, inbuilt LNA and support both online and offline GPS services. Figure 5 shows the circuit connection of GPS and Bluetooth module to the controller.

![Figure 5: Circuit diagram of HC-05 and VK2828U7G5LF GPS Connection](image)

The HMC5883L module is the magnetometer used for this work. It is a 3-axis magneto resistive sensors and ASIC in a 3.0x3.0x0.9mm LCC Surface Mount Package which can be used in strong magnetic field environments with a 1 to 2 degree. This fast 160 Hz maximum output rate module with compatibility for battery powered applications measures the direction, strength, or relative change of a magnetic field at a particular location. Whereas the magnetometer is able to acquire data by measuring the magnetic field of the earth, on the other hand the GPS module has the ability to connect to a satellite from whence it receives real time coordinates of its current location. The data acquired is sent to the microcontroller which is responsible for comparing the data received and controlling the obstacle detector robotic vehicle based on predefined instructions to any given location.

Communication Unit

This unit consist of a Bluetooth module which is interfaced with the Atmega328p microcontroller to make communication possible. In the obstacle detector robotic vehicle, a short range communication is established using a Bluetooth module, and UART communication protocol. The universal asynchronous receiver/transmitter (UART) is a physical circuit incorporated into a microcontroller. The UART transmits and receives serial data between UART supported devices like Bluetooth module and microcontrollers.

A short range communication (5 - 10 meters) is established between the microcontroller and the Bluetooth module in order to send the coordinates of a location for the navigation of the obstacle detector robotic vehicle. The Bluetooth module used is the HC-05. Specifications of the HC-05 Bluetooth module are typical -80dBm sensitivity, up to +4dBm RF transmit power, low power 1.8V operation- 1.8 to 3.6V I/O,
PIO control, UART interface with programmable baud rate, with integrated antenna and with edge connector.

**Control Unit**

The control unit which is responsible for controlling the navigation and movement of the obstacle detector robotic vehicle was designed around the Atmega328p microcontroller. The ATmega328P is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega328P achieves throughputs close to 1MIPS per MHz. This empowers system designers to optimize the device for power consumption versus processing speed. Also, it is easy to use with simple sensors and output devices, and can communicate with desktop computers fairly simply as well (Igoe, 2015).

The controls as implemented by the Atmega328p microcontroller are shown in the analysis of robot navigation in Table 2.

**Table 2: Analysis of Robot Navigation**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Left wheel</th>
<th>Right wheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward</td>
<td>Clockwise</td>
<td>Clockwise</td>
</tr>
<tr>
<td>Back ward</td>
<td>Anticlockwise</td>
<td>Anticlockwise</td>
</tr>
<tr>
<td>Left</td>
<td>Stop wheel</td>
<td>Clockwise</td>
</tr>
<tr>
<td>Right</td>
<td>Clockwise</td>
<td>Stop wheel</td>
</tr>
<tr>
<td>Stop</td>
<td>Stop wheel</td>
<td>Stop wheel</td>
</tr>
</tbody>
</table>

**Power Supply Unit**

The power supply unit is dedicated to ensuring that the required input voltage needed for the proper operation of the obstacle detector vehicle is supplied. The DC power source used for the design of the obstacle detector robotic vehicle is an 11.1V, 3000mA rechargeable LI-PO cell. The obstacle detector robotic vehicle requires two DC supply voltage levels of 5V and 3.3V to operate. The input voltage of 3.3V is for the HC-05 Bluetooth module. In order to achieve the desired voltage levels of 5V, the LM7805 IC voltage regulator is used. This voltage regulator gives the desired voltage of 5V and prevents over voltage from the DC source. The 3.3V was achieved using the voltage divider rule. A suitable capacitor was integrated into the unit to filter out undesirable AC component that may occur in the unit due to fluctuation caused by a drop in input voltage. The complete circuit diagram of the designed system is shown in Figure 6.

2.3 **Software Design and Implementation**

A suitable algorithm was developed on how the system should operate and a program was written with respect to this algorithm. The program for the obstacle detector tricycle was written in embedded C language in the Arduino integrated development environment (IDE) for ATmega328P microcontroller. The software used for the software design analysis and implementation include IDE for Arduino, Proteus 8.0 professional and Bluetooth Terminal android software. Some of the steps taken before the actual line of codes were written include downloading of libraries for the motor driver and ultrasonic sensor and defining the various pins of the microcontroller as input/output pins.
Algorithm

The flowchart of the designed system is shown in Figure 7.
Figure 7: Flow chart of Obstacle Detector Vehicle

The following steps are taken by the robot to navigate through an obstacle plagued environment, avoiding possible obstacles in its path to get to its destination:
(a) The obstacle detector robotic vehicle is switched on and allowed to gather facts about its environment with the help of the Ultrasonic sensor.
(b) The coordinates for a desired location is communicated to the GPS receiver through Bluetooth communication from an android phone.
(c) The robot then compares this information to stored data.
(d) The robot then decides the significance of the information.
(e) The robot aligns to the direction inputted with the help of the magnetometer.
(f) The robot then executes the suitable action and moves accordingly.

Implementation

Figure 8 shows the simulation of the designed circuit which was done on Proteus 8.0 work bench in order to determine the workability of the circuit in the desired manner if breadboarded and subsequently soldered. It was discovered that it functioned perfectly when simulated in this environment. The designed circuit of the obstacle detector vehicle was physically implemented on a breadboard to ascertain if results achieved in simulation would be obtained in reality. After which it was implemented on a Vero board successfully. The complete pictorial view of the Obstacle Detector Robotic Vehicle is shown in Figure 9.

![Image of obstacle detector robotic vehicle](image)

**Figure 8:** Complete Simulation of the Obstacle Detector Robotic Tricycle

Mode of Operation

Figure 9 shows the complete circuit diagram of the Obstacle Detection and Avoidance Robotic Tricycle which can be used to navigate through any environment to any desired location. The operation of the obstacle detector robotic tricycle is divided basically into two parts; the mobile vehicle and the...
Bluetooth Terminal android software installed in an android phone. The robotic tricycle makes use of a dc voltage of 5V and 3.3V to the microcontroller and the Bluetooth module respectively. The obstacle detector tricycle also consists of the ultrasonic sensor, magnetometer and the GPS receiver. These are responsible for interfacing the obstacle detector robotic tricycle with its environment. They sense the environment in order to detect obstacles, determines the amount of free space around them and measures the distance between these obstacles, measure magnetic field of the earth and connect with satellite so as to properly navigate the robot to a desired location.

When the tricycle and the phone are powered on, the Bluetooth software searches for the tricycle and connection is established with it. After that, the coordinates of the desired destination is inputted in the android phone. The coordinates are communicated to the obstacle detector robotic vehicle using Bluetooth communication. When a location has been acquired, the motor driver is initiated, it controls the speed of the two motors enabling both clockwise and anti-clockwise movement. Obstacles are detected and avoided with the aid of the ultrasonic sensor which is mounted on a micro servo motor and rotates while the communicated location is achieved using the GPS receiver.

![Figure 9: Complete Pictorial View of the Obstacle Detector Robotic Tricycle](image)

3. Results and Discussion

Several experiments were carried out in both indoor and outdoor scenarios in order to verify the effectiveness of the autonomous tricycle and validate the correct operation of the detection/avoidance algorithm designed. The tests were such that different kind of obstacles were placed in different positions in these two environments. It was found that given these number of obstacles, the vehicle showed great accurate movement in spite of the conditions and navigated successfully to its desired destination by detecting and avoiding them.

4. Conclusion

In this paper, we developed a tricycle which has the capability of autonomously navigating its path to any desired location by detecting and avoiding various obstacles on its way. This proposed system
which is a first step to making driving fully automated is aimed at providing accessibility to any desired location, prevent accidents and possibly for surveillance/monitoring of any given location. The concept works well using reactive control algorithm for detection/avoidance of obstacles instead of pre-computation of an obstacle-free path in which a robot is programmed/trained to navigate through. Performance evaluation of the system from test results showed that given a number of obstacles, the vehicle showed great accurate movement and navigated successfully to its desired destination by detecting and avoiding them.

References


Igoe, T. (2015), All About Microcontrollers, Codes, Circuits & Construction, Available at: https://www.tigoe.com/pcomp/code/controllers/all-about-microcontrollers


Production Strategy Change from Long-cycle Cellular Manufacturing to Short-cycle Serial Line Assembly: A Categorical Imperative in Ergonomics

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Abstract—The absent of ergonomics in production systems can cause musculoskeletal disorders (MSDs) and attracts a huge cost when performance is compromised. This work presents the development of an approach to integrating ergonomics into a companies’ regular development work. The case of engine assembly compared cellular and line production strategies. The line demonstrated system, balance, and disturbance related losses resulting in forced operator waiting. Nevertheless, the line overcame productivity barriers in the operation of the cellular system. The line system showed increased repetitiveness with cycle times that were 6% of previous, uneven distributions of physical tasks such as nut running, and reductions in influence over work scales all implying increased risk. Teamwork in the line system contributed to significantly increased co-worker support – an ergonomic benefit. Workplace risk factors can be precisely and accurately quantified. These risks are embedded in strategic choices in the design process. Load amplitudes were determined by workstation layout and the material supply sub-system. Risk related to the pattern and duration of loading are determined more by flow and work organisation elements. Psychosocial risk factors appear to be affected by a combination of system design elements. Managing the emergence of these risks proactively requires attention to ergonomics throughout the design process, especially in strategic choices. Integrating ergonomics into early development stages implies changing roles for groups and individuals in the organisation. This approach appears feasible but is difficult and remains an under-utilised strategy for sustainable competitive advantage.

Keywords: Human Factors Engineering, Manufacturing, Musculoskeletal disorders, Production, Work System Design.

1. Introduction

The problem under study in this thesis is the occupational source of work-related musculoskeletal disorders (MSDs). The opportunity under study is the ability of an organisation to apply knowledge
about humans, ‘Human Factors’ or ‘Ergonomics’ (IEA Council, 2000), to create high performance work systems that are effective, profitable, and healthy workplaces. These two aspects – the human health, and the system performance – are central to the research approach of the ‘Production Ergonomics’ group at the National Institute for Working Life West in Gothenburg Sweden, from which this thesis emerges. It is through the joint optimisation of these two aspects that sustainable development can be achieved.

This paper presents a ‘systems’ framework and new data for understanding how MSDs can emerge as an unintended result from the design of a work system. Four research papers are used to study the problems on: how are risk and other productivity factors related to core ‘strategic’ elements in the design of the production systems? In this paper, the examination of production systems that have undergone redesign after changes production strategy is considered.

1.1 Ergonomic Impact of Production System Design

The production system itself is the product of a design process. The design process will shape the eventual production system which, in turn will determine MSD risk factor levels for system operators. The design of the production system is divided into two main areas of concern: 1) the setting of production strategy, primarily the responsibility of corporate management, and 2) the system design process itself. Understanding the design process provides a first step to understanding how designers deal with ergonomic factors in their work. Production system design decisions are made within the context of the direction established by the corporation’s production strategy. Very few studies have examined this process with regards to ergonomics.

Skepper et al. (2000) have described a deliberately simplified design process with a linear series of stages with iterative elements. In the case of product design, the process has been shown to be neither rational nor linear but instead represents a complex organisational process involving uncertainty, iteration, and negotiation (e.g. Broberg, 1997). Burns and Vincente (2000), examining control station design, have described the negotiation process involved in resolving the web of design constraints which often conflict. Designers of complex systems can face an overwhelming number of criteria and constraints and conflicts must be resolved based on personal interpretation as well as the influence of other stakeholders (Wulff et al., 2000; Wulff et al., 1999a; b). In this context, knowledge of ergonomic factors in design decisions does not necessarily guarantee their implementation, especially when these are seen as ‘soft’ or ‘vague’ criteria which are difficult to verify or demonstrate (Wulff et al., 2000; Wulff et al., 1999b).

Even when ergonomic factors are applied to a local design aspect this does not guarantee success because locally optimal ergonomic designs do not necessarily result in globally optimal solutions in the resulting system (Burns and Vicente, 2000). There has been little systematic documentation regarding the relationships between decision-making at this level and the emergence of MSD risk factors in the production system. Indeed it seems that there is generally a lack of feedback to designers about problems that emerge in the systems that they design: “Short of a well-publicised catastrophe, the design engineer will probably never know the consequences of his or her design, and top management will only hear of it faintly and perhaps not until the next project is already under construction” (Perrow, 1983). For this reason the model makes explicit the production strategies chosen in the development of the new system.
### 1.2 Production Strategy as an Ergonomic Determinant

Strategic choices in design may be a root source of MSDs. Production system designers react to strategic priorities set by senior management. Strategic thinking sets the stage for system design and eventual MSD risk factor patterns. Some 75 years after Ramazzini began writing on the medical consequences of poor ergonomics (although the word “ergonomics” was not coined until 150 years later by Jastrzebowski in 1857 (Koradecka, 2001)), Adam Smith described the productivity benefits he observed in the division of labour (Smith, 1776). By the twentieth century authors such as Taylor (Taylor, 1911) had extended the idea of division of labour into a strategy of ‘Scientific management’ whereby the work of assembly was atomised into minute tasks with each worker repeating their task many times.

This strategy set the foundation for the modern assembly line as first realised by Henry Ford in his car factories (Ford, 1926). Since the time of Taylor we have seen a vast array of production strategies presented and discussed in both scientific and popular literature. Some of these, such as the famous ‘lean manufacturing’ (Womack et al., 1990), or ‘reflexive production’ (Ellegård et al., 1992), may really be thought of as a collection of strategic elements intended to work in concert. In this thesis I emphasise the importance of ‘production strategy’ because these reflect fundamental choices early in the development process that set the stage for risk factor patterns in the resulting system. Production strategies, I argue, present the seeds from which operators’ MSDs can result. Compared to the volume of research around risk factors very little is known about production strategies from an ergonomics perspective.

“The greatest improvement in the productive powers of labour… seem to have been the effects of the division of labour” - Adam Smith (1776). Strategy is a broad and imprecise term. Mintzberg (1987) characterised strategy as a plan, a pattern, a position, a ploy, or as a perspective. Manufacturing can include a number of the characteristics outlined by Mintzberg (1987). ‘Just In Time’ (JIT), for example, has been termed a philosophy that incorporates a number of more specific strategies (Gunasekaran and Cecille, 1998) such as reduction in buffer sizes, and fast change-over. The extent to which a strategy is realised in practice may vary (Ghobadian and Gallear, 2001; Womack et al., 1990), with the gap between strategy and practice being apparently a more important indicator of (poor) performance than the strategy itself (Rho et al., 2001). It is difficult therefore to determine the ergonomic consequences of production strategies directly without considering the specific implementation for each case.

Winkel & Aronsson (2000) have discussed the strategic objective of ‘flexibility’ with respect to potential ergonomic impacts in a number of performance areas. Reviewers suggest that some production strategies, such as business process re engineering, may provide better potential for good ergonomics than do other strategies, such as lean manufacturing (Björkman, 1996; Eklund and Berggren, 2001). Like other design decisions, strategies can be difficult to isolate and cannot always be directly measured but must be inferred from observation. Strategic decisions regarding manufacturing approaches occur relatively infrequently and are most obvious during the development of a new production system that may then operate for a number of years. Health consequences of different production strategies are not well understood although the linkages between these strategies and ergonomics are readily apparent (Björkman, 1996). Vahtera et al. (1997) have found MSD risk to increase by 5.7 times during ‘corporate downsizing’. The individuals’ perception of the downsizing process itself also appears to affect health (Kiviväki et al., 2001; Pepper et al., 2003). Landbergis et
al. (1999), in their review of available literature, noted increased negative health outcomes are often associated with the adoption of Lean Manufacturing approaches.

Karltun et al. (1998) found signs of increased physical loading with the implementation of ISO 9000 standards. Looking at more specific system design elements Coury et al. (2000) have demonstrated increased physical risk with partial automation strategies which couple workers more tightly to the production system. An increasing number of studies are finding risk increases with the adoption of line-based production approaches (Fredriksson et al., 2001; Neumann et al., 2002; Ölafsdóttir and Rafnsson, 1998). On the positive side, Kadefors et al. (1996) found that ergonomics improved in the application of long-cycle parallelised assembly flows without sacrificing productivity. This small but growing body of research demonstrates how higher level strategic decisions can result in increased, or decreased, MSD risk for employees. Nevertheless, not enough is known to develop tools by which industrial stakeholders can judge the ergonomic consequences of their decisions.

Research needs

In this paper, an attempt to isolate ‘strategic’ production elements that form a critical role in shaping the production system is made. By dealing with specific strategic design choices we attempt to move beyond the ‘lean’ ‘not-lean’ dialectic initiated by Womack et al. (1990). It is in the early stages of design that the greatest latitude for good ergonomics exist while the system concept is still malleable (Burns and Vicente, 2000; Engström et al., 1998; Imbeau et al., 2001; Kilker, 1999).

Early design choices allocate the majority of project resources and set critical initial design constraints (Buur and Andreasen, 1989; Wild, 1995). While design choices at subsequent stages in the design process may affect MSD risk these are generally less expensive to retrofit, and are thus possible targets for shop floor level improvement schemes such as participatory ergonomics (Haines and Carayon, 1998; Haines et al., 2002; Nagamachi, 1995; Noro and Imada, 1991). Strategic design elements, however, tend to be ‘locked in’ and thus pose critical decisions with regards to ergonomics. The relationship between ergonomics, productivity, and these strategic design choices is not well understood and poses a critical research need.

1.3 Societal Context of Ergonomics

Companies are acting in a society with particular market conditions, legislation, and cultural attitudes. These forces create the context in which the organisation operates and can influence ergonomics. Social contexts influence selection of production models (Boyer and Freyssenet, 2002), and influence change processes (Bamford and Forrester, 2003). Current social trends of relevance for ergonomics may include: rapid pace of change – with technology changing faster than management structures, increasing scale of industrial operations (globalisation), integration of operations (with tight supply chains), aggressive competition, work intensification, and deregulation (D’Aveni, 1994; Docherty et al., 2002; Mergler, 1999; Merlii and Paoli, 2000; Moray, 2000; O’Neill, 2000; Paoli and Merlii, 2001; Rasmussen, 2000; St. John et al., 2001).

This article does not specifically study social factors. Nevertheless, companies are social institutions (Hatch, 1997) and design is a social process that plays out in an array of conflicting interests (Gustavsen et al., 1996) and is thus inherently (micro) political (Broberg, 1997; Engström et al., 1998). Organisations and individuals both act on and are acted upon by their social environment.
1.4 Organisational Context of Ergonomics

How a company responds to an intervention effort will depend in part on the structure and culture of the organisation. These factors can also influence how well human factors are incorporated in production system design.

The developmental model presented is embedded in an organisation. Organisations have many features including a social structure, organisational culture, physical structure, technology, and strategic profile (Hatch, 1997), each of which can influence developmental and change processes. From an interventionist perspective, involvement of a broad range of stakeholders in the organisation has shown good promise for effective ergonomics development (Gustavsen et al., 1996; Westgaard and Winkel, 1997).

Securing support of these stakeholders may require an attempt to ‘solve ergonomics problems in a profitable way’ (Winkel and Westgaard, 1996). By emphasising the interconnectedness of ergonomics and productivity it may be possible to ‘jointly optimise’ these two output domains – an approach advocated by a growing number of researchers (e.g. Burns and Vicente, 2000; Clegg, 2000; de Looze et al., 2003; Gustavsen et al., 1996; Hendrick and Kleiner, 2001; Huzzard, 2003; Ingelgård and Norrgren, 2001). Achieving this is a problem of organisational change – an entire field of study itself (Hatch, 1997). Saka (2001), among others, has pointed out the organisational complexities here: “The heavy emphasis in the literature on a rational-linear approach to understanding organisational change overlooks the significance of the cultural and political dimensions of organisational life.” - (Saka, 2001)

This irrational nature of organisational change might even be exacerbated by an organisation’s own psychotic tendencies (De Vries, 2004). Broberg and Hermenud (2004) have also emphasised politicality suggesting that ergonomists need to act as ‘political reflective navigators’ as they attempt to negotiate priorities in a company’s development projects amongst a network of different actors. Organisational actors such as production engineers tend, for example, to have no social mandate (Ekman Philips, 1990), to have little ergonomics training (Neumann et al., 1999a), and can be technology focussed (Kilker, 1999) which can provide a tremendous contrast to the ergonomist’s own context.

1.5 Individual Contexts of Ergonomics

How individuals respond to the work demands will depend on their role in the company and their physical and mental capacities. We humans are only partially rational. ‘Individuals’ in this model are everywhere in the organisation – not just the production operator. The operator is important and individual tolerance to some physical load patterns vary with individual characteristics (Kilbom and Persson, 1987; NAC et al., 2001; NRC and Panel on musculoskeletal disorders and the workplace, 2001), and tolerance may be successfully improved (Westgaard, 2000; Westgaard and Winkel, 1997).

This model attempts to highlight the role of all the stakeholders in the organisation who might influence the development process – and thus MSD risk factors – in the organisation. When dealing with a specific individual the arch types from general analysis (Ekman Philips, 1990; Neumann et al., 1999a) may not apply fully – the practitioner must be open to the uniqueness of the individual. Furthermore, humans tend to operate within a ‘bounded’ rationality (Schwartz, 2002); implying a
certain amount of irrationality, or non-linearity, in the entire system (Guastello, 2003; Skyttner, 2001). “When individuals are not involved in establishing their goals, they are much less likely to feel motivated to achieve them than when they are allowed to participate in the process” - Hatch 1997

The aim of paper is to examine productivity and ergonomics consequences of a change in production strategy from a long-cycle parallel flow workshop to a serial flow line assembly. Here, as in previous study, a ‘vertical’ analysis through the development system is made.

2. Method

This study was conducted in a Nigerian company assembling large diesel engines (Esckallante Engineering Nigeria Limited). After decades of using a cellular manufacturing approach with parallel flow and long cycle times (1¼ hours), the company decided to implement a serial flow ‘line’ based assembly system with a cycle time under 5 minutes. This case appears consistent with a trend we have observed in PPF Engineering Ltd to return to line-based production after decades of using more sociotechnically based approaches. This trend appears despite theoretical and empirical evidence that parallel flow assembly can be more effective (Ellegård et al., 1992; Engström et al., 1996; Medbo, 1999; Nagamachi, 1996; Rosengren, 1981) and have better physical and psychosocial ergonomics than conventional lines (Engström et al., 1995; Kadefors et al., 1996). This case allowed further exploration of the relationship between core system design elements, such as flow strategy or work organisation, and system outputs such as productivity and ergonomics. The product itself was largely unchanged between systems.

2.1 Evaluation Approach:

The paper integrated qualitative and quantitative methods in the evaluation. Informal interviews and document analysis were conducted to understand both process and outcomes in the system redesign project. Production and economic data were obtained from company records and interviews. Questionnaires (n=54 pairs) were used to assess operators’ perceptions of pain status (Kuorinka et al., 1987), workload (Borg, 1990), and psychosocial conditions (Karasek et al., 1998; Karasek and Theorell, 1990; Karasek, 1979; Rubenowitz, 1997). Video recordings were made and analysed (Engström and Medbo, 1997; Medbo, 1998) with respect to the time used for work activities including direct (e.g. value adding assembly) and indirect (e.g. getting components or checking instructions) work.

Biomechanical models (Neumann et al., 1999b; Norman et al., 1998) were used to assess individual loading and flow simulation models were used to understand system behaviour and working patterns (AUTOMOD). This was a pre-post case study and comparisons were made with 1 year interval for 2 matching months to control for seasonal production variability. The data from these methods were used to support an analysis of the advantages and disadvantages, in terms of both productivity and ergonomics, for each of the major elements in the production system design: The adoption of serial flow with its associated reduction in cycle time, workstation layouts, material supply sub-system, change away from product kits, the adoption of automated guided vehicles (AGVs) for transport and IT systems, and the work organisation approach used. We focus our comparison on that portion of the production system which was changed from work cells (‘OLD’) to line assembly (‘NEW’).
3. **Results**

The new line system had slightly higher output with higher costs, poorer physical ergonomics and worker autonomy, but better co-worker support compared to the old cell assembly.

3.1 **Old system**

The OLD production system, designed with 18 ‘dock’ stations, was studied having 12 Docks and a small ‘learning line’ in parallel for newer Operators. Operators worked alone at each dock to assemble each motor. Operators were required to finish 5 engines per day, which increased to 5.5 shortly before measurement. Operators could stop working once this quota was reached. The system was designed, based on standard times, to allow 6.2 motors to be completed per shift per dock but this target was not enforced and not all operators were believed to be capable of this pace. Hand steered motorized carts allowed transport and lift-tilt position adjustment of motors. Parts were supplied to the dock using a 5-shelf ‘kit’ stocked with variant specific components by ‘order pickers’.

3.2 **New system**

The New line system used a serial flow of 18 stations. Automated Guided Vehicles (AGVs) provided motor transport and eliminated short walks between assembly cycles. Parts were supplied directly to the line in large crates. Operators retrieved parts directly from the crates occasionally adopting awkward postures. The AGV contained a computer monitor providing part numbers for the particular variant to the operator. The product itself was largely unchanged between OLD and NEW systems requiring about the same component assembly work. There were however many product variants requiring different components that, for lower volume variants, were positioned further away from the operators’ workstation resulting in load carrying. Production volumes, a primary change driver, were 12% higher in the NEW system where cycle times had been reduced to 6% of those in the OLD system.

Time to learn a single station in the new system was about 1 day although time to learn the entire system, an organisational objective, was about the same in both systems at 1 month. Total staffing levels were about the same with 46 people in the OLD and 47 in the NEW system – 6 persons were no longer needed to pick OLD kits, but 7 more people were needed along the NEW line. Unit labour costs were 3% higher in the NEW system when adjusted for scheduled wage rate increase. Costs per motor were 32% higher in the NEW system in the period of comparison driven mostly by capital and support costs for the new high-tech AGV system.

As predicted by the companies own corporate standard “serial flows with short cycle times generate waiting times that are not experienced as pauses but as disturbances in the work rhythm. This also generates accelerated work with poor ergonomics as a consequence” (Backman, 2003). It was observed this in the video analysis that waiting was 0.1% of assembly time in the OLD system and 18% of assembly time in the NEW system. This waiting was largely caused by starving and blocking disturbances that are inherent in serial flows with normal human variability in performance. Flow simulation illustrated the effects of human variability and the additional vulnerability lines have to other disturbances such as machine downtime. Psychosocial indicators revealed significant (p <0.05) reductions in Decision latitude and control over work scales and significant improvements in co-worker support and team climate scales depicts the spread of operators’ opinions when asked to make direct comparisons of the two systems themselves.
Pain levels were highest for the low back with 72% in the New system reporting pain in the previous 3 months, down 9% over OLD. Hand-wrist pain was also high and similar in both systems with 62% reporting pain in both systems. Shoulder pain increased 28% in the New system with 60% of operators reporting pain in the past 3 months. Perceived physical exertion rates showed a pattern similar to the pain reporting, ranged from 5.3–6.5 (“hard” to “very hard”) on the Borg scale, and tended to be lower in the NEW system but were only significantly \((p <0.05)\) reduced for the Back. We examined nut running activity on video recordings as an indicator of upper limb loading and found a range from under 500 nuts/day to just under 3000 nuts/day depending on the workstation. In comparison the old system, with its production quota, had a consistent load of about 1200 nuts/shift based on designed work pace. This unevenness of load was also observed for peak spinal loading which, when considered system wide, was similar in both systems with 470 N L4/L5 Shear load and 2600 N compression. In the New system however not all operators were exposed to the ‘worst case’ lifting situation every day.

4. Conclusion

With regards to production strategies effects on ergonomics, the automation of repetitive assembly work (robots) increased productivity reduced system-wide operator exposure to manual assembly work, and thus system-wide MSD risk. The automation of transportation functions (to serial flow conveyors), however, contributed to starving and blocking losses, increased repetitive monotonous work, and hence increased MSD risk for remaining manual assembly workers. The ergonomics impact of automation appears to depend on the tasks automated and the tasks remaining to the operators. The performance of parallel flow systems can be compromised by the work organisation, such as the use of quotas, as well as inefficiencies in the kitting system. In addition, the serial line systems studied here showed increased risk of musculoskeletal disorders due to increased repetitiveness and physical monotony, as well as reduced job control with elements of machine pacing, and uneven load distribution across stations. Furthermore, serial flow systems exhibit system and balance losses, while these reduce physical workload and movements, operators do not experience this forced waiting as a ‘pause’. The use of team structures in the serial line system improved co-worker support, which implies a risk reduction. Teamwork also seemed to support productivity by reducing the impact of system disturbances.

References


A Categorical Examination of Ergonomics Productivity Consequences using Multiple Mixed Method Automation Technology Implementation in Esckallante Engineering Ltd

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Abstract—Inadequate ergonomics in production systems can compromise performance and cause musculoskeletal disorders (MSDs). In any case, the implication is expensive to actualize in reality. This article identifies how these risks relate to production strategies. Two pre-post case studies using multiple mixed methods were conducted to examine how production strategies can affect productivity and ergonomics outcomes. The case of electronics assembly, showed how automation can increase output while eliminating repetitive monotonous work. Automation to serial flow, however, resulted in increased repetitiveness at remaining assembly stations. Despite ergonomic workstation design efforts, shoulder loading increased 14%. Workplace risk factors can be precisely quantified. These risks are embedded in strategic choices in the design process. Load amplitudes were determined by workstation layout and the material supply sub-system. Risk related to the pattern and duration of loading are determined more by flow and work organisation elements. Psychosocial risk factors appear to be affected by a combination of system design elements. Managing the emergence of these risks proactively requires attention to ergonomics throughout the design process, especially in strategic choices. Integrating ergonomics into early development stages implies changing roles for groups and individuals in the organisation. This approach appears feasible but is difficult and remains an under-utilised strategy for sustainable competitive advantage.

Keywords: Human factors, Manufacturing, Musculoskeletal disorders, Organisational development, Production system design, Strategy.

1. Introduction

The production system itself is the product of a design process. The design process will shape the eventual production system which, in turn will determine MSD risk factor levels for system operators. Production system design decisions are made within the context of the direction established by the
corporation’s production strategy. Very few studies have examined this process with regards to ergonomics. Skepper et al. (2000) described a deliberately simplified design process with a linear series of stages with iterative elements. In the case of product design, the process has been shown to be neither rational nor linear but instead represents a complex organisational process involving uncertainty, iteration, and negotiation (e.g. Broberg, 1997). Burns & Vincente (2000), examining control station design, have described the negotiation process involved in resolving the web of design constraints which often conflict. Designers of complex systems can face an overwhelming number of criteria and constraints must be resolved based on personal interpretation as well as the influence of other stakeholders (Wulff et al., 2000; Wulff et al., 1999a; b). In this context, knowledge of ergonomic factors in design decisions does not necessarily guarantee their implementation, especially when these are seen as ‘soft’ or ‘vague’ criteria which are difficult to verify or demonstrate (Wulff et al., 2000; Wulff et al., 1999b).

Even when ergonomic factors are applied to a local design aspect this does not guarantee success because locally optimal ergonomic designs do not necessarily result in globally optimal solutions in the resulting system (Burns and Vicente, 2000). There has been little systematic documentation regarding the relationships between decision-making at this level and the emergence of MSD risk factors in the production system. Indeed it seems that there is generally a lack of feedback to designers about problems that emerge in the systems that they design: “Short of a well-publicised catastrophe, the design engineer will probably never know the consequences of his or her design, and top management will only hear of it faintly and perhaps not until the next project is already under construction” (Perrow, 1983) For this reason the model makes explicit the production strategies chosen in the development of the new system.

Strategic choices in design may be a root source of MSDs. Production system designers react to strategic priorities set by senior management. Strategic thinking sets the stage for system design and eventual MSD risk factor patterns. Some 75 years after Ramazzini began writing on the medical consequences of poor ergonomics (although the word “ergonomics” was not coined until 150 years later by Jastrzebowski in 1857 (Koradecka, 2001)), Adam Smith described the productivity benefits he observed in of the division of labour (Smith, 1776). By the twentieth century authors such as Taylor (Taylor, 1911) had extended the idea of division of labour into a strategy of ‘Scientific management” whereby the work of assembly was atomised into minute tasks with each worker repeating their task many times.

This strategy set the foundation for the modern assembly line as first realised by Henry Ford in his car factories (Ford, 1926). Since the time of Taylor we have seen a vast array of production strategies presented and discussed in both scientific and popular literature. Some of these, such as the famous ‘lean manufacturing’ (Womack et al., 1990), or ‘reflexive production’ (Ellegård et al., 1992), may really be thought of as a collection of strategic elements intended to work in concert. In this paper, emphasis is on the importance of ‘production strategy’ because these reflect fundamental choices early in the development process that set the stage for risk factor patterns in the resulting system. Production strategies, I argue, present the seeds from which operators’ MSDs can result. Compared to the volume of research around risk factors very little is known about production strategies from an ergonomics perspective.
The extent to which a strategy is realised in practice may vary (Ghobadian and Gallear, 2001; Womack et al., 1990), with the gap between strategy and practice being apparently a more important indicator of (poor) performance than the strategy itself (Rho et al., 2001). It is difficult therefore to determine the ergonomic consequences of production strategies directly without considering the specific implementation for each case. Winkel and Aronsson (2000) discussed the strategic objective of ‘flexibility’ with respect to potential ergonomic impacts in a number of performance areas. Reviewers suggest that some production strategies, such as business process reengineering, may provide better potential for good ergonomics than do other strategies, such as lean manufacturing (Björkman, 1996; Eklund and Berggren, 2001). Like other design decisions, strategies can be difficult to isolate and cannot always be directly measured but must be inferred from observation. Strategic decisions regarding manufacturing approaches occur relatively infrequently and are most obvious during the development of a new production system that may then operate for a number of years. Health consequences of different production strategies are not well understood although the linkages between these strategies and ergonomics are readily apparent (Björkman, 1996). Vahtera et al. (1997) have found MSD risk to increase by 5.7 times during ‘corporate downsizing’. The individuals’ perception of the downsizing process itself also appears to affect health (Kivivmäki et al., 2001; Pepper et al., 2003). Landbergis et al. (1999), in their review of available literature, noted increased negative health outcomes are often associated with the adoption of Lean Manufacturing approaches.

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Early design choices allocate the majority of project resources and set critical initial design constraints (Buur and Andreasen, 1989; Wild, 1995). While design choices at subsequent stages in the design process may affect MSD risk these are generally less expensive to retrofit, and are thus possible targets for shop floor level improvement schemes such as participatory ergonomics (Haines and Carayon, 1998; Haines et al., 2002; Nagamachi, 1995; Noro and Imada, 1991). Strategic design elements, however, tend to be ‘locked in’ and thus pose critical decisions with regards to ergonomics. The relationship between ergonomics, productivity, and these strategic design choices is not well understood and poses a critical research need.

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This article does not specifically study social factors. Nevertheless, companies are social institutions (Hatch, 1997) and design is a social process that plays out in an array of conflicting interests (Gustavsen et al., 1996) and is thus inherently (micro) political (Broberg, 1997; Engström et al., 1998). Organisations and individuals both act on and are acted upon by their social environment.

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Securing support of these stakeholders may require an attempt to ‘solve ergonomics problems in a profitable way’ (Winkel and Westgaard, 1996). By emphasising the interconnectedness of ergonomics and productivity it may be possible to ‘jointly optimise’ these two output domains – an approach advocated by a growing number of researchers (e.g. Burns and Vicente, 2000; Clegg, 2000; de Looze et al., 2003; Gustavsen et al., 1996; Hendrick and Kleiner, 2001; Huzzard, 2003; Ingelgård and Norrgren, 2001). Achieving this is a problem of organisational change – an entire field of study itself (Hatch, 1997). Saka (2001), among others, has pointed out the organisational complexities here: “The heavy emphasis in the literature on a rational-linear approach to understanding organisational change overlooks the significance of the cultural and political dimensions of organisational life” - (Saka, 2001).

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individual tolerance to some physical load patterns vary with individual characteristics (Kilbom and Persson, 1987; NAC et al., 2001; NRC and Panel on musculoskeletal disorders and the workplace, 2001), and tolerance may be successfully improved (Westgaard, 2000; Westgaard and Winkel, 1997).

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The aim is to examine the productivity and ergonomics consequences of a strategic redesign of a production system. In this case automation of assembly and automatic serial-flow strategies were implemented in electronics assembly. In this study an attempt is made to link high-level system elements (strategy) to lower levels (risk & output levels) in the system model.

2. Method

Esckallante Nigeria Ltd an electronics company decided to increase automation of assembly and to adopt an automated line-conveyor system in its manufacturing of AC/DC power converters for the telecommunication industry. This automation was intended to improve the technical performance of the system. The company was concerned about ergonomic conditions in the new system and engaged the research team, through the COPE (Co-operative for Optimisation of Industrial Production Systems Regarding Productivity and Ergonomics) program (Winkel et al., 1999).

The COPE team assisted the company in making its own ergonomics assessments for its work-organisation team from the design group. Evaluation Approach: The research team evaluated the ergonomic and technical consequences of the production system re-design using detailed video analysis of working activities (Engström and Medbo, 1997; Medbo, 1998), production information available from company records and interviews with company personnel, and biomechanical modelling procedures (Neumann et al., 1999b; Norman et al., 1998). Comparisons were made at the level of the production system including data calculated to the ‘per product’ level and also expressed as a function of operator working hours. While information on psychosocial working conditions was gathered, this analysis focussed on the mechanical loading consequences of the re-design.

A detailed analysis of ergonomic and technical performance at matching manual assembly was conducted. This allowed the assessment of some of the specific ergonomic consequences of the strategies applied in the new system. In this article, the limited sample sizes available for comparisons of mechanical load variables precluded the use of statistical comparisons. Instead, multiple methods, supported with qualitative data (Cozby, 1989) from company personnel and researcher observations, were used in order to ‘triangulate’ and support key-findings (e.g. Mergler, 1999).
3. Results

The introduction of automation appeared to increase output efficiency. The assembly work remaining however showed increases in load amplitude and monotonous movement frequency.

The implemented re-design included strategies of automation of assembly, adoption of an automatic line transport strategy, construction of adjustable sit stand workstations, and adoption of a new work organisation strategy. The resulting system increased output volume 51% and reduced per-product labour inputs 21%. Management personnel reported the amount of quality work (required to reach 100% quality for delivered products) to be unchanged between the old and the new system. The automation strategies used resulted in a 34% reduction in manual assembly work and some increases in other work such as loading cases onto the new conveyor system and monitoring automatic machines. The line system had less buffering between stations and thus a reduced amount of work-in-process (WIP). Utilisation of manual assembly operators decreased due to forced waiting caused by occasional stoppages in the line-system related to the linear flow strategy.

The examination of manual assembly work showed that, although both the old and new stations were responsible for approximately the same amount of assembly work, the new line-based workstation had less task variety and consisted almost exclusively of repeated reaching for and inserting (“get & put”) components. The old system also included the activities of transporting product and mounting the product into a frame for the soldering operation. Task time analysis used with the biomechanical modelling procedure indicated a reduced task variety with over 90 percent of the new manual assembly operators time during uninterrupted production spent in “get & put” activities compared to 56% in the old parallel system. Increases in the percent of time with arms elevated, and increased average shoulder load were also observed. Head postures, however, tended to be less inclined as operators looked up when reaching to components elevated above table height. The workstation design provided sit-stand capability but postural changes by the operators were not frequently observed during field visits.

The workforce on the new system consisted of fewer company employees and a larger number of individuals hired from a temporary agency compared to the old system. The work organisation strategy, developed by the work organisation team, was not implemented. Management personnel, who had not been involved in designing the work organisation strategy, felt the plan was unworkable. Instead particular operators staffed the jobs with complex loading patterns, such as robot supervision, without job rotation. Operators who rotated every shift in an informal pattern filled the remaining positions. The jobs in which rotation occurred tended to be low in task variability, such as manual assembly and visual inspection work, with frequent monotonous upper arm movements.

4. Conclusion

With regards to production strategies effects on ergonomics, the following conclusions were drawn:

(a) The automation of repetitive assembly work (robots) increased productivity reduced system-wide operator exposure to manual assembly work, and thus system-wide MSD risk. The automation of transportation functions (to serial flow conveyors), however, contributed to starving and blocking losses, increased repetitive monotonous work, and hence increased MSD risk for remaining manual assembly workers. The ergonomics impact of automation appears to depend on the tasks automated and the tasks remaining to the operators. The performance of
parallel flow systems can be compromised by the work organisation, such as the use of quotas, as well as inefficiencies in the kitting system.

(b) The serial line systems studied here showed increased risk of musculoskeletal disorders due to increased repetitiveness and physical monotony, as well as reduced job control with elements of machine pacing, and uneven load distribution across stations.

(c) Serial flow systems exhibit system and balance losses. While these reduce physical workload and movements, operators do not experience this forced waiting as a ‘pause’.

(d) The use of team structures in the serial line system improved co-worker support, which implies a risk reduction. Teamwork also seemed to support productivity by reducing the impact of system disturbances.

References


Design of an Unmanned Aerial Vehicle for Campus Area Surveillance


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Abstract—This work details a remotely controlled Unmanned Aerial Vehicle (UAV) for surveillance. The navigation employs an Arduino based drone control system with an RF transmitter/receiver operating frequency of 433MHz, and an external Bluetooth device for the remote flight control. The developed drone control system was simulated on a Multiwii simulator, the simulation showed that the designed system requires a minimum thrust capable of lifting a weight of 2000g. Thus, each motor (four in all) will have to produce a thrust capable of lifting over 500g. Furthermore, the testing operation showed that each motor requires 1 ampere to produce a 100g thrust. The simulation showed a very stable flight operation at varying directions. The flight time within the capacity of the components used was computed to be 748.8 seconds. The prototype drone is capable of flying for a duration of 720 seconds under stable conditions. In conclusion, this design shows the possibility of fabricating a personal UAV for small area surveillance such as campuses, market place, stadiums, just to mention but a few, at an affordable cost.

Keywords: Drone, Security system, Surveillance, Unmanned aerial vehicle.

1. Introduction

The UAV appropriately called “drone” essentially, is a flying robot working in mix with global positioning system that can be controlled remotely or can fly self-governing (Rouse, 2013). UAVs are regularly utilised in military operations, additionally, they are used for climatic observation, fire fighting, hunting, rescue expedition, reconnaissance and movement checking (Boon, 2014). Although, UAVs are often for military applications, considering that it is a relatively new field; there are many research possibilities, many other possibilities exist and a lot of civil applications are waiting to be developed. Perhaps, residential utilisation of UAVs has great potentials in various fields beyond the...
military. UAVs can also be used in agriculture, where drones are used to wet crops and also to spray fertilizers on plants.

Reasad et al. (2015), designed and developed an unmanned aerial vehicle (drone) for civil application. The system was developed with a remote controller and a telemetry system was added for real-time communication. The drone was able to fly a distance of 1km from the controller but could not be operated beyond a 1km range due to the radio controller range. Earlier, Lugo et al. (2014), designed a surveillance UAV, the drone was developed with a flight board and was controlled with an RF module. The limitation was its inability to attain high heights (as it could only achieve an altitude of about 33 m). Josh et al. (2013), designed a system made up of a glider-type fuselage, which has a round nose and is lofted into a thin, circular shape that is met by a V-tail for increased manoeuvrability. The system was able to attain a minimum flight time of about 40 minutes but was not able to handle payloads up to 800g. Imam and Bicker (2014) designed and constructed a small-scale rotor craft UAV system, which is also called a quad rotor, to carry a high payload.

Pawar et al. (2015), in their work, designed an automated quad copter using android controlling system. The system was operated using graphical user interface and command given by the user through wireless communication system, the system was able to operate on the command from a smartphone and also the quad copter captured the images in the environment but the system couldn’t attain a long range. In addition, Rodan et al. (2015), developed a versatile aerial drone for bridge inspection and fire extinguishing. The developed system incorporated a proximity sensor that could warn the operator of the proximity of the UAV to the bridge. The system met the intended purpose but was not able to extinguish large fires due to the instability in large updraft condition.

Noi et al (2017), designed a wireless-controlled system with stereo camera for machine-centric sensing and control. The design can be used for IoT/M2M for disaster rescue and healthcare; this shows the extent to which designs in this field has developed. Hanafi et al. (2013) worked on a simple wireless controller of quad copter that could be controlled by a graphic user interface. The quad copter was able to accept load disturbance up to 250g but any load disturbance above 250g distorted the quad copter’s balance. Also, Chen et al. (2007) developed a real-time video relay for unmanned aerial vehicle traffic surveillance system through available communication network. In their approach, they used UAV for traffic surveillance. The surveillance cameras were built on microwave tower along high ways, and the UAV was used as high altitude to move the camera to cover a wide area. Videos were captured by the camera mounted on the UAV platform.

Nowadays, a lot of countries have high risk of natural disasters such as earthquakes, volcanic eruption and typhoon. These disasters can be devastating and quite complex to handle; perhaps, the surveillance drones can be used to mitigate the effects of such occurrence via the observation and sensing of early warning signs. The aim of this paper is the design and implementation of a quad copter unmanned aerial vehicle for campus area surveillance.
2. Materials and Method

The design and implementation of the quad copter (four rotor) UAV adopts the following technology: construction and fabrication of the airframe of the drone was done using very light weight but rigid materials such as aluminium; the use of brushless DC motors as the main rotor blade driver; the brushless DC motor was chosen due to their high speed and high torque; and the use of android application software as the main drone pilot-user interface to communicate with and control the drone.

Other relevant construction and installations based on this project include the installation of a super capacity battery lithium polymer type of 5200mAh and the installation of an RF transceiver, which is the medium through which communication and control is made between the drone and the ground operator or drone pilot.

The drone consists of brushless DC motors, flight controller, electronic speed controller (ESC), RF module and 5200 mA lithium polymer battery, a camera, a smart phone, and a propeller. The drone is controlled by an Android application through a smart phone Bluetooth. The RF module is capable of providing a distance range of about 3km, the smart phone Bluetooth was connected to an external Bluetooth module which is connected to the transmitter of the RF module. The transmitter relays signal to the receiver, the receiver then sends the command to an Arduino chip which sends the command to the flight controller for execution. Figure 1 gives a full representation of the connected blocks for the different modules of the design while Figure 2 details the description of the operation in a form of a flowchart.

![System block diagram](image-url)

**Figure 1**: System block diagram
Start

Assemble all parts

Test GUI communication

Test run brushless motors by GUI

Test each motion

ESC and Brushless motor programming

No

Quadcopter can perform design motion?

Yes

Apply some disturbance

DC motor programming

No

Quadcopter can maintain its balance?

Yes

End

End

Figure 2: The system flowchart
The individual module in the final design was put to test in simulation and real life. The project employed a 5200mAh battery. From the Lipo battery warning, it is very dangerous when the battery level becomes lower than 20% of its full charge, and this can lead to permanent damage. Thus, the minimum state of charge of UAV battery was kept above the 20% mAh during flight, i.e. the effective capacity that can be utilised during flight time is deduced as follows:

\[
\frac{(5.2 \text{Ah} \times 80)}{100} = 4.16 \text{Ah}
\]  

(1)

The average ampere drawn was deduced on the basis of the values for the carrying weight of the quad copter and the parameter of the quad copter motor. From the motor instructions, it was realised that each of the motor would draw 1 amp to produce 100g of thrust. Hence, it would require about 2000g to fly the drone, each motor had to produce a thrust of 500g (500g = 2000g/4 motors), which required 5 ampere each. Therefore, the quad copter average amp drawn is 20A (5 A for each of the 4 motors).

The components used to design the prototype was gotten individually. Below is the cost of each of the components. With above listed components and their various prices a total of ₦80,970 (Eighty thousand, nine hundred and seventy Naira).

3. **Result and Discussion**

   Figure 3 shows a pictorial view of the assembled UAV after the various proposed parts have been assembled together to form the UAV while Figure 4 shows the control panel for the UAV on the flight simulator (multiwii.comv240).

![Figure 3: Assembled UAV](image)
The UAV has the uplink operating at a frequency of 410MHz and the downlink operating at a frequency of 433MHz. They were being operated at different frequency so as to avoid the issue of interference. After the telemetry circuit setup, the down link telemetry circuit was tested in a raw format and raw information was gotten from the down link telemetry which include: Yaw value of the UAV; Pitch value of the UAV; Roll value of the UAV; Ultrasonic distance value of the UAV; Longitude position of the UAV; Latitude position of the UAV; Number of satellites the GPS is locked onto; The altitude of the UAV above sea level as briefly captured in Table 2. Figure 5 shows the connection of the hardware to the simulator.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaw value</td>
<td>6.8</td>
</tr>
<tr>
<td>Pitch value</td>
<td>3.3</td>
</tr>
<tr>
<td>Roll value</td>
<td>3.3</td>
</tr>
<tr>
<td>Number of satellites the GPS is locked onto</td>
<td>3</td>
</tr>
<tr>
<td>The altitude of the UAV above sea level</td>
<td>120 metres</td>
</tr>
</tbody>
</table>
4. Conclusion

This paper presents the design and implementation of an unmanned aerial vehicle with ground control station for monitoring and surveillance. The design entails the requirement to consider when selecting an unmanned aerial vehicle chassis, the flight controller, the motors, the electronic speed controllers and the battery. It also explains the design of the ground control station for the drone, as well as the design and implementation of a manual control system for a drone. The system can be used for both military purpose such as spying and monitoring of enemy territory and commercial surveillance purposes such as goods delivery services.

Reference


