EMERGING INFORMATION, COMMUNICATION AND TECHNOLOGY SYSTEMS APPLIED TO CONSTRUCTION VEHICLE SAFETY

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Management Information Systems (MIS) have been widely used in the construction industry for a number of Information Communication and Technology (ICT) systems ranging from payroll to machine inventory applications. However, in recent years MIS has also been utilised by occupational health and safety advisors, specifically, when dealing with plant and equipment operations. Anecdotal evidence would suggest that the high (and largely unchanged) incidence of plant and equipment accident rates coupled with the growing number of new legislative requirements have been instrumental factors driving this change agenda. This uncontrolled change of MIS utilisation has lead to an explosion of bespoke system applications being developed and often these focus on single applications such as machine maintenance, vehicle tracking or continuous mechanical health monitoring. At present there is no single holistic package that covers the whole scope of machine related activities that could benefit health and safety. This paper presents some of the first research to produce a critical appraisal of existing MIS systems applied to the safe management of mobile plant and equipment on construction sites. Leading on from this, the work then proposes a new system that encapsulates the desirable attributes of various systems into one integral hybrid system.

Keywords: construction MIS, construction site safety, ICT in construction.

INTRODUCTION

The construction industry is the largest industry within the UK as it contributes almost £80 billion annually to national Gross Domestic Product (GDP) and employs nearly 2 million people across 168,000 firms (NAO 2004). Similarly, the demand and investment in the construction plant and equipment sector has also increased exponentially (Mintel 2005). However, accidents involving mobile plant and equipment have continually plagued the UK construction industry during the past decade (HSE 2005). Indeed, the static accident trend involving plant and equipment suggests that current safety mechanisms and procedures employed by contractors have failed to reduce plant related accidents (Edwards 2004). These safety systems include the use of additional machinery aids (e.g. convex or pencil beam mirrors, rear view cameras, radar systems and audible alarms) or the use of risk control procedures (e.g. training, competence development and risk assessment) (*ibid*). HSE statistics illustrate that a re-evaluation of existing systems and procedures should be undertaken and that the potential of new technology (e.g. tracking and tagging systems) to

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Riaz, Z, Edwards, D J, Mackenzie, J and Thorpe, T (2006) Emerging information, communication and technology systems applied to construction vehicle safety. *In:* Boyd, D (Ed) *Procs 22nd Annual ARCOM Conference,* 4-6 September 2006, Birmingham, UK, Association of Researchers in Construction Management, 675-684.

augment existing control measures utilised should be explored (Riaz *et al.* 2005). It is envisaged that emerging Information Communication Technologies (ICT) could support the development of a plant/pedestrian collision detection mechanism if integrated into a plant Management Information System (MIS). The culmination of such work will provide a far more advanced and comprehensive health and safety management solution than those currently available. With this in mind, research work is presented that explores some of the factors that contribute to accident causation on site and also proposes innovative technological solutions to these problems identified. Specifically, a MIS framework to facilitate the integration of health and safety information for construction plant management which incorporates various existing standalone plant applications is proposed.

SAFE SITE: HSE INITIATIVES WITHIN THE SUPPLY CHAIN

Health and Safety Executive (HSE) accident statistics for plant related accident categories (i.e. 'contact with machinery/material being machined' and 'struck by moving vehicle') for the period 1994 to 2004 show that a fairly consistent accident trend amongst construction employees and self-employed workers prevails (Riaz *et al.* 2005) refer to Figures 1 and 2. According to the HSE (1996), the duties under relevant safety regulations include ensuring a safe place of work and safe means of access to and from that place of work. In particular, Regulation 15, 16 and 17 of the Construction Health, Safety and Welfare (CHSW) Regulations 1996 (HSE 1996) require contractors to: i) ensure construction sites are organised in a way that pedestrians and vehicles can both move safely without risks to health; ii) ensure routes are suitable and sufficient for the use of pedestrian or vehicles; iii) control the unintended movement of any vehicle; iv) ensure warnings of any possible dangerous movement e.g. reversing vehicles; and v) make certain safe operation of vehicles including prevention of riding or remaining in unsafe positions.

Interpretation of these regulations by the HSE Inspectorate means that individual inspectors expect contractors to: i) implement a traffic management plan as part of the health and safety plan; ii) keep pedestrians separated from vehicle movements e.g. plant slewing and loading; iii) maintain one-way traffic system(s) for minimised

Figure 8: Injuries to employees and self-employed (per thousand) caused due to 'contact with machinery or material being machined' for the period 1996-2004

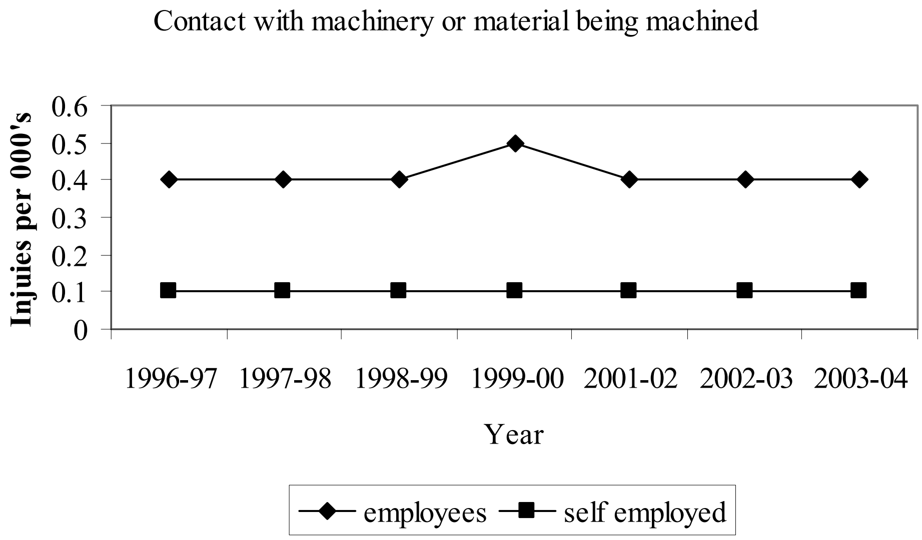
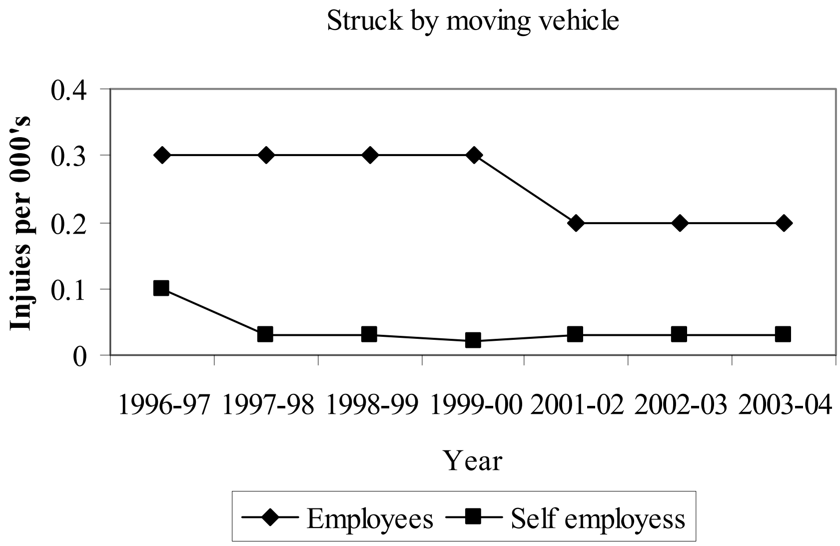


Figure 9: Injuries to employees and self-employed (per thousand) caused due to being 'struck by a moving vehicle' for the period 1996-2004



vehicle warning devices; v) adopt appropriate maintenance systems; vi) train drivers and plant operators; and vii) ensure that workers wear high visibility clothing and other personal protective equipment (HSE 2004a). The overriding emphasis is to provide a culture of safe site, worker and machine in order to create a safer working environment. Yet clearly accident statistics reveal that additional measures are required to reduce accident rates to acceptable levels. Reasons for accidents are many and varied. In the context of vehicle/pedestrian collisions these reasons include the following: inadequate training and competence development of staff employed to both manage and operate plant and equipment; failure to separate mobile plant and equipment from pedestrians by way of designated transportation only routes; failure to provide fully trained and competent banksmen as and when required; inappropriate selection of mobile machinery; failure to keep mobile plant properly maintained; stress and fatigue induced upon an operator due to long operating hours; and the tendency for pedestrians (workers and public) to stray within a machine's operating envelope (Edwards 2004).

However, the root causes of accidents can be avoided by careful management of people, contractors and machines within the supply chain. Due to high variability in construction environments and increased complexity of construction processes, supply chain management is critical for successful construction management (Tserng 2006). The contribution of specialist and trade subcontractors to the total construction process can account for as high as 90% of the total value of the project (Nobbs 1993). This highlights that in a construction project, major contractors are heavily reliant upon subcontractors (medium or small enterprises, so called SMEs) in order to complete the job on time and to a reliable standard. Unfortunately, SMEs in the industry are currently experiencing a dearth of skills within the workforce and the National Audit Office (NAO 2004) has recently cited that only 22,000 people enter the construction industry every year via formal education and training routes (NAO, 2004). In addition, the Construction Industry Training Board (CITB) reported that many major contractors have reduced funding for training and are unlikely to provide any training to labour-only subcontractors (*ibid*). The supply chain and operatives within it, undoubtedly influence quality standards in the downstream (contractor/subcontractor) supply chain. Low quality subcontractors and reduced process conformity also effects the health and safety processes on a construction site. Guidance from the HSE (2002) states that before awarding a contract, major contractors should discuss: i) a subcontractor's health and safety performance; ii) proposed working methods; iii) equipment brought onto site; and iv) identification of health and safety risks which their operation may create for other workers at the site. As the information from the subcontractors becomes available, it should be included in the health and safety plan for the construction phase which is required under the CDM Regulations (HSE 1994). The problem here is that smaller companies working for larger organisations may not necessarily follow the same guidance to the same level of conformity and in addition, site managers are under immense pressure to complete works on time and to budget. Hence, the need for automated ICT systems and procedures that protect the workforce regardless of their skill, knowledge and ability.

MACHINE CONFIGURATION: SAFE WORKING ENVELOPE FOR EXCAVATORS

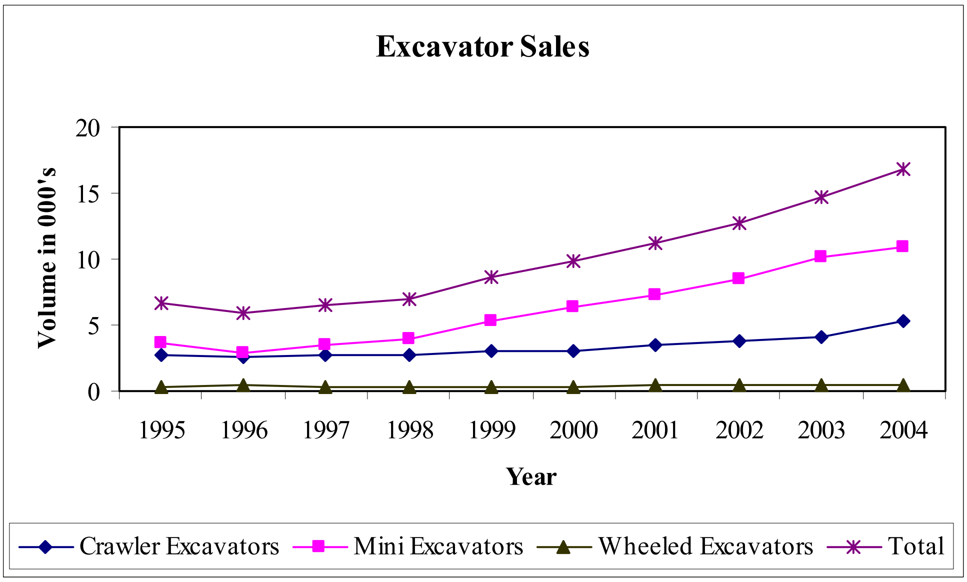
Earth moving equipment is a generic class of machines that include dozers, loaders, scrappers, hydraulic excavators, haulers, graders, trenchers and compactors (Edwards *et al*. 2003). Machine selection decisions are based upon the nature of the task, site conditions, volume of material to be moved, type of material and time available (Nunnally 2000). Amongst these machines, excavators are one of the most versatile and diverse pieces of equipment as exhibited in Table 1 (Harris 1994; Caterpillar Inc. 2005; JCB 2005).

Table 3: Attachment and Operations of Hydraulic Excavators (Wheeled and Tracked Type)

Attachment	Operation
Face Shovel Buckets	To loosen and load material when working above the track level against an excavation face
Backhoe	To loosen and load material when working below the track level; handling operations e.g. pipe-laying, installing trench sheets etc.
Grapples	To handle loose material, sorting waste and demolition site clean-up
Hammers	To demolish concrete and oversize rocks; to break frozen or hard ground; and trenching;
Pulverizers	To recycle and process demolished concrete debris
Rippers	To break up hard soil during ground preparation particularly for pipeline and trenching

As a prelude to developing the proposed MIS on other equipment items, excavators are examined in this work for two reasons. Firstly, the diversity of applications (see Table 1) has helped in the increased popularity and demand of the machine (Mintel 2005). In particular, mini and crawler excavators have shown a significant rise in sales (see Figure 3) reflecting the major role these versatile machines play on a modern construction site. Secondly, according to HSE (2004b) the widespread usage of the machine has resulted in increased workplace transport accidents. In a recent HSE report (*ibid*) the problem of all round visibility was cited as being an underlying 'causal' factor of many plant related accidents investigated. Moreover, the HSE reported that accidents involving a range of excavators often include people being struck by cabs, counterweights or backhoes when the excavator is slewing; this reinforces the fact that a driver's vision is impaired at the back by the counterweights and on the right-hand side (excluding mini excavator type) by mast of the machine.

Figure 3: Sales (in No.) for all companies in UK from 1995 to 2004 (Source: JCB)



Developing a mechanism with which to avoid vehicle/pedestrian collisions requires the safe operational envelope around the machine to be defined using the machine's configuration and mode of operation. In particular, the machine's maximum reach capacity (including boom, dipper and attachment) must be calculated (JCB 2005). Another important factor that requires consideration is the make, model and type of excavator being used. As an illustrative example, Table 2 lists some typical models of Caterpillar excavators (Caterpillar Inc. 2003) and states the parameters of the maximum digging envelope.

Table 2: An Indicative example of data compiled from Caterpillar (2003)

Model	**Maximum Digging Envelope**			**Track Width**	**Tail Swing**
	A m	**B m**	**C m**	**mm**	**mm**
313C CR, 314C CR, 314C LCR	7.19	8.63	5.95	2490	1420(313), 1480(314)
317B L, 317B LN	6.44	9.10	6.51	2800(L), 2495 (LN)	2450
320C, 320C L, 320C LN	6.67(rb), 6.25(mb), 8.11(vb)	9.71(rb), 9.19(mb), 9.57(vb)	6.55(rb), 6.14(mb), 6.03(vb)	2800	2770
345B Series II	7.32(rb), 6.94(mb)	12.23(rb), 11.03(mb)	8.31(rb), 7.09(mb)	3490	3650
365B L – Series II	9.19(rb), 7(mb)	14.09(rb), 11.83(mb)	9.46(rb), 7.26(mb)	3500	1540
385B	10.45(rb), 8.39(mb)	15.61(rb), 12.54(mb)	10.44(rb), 7.46(mb)	3500	4590

A= Maximum loading height of bucket with teeth; B= Maximum reach at ground level;
C= Maximum digging depth; (rb) = Reach Boom; (mb) = Mass Boom; (vb) = VA Boom;

These parameters include maximum height a bucket can reach and maximum digging depth of the machine arm (boom stick and bucket). In addition, various booms are also taken into account: a reach boom maximises digging envelopes with various stick combinations; a mass boom maximises productivity due to higher digging force; Variable Angle (VA) boom enhances visibility on the right side of the machine and maximises flexibility when lifting heavy loads or working in tight quarters (Caterpillar Inc. 2005). Using a combination of these factors, the safe operational envelope around a machine can be readily determined. However, such data must be input into an ICT system (or manual procedure) in order for it to be useful.

APPLICATION OF TECHNOLOGY

Table 3 generalises the most common technology applications available for plant and equipment in the construction industry. This table not only draws attention to the currently available wide range of technological solutions but also highlights the fact that major efforts have been made in the operation specific robotics, automation and information systems.

Table 3: Available Technology Applications for Plant and Equipment

Applications	Technology	References
Operation/Vehicle Specific Control Systems e.g. bucket, blade, grade, speed, stress, vibration controls etc, load sensing systems	Laser, Global Positioning Systems (GPS), sensor based systems	Caterpillar (2005); Sobczyk and Tora (1998); Klaus and Urbaniak (1998); Frimpong *et al* .(2005); Ha *et al.* (2000); Park and Chang (2004); Komatsu (2005); Greer *et al.* (1997)
Automation e.g. programmable handling system and motion control, metal detection, tool movement and guidance; teach and learn capability (repetition/recognition of specific tool trajectory)	Robotics, remote controls and sensor based systems	Huang *et al.* (1996); Lorenc and Bernold (1998); Lee *et al.* (1999); Plonecki *et al.* (1998); Leyh (1995); Lytle *et al.* (2004); Greer *et al.* (1997)
Information System e.g. fleet management systems (information on theft control, machine function, production and performance), operator or operation specific information systems (machine assignment, fleet analysis, production reporting), operation specific real time data capture	Software and On-board computing based IS, WAN, mobile computing	Caterpillar (2005); Ward *et al.* (2003)
Safety Systems e.g. collision detection systems	GPS, video systems, radar based systems	Abderrahim *et al.* (2005) ; Rosenfeld and Shapira (1998); Everett and Slocum (1993); Engineeringtalk (2005); Perco (2005);
Tracking Systems e.g. monitor and record real time positioning, collision detection; navigation systems for collision free path planning etc.	GPS, wireless, sensor and web technologies, Radio Frequency IDentification (RFID) tags and Micro-Electromechanical Systems (MEMS) devices	Qinetiq (2002); Oloufa *et al.* (2003); Kim and Russell (2003); Durfee and Goodrum (2002)
Equipment Health Monitoring and Maintenance Systems	RFID tagging systems	COMIT Project (2005b), Durfee and Goodrum (2002)

However, it is apparent from the table that there is a need for a more holistic information system for plant and equipment management. The envisaged system, in addition to encapsulating the required features of various existing systems into one central hybrid system, should explore emerging ICT more fully to address the safety concerns on a construction site.

When considering factors that contribute towards plant accidents on construction sites, it is apparent that site managers have an extremely difficult task in managing the risk. Therefore, a more simplified and automated process should be used to improve the safety process, protect workers and assist managers. Although a number of technological solutions exist, vehicle tagging has proved to be a reliable and cost effective means of reducing vehicle/pedestrian collisions. Using RFID technology with real time monitoring, the movement of material, vehicles or people can be tracked (RFID Journal Inc. 2005).

Tagging Applications in Construction Industry

Similar to other industries, tagging systems within the construction sector are gaining popularity (COMIT 2005a). RFID tagging systems that are capable of contact-less detection and data storage can provide the necessary security and information storage required for an effective construction material tagging system (Intensecomp Ltd. 2004). Storing information (e.g. material ID, production date, manufacturer's details, material characteristics, installation location, certification details etc.) onto the RFID tag provides reliable on-site information retrieval and effective on-site material accountability for construction material. Others such as Byzak Ltd (Comit 2005b) employed RFID tags in a Planned Preventative Maintenance System to monitor and keep records of machine service and maintenance history information. However, due to the harsh working environment of the construction industry, further investigation is required to test the technology's potential to function in open (outdoor) environments (CPI 2000).

PLANT MANAGEMENT INFORMATION SYSTEM ADDRESSING SITE SAFETY

MIS provides a data repository for managers who wish to collect, process and communicate information throughout the organisation (Collier *et al.*1995). MIS are an integral part of dynamic industries where business processes are constantly reviewed for increased efficiency, quality of service/product and reduced costs (Kelly *et al*. 1997) and are therefore considered well suited for adoption in the UK construction industry. Various MIS are available for mobile plant and equipment and these range from fleet management to tracking systems (Caterpillar Inc. 2005). Yet, a management system for construction plant and equipment requires a more all inclusive system that shares information among different software applications rather than each application maintaining its own subset of information. The architecture should deliver information integrity needed to address compliance and management requirements of plant operators and safety managers respectively. The incorporation of emerging ICT such as mobile computing, real time tracking systems and Automatic Identification and Data Collection (AIDC) technology (such as RFIDs) with MIS can make machines more productive and safer. The integration is presumed to lead to a far-reaching technology platform where plant operator and safety manager information needs are addressed and underlying causes of accidents minimised. The proposed MIS system (aptly entitled *SightSafety*; Riaz *et al.* 2005) should support data collection on factors such as the machine's safe operational envelope, machine configuration, maintenance undertaken and so forth. Typically data collection ranges from entry by workers (Personal Computers, Laptops, PDAs etc.) to automatic data collection through AIDC technology to access data from other management databases e.g. training, personnel etc. The relevant information would then be transferred to pedestrians (workers/managers operating in the vicinity of plant and equipment) and operators in a user friendly format. The main database which would be linked to the MIS should also be used for the generation of management reports to assist managers who plan and direct organizational and site operations. The reporting structure should provide both management and workforce with timely and relevant information on four key areas. i) *Information for Plant Operators* that includes information shared by the MIS system with the plant operator including: maintenance histories, service reports, alert signals and messages on the violation of the prohibited-zone/restricted-areas, training received and so forth. ii) *Information for Pedestrians* that includes information shared by the MIS system with the plant operator such as alert notifications depending on the distance of the pedestrian from the plant, hazard alerts and risk management reports. iii) *Information for Managers and Decision Makers* that will include plant and equipment history reports, vehicle inventory management and service schedules, tracking system and accident management. iv) *Information Dissemination* to ensure that information and reports are distributed to the target audience through various channels via a wired network. The reports are also available to the management through the Internet and any user connected to the Internet can request various reports e.g. vehicle/pedestrian locations, safety reports, on-site health and safety practices etc.

CONCLUSION

Findings emanating from the HSE research work have resulted in an acknowledgement that accidents involving plant/pedestrian collisions have remained relatively high year on year. This is in spite of many initiatives taken to improve health and safety on construction sites by HSE. Examination of a construction process and in particular, the relationship between contractors and sub-contractors, highlights some of the root causes of accidents. There are various parties working within the construction supply chain and although one group leading a project may have excellent systems and procedures, those lower down in the chain may not be working to the same standards and procedures. To work towards resolving these problems, managers on site must be equipped with fully integrated ICT systems that allow them to manage the risk more efficiently and effectively. Such as systems should include details on the machine's safe operational envelope for a range of configurations and operational modes. Operators and machines should be tagged and histories of these recorded as part of the advanced plant MIS system entitled *SightSafety.* Whilst not a panacea to safety problems, such a system would significantly advanced the management of risk imposed whilst operating mobile plant and equipment on construction sites.

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