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InterSafe
International safety, ergonomics and forensic engineering

Docket S030
Ex. 48-5

US CRANE FATALITIES

A TAXONOMIC ANALYSIS

December 1996

Presented by

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Revision Date April 2000
Revision No. 1

ABSTRACT

Cranes are remarkable and invaluable tools for hoisting and carrying. Like all other tools they have significantly increased humans capacity to work; they marshal far more energy than can human or animal muscle.

However, the large quantities of energy involved and the human, crane, environment interactions required results in there being a high potential for damage to occur to people and equipment.

The current situation is that similar serious crane occurrences continue to repeatedly recur, albeit separated in terms of time and space. As a result, crane fatalities can be considered as endemic, at least; many would suggest epidemic.

However, as one examines literature pertaining to crane related injuries and fatalities, it becomes clear that there is a paucity of information regarding the size and nature of the problem.

To gain sufficient insight into the aetiology of crane related damage, and establish key focus areas for future control, there is a need to establish the pattern of crane related damaging occurrences. To achieve this for fatalities, an approach was made to the US Occupational Safety and Health Administration (OSHA), which provided over 500 crane fatality narratives for the years 1985-1995.

This information was scientifically organised using the taxonomic process involving observation, description and classification of the data into hierarchical groups. The pattern is presented and key focus areas for future control are established. It is proposed that the next most significant gains with respect to reducing crane fatalities will be made by providing equipment which accommodates predictable and undesirable human behaviour.

The data is intended to add to the information base of crane designers, owners and users and present challenges with respect to effective change for the future.

ACKNOWLEDGEMENTS

This Report represents the culmination of a project that began in September 1996. The initial work (gathering of data from United States OSHA and generating the taxonomy) was conducted by the author during late 1996. This phase of work was funded by Minenco Pty Ltd and supervised by Roger Kahler.

The final phase of the project involved analysis of patterns revealed by the data and consideration of effective counter-measures, under the guidance of Jean Cross.

There are a variety of people whom the author wishes to extend warm and sincere thanks, as follows:

- Lindsay Allsopp of Minenco Pty Limited (Project Managers and Engineers) - for providing generous funding for the first stage of work;
- Bruce Beveridge, Manager Office of Data Management, OSHA - for supplying the data and providing initial assistance;
- Professor Jean Cross, University of New South Wales - for providing invaluable and timely guidance throughout the analysis and documentation phases of the project, and;
- Roger Kahler, Director, The InterSafe Group Pty Ltd - for initiating the project and providing a constant source of wisdom, encouragement and direction.

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1.0 INTRODUCTION

> *"It should not be necessary for each generation to rediscover principles of safety which the generation before already discovered. We must learn from the experience of others rather than learn the hard way. We must pass onto the next generation a record of what we have learnt."*
>
> Jessie C Ducommun

In order to obtain insight into the pattern of crane related personal damage, a taxonomic classification of 525 US crane fatalities has been developed.

The taxonomy is based on fatality descriptions supplied by the United States Occupational Safety and Health Administration (OSHA) for the years 1985 to 1995.

The goal of the project is to understand the pattern of crane related personal damage and provide information to assist in the reduction of future damage.

The objectives of the project are to;

- describe the pattern of crane related personal damage;
- demonstrate the ability of the process of taxonomy to gain insight into the pattern of incidents;
- identify priority areas which produce the majority of the damage;
- establish key focus areas for future control;
- present a challenge to crane designers, owners and users with respect to change for the future.

The purpose is to help set future direction, such that crane manufacturers, owners and users can be confident that safety initiatives are focussed on priority areas.

2.0 DEFINITIONS

The terminology used in this document is defined below.

Crane – in this document the term "crane" refers to a wide range of equipment including mobiles cranes (eg truck mounted, crawler cranes), tower cranes, derrick cranes, and elevating work platforms – EWPs (eg vehicle mounted permanent aerial buckets such as cherry pickers, and temporary baskets/platforms suspended from cranes).

Damage – damage to people can be considered a consequence of an energy exchange, where energy exposures go outside tolerable limits of a person. The term "damage" is used to describe what is usually known as an injury. Damage allows a variety of concepts and techniques to be related to equipment, the working environment as well as to people. The term "damage" also facilitates removal of the blurred area/overlap in the definition of "injury" and "disease" phenomena.

Energy - the use of the term "energy" is based on the concept of energy being an etiological agent in the determinant of damage, as developed by King[1], Gibson[2] and Haddon[3].

Epidemiology – the study of epidemics. It can be defined as the study of the distribution and determinants of damage in human populations. The epidemiologic approach applies equally to injury and illness/disease phenomena.

Hazard – any thing or any condition which has the potential to result in damage (a source of potentially damaging energy or potential lack of energy)[4].

Incident (or damaging occurrence) – a sequence of events which culminates, or could culminate, in a damaging energy exchange to people, property or production. The use of the term "accident" is deliberately avoided as the author is in agreement with opinion leaders who suggest the term denotes unforeseeable random events, and tends to be an emotive term which can also refer to concepts such as carelessness or thoughtlessness etc.

Permanent damage – permanently alters the future of the individual (eg fatality, quadriplegia, impaired back etc). The person is generally invalided out of work, or sustains long periods of absence followed by permanently reduced income. The use of severity classifications (i.e. permanent, temporary, minor) has proved beneficial in the fields of road safety and environments science, and is an extremely useful concept when applied to OH&S problems.

Risk – likelihood of a damaging energy exchange producing a particular consequence (the concept of risk incorporates the probability of a hazard resulting in damage, the duration and degree of exposure to the hazard, and possible consequences of an energy exchange).

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[1] King, B.G., Accident Prevention Research, Public Health Rep, 64:373-387, 1949

[2] Gibson, J.J., The Contribution of Experimental Psychology to the Formation of the Problem of Safety – A Brief for Basic Research, Behavioural Approaches to Accident Prevention, Association for the Aid of Crippled Children, New York, 1961, pp77-89

[3] Haddon, W. Junior, On the Escape of Tigers: An Ecologic Note, American Journal of Public Health, 60:2229-2234, 1970

[4] Wigglesworth, E.C., A Teaching Model of Injury Causation and a Guide for Selecting Countermeasures, Occupational Psychology, Melbourne 1972

Safety – a state in which the risk of damage to people is minimised to acceptable levels[5].

Taxonomy – one of the oldest scientific disciplines. Taxonomy involves observation, description and classification of "units" (ie incidents) into groups according to common patterns and individual differences. Rather than being an abstract technique, taxonomy is simply a describer of the human brain's tendency to classify observations into hierarchical groups. A well known scientific application of this process is the classification of the biological world into species, families, etc. It is a powerful tool, which unfortunately is rarely used in the field of occupational health and safety. Geoff McDonald, of Geoff McDonald & Associates (Qld), pioneered the use of taxonomy for classifying incident data.

[5] Standards Australia / Standards New Zealand, Occupational Health and Safety Management Systems – General Guidelines on Principles, Systems and Supporting Techniques, AS/NZS 4804:1997

3.0 BACKGROUND

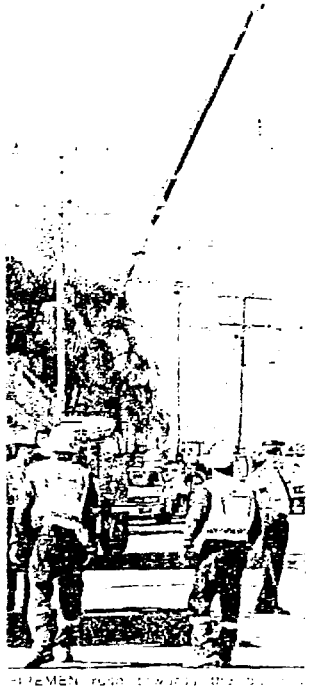
"Study the past if you would divine the future."

Confucious

Cranes are remarkable and invaluable tools for hoisting and carrying. Like all other tools they have significantly increased human's capacity to work; they marshal far more energy than can human or animal muscle.

However, the large quantities of energy involved and the human, crane, environment interactions which are required results in there being a high potential for damage to occur to people and equipment.

The problem was again brought to the attention of the public recently when two Queensland construction workers were killed following crane contact with overhead power lines, as described by the following newspaper article[6].



Two die as crane hits power lines on Chevron Is

BUILDING workers watched in horror yesterday as two of their mates were electrocuted in a freak crane accident.

A cable of the crane touched high-voltage power lines at a construction site in Purli Street.

The crane operator was killed instantly and a fellow worker who tried to rescue him from the crane cabin also died.

The crane erupted in flames and burned for about one and a half hours.

● Report Page 2

The following sections of this document are intended to describe what is currently known regarding the size and nature of crane related personal damage, and also a brief consideration of the existing industrial paradigms regarding safety which tend to be inhibitive of future change.

[6]Gold Coast Bulletin, Two die as crane hits power lines on Chevron Is, 14 August 1998

3.1 The Size of the Problem

"It is a capital mistake to theorise before one has data."

Sir Arthur Conan Doyle

When one examines industrial injury and fatality statistics in developed countries, those involving cranes are over-represented.

Most crane related injuries and fatalities occur in the Construction industry, although other industries such as Manufacturing, Transportation and Public Utilities, and Services are also represented.

To put the problem in context, for Australia, compensated fatalities in the construction industry represent approximately 15% of all occupational fatalities[7] [8]. Recent figures indicate fatality incidence rates for construction labourers are in the order of 21-43 per 100,000 persons per year[9].

For the United States, reviews of fatal workplace injuries by the US Department of Labor[10] [11] revealed that construction fatalities represent between 15-20% of all workplace fatalities.

The US Department of Labor documents referenced previously, also describe the problem in terms of the risk of a fatal injury per 100,000 workers (ie, fatality incidence rate). For construction labourers, the fatality incidence rate was 33 fatalities per 100,000 workers (in 1994), and was 39 fatalities per 100,000 workers (in 1995). This represents a two year average incidence rate of 36 fatalities per 100,000 workers, or one fatality per 2,800 workers (per year). Thus the following statement can be made:

The risk of a US construction labourer being fatally injured at work in any one year is greater than 1:3000.

The proportion of fatalities and injuries that are crane related is difficult to accurately deduce. In the US, approximately 30-50 crane fatalities occur in the construction industry per year, with there being a total of approximately 70 crane fatalities per year (all industries).[12] As described in the aforementioned OSHA document "Crane and Hoist Safety", over 1,000 construction injuries were reported to involve cranes and hoisting equipment in 1987 (23 states reporting). The document goes on to make the following point:

> *"However, underreporting of crane related injuries and fatalities, due to misclassification and a host of other factors, masks the true magnitude of the problem."*

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[7] Worksafe Australia, Estimates of National Occupational Health and Safety Statistics, Australia, 1992-93, Australian Government Publishing Service, October 1994

[8] Worksafe Australia, Estimates of National Occupational Health and Safety Statistics, Australia, 1993-94, Australian Government Publishing Service, December 1995

[9] NOHSC, Work-related traumatic fatalities in Australia, 1989 to 1992 AusInfo, Canberra, December 1998

[10] Bureau of Labor Statistics, Fatal Workplace Injuries in 1995: A Collection of Data and Analysis, US Department of Labor, April 1997

[11] Bureau of Labor Statistics, Fatal Workplace Injuries in 1994: A Collection of Data and Analysis, US Department of Labor, July 1996

[12] Occupational Safety & Health Administration, Crane and Hoist Safety, OSHA Summary Sheet for Individual Priorities, February 1996

Best estimates that have been made is that crane hazards are the source of about 25-33% of casualties in construction and maintenance activities[13]. With respect to fatalities only, the Construction Safety Association of Ontario reports that an average of 10% of construction fatalities were related to cranes and riggings from 1979 to 1994[14]. A taxonomy of 193 construction fatalities in the New South Wales construction industry (1980-1986) indicates that approximately 12% of fatalities were crane related.

The size of the problem is such that crane and hoist safety is currently on OSHA's list of priority problems, as described in the OSHA document "Crane and Hoist Safety"[12].

> *"Crane and Hoist Safety meets several of the criteria for designation as an OSHA priority. The very serious nature of the hazard, the magnitude of the risk (high rate of fatalities and serious injuries relative to the number of workers exposed), the potential for catastrophic accidents, and the considerable knowledge about effective protective measures clearly demonstrate the need for action to address crane and hoist safety."*

The tragedy described at the beginning of this section again brought the problem of crane fatalities into the public spotlight. The magnitude and severity of the problem demands an effective response. This requires an adequate description of the problem.

The current situation is that similar serious crane occurrences continue to repeatedly recur, albeit separated in terms of time and space. As a result, crane fatalities can be considered as endemic, at least; many would suggest epidemic.

3.2 The Nature of the Problem

> *"On the occasion of every incident that befalls you, remember to turn to yourself and enquire what power you have to turn it to use."*
>
> Anonymous

As one examines literature pertaining to crane related damaging occurrences (injuries and fatalities), it becomes clear that there is a paucity of data regarding the size and nature of the problem.

A number of authors have provided some insight into the problem, such as Dickie[15], Butler[16], Hakkinen[17] and Jarasunas[18]. Based on data sources including incident statistics held by insurance and government agencies, these authors were able to elucidate the breakdown of fatalities and serious incidents involving cranes. It was revealed that serious and fatal incidents occurred largely as a result of the following situations:

- powerline contact;

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[13] MacCollum, D.V., Crane Hazards and Their Prevention, American Society of Safety Engineers, 1993
[14] Construction Safety Association of Ontario, Crane and Rigging Fatalities, Province of Ontario, 1969-1994
[15] Dickie, D.E., Crane Handbook, Construction Safety Association of Ontario, 1975
[16] Butler, A., An Investigation into Crane Accidents, Their Causes and Repair Costs, Cranes Today, Vol 62, March 1978, pp24-28, 30-31; Vol 63, April 1978, pp28-34; Vol 65, June 1978, pp25-27
[17] Hakkinen, K., Crane Accidents and Their Prevention, Journal of Occupational Accidents, Vol 1, 1978, pp353-361
[18] Jarasunas, E., Crane Accidents: Causes and Prevention, Hazard Prevention, January/February 1978, pp4-6

- boom collapse or overturn;
- being struck by a falling load;
- dismantling of lattice boom cranes;
- rope failures.

More recently, some government and research bodies have undertaken retrospective studies of crane related fatalities. For example, the following table was produced by the Construction Safety Association of Ontario (CSAO) based on the records of 26 years of mobile crane fatalities in Ontario[12].

MOBILE CANE DEATHS IN ONTARIO, 1969-1994		
CAUSE	NUMBER	%
Power line contact	49	43
Load handling	17	15
Rigging	16	14
Overload	10	9
Operator error	8	7
Dismantling boom	5	4
Wire rope failure	3	3
Struck by crane/counterweight	3	3
Miscellaneous	2	2
Total	**113**	**100**

The document entitled "Census of Fatal Occupational Injuries 1992-1995", by the US Department of Labor[19] produced the following table as a result of their analysis of 312 cranes (all industries)

EVENT OR EXPOSURE	NUMBER	PERCENT
Contact with objects and equipment	157	50
Struck by object	126	40
Stuck by falling object	81	26
Struck by swinging or slipping object	28	9
Caught in or compressed by equipment or objects	28	9
Falls	42	13
Fall from nonmoving vehicle	8	3
Exposure to harmful substances or environments	84	27
Contact with electric current	82	26
Contact with overhead power lines	72	23
Transportation incidents	26	8
Nonhighway incident, except rail, air, water	14	4
Overturned	9	3
Other or unspecified	3	1

These documents are invaluable in describing the problem at the first level. They have assisted in providing an information base for many safety alerts that have been published, for example

[19] Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 1992-1995, US Department of Labor

by the National Institute of Occupational Safety and Health (NIOSH)[20 21], and the development of Standards[22 23 24].

However, because of the encoded or tabulated form of the data which is available, the problems have often not been defined in sufficient detail to allow effective analysis and development of control measures.

For example, it is known that electrocutions as a result of contact with overhead powerlines incur the largest number of crane related fatalities. However to gain insight into these occurrences, it is necessary to answer questions such as:

- what part of the crane contacted the overhead powerlines (eg loadline, load or boom);
- where was the person when the crane contacted the powerlines (eg contacting a load, operator, contacting the truck crane);
- what was the mechanism of contact with the powerlines (eg the crane was driven into, the boom raised, lowered or slewed into etc).

There has been attempts at answering similar questions, such as recent papers by Pacques[25] and Janicak[26], however there are many remaining unanswered questions.

In summary, major crane hazards have been known and recognised for many years, however the pattern of crane related personal damage has not been established. There is a need for historical data which is scientifically organised (eg taxonomic form) and can assist in gaining insight into the incident phenomena, and as a predictor of the future. The point is eloquently made by one of the world's leading crane safety engineers, David MacCollum[13]:

> *"Serious injury or death that occurs repeatedly from similar circumstances should be considered epidemic. These occurrences should be examined to identify hazards so that appropriate hazard prevention measures can be initiated in the same diligent manner that the medical profession examines a disease or infection to develop a vaccine or antibiotic for its prevention or control. Unfortunately, at the work site, many occurrences are often labelled as 'freak incidents' because operating personnel are sometimes totally unaware of similar repetitive occurrences because of their wide dispersal."*

The media and other popular channels of information tend to reinforce the mythology of the freak occurrence. The following quote from the newspaper article[27] depicted at the beginning of this section, serves as an example.

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[20] National Institute of Occupational Safety and Health, Request for Assistance in Preventing Electrocutions from Contact Between Cranes and Power Lines, NIOSH Alert, July 1985

[21] National Institute of Occupational Safety and Health, Request for Assistance in Preventing Electrocutions of Crane Operators and Crew Members Working Near Overhead Power Lines, NIOSH Alert, May 1995

[22] Australian Standard AS1418.1 - 1986 SAA Crane Code Part 1: General Requirements Standards Association of Australia

[23] Australian Standard AS2550.1 - 1993 Cranes - Safe Use Part 1 - General Requirements Standards Association of Australia.

[24] American National Standards Institute, Safety Code for Crawler, Locomotive and Truck Cranes, ANSI B30.5 - 1994

[25] Paques, J-J., Crane Accidents by Contact with Powerlines. Safety Science, Vol 16, 1993, pp129-142

[26] Janicak, C.A., Occupational Fatalities Caused by Contact with Overhead Power Lines in the Construction Industry, Journal of Occupational and Environmental Medicine, Vol 39, No. 4, April 1997, pp328-332

[27] Gold Coast Bulletin, Two die as crane hits power lines on Chevron Is, 14 August 1998

"Building workers watched in horror yesterday as two of their mates were electrocuted in a freak crane incident."

Almost 50% of the crane fatalities are related to electrocutions after crane contact with overhead lines; however, the incident is reported as 'freak'.

This project seeks to counter the mythology of the "freak incident" and take up the challenge set by MacCollum by establishing a taxonomic classification of a large number of crane fatalities.

This is considered a first step. However, it is recognised that the majority of personal damage arises from non-fatal permanent disabling incidents rather than fatalities[28] [29]. This is an important distinction as the pattern of damage is likely to be different. Therefore, the future lies in developing a taxonomy of non-fatal permanent disabling occurrences. Currently, this is a difficult proposition as when one attempts to examine or locate descriptive data for non-fatal permanent disabling occurrences, there is little information. This point is expounded in the section of this report entitled "Methodology". It is anticipated that this goal will become achievable as the quality of recording of workplace permanent disabling incidents improves in the years to come.

3.3 Existing Industrial Safety Philosophy

"We all have our philosophies, whether or not we are aware of the fact, and our philosophies are not worth very much. But the impact of our philosophies upon our actions and our lives is often devastating. This makes it necessary to try to improve our philosophies"

Paraphrased from Karl Popper (1972)

This section considers two common models used by people when thinking about or analysing incidents. A model can simply be defined as a conceptual frame of reference for organising and interpreting information. It is well recognised that human perception is highly subjective, and that people tend to see what they want or expect to see. When analysing incidents, it is critical to understand the model being used to organise information. The test of value is usefulness.

Common models used when analysing incidents can be generalised into the following two broad categories;

- Traditional view of "accident causation" - accidents are seen to occur largely as a result of human error, therefore future control focuses on the individual (or human) involved in the damaging incident. This is a powerfully ingrained community belief. This type of thinking has been labelled the human error (or **egocentric model**) as it places the person at the centre, or focus, of attention. The expectation is that the primary point of control is the person.

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[28] Kahler, R.J. & Shepherd, G., How and Where is the Damage Occurring, International Fall Protection Symposium and Exhibition, September 1998

[29] Work Safety & Health Inquiry into Occupational Health and Safety, Industry Commission Report, Volume II, Industry Commission, September 1995

- Multi factorial model of "accident causation" - accidents are seen to be a culmination of a sequence of events which results from a multi-factorial breakdown of the people, equipment, environment interaction. This has been dubbed the **ergonomic model**[30]. The expectation is that points of control may lie with the person, the equipment and the environment.

These models are briefly discussed as follows.

3.3.1 Human Error (Egocentric Model)

"The folklore of incidents is perhaps the last folklore subscribed to by rational men, including well-educated professionals who have been trained to identify and reject folklore in their own areas of competence."

Haddon, Suchman & Klien, 1964

The major crane hazards have been known and recognised for many decades. However, it can be seen that incidents continue to recur. The belief in "human error" as the "cause" of incidents has been a major stumbling block[31]. The problem is common to other areas of incident investigation.

It is often the case that analysis of incidents is completed using the human error-unsafe acts-unsafe conditions terminology. The terminology is linked to the philosophy that 88% of incidents are caused by human error (unsafe acts), 10% by machine design (unsafe conditions), and 2% could not be explained (acts of god). The 88:10:2 ratio was developed by Heinrich[32] during the 1930s when he studied 75,000 incident reports to gain an understanding of injury causation. The ratio was enthusiastically embraced by a population which had at last been given secure figures to reinforce their existing belief that faulty human behaviour caused most incidents.

The primary thrust of recent thinking is that it is scientifically nonsensical to focus on any particular factor when analysing an incident. An alternate way of thinking is well expressed by Kletz:

"Incident statistics for many companies show that over 50% and sometimes as high as 90% of incidents are due to human failing; this is comforting to managers, it implies that there is little or nothing they can do to stop most incidents. To say that incidents are due to human failing is not so much untrue as unhelpful. It does not lead to any constructive action."

---

[30] The InterSafe Group Pty Ltd., Personal Damage Reduction through Engineering Design Book 1 - Concepts, Philosophy, Roger Kahler, 1996

[31] McDonald, G., The Curse of Cause, Control, August 1974

[32] Heinrich, H.W., Industrial Accident Prevention: A Scientific Approach, McGraw Hill, New York, 4th edition, 1959

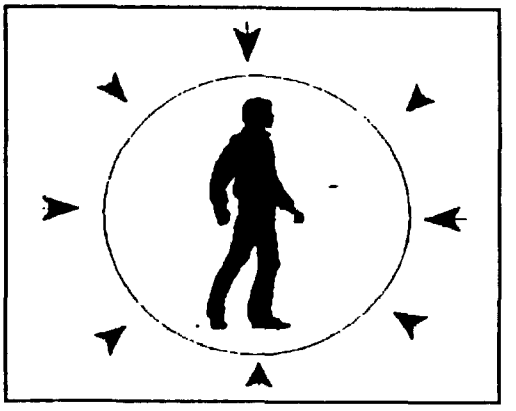

Figure 3.3.1.1 Human Error Model

Assessing an incident based on a human error model has the ability to seriously limit the information available to the person and subsequent understanding of the incident, and prevention of recurrence. Expectation plays an important role in processing of information with regard the incident sequence and particularly with respect to selection of appropriate solutions. If one investigates incidents with the expectation that 88% of incidents are caused by human error, then it is highly likely that information will be selected and processed such that the expectation is fulfilled. A useful aphorism is that people tend to 'see' what they want, or 'expect' to see. To paraphrase an anonymous statement, *"I wouldn't have seen it if I hadn't believed it"*.

Where a human error model is applied, control measures identified are often skewed towards procedural or behavioural control. These commonly include the person was told to take more care, the person was not following procedures, the person was not adequately trained etc. These control measures do not eliminate the underlying hazards, thus have limited effectiveness in reducing the recurrence of incidents.

With respect to the management of crane hazards, it can be seen that many current control measures rely heavily on a desirable behaviour being displayed by the crane operator, linesman, dogger etc. These countermeasures will not provide substantial improvements in the incident problem; merely perpetuate the status quo.

The situation is reflected in documents produced to identify and provide recommendations for dealing with hazards. An example of one such document is the "Australian Crane Safety Manual for Operators and Users"[33], which makes the following opening comments:

> *"Human error is the predominant cause of crane incidents.*
>
> *Cranes are dynamic machines. They demand and deserve the respect and safety consciousness of everyone associated with their use, maintenance, and operation.*
>
> *People are the biggest influence on safe working conditions. The single most important factor in preventing injury on the job is having competent and reliable personnel, who are safety conscious."*

[33] The Australian Crane Safety Manual for Operators/Users. The Australian Crane Marketers Association, 1983.

A similar outmoded viewpoint is imparted by reading the safety guide "Electricity and Using it Safely at Work"[34]:

> *"Overhead powerlines can pose a real danger in some work situations, if their presence is ignored, neglected or unknown. This danger can be eliminated if you simply look up and check the surroundings of your work location before starting work."*

At this stage it is worthwhile making the point that for an incident to occur it takes more than human error; the error must occur in the presence of potentially damaging energy[35]. The difference is that human error cannot be eliminated, whereas damaging energy can be minimised and controlled.

It is considered that the inhibiting effects of cause/effect thinking and assigning causation to human error has contributed to delays in the adoption of safety innovations, including the following examples:

- Seatbelts were compulsory in all aircraft seats during World War II, but it wasn't until 30 years later that this situation existed with motor cars. A conservative estimate of seatbelt effectiveness is a 30% reduction in fatalities.

- Fitting rollover protective structures to all tractors and tractor derivatives – this has only become a requirement (for tractors over 800kg) recently despite the fact that at least 50% of tractor fatalities occur as a result of overturning of the vehicles. In the US, an average of 132 farm workers each year are crushed to death as tractors overturn during operation[36].

- Earth leakage devices (also known as "Safety Switches"), were required in mining operations within Queensland for well over ten years before they were required to be fitted to new houses.

- A large number of children under the age of five drown each year in backyard swimming pools; however pool fencing legislation was not introduced until April 1992, a technology which has been used to separate people and hazards for hundreds of years.

- Crane insulated links have been available and used in aluminium smelters for 30-40 years, however they are still only rarely used in construction activities, where approximately 30-40% of crane fatalities are due to the crane boom striking overhead powerlines.

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[34] Department of Mines and Energy, Electricity and Using it Safely at Work

[35] Sundstro'm-Frisk, The Challenge of Promoting Safety Behaviour: Why Don't They Do as They Are Told?, Productivity Ergonomics & Safety Conference Proceedings, November 1997

[36] National Institute of Occupational Safety and Health, NIOSH Reports on the Preventability of Tractor Rollovers, NIOSH Update, January 1993

3.3.2 Ergonomic Model

"All models are wrong, some are useful."

George Box, 1979

It is proposed that the next most significant gains with respect to reducing crane fatalities will be made by providing equipment which accommodates predictable and undesirable human behaviour. Increasingly, there is an acceptance of our "humanity" in design but there remains a necessity for increased understanding of a persons information detection, processing, and execution mechanisms, and in the ways in which these highly complex systems can fail. It is of paramount importance that crane designers and manufacturers challenge the human error, unsafe acts, unsafe conditions model and replace it with an ergonomic model which sees the person as part of a larger and complex system. Understanding of people's behaviour is only one of the elements that must be addressed. It is also necessary to come to a clear understanding of the features of the equipment and the environment which are interacting with the people to allow the damage sequence to continue.

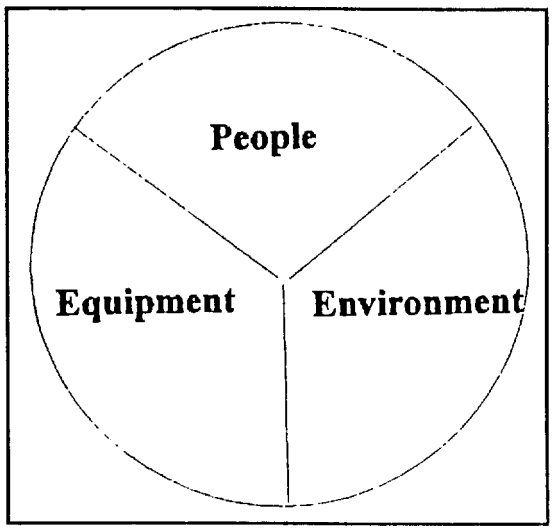

Figure 3.3.2.1 Ergonomic Model

The egocentric model tends to operate under the ideology that "idiots cause incidents, and that you can't protect idiots".

The ergonomic model considers that incidents occur as a result of a multi-factorial breakdown of people with the equipment and the working environment. The ergonomic model facilitates the development of countermeasures which can accommodate human errors. To quote Alphonse Chapanis[37]:

"To err is human, to forgive, design."

The point has been made many times in the past, for example *"the experience of more than 60 years of organised accident prevention has demonstrated that it is unwise to place principle*

[37] Chapanis, A., To Err is Human, To Forgive Design, Proceedings of 25th Annual Conference, The American Society of Safety Engineers, 1986

reliance on cooperation, training or constant attention on the part of the employee" (Jarasunas[38]).

The ergonomic model also provides opportunity to identify points of control to eliminate or reduce damaging energy. These are the most reliable control measures.

Significant gains with respect to reducing injuries and fatalities can occur by application of an ergonomic model in conjunction with historical data which is scientifically organised (e.g. taxonomic form) and can assist in gaining insight into the incident phenomena and areas for future control.

An appropriate balance of effective engineering (design) and behavioural interventions can then be identified to prevent and reduce damage to people.

[38] Jarasunas, E.K., Crane Accident Prevention, Hazard Prevention, July/August 1984, pp30-32

4.0 METHODOLOGY

> *"The employer who wants to prevent injuries in the future, to reduce loss and damage, and to increase efficiency, must look systematically at the total pattern of accidental happenings – whether or not they caused injury or damage – and must plan a comprehensive system of prevention rather than rely on the ad hoc patching up of deficiency which injury or accidents have brought to light."*
>
> Robens Committee 1972

The problem solving process is well documented. It involves:

(a) identification and description;
(b) analysis;
(c) selection of recommendations;
(d) trial and audit;
(e) implementation.

As stated earlier in the document, the crane fatality problem is of such a magnitude and severity that it can be considered as epidemic. The study of any epidemic, by definition, warrants application of the discipline of epidemiology. Epidemiology is the scientific study of the patterns and determinants of damage in human populations.

The first step of the process is dependent on the availability of quality data which generate understanding of the patterns of aetiology of crane fatalities.

For Australia, it is not possible to validly describe the problem as a result of the following:

- a lack of quantity of data – it would be considered that Australia incurs roughly the same incidence of crane fatalities relative to other western countries, but the total number is much smaller due to a much smaller exposure (relative to countries which have populations ten times or more of our own);

- a lack of quality of data – workers compensation statistics are published in tabulated form, however due to the encoded form of the data, the data sets do not yield sufficient insight into control measures which need to be applied to manage the damaging energy exchanges.

Against this backdrop there is a need to harvest larger experience bases in order to establish the patterns of damaging occurrences and a valid focus for control measures. The central tenant is that it is desirable to base change on information. Observation and description precedes analysis and control. The alternative is to base change on "opinions", "heuristics", "feelings"; basically shoot in the dark.

Thus, a decision was made to explore the United States experience due to the larger population base. The underlying hypothesis is that the pattern of incidents for America will reflect the pattern of incidents for Australia.

The hypothesis is based on there being similarities in construction industries in the two countries, including equipment (eg types of cranes used), types of construction activities undertaken, and standards pertaining to construction etc. Detailed crane fatality data for Australia is unavailable, thus the hypothesis cannot be tested. However, there are some general

studies such as the "Comparison of Work-Related Fatality Surveillance in the USA and Australia"[39] which reveal similarities in industry fatality data between the USA and Australia.

Crane related fatality data is published by the US Department of Labor Bureau of Labour Statistics, in tabulated form. This describes the problem in terms of things such as age of deceased, time of incident, worker activity at the time, occupation of person etc. However, again this data is of insufficient detail.

To gain sufficient insight into the aetiology of crane related fatalities, it became clear that there is a need for information of a much higher quality than the traditional incident data.

An approach was made to the US Occupational Safety and Health Administration (OSHA), which provided over 500 fatality narratives for the years 1985 to 1995. The narratives, or fatality reports, are based on fatality/catastrophe inspections conducted by State or Federal OSHA, which were reported as violations of the relevant sections of the Construction Industry Code[40]. The data is from the OSHA Integrated Management Information System (IMIS). It is anticipated that the data slightly under-estimates the absolute size of the problem, as a result of the following:

- not every workplace fatality is necessarily reported to Federal OSHA;
- OSHA does not necessarily investigate all reports;
- the search does not capture any fatalities not listed against the Standard;
- narratives are not available for all the reports.

Despite these limitations, the information stored in the IMIS is considered by the author to be the world's best source of fatality data.

An example of the incident descriptions provided is given below.

**** Incident DATA ****

SUMMARY: 170067276 DATE: 7-14-92 KEWDS: DESCRIP: BODY CRUSHED BY THE CRANE BOOM

ABSTRACT: EMPLOYEE WAS IN A CROUCH POSITION UNDERNEATH THE 29' LONG BOOM-SECTION OF A LATTICE BOOM THAT WAS 60' LONG ATTACHED TO A LINK-BELT CRAWLER, 45 TONS S/N 9LG5674M MODEL 5-108B, REMOVING THE TWO BOTTOM PINS WITH A SLEDGE HAMMER WHEN THE BOOM COLLAPSED ON HIM. EMPLOYEE WHO HAD MULTIPLE INJURIES WAS PRONOUNCED DEAD AT THIS JOBSITE ON THE SOUTHBOUND LANES SIDE OF I83 HWY & WARREN ROAD – "D", BRIDGE AREA. THE WEATHER WAS SUNNY, HOT AT 102 DEGREE AND THE Incident HAPPENED IN THE AFTERNOON. PROPER TRAINING HAD NOT BEEN GIVEN TO THE ABOVE EMPLOYEE AS PER CRANE MANUFACTURER SPECIFICATION REQUIREMENTS WHEN DISMANTLING THE BOOM SECTION. BLOCKING WAS NOT INSTALLED UNDERNEATH THE CRANE BOOM SECTIONS TO PREVENT IT FROM MOVING.

---(ABSTRACT NOT REVIEWED)

In order to elucidate patterns, there is a need to organise the data in a scientific and useful way.

The method that was used for organising the data was the taxonomic process. The taxonomic process can be described as the observation, description and classification of data into groups according to common patterns and individual differences. The aim is to paint a broad picture of what exists and to indicate the relative importance of different phenomena according to how frequently they occur. Geoff McDonald of Geoff McDonald & Associates (Qld) pioneered the use of taxonomy for classifying incident data.

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[39] Stout, N., Frommer, M.S. & Harrison, J., Comparison of work-related fatality surveillance in the U.S.A. and Australia, Journal of Occupational Accidents, Vol 13, 1990, pp195-211

[40] Code of Federal Regulations: Labor, 29, Part 1926, National Archives and Records Administration, July 1995

The general format that a taxonomy takes is illustrated in the following figure.

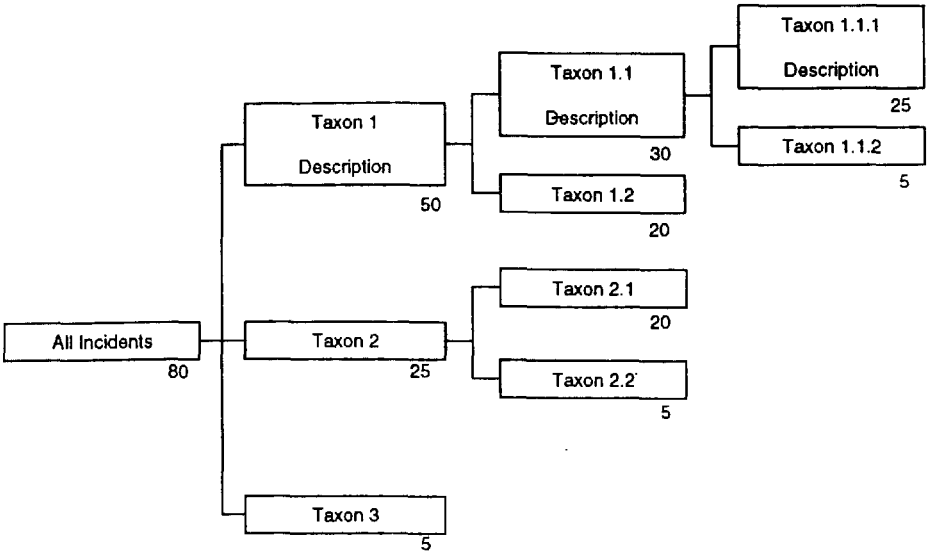

Figure 4.1

A variety of classifications are possible, for example: by age of deceased, year of occurrence, type of crane etc. These classifications were completed and are discussed in Section 5 of this document. They are useful describers of the problem, but are of only limited use in terms of understanding aetiology and determining countermeasures.

In order to determine the most useful and logical way to classify crane fatality data, the following classification systems were assessed;

- Classification by mechanism of injury/disease or breakdown agency as used by the National Occupational Health and Safety Commission (NOHSC) in the development of the national data set of compensation based statistics (NDS) - as described in Australian Standard for Workplace Injury and Disease AS1885.1:1990[41].
- Classification by event or exposure, as defined in the United States Bureau of Labor Statistics Occupational Injury and Illness Classification Manual[42].
- Classification by damaging energy as suggested by safety practitioners such as Derek Viner[43] and Geoff McDonald[44] (arising from the energy/damage concept).

It is considered that each of the above classification systems has both benefits and limitations, and it is pointed out that there is no "right" or "wrong" classification system; the measure should simply be usefulness.

Without detracting from other systems, in this particular study the major classification has been completed on the basis of the type of energy that is involved in the damaging energy exchange.

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[41]Australian Standard AS1885.1 - 1990. (NS002-1990) Workplace Injury and Disease Recording Standard Standards Association of Australia/Worksafe Australia National Standard

[42]Bureau of Labor Statistics (BLS) 1992 Occupational Injury and Illness Classification Manual Washington, DC: US Dept of Labor

[43]Viner, D. (1991) Accident Analysis and Risk Control, Delphi, Australia

[44]McDonald Geoff & Associates 1995, Occupational Personal Damage Causation, Consultancy into the Causes of Occupational Injury, Illness and Disease in Australia, Industry Commission, Melbourne

The concept of energy being an aetiological agent in the determinant of injury, and the classification of occurrences against the energy that damages has grown from the concept of energy developed by King[1], Gibson[2], and Hadden[3]. It is a powerful concept which is fundamental to understanding how people are damaged, and how future damage can be prevented or reduced.

Experience has shown that the concept of damaging energy is extremely useful in logically classifying incident phenomena, and generating insight. Insight into the energy which resulted in the damage allows control measures to be focussed on preventing or reducing this damaging energy exchange. As stated by Haddon[45]:

> *"An important landmark is reached in the evolution of a scientific field when classification of its subject matter is based on the relevant, fundamental processes involved rather than on descriptions of the appearances of the phenomenon of interest."*

Damaging energies can be defined in the following categories:

DAMAGING ENERGY	DEFINITION
Thermal	Damage arising from extreme temperatures
Machine (mobile)	Damage arising from mobile machinery
Machine (fixed)	Damage arising from contact with fixed machine which is in powered operation
Gravitational (people)	Damage arising from people falling
Gravitational (objects)	Damage arising from falling objects
Object	Damage arising from a free moving non-powered object
People	Damage arising from physical/muscular exertion
Chemical	Damage arising from contact of body tissue with chemical
Biological	Damage arising from any type of infections
Electrical	Damage arising from contact with electricity
Magnetic	Damage arising from handling steel tools in magnetic field
Noise	Damage arising from excessive sound pressure
Vibration	Damage arising from excessive vibration
Other	Any energy not listed above

As increasing numbers of incidents and quality of incident descriptions improve, it is possible to go to an increasing level of detail. The various taxons are identified with numerical notation and the numbers of incidents occurring in each taxon are shown adjacent to the taxon descriptions. In this particular study, the taxonomies are included in the appendices along with descriptions of the individual incidents.

Essentially, the output is a descriptive taxonomy of the crane fatality problem, broken down at the first level by the damaging energy involved. Subsequent levels of the taxonomy were developed based on an assessment of "usefulness" in terms of the information for prevention.

The initial objective of developing the taxonomy provided is to describe the patterns of damage relating to the use of cranes for those incident which cause the majority of damage. Previous work has revealed that permanent damage (fatalities and permanent injuries) account for about 13% of incidents, but produce approximately 82% of the costs (the 80:20 rule or Pareto

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[45]Haddon, W. (1973) Energy damage and the ten countermeasure strategies J Trauma. Vol 13, 4, pp321-331

principle)[43, 46]. In other words, it can be observed that the majority of damage results from the minority of incidents. Therefore, emphasis must be given to the management of the major damaging energy types which result in permanent damage. This document seeks to analyse patterns of fatal incidents and focus on those taxons which produce the majority of the damage.

While this particular taxonomy is of fatalities, it is highly probable that the vast majority of damage when measured in terms of years of living impaired or financial loss occurs in a non-fatal permanent damage context. The pattern of damaging energy is likely to be different for the different levels of personal damage classifications. Therefore it is not possible to assume that a fatality study (while useful and important) yields sufficient insight into non-fatal permanent disability. Incident descriptions with respect to non-fatal permanent damage incidents are currently very difficult/impossible to obtain. It is highly likely that the pattern of damaging energies alters with the human energies/simple lifting, pushing, pulling becomes increasingly represented. In addition it can be predicted that damage resulting from falls of people, for example due to mobile equipment access, will also become prominent.

With this in mind fundamental applications and limitations of the taxonomy can be stated:

- application: the taxonomy is based on fatalities which can provide a focus of attention to problem areas which produce a majority of the damage, and serve as a basis for further discussion and investigation;

- limitation: the taxonomy is based on fatalities only, and does not include non-fatal permanent damage, thus further consideration should be given to those taxons which would be strengthened by the inclusion of non-fatal data.

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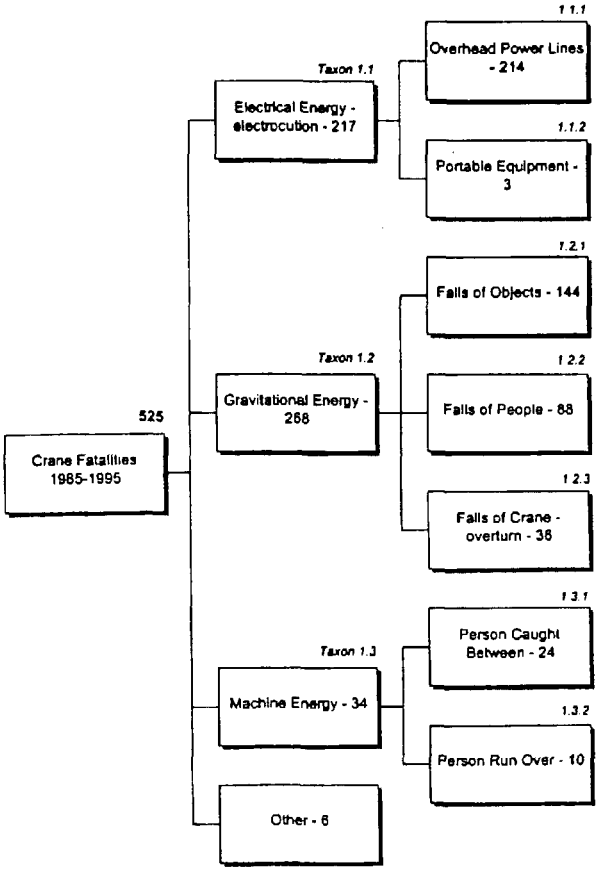
[46] The InterSafe Group Pty Ltd, Personal Damage Reduction through Engineering Design, Book 1 – Concepts and Philosophy presented by Roger Kahler, 1996

5.0 TAXONOMY OF OSHA DATA (525 Fatalities)

The complete taxonomy of U.S. Construction Industry crane fatalities reported to OSHA (1985-1995) is given in *Appendix A*. Individual incident descriptions are included in *Appendix B* by taxon.

A second level breakdown of the taxonomy is depicted below:



With reference to the taxonomy presented, it is evident that patterns emerge with respect to crane related fatalities. This is consistent with the core concept in epidemiology that fatality (and injury) distributions are highly non-random[47]. Gravitational energy and electrical energy are over-represented, similar to many other studies of fatalities[46].

Like all taxonomies, it is possible to become lost in the maze of taxons and percentages, particularly when the numbers of incidents represented by particular taxon become quite small. At this point in time in the management of crane related fatalities, it is necessary to focus on those few taxon that embrace a significant percentage of all fatalities without detracting from any of the current effort being applied by government, industry and manufacturers.

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[47]Haddon, W., 1980, *Advances in the Epidemiology of Injuries as a Basis for Public Policy*, Public Health Reports, Vol 95, No. 5, pp411-421.

The complete crane taxonomy indicates that approximately 79% of the crane fatalities can be managed with focus on the following few taxons;

- Crane contact with overhead powerlines - 190 (36%)
- Falls of people from a height - 88 (17%)
- Falls of a suspended load onto a person under the load - 55 (10%)
- Crane overturns and falls onto people - 36 (7%)
- Falls of lattice boom during dismantling - 30 (6%)
- Person caught between swinging counterweight and crane structure - 15 (3%)

In other words, it can be observed that again the Pareto Principle applies; roughly 80% of the problem arises from about 20% of the taxons.

General trends revealed by an analysis of OSHA data are examined in *Section 5.1.*

Sections 5.2-5.7 provide a description and analysis of the incident types published above with preliminary recommendations made for the management of each incident type.

5.1 General Trends

Analysis of OSHA data reveals a number of trends in various aspects of crane fatalities. The most useful areas to investigate include major energy and incident types contributing to fatalities; distribution of crane fatalities over time; age groups involved in crane fatalities, and; involvement of various crane types in the data. General trends emerging from these areas are examined in *Sections 5.1.1 to 5.1.4.*

5.1.1 Crane Fatalities by Damaging Energy

The major energy sources contributing to fatalities are depicted in *Figure 5.1.1.*

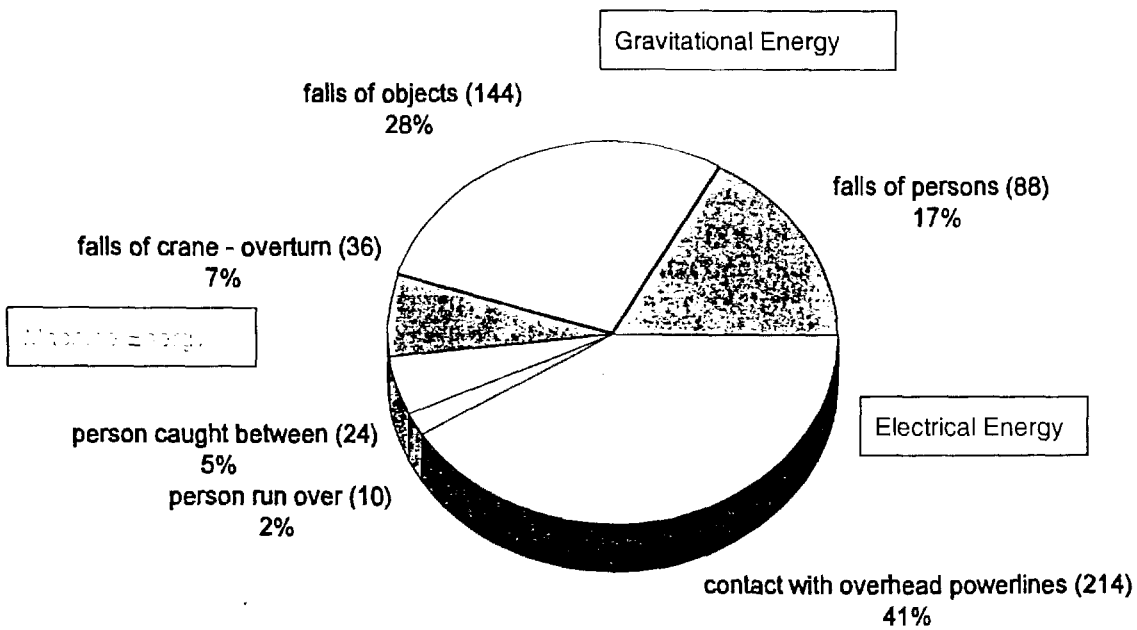

Figure 5.1.1.1 Breakdown of crane fatalities by damaging energy (OSHA)

Electrical Energy and Gravitational Energy contribute significantly to the number of fatalities. Quantitatively, Electrical Energy (electrocution) is the damaging energy source in about 41% of crane fatalities, and Gravitational Energy is the damaging energy in approximately 51% of fatalities. Most electrocutions involve contact with overhead power lines. Gravitational Energy includes falls of objects (crane boom, hoisted load etc), falls of people, and falls of crane (overturns).

5.1.2 Crane Fatalities by Year of Occurrence

A chart depicting the relative number of crane fatalities for the years 1985 to 1995 is given in *Figure 5.1.2.1*. It can be seen that there is a general decrease in the number of crane fatalities over the 11 year period; however, given several unknown variables such as the number of cranes used in construction during these years (i.e. exposure data), no confident conclusions can be drawn about this decrease.

Nevertheless, comparisons between contributions of the various energy types can be made. As a general observation, the number of electrocutions has decreased fairly consistently between 1985 and 1995, whereas the number of fatalities related to Gravitational and Machine Energy have not.

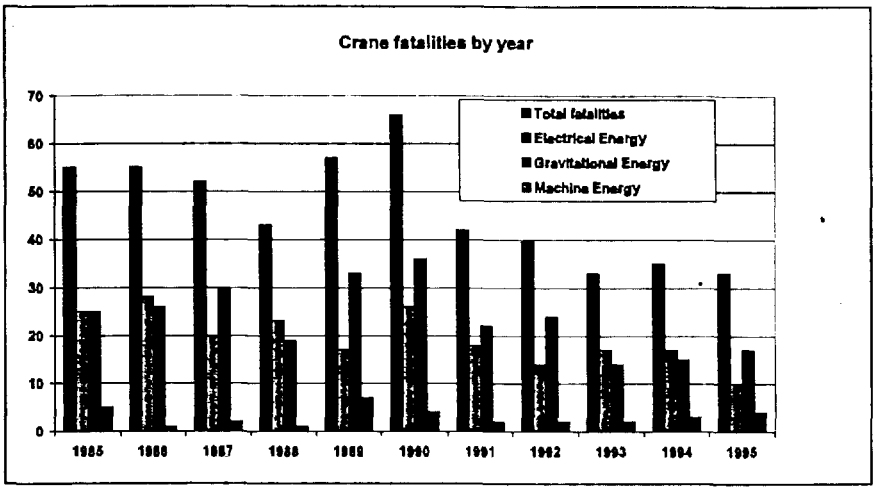

Figure 5.1.2.1

A correlation analysis of fatalities by energy source over time was conducted. It was found that there was a strong trend in the reduction of electrical energy incidents over time (correlation coefficient 0. 79), a weak trend in the reduction of gravitational incidents over time (correlation coefficient 0.55), with machine energy events remaining relatively constant over time.

5.1.3 Crane Fatalities by Age of Deceased

Figure 5.1.3.1 illustrates the relative proportions of age groups involved in crane fatalities.

Although data is not available, it is probable that the numbers of fatalities in each age bracket simply reflect the number of people employed as crane operators and construction workers in that age group.

The chart would seem to question the perception sometimes held in the industry that younger people are largely over-represented in crane fatality statistics, and that older, experienced operators are under-represented in fatality statistics.

There seems to be a discrepancy between age of deceased person and type of damaging energy. For the two age groups 17-25 and 26-35 Electrical Energy marginally exceeds Gravitational Energy as the damaging energy source; however, for the age groups 36-45, 46-55, and 56-65 gravity far exceeds damage through electricity. Again definite conclusions cannot be drawn as these differences may simply be related to the type of work each age group is involved in, or other factors.

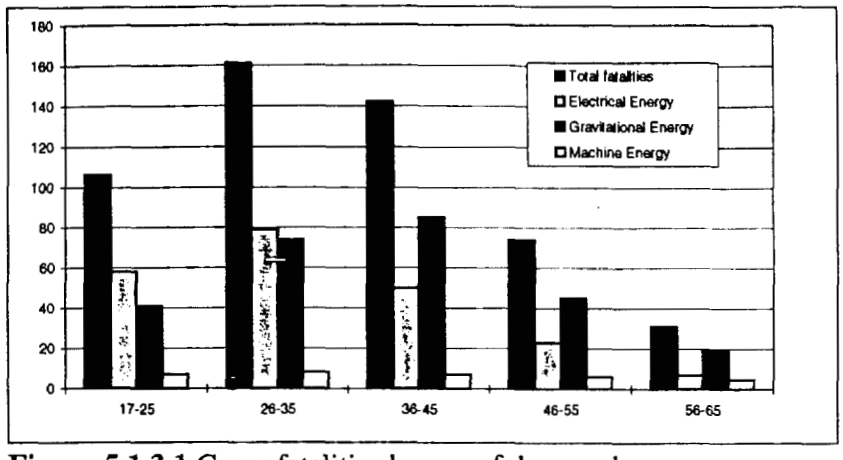

Figure 5.1.3.1 Crane fatalities by age of deceased.

5.1.4 Crane Fatalities by Type of Crane

Cranes described in OSHA data can be classified as follows: Mobile Cranes - including truck mounted, crawler cranes etc; Tower Cranes; Derrick Cranes, or; Elevating Work Platforms (EWPs) such as vehicle mounted permanent aerial lift buckets ('cherry pickers'), and temporary baskets/platforms suspended from cranes.

Table 1 illustrates the number of fatalities for each energy classification, by type of crane. Detailed analysis of the data is problematic due to the large number of cases in the OSHA database which did not specify crane type. In fact, *Table 1* demonstrates that 172 cases out of 518 (33%) do not specify the type of crane involved in the incident.

Nevertheless, the following general trends are observed in incidents *where crane type is specified*:

- a majority of crane fatalities involve mobile cranes (65%)
- most electrocutions involve Mobile Cranes (81%)
- most fatalities relating to Tower Cranes are due to Gravitational Energy (88%)
- for EWPs, gravity exceeds electrocution as a major damaging energy source (gravitational energy 62%, electrical energy 30%)

TYPE OF CRANE	ELECTRICAL ENERGY	GRAVITATIONAL ENERGY	MACHINE ENERGY	TOTAL
Mobile	121	98	7	226
EWP (temporary)	2	13	0	15
EWP (permanent)	26	45	7	78
Tower	0	14	2	16
Derrick	0	5	0	5
Other	0	4	2	6
Non-Specific	68	89	15	172
Total	**217**	**268**	**33**	**518**

Table 1 Crane fatalities by type of crane

5.2 Crane Contact with Power Lines (190 Cases) Taxon 1.1.1.1

This taxon consists of cases which involve the crane boom, load line, or load contacting/arcing with energised overhead power lines where a person was in a position to provide a path for the electricity to ground (touching load, or crane etc). The incident descriptions that constitute this taxon are found in *Appendix B*.

Description of Taxon:

- Crane types involved. Analysis of the data reveals that electrocutions are predominately associated with Mobile Cranes (120 cases, or 95% of cases where crane type is specified).
- Point of Contact. *Figure 5.2.1* illustrates that power line contact occurs either by the crane boom (102 cases, 54%), by the load line (72 cases, 38%), or by the hoisted load (16 cases, 8%).

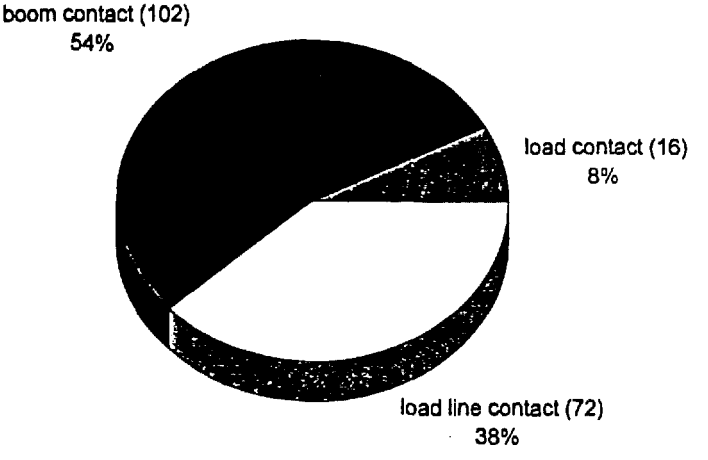

Figure 5.2.1 Point of contact of crane with overhead power lines (190 cases).

- Location of electrocuted person. *Figure 5.2.2* illustrates that the majority of fatalities in this taxon involve the person: contacting the load (109 cases, 57%); contacting some part of the crane or truck body (24 cases, 13%); operating the crane/boom from the cabin, pedestal, or remote control (18 cases, 9%), or; connected to the crane by some kind of conductor - for instance water or scaffolding (14 cases, 7%).

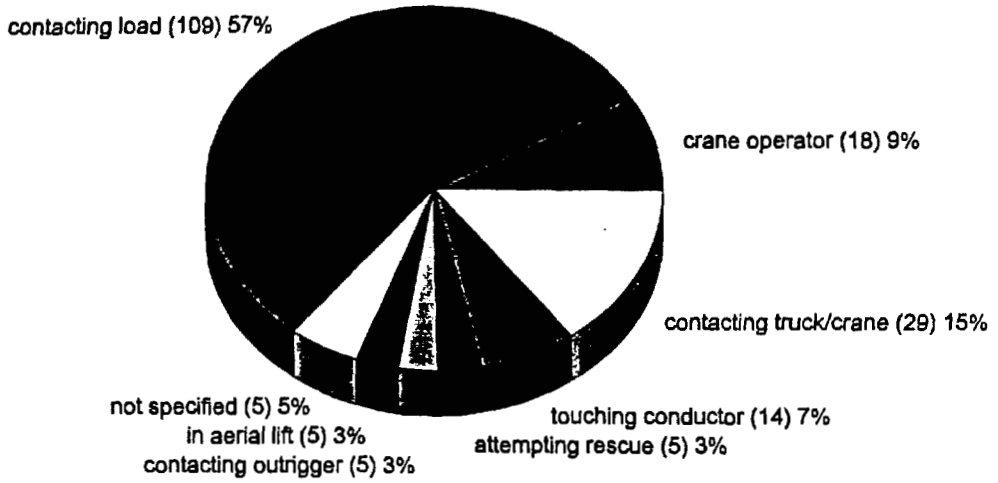

Figure 5.2.2 Location of person when crane contacted energised lines (190 cases).

- Mechanism for Contact. *Figure 5.2.3* reveals that power line contact occurs predominately while the crane boom is being raised/lowered or slewed (84 cases, 44%), although again the data is incomplete as 38% of cases do not specify the type of crane. Other contact mechanisms include: raised boom being driven into wires (15 cases, 8%); load or load line being carried into wires by ground workers (10 cases, 5%), and; load or load line swinging into overhead wires by wind action (10 cases, 5%).

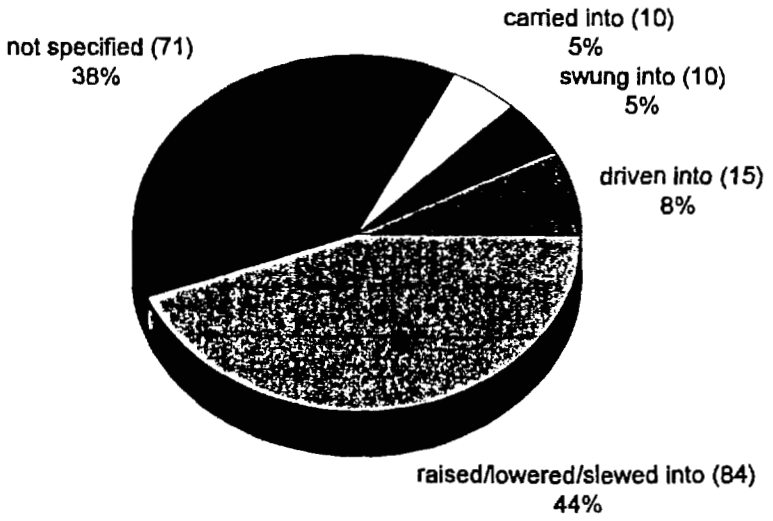

Figure 5.2.3 Mechanism of contact with power lines (190 cases)

Analysis of taxon:

- Factors which are essential in all 190 fatalities, include: overhead power lines proximal to crane operation; power lines energised; crane/load or load line contacted power line; crane/load or load line became energised; electricity conducted to person; person provided a potential difference (eg. standing on the ground); electricity flowed through person.

- Perceived risk versus actual risk. Many of the incidents involved situations where the crane crew knew of their proximity to live overhead power lines (ie. were operating at a perceived safe clearance), but unexpected mechanisms caused contact. These mechanisms include; inadvertent luffing or slewing into overhead lines; violent boom movement due to ground depressions (potholes etc); stretch or deflection of ropes or boom due to loading; momentum of swinging crane cable or load, and; swinging lines or load by wind action.

Based on the taxonomy *Figure 5.2.4*[33] illustrates the most common fatal crane incident type; that is crane/loadline contact with overhead powerlines, with the person touching or guiding the load or crane.

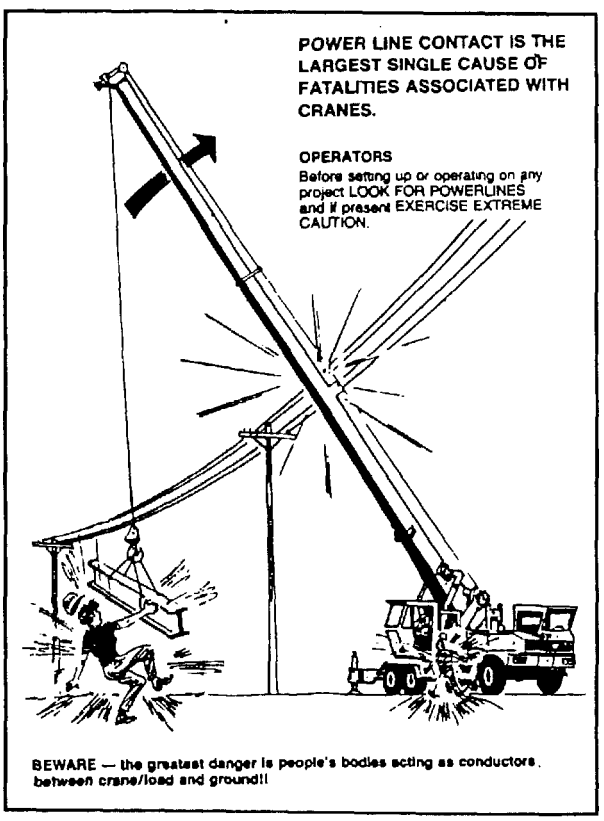

Figure 5.2.4

Current control measures are focussed on training of employees, and procedures such as maintaining safe clearances from electrical lines and apparatus. A public advertising campaign was run in some Australian states, instructing people to "look up and live", after a string of powerline contacts.

The well known ten foot rule is required by OSHA regulations, as indicated in a copy of a decal generally furnished by crane manufacturers shown in *Figure 5.2.5*[48].

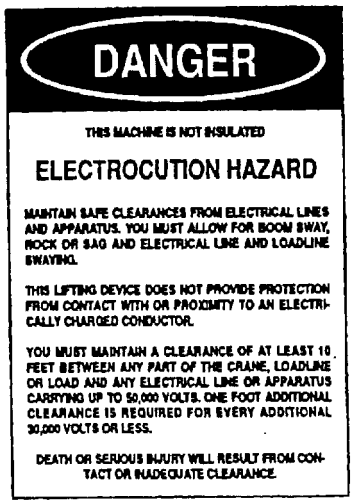

Figure 5.2.5

Similar requirements are published by Australian Guidance documents, such as Australian Standard AS2550.1 - 1993[49].

However, when one applies an appropriate model to analyse near miss type incidents in detail, it becomes clear that heavy demands are placed on crane operators, with there being little tolerance for human error.

As stated by Frisk[35] human error occurs when situational demands exceed human capacity.

The point is made in a paper by Lehman and Gage[50], that crane operators involved in mishaps often report that they suffered from mental overload. Problems occur as the operator is required to appropriately process and react to multiple stimuli, and to carry out multiple actions.

Other problems cited include the difficulty in gauging distances of the boom to overhead powerlines. For example, a paper by Cunlitz and Middendorf[51] revealed that operators could not estimate the distance between their hoist line and a powerline with sufficient accuracy to ensure safety. The conclusions were as follows:

> *"It has been shown that a powerline represents an impoverished visual stimulus to an observer whose very life may depend upon making accurate clearance judgements. Clearance judgements between a crane and a powerline will be negatively affected by the inability of the human observer to determine accurately the distance to the powerline. Safety demands accurate judgements, but accurate judgements appear not to be possible without assistance. It is not appropriate to*

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[48] Perlman, P., Trial Strategy in an Electrical Injury Case, Automotive Engineering and Litigation, Vol 4, John Wiley & Sons, 1991

[49] Australian Standard AS2550.1 - 1993 Cranes - Safe Use Part 1: General requirements Standards Association of Australia

[50] Lehman, B.J. & Gage, H., How Much is Safety Really Worth? Countering a False Hypothesis, American Society of Safety Engineers, May 1995, pp37-40

[51] Cunlitz, R. & Middendorf, L., Problems in the Perception of Overhead Power Lines, Hazard Prevention, March/April 1985

blame careless operators when careful operators have difficulty making such decisions."

The control measure of "look up and live" is challenged.

Preliminary Recommendations:

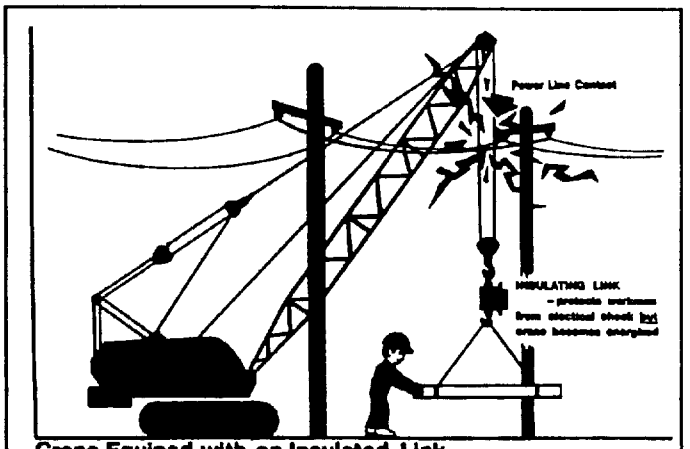
The preceding analysis of crane contact with the power line incidents reveals the multi-factorial nature of occurrences.

In the past, control measures for the hazards described have been focussed on training and education of employees, and procedures such as maintaining safe clearances from electrical lines.

These countermeasures are essential, but limited, as they do not effectively manage the damaging energies involved or the propensity for human error to be involved in the release of these energies. Continued emphasis on these controls alone will simply ensure the pattern of damage continues.

It is proposed that the next most significant gains with respect to reducing crane fatalities and serious injuries will be made by providing equipment which accommodates predictable and undesirable human error and behaviour. Application of this principle in conjunction with historical data which is scientifically organised, can assist developing focus areas for future control.

For example, the use of insulated links on crane cables (as per *Figure 5.2.6*[13]) has the potential to manage up to 57% of inadvertent powerline contact fatalities (about 20% of the crane fatality problem).



Crane Equiped with an Insulated Link

Figure 5.2.6

Insulating links have been available for a long period of time[52] and are often used on cranes in other industrial environments - for example, in aluminium smelters. However, they are currently rarely used on mobile cranes and are not mentioned in Australian or US crane standards.

[52] US Patent 2897257, "Insulated Link", United States Patent Office, 1958.

Therefore the key recommendation arising is the fitment of high voltage insulating links to mobile cranes. It would be recommended that usage of insulated links complement other energy management measures such as de-energisation of powerlines prior to work, the use of insulating line sheaths, non-conductive tag lines (dry polypropylene) and electrostatic warning devices which are already in use in industry.

5.3 Falls of Hoisted Load (55 Cases) Taxon 1.2.1.2

This taxon consists of cases which involve the hoisted load (or part thereof) falling from height. This includes mechanical failures of the rigging equipment (hook block and load fall), and cases where the load came off the hook (load free-fall). As before, the taxon is given in *Appendix A* (page 6). Individual incident descriptions are given in *Appendix B*.

Description of Taxon:

- There are 26 cases where the load fell from the crane attachment. This includes loads slipping through the sling supports (9), rigging equipment failure (8), and the load disconnecting from the hook (5).
- There were 15 cases of the load falling whilst still attached to the crane. This involved cables slipping through brakes on 7 occasions, and cable failure on 5 occasions.
- The falling of loads whilst uncoupling on the ground or a truck accounted for 11 fatalities. 5 of these occurred when a grounded load fell over, with 3 occurring when a load slipped off a truck.

Analysis of Taxon/incident type:

- Factors which were essential to all 55 incidents, include: a failure occurred; the hoisted load fell; a person was under the load; the load struck and crushed the person.
- Inadequate rigging and sling supports are responsible for many falling loads.
- The use of hooks without a safety catch (or with a defective catch) is an essential factor to some of these incidents.

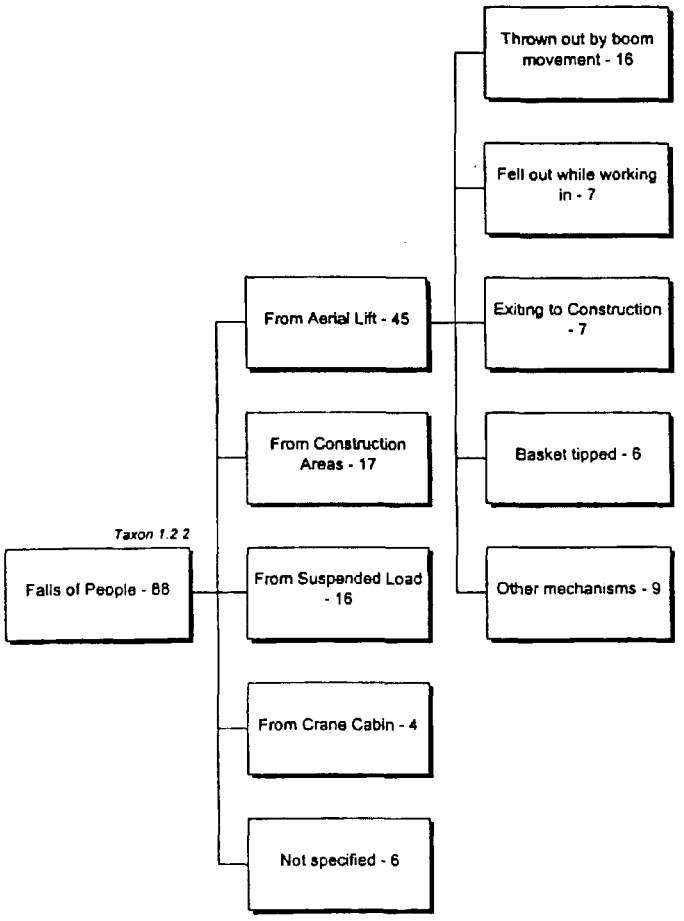
Preliminary Recommendations:

It is recommended focus be placed on ;

- Continuing to emphasise the behaviour that people are not to be underneath hoisted loads
- Fitting fail-safe systems to failure mechanisms that are catastrophic (e.g. free falling of load/boom etc).
- Reinforce the use of appropriate rigging practices and well maintained equipment.
- The use of safety catches on hooks.
- Separation of people and hoisted load when unloading unto ground or truck, until load is grounded and stable.

5.4 Falls of People (88 Cases) Taxon 1.2.2

This taxon consists of cases which involve people falling with or from elevated surfaces. The taxon is given in *Appendix A*, with individual incident descriptions given in *Appendix B*. A breakdown of the taxon is depicted below.



Description of Taxon:

- Use of fall protection equipment. There were 76 cases of falls from elevation without a safety harness connected. There were 3 cases of falls in which the travel restrict or fall arrest equipment failed.
- Origin of falling person; *Figure 5.4.1* illustrates the origin of the falling person.
- Falls from Elevating Work Platforms are highly represented in this taxon (45 cases, 51%). The taxonomy reveals that the majority of falls from EWPs occur as a result of violent boom movement (16 cases), while exiting to construction areas (7 cases), while working out of buckets (7 cases), or due to tipping of the basket (6 cases).

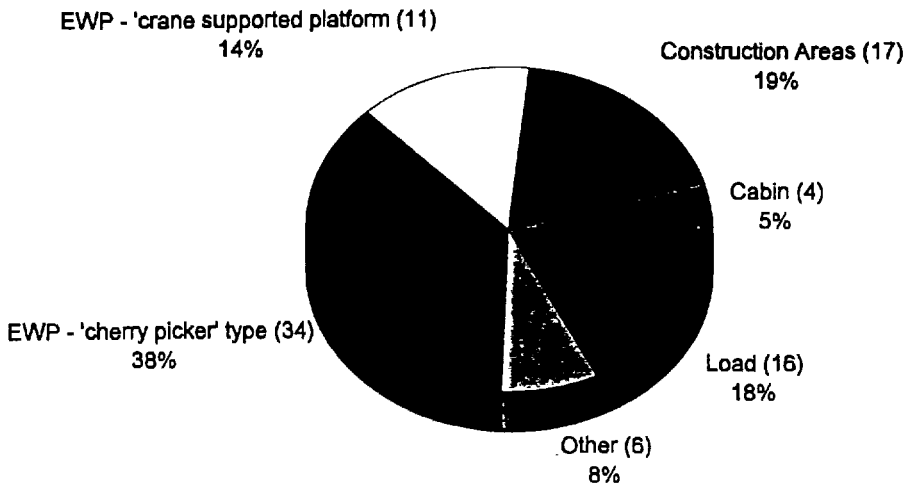


Figure 5.4.1 Origin of falling person (88 Cases).

- Falls from construction areas that are attributable to crane operation are also significant (17 occurrences, 19%). These falls are usually preceded by the person being struck by a hoisted load (7 cases), while manoeuvring the load (6 cases), or while being distracted by the load (3 cases).

- Falls from crane cabins, and falls of persons while travelling upon loads or escorting loads also result in fatalities. The small number of fatalities underestimate the size of the problem as large numbers of permanent disability injuries occur as a result of these types of incidents.

Analysis of Taxon:

- Factors which are essential to all 88 fatalities, include: a person was working at height (greater than 1 metre.); person became unstable (due to various mechanisms); person fell (no travel restrict system); there was nothing to stop the person free-falling (no fall arrest system, net etc.); person struck the ground.
- The use of a safety harness in EWPs and elevated construction areas would have prevented most of the fatalities.

Preliminary Recommendations:

The data provided merely support the need for the following longstanding countermeasures:
- Safety harnesses or similar Fall Protection measures should be provided, used and connected correctly at all times (in EWPs and in construction areas).
- People should not travel upon hoisted loads.
- Parts which fail catastrophically on EWPs (eg. basket connections, boom hydraulics/pneumatics) should be identified, and a policy of regular inspections and replacements should be developed. Valves should be fitted which ensure controlled descent in the event of power/air failure.

- Cabin access should be based on principles contained in Standards such as AS1657-1992 "SAA Code for Fixed Platforms, Stairways, and Ladders", ISO2867-1989/AS 3868-1994 "Earth Moving Machinery - Access Systems" , etc.

5.5 Fall of Crane - Overturns (36 Cases) Taxon 1.2.3

This taxon consists of cases which involve the crane overturning and causing damage either due to the boom striking people, or due to people falling from the overturning crane. The taxon is illustrated in *Appendix A*. Individual case descriptions can be found in *Appendix B*. A breakdown of the taxon is depicted below.

Description of Taxon:

- Cranes were reported to have overturned as a result of the following mechanisms: crane overloaded in 14 cases (38%); crane bearing surface was unstable in 5 cases; outriggers not fully extended in 5 cases.

- Location of fatally injured persons. The deceased person was located in the crane cabin in 13 cases (36%), on the ground in 12 cases (33%), and within a 'cherry picker' type EWP in 9 cases (25%).

Analysis of Taxon:

- Overturning of cranes is a long standing problem. These incidents most often occur as a result of one or more of the following factors: crane overloaded; poor bearing surface; outriggers not fully extended; high wind forces on load; working on an inclined surface; crane slewed out of working zone; support base struck by mobile equipment .

- Most of the cranes that tipped with overloads would have been equipped with load-indicating devices of some sort. Either the devices were not functioning, were ignored or bypassed, were miscalibrated, or were not sufficiently accurate. It is clear that load-indicators are not be relied upon to prevent overloads. Mythologies relating to the ability to "rely on signs of tipping to predict overturning", and that "SWLs are overly conservative and can be safely exceeded" contribute to the lack of effectiveness of these devices.

Preliminary Recommendations:

- Preplanning is essential to ensure the correct crane is chosen for the job - once a crane is on site it is likely that the crew will do everything possible to do the job, even if it means knowingly overloading the crane.

- Analysis of the following failure mechanisms should be undertaken with a view towards implementing effective design, administrative and behavioural solution strategies:
  - overloading - a rated capacity limiter should be fitted to cranes;
  - outriggers not fully extended - an outrigger limit switch should be used to ensure full outrigger extension;
  - wind forces - it is well known that cranes are very sensitive to winds, anemometer should be fitted to boom with a display in the cabin;

- inclined surface - levelling of crane extremely important, effective angle indicators should be provided and interlocked to operation;
- crane slew out of working zone - provide a slew indicator/limiter;
- crane support struck by vehicles - outrigger supports should be clearly visible and barricaded (paint counterweight and outriggers with highly visible stripes);
- failures of EWP limit switches; these types of systems should be effectively serviced and maintained.

5.6 Falls of Lattice Boom during dismantling (30 Cases)

Taxon 1.2.1.1.2

This taxon consists of cases where the crane boom fell and struck or crushed people underneath, during dismantling/assembly of the boom. The taxonomic breakdown is depicted in *Appendix A* with individual incident descriptions in *Appendix B*.

Description of Taxon:

There were 30 cases involving falls of the crane boom during dismantling or assembly of the boom. Typically these occur when the workers underneath the boom are removing lower superstructure pins before the upper pins (without adequate blocking support). This causes the boom to scissor down onto the person.

One such situation is illustrated in *Figure 5.6.1.*[53]

The correct procedure is to never remove boom pins unless the boom peak is resting on the ground, or each boom section is blocked. In addition the procedure dictates that pins should be inserted and removed from outside the boom, not underneath.

[53]West D. ed., (1997). A Guide to Rigging 2nd Ed., June 1997. WorkCover Authority of New & Victoria

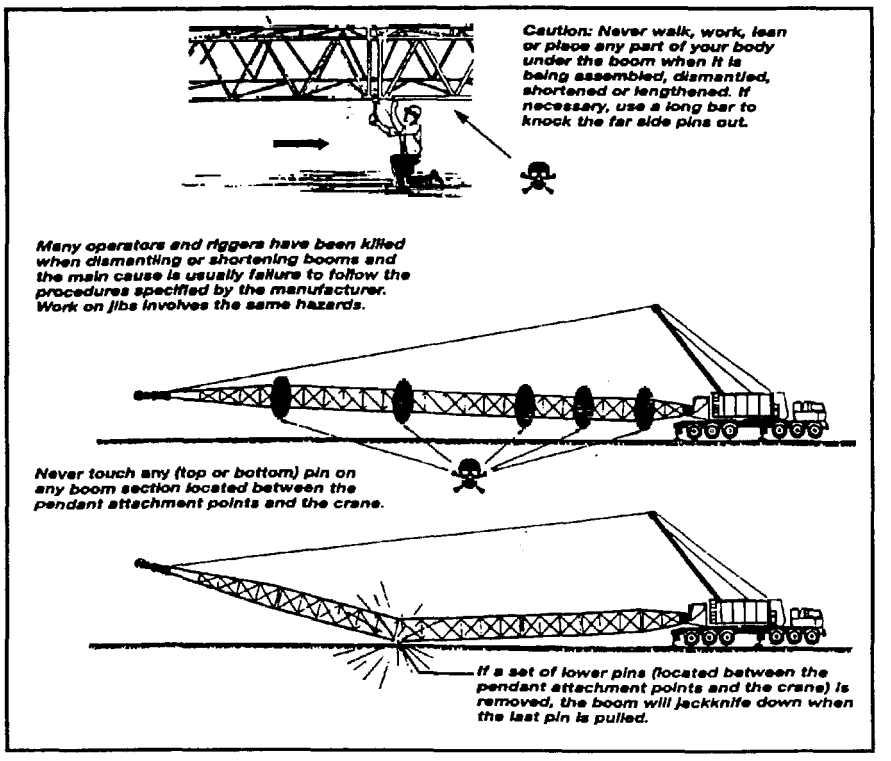


Figure 5.6.1

Analysis of Taxon:

- Factors which are essential to all 30 incidents include: a lattice boom is used; the boom requires manual dismantling; dismantling requires knocking out of pins; it is possible to do this whilst under the boom; displacement of the pins allows booms sections to scissor down and will do so without provision of adequate blocking; the person is standing beneath unsupported boom.

Preliminary Recommendations:

Fatalities due to boom collapse during dismantling or assembly are a long standing continuing problem. Administrative and training (behavioural) solutions have long been adopted to reduce this hazard. However, the taxonomy indicates this reliance on behaviour is failing. There are two conclusions which can be drawn:

(a) do nothing and allow the patterns of incidents to recur; or
(b) see the incidents as an opportunity to analyse the problems, describe all the factors and find design solutions which will accommodate these infrequent situations in which a person attempts to drive out a pin on a loaded tension member. The design solution is considered to be relatively simple.

It is not difficult to envisage a device which prevents the boom from falling if lower pins removed, or prevent the lower pins being removed before upper pins. Such an engineering solution would prove far more effective than reliance on procedures and behavioural modifications.

5.7 Person Caught Between Swinging Counterweight (15 Cases)

Taxon 1.3.1.1This taxon consists of cases which involve a person being caught between two surfaces (eg.counterweight and crane) due to rotation or movement of machinery.

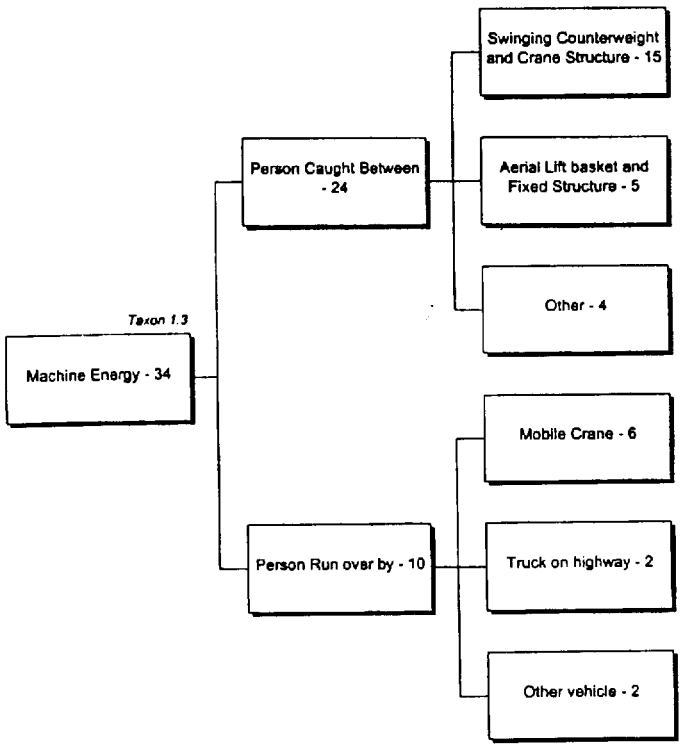


Figure 5.7.1

Description of Taxon:

- Cases where a person was caught between the counterweight and the crane/truck structure are highly represented (15 occurrences). These cases consists of a person being caught between the: counterweight and crane in 6 cases; counterweight and cab in 3 cases; counterweight and outrigger in 3 cases, and; counterweight and truck in 2 cases. The reasons for people being in these areas are unclear.

Analysis of Taxon:

- It is evident that people are within the slew radius of the crane when rotating, and are not observable by the crane operator.

Preliminary Recommendations:

- The crane operator should have increased vision of the pinch points within the slew radius of the crane, or be provided with a proximity detector.
- Accessible areas within the swing radius of the rear and rotating superstructure of the crane should be barricaded to prevent entry.

This is also required by the Australian Standard AS2550.1 - 1993 Cranes - Safe Use[54], which under Section 7 'Operation' requires the following;

> *"7.8Persons approaching the proximity of a crane. No personnel should be allowed to approach a crane when it is operating or travelling as there is a danger that they may be struck by the crane or load, or trapped between fixed and moving parts of the crane, e.g. between the slewing superstructure and the non-rotating structure of the crane.*
>
> *Barricades or guarding shall be provided where practicable."*

It is believed that this recommendation can be strengthened by provision of equipment on cranes that can be easily extended (automatically or manually)to provide a barrier to rotating crane parts.

[54]Australian Standard AS2550.1 - 1993 Cranes - Safe Use Part 1: General requirements Standards Association of Australia

6.0 SUMMARY AND CONCLUSIONS

In order to gain insight into crane accidents, a classification of 525 crane fatalities was developed. Fatality descriptions were supplied by the United States Occupational Safety and Health Administration (OSHA) for the years 1985-1995.

The goal of the project was to understand the pattern of crane fatalities and identify key areas for future control.

The human tragedy of over 500 lives lost, described by summary abstracts of each occurrence, cannot be expressed in words. Data and statistics are grossly limited in this respect; one can describe a problem with statistics, but one cannot fully comprehend a problem merely with statistics.

The first phase of any scientific problem solving process, however, is observation and description of the problem. Description should proceed analysis. Understanding the what, when, who, how and why of any occurrence maximises opportunity for effective control.

The taxonomic method was used to observe, describe and classify the 525 US crane fatalities.

Fatalities were classified on the basis of the damaging energy involved (at the first level), based on the concept that damage results from an energy exchange which goes outside tolerable limits. The following categories were used.

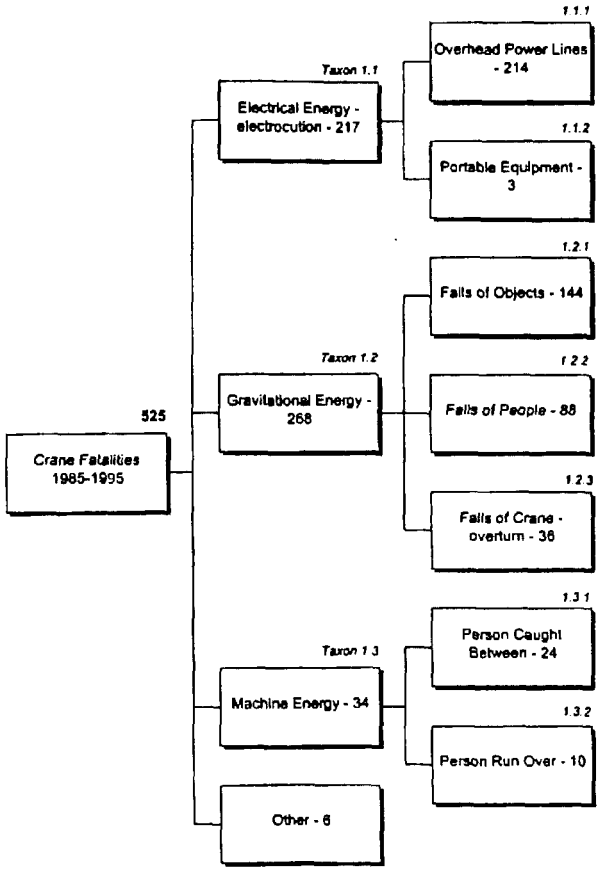
DAMAGING ENERGY	DEFINITION
Thermal	Damage arising from extreme temperatures
Machine (mobile)	Damage arising from mobile machinery
Machine (fixed)	Damage arising from contact with fixed machine which is in powered operation
Gravitational (people)	Damage arising from people falling
Gravitational (objects)	Damage arising from falling objects
Object	Damage arising from a free moving non-powered object
People	Damage arising from physical/muscular exertion
Chemical	Damage arising from contact of body tissue with chemical
Biological	Damage arising from any type of infections
Electrical	Damage arising from contact with electricity
Magnetic	Damage arising from handling steel tools in magnetic field
Noise	Damage arising from excessive sound pressure
Vibration	Damage arising from excessive vibration
Other	Any energy not listed above

Subsequent levels of the taxonomy were classified based on an assessment of "usefulness" with respect to prevention.

This section of the report summarises the outcomes of the project and identifies possible

directions for future work.

6.1 Outcomes and Future Work Regarding Crane Fatalities



The second level breakdown of the taxonomy is given as follows (the complete taxonomy is given in *Appendix A*, with incident descriptions in *Appendix B*).

With reference to the taxonomy presented above, it is evident that patterns emerge with respect to crane related fatalities. In particular, Gravitational Energy and Electrical Energy are highly represented (485 fatalities - 90% of the problem). Six fatalities (1%) could not be classified.

The complete taxonomy indicates that approximately 79% of the crane fatalities can be managed with focus on the following few taxons:

- Crane contact with overhead powerlines - 190 (36%);
- Falls of people from a height - 88 (17%);
- Falls of a suspended load onto a person under the load - 55 (10%);

- Crane overturns and falls onto people - 36 (7%);
- Falls of lattice boom during dismantling - 30 (6%);
- Person caught between swinging counterweight and crane structure - 15 (3%)

In other words, it can be observed that patterns emerge in accordance with the Pareto Principle; roughly 80% of the problem can be managed by focus on 20% of the taxons.

Future direction in reducing crane fatalities lies in controlling the aforementioned incident types.

In the past, control measures for the hazards described have been focussed on training and education of employees, and procedures such as maintaining safe clearances from electrical lines.
These countermeasures are essential, but limited, as they do not effectively manage the damaging energies involved nor the propensity for human error to be involved in the release of these energies. Continued emphasis on these controls alone will simply ensure the pattern of damage continues.

It is proposed that the next most significant gains with respect to reducing crane fatalities and serious injuries will be made by providing and using equipment which accommodates predictable and undesirable human error and behaviour.

Preliminary recommendations for control measures are published within the report. The taxonomy indicates the following six key recommendations could have been implemented to prevent up to 304 (58%) of the recorded fatalities:

- Provision of insulated links on mobile crane cables or hooks (potential to prevent electrocution of the person guiding the load - 21% of fatalities);
- Provision and use of appropriate fall protection equipment when working on Elevating Work Platforms and with cranes in construction (potential to prevent up to 76 falls of people fatalities - 16%);
- Separating people and suspended loads by using taglines and ensuring loads are not lifted above people - although this does not diminish the need for safety hooks and anti-two blocking devices (potential to prevent up to 55 fall of load onto person fatalities - 10%);
- Redesigning retaining pins to prevent lattice boom collapse onto people whilst dismantling (potential to prevent up to 30 fatalities - 6%);
- Fitting rated capacity limiters and outrigger limit switches to mobile cranes (potential to prevent up to 19 fatal crane overturns - 4%);

- Barricading or guarding pinch points within crane slew radius (potential to prevent 15 fatalities - 3%).

In summary, the taxonomy indicates that crane fatalities are not "freak occurrences"; they are both predictable and preventable. The massive loss of human life is unnecessary. Effective management of the energies marshalled and focus on the priority areas identified will avoid continuation of the pattern of crane related damage. This requires action (change for the future) on behalf of crane designers, manufacturers, owners and users and other stake holders including government and industry

Some limitations of the taxonomy for identifying key areas for future control are stressed:

- The taxonomy is for the US construction industry; the pattern may be different for other Western countries (eg Australia);

- Most importantly - the taxonomy is based on fatalities only. The number of fatalities in each taxon is only one indicator of where industry priorities should lie in terms of crane safety development. Previous studies of other large injury and fatality groups indicate the majority of personal damage arises from non-fatal permanent disability. Thus in the short term, further consideration should be given to those taxon which would strengthened by the inclusion of non-fatal permanent disability data (eg. access to crane cabin).

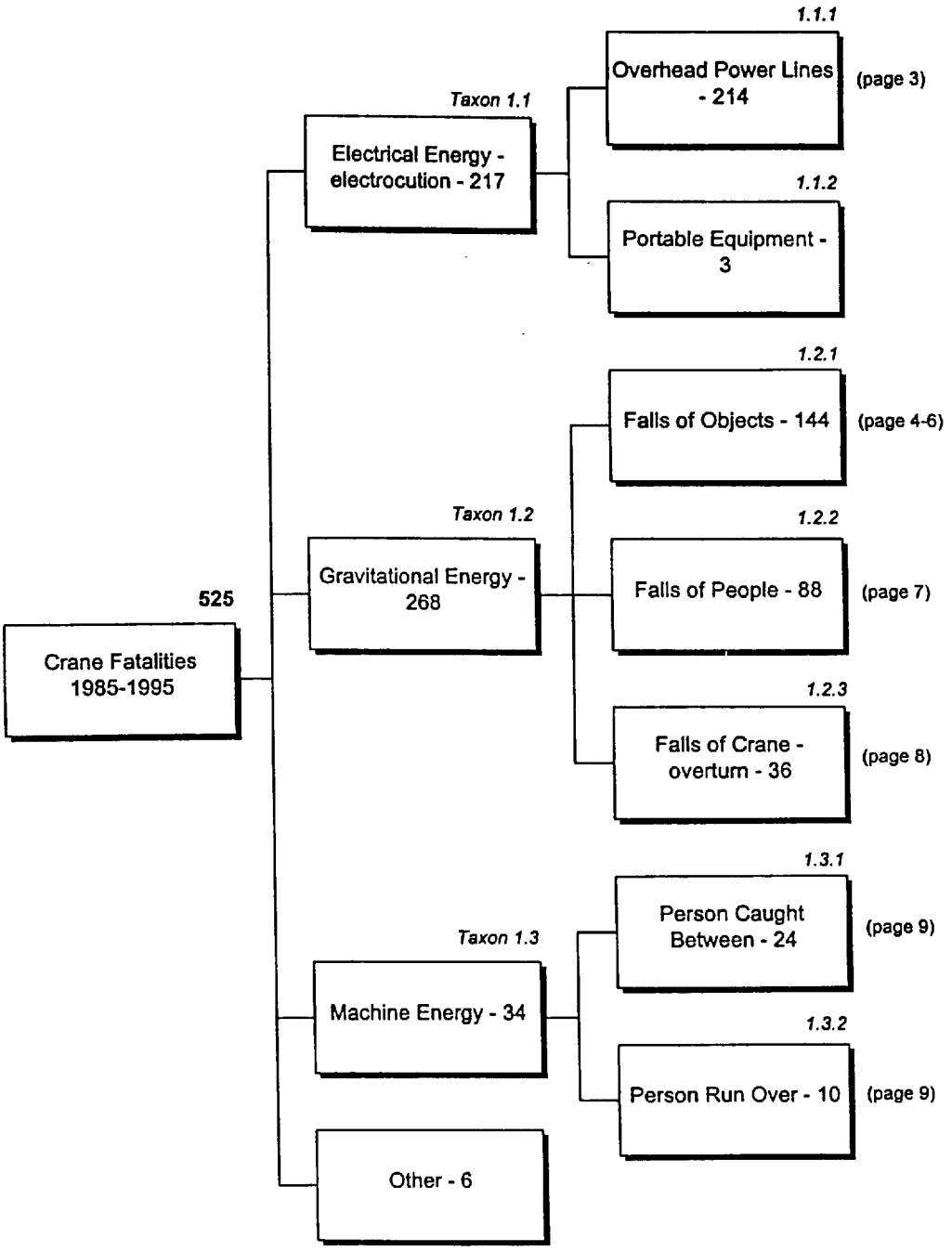
Future work should involve establishing the pattern of non-fatal permanent disabling crane incidents and conducting a similar analysis. Progress is dependent on an accurate recording and description of the problem.

Appendix A

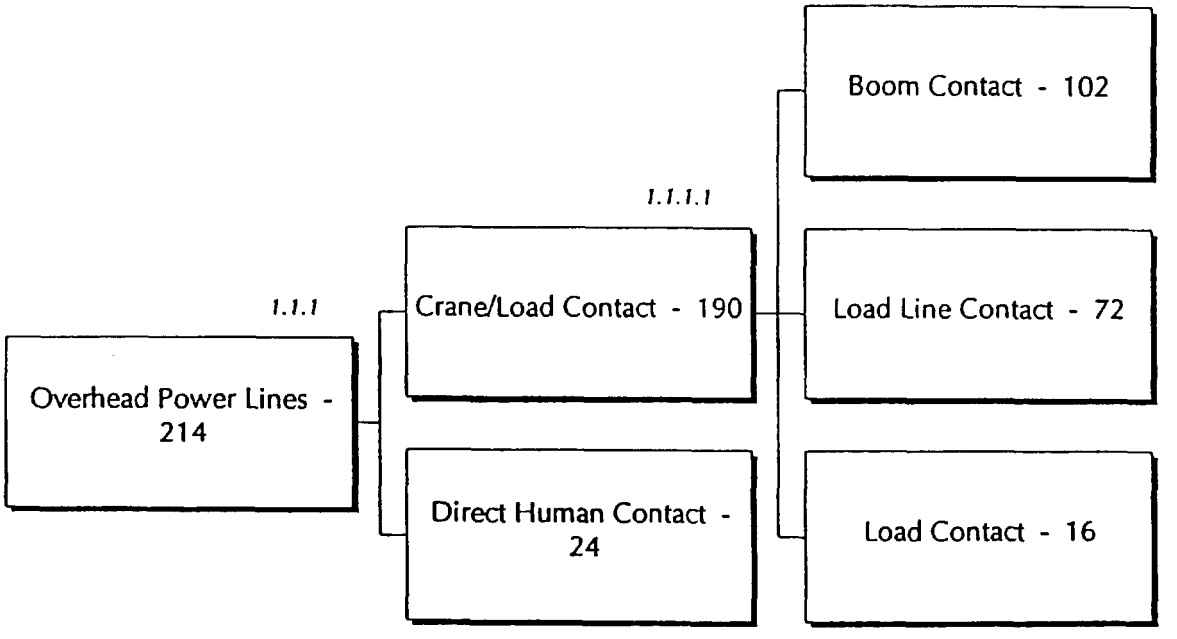
Taxonomy of OSHA Data

525 Crane Fatalities 1985-1995

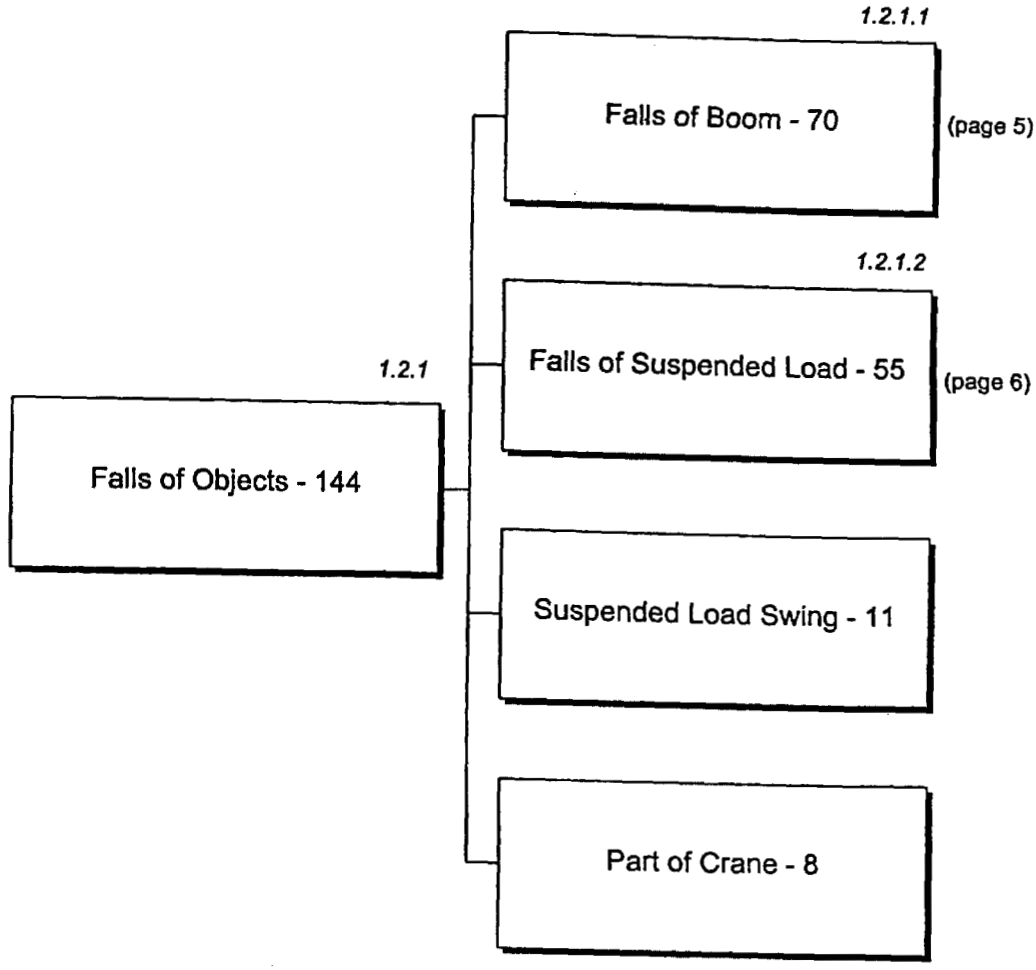
Crane Fatalities - a Taxonomic Analysis



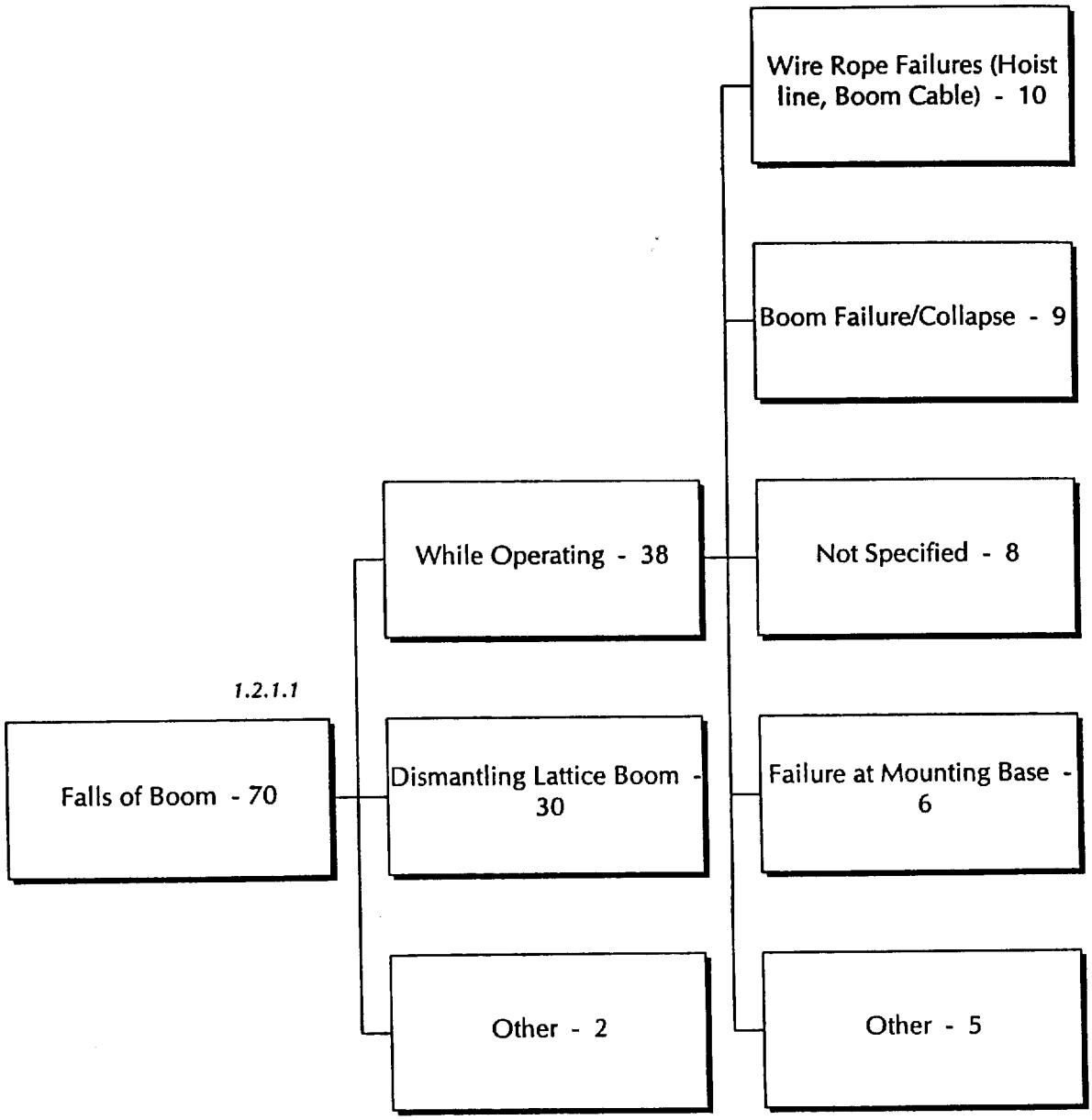
Electrical Energy
Taxon 1.1.1 Overhead Power Lines



Gravitational Energy
Taxon 1.2.1 Falls of Objects

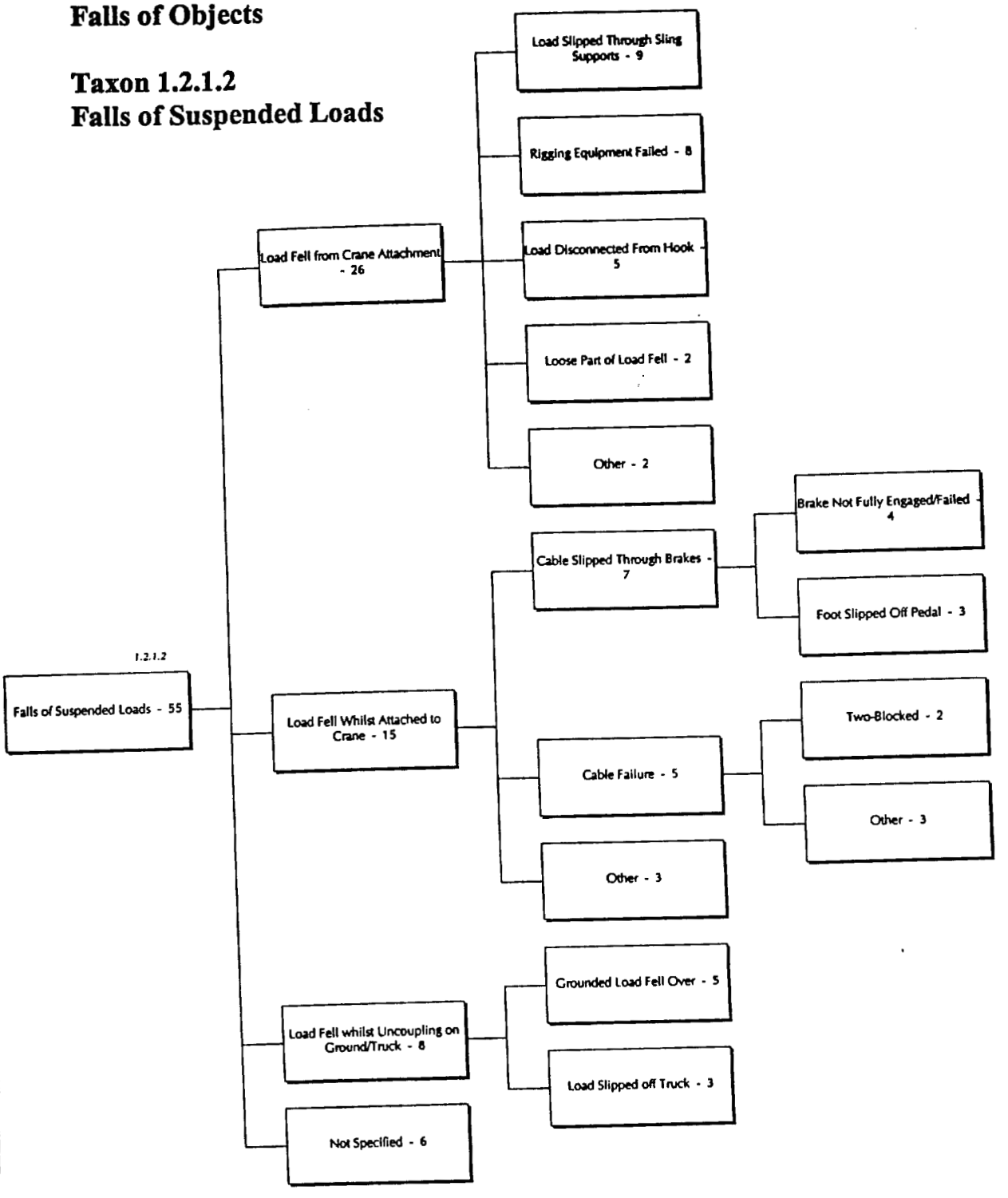


Gravitational Energy
Fall of Objects
Taxon 1.2.1.1 Falls of Boom

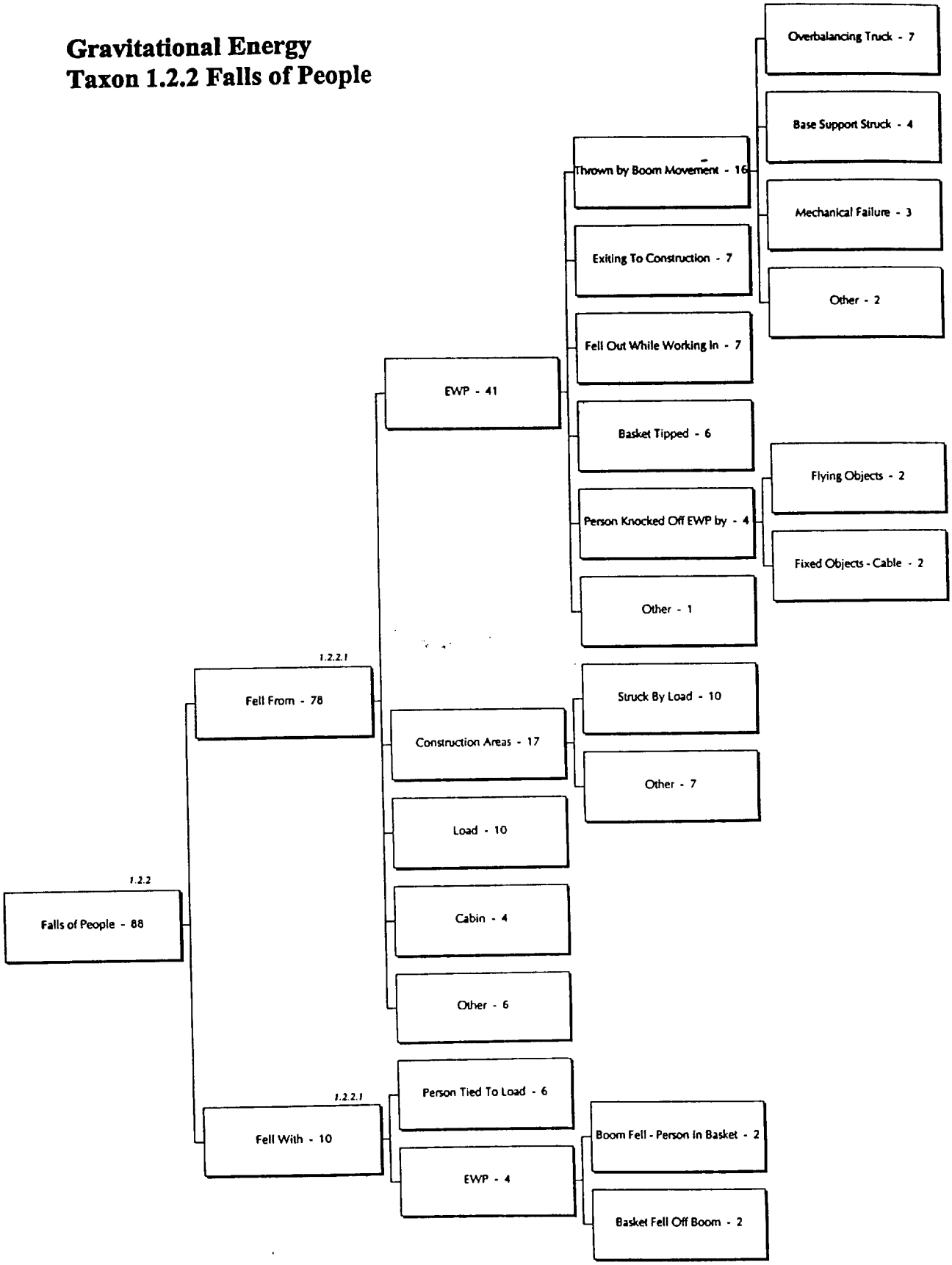


Gravitational Energy
Falls of Objects

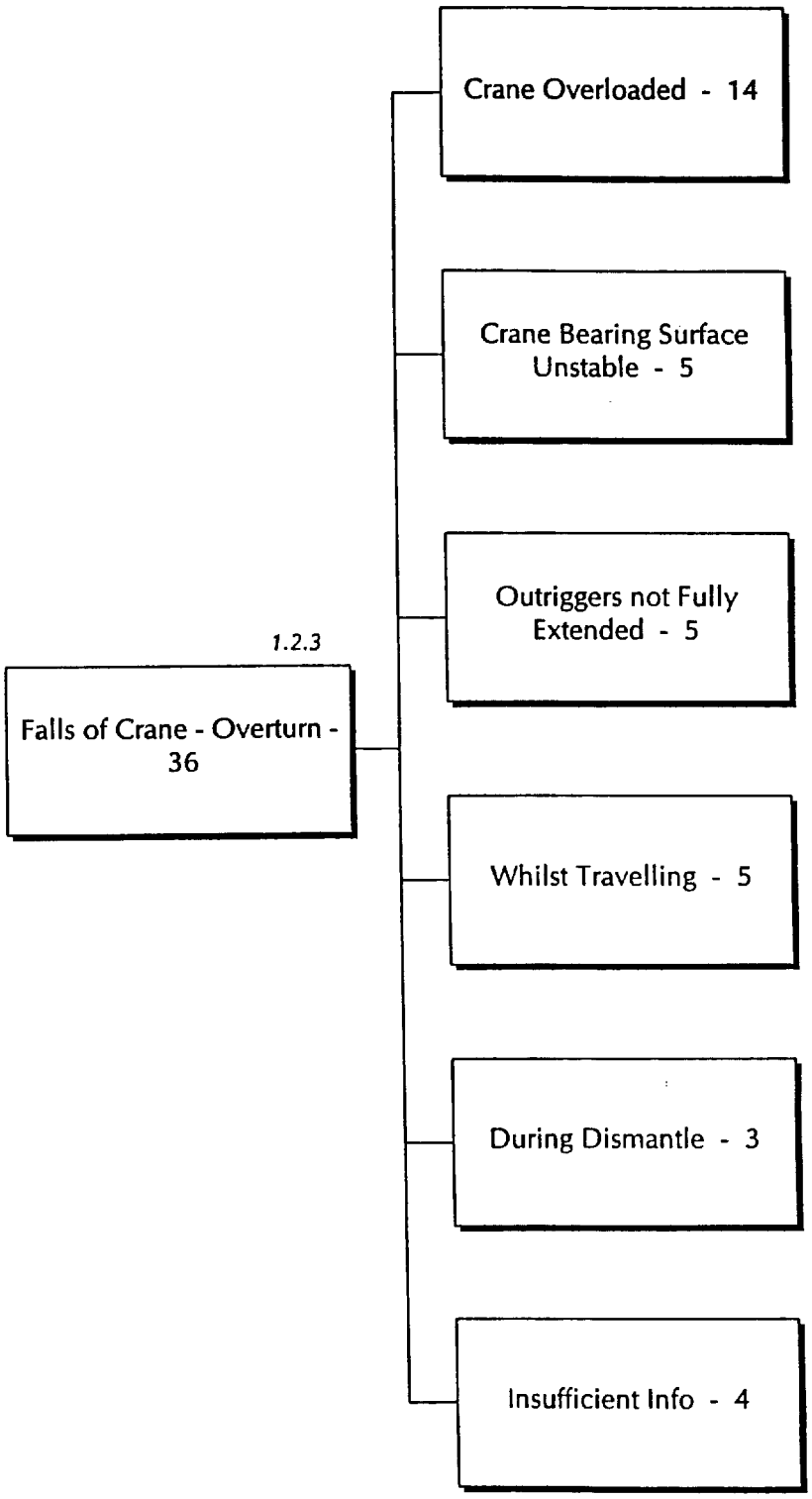
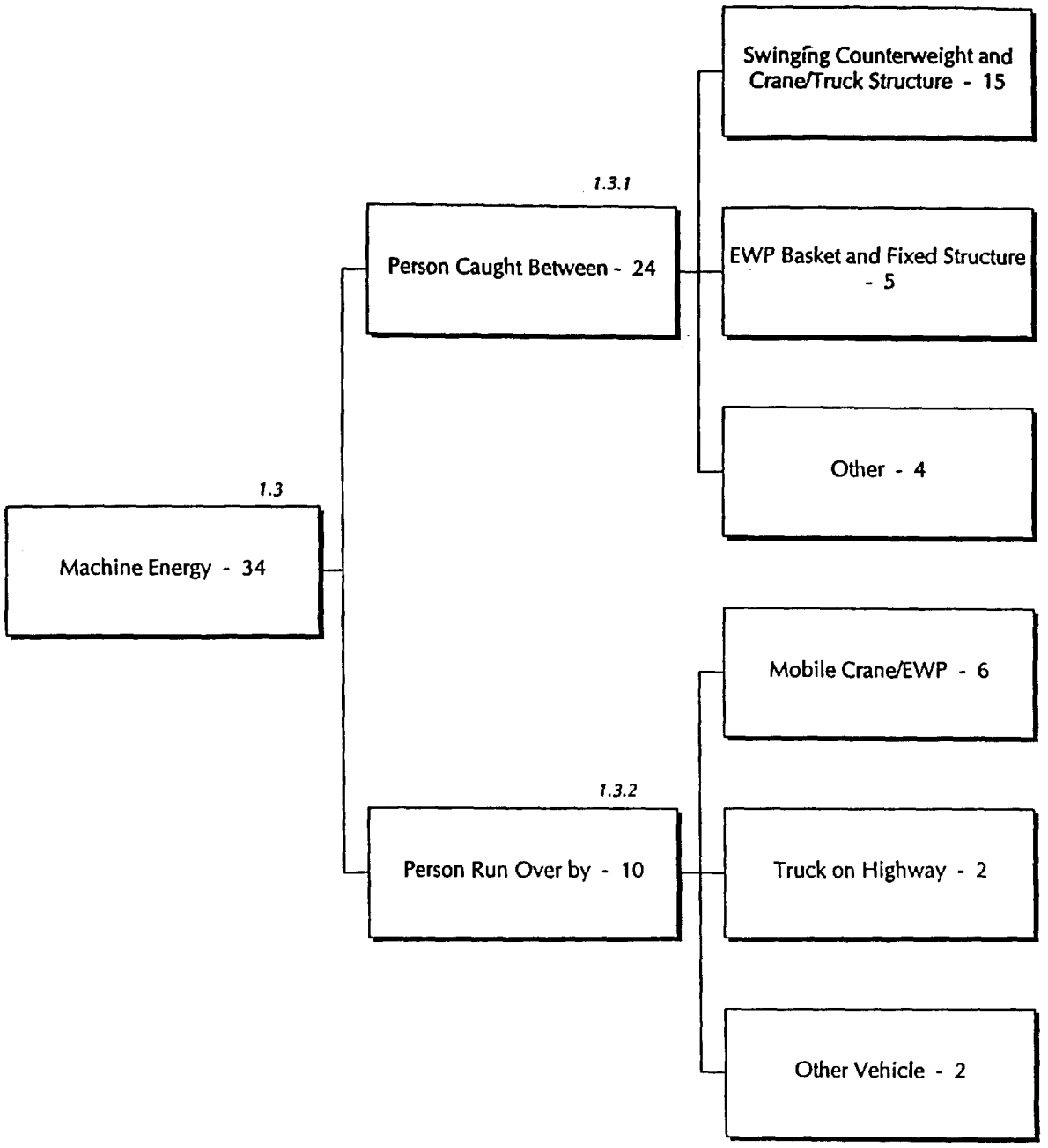
Taxon 1.2.1.2
Falls of Suspended Loads



Gravitational Energy
Taxon 1.2.2 Falls of People



Gravitational Energy
Taxon 1.2.3 Falls of Crane



Machine Energy
Taxon 1.3