New Engineer JOURNAL

Servicing Manufacturing, Industrial Engineering and Engineering Societies

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Contents

FORMAL PAPER REVIEWS

Leading papers published in this Journal are usually fully refereed. This service is available through the **New Engineer JOURNAL**. Papers which are to be fully refereed for formal publication may be submitted at any time.

Industrial Engineering in the "New World Order"

With the worst of the Global Financial Crisis apparently behind us, the World now awaits the outcome of the next momentous event – the meeting of world-leaders in December, in Copenhagen, to address an apparent myriad of world issues – Global Warming being among them. Whatever issues are identified, however, and whatever outcomes (goals) are agreed upon, one thing is for certain – any "new world-order" will need the knowledge and skills of IEs (both here and internationally) to address the many 'productivity' issues that are sure to follow.

Industrial engineering has a unique role to play in any new world order. With a long and proven record in improving productivity (in all its forms), IEs will again be at the forefront in the design and realisation of even more effective and efficient productive systems. Such improvements will need to target not only the traditional productivities of individual organisations, but will now (most likely) need to take on the productivity issues of whole supply chains, networks and even whole industries themselves – local, national and in some cases global. It is the expertise of IEs that will be required to help realise many of the goals set by national and global leaders in Copenhagen.

The articles in this edition of **New Engineer** address these and other issues relating to productivity improvement, and do so in their own and unique way.

The articles by Selvarajah Radhakrishnan and David Karr look at productivity improvement through the use of 5S tools and effective and efficient communications techniques. Such tools and techniques have a proven record in minimising obstacles to the effective and efficient flow of production and information. As such, they can be said to help eliminate destructive interferences that are a major cause of impaired productivity.

John Blakemore addresses the issue of Global Warming directly and presents data and information that may make the issue 'not so clear cut'. John states that there may indeed be a 'silver lining' to *more* heat and CO_2 in the Earth's atmosphere in improving, for example, plant yields, crop productivity, etc. He seeks reader's comments to his article.

Roger La Brooy 'chips in' with an article on the design of an expert system to improve the bowl feeding of parts. He further suggests that the system provides guidance to productivity improvement via Bothroyd-type Design For Assembly (DFA) part simplification strategies.

The final article addresses the issue of desirable and undesirable utility of resources and productivities of process. This follows on from a related article in the last issue of **New Engineer** and is intended to further illustrate the use of the utility-productivity performance equation. Productivity improvement is addressed in its broader context and addresses the issues of both 'bad' and 'undesirable' productivities. It concludes by offering some guidance in the improvement of resource utilities and process productivities in all their forms.

Dr. Damian Kennedy
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Federal President's Report

The 2009 Annual General Meeting for the Institute of Industrial Engineers was held in Melbourne on the 29th of August. This is always a valuable occasion as members from across Australia can meet and debate the future of Industrial Engineering in general, and the Institute specifically.

This year at the AGM, our Federal President for the past four years, Dr Damian Kennedy, advised that he would stand down from this position. Dr Kennedy has been instrumental in unifying the Institute during this period and in providing a vision for the future that we could all rally behind. He was always keen to meet members and the wider industry in general, and spent much of his private time in service to the Institute. I thank Dr Kennedy for his contributions to the Institute in general, and the support and mentoring he has provided me personally.

We are fortunate that Damian Kennedy has agreed to remain on Federal Council as the Institute's Journal Editor. To this role Damian brings his depth of experience as a leader in Industrial Engineering studies and teaching to produce a publication that reflects the current challenges and insights of our profession. With the opportunity for all members to contribute, the New Engineer can grow as the cornerstone of our Institute.

This AGM also saw the retirement of Mr David Karr as Federal Secretary and long-standing Council member from Western Australia. Without doubt the Federal Secretary is a demanding role, and I thank David for assuming this role over the last 12 months. We hope to see you part of the Institute's activities again soon. As part of the transition for the Council this year, we welcome a new Council member, Mr Priyantha Perera from Victorian Division. I am confident Mr Perera can bring another dimension to the Council's activity.

Daniel Kulawiec presenting Damian Kennedy with his fellowship

On the occasion of the AGM, I am pleased to advise that the Council voted to bestow the grade of Fellow on two long-serving and hard working members: Dr Damian Kennedy and Mr Lex Clark. This is a great recognition for both gentlemen. Dr Kennedy was recognized for his work as Federal President, Journal Editor, and general promotion of Industrial Engineering in many parts of our society as I have previously covered.

Mr Clark has dedicated his career to the advancement of Industrial Engineering. As Mr Robert Watson described "Lex in an IE career spanning thirty years has conducted IE training in the defense, public service and private sectors. He has published IE articles the most recent substantial work appeared in the Institute Journal. Lex has served with honor over five years as Membership and Grading Director. A significant contribution by Lex has been his liaison role with Engineers Australia. He is also a successful IE consultant." I can personally add that the Institute would not be able to operate without the many years of time and dedication that Lex has invested into his various roles.

In electing the 2009/10 Federal Council, I was nominated as Federal President, and in turn accepted this nomination. I have been on Federal Council for four years, three of these as Federal Secretary. Prior to this I have served on both the Victorian and NSW division councils. I am familiar with the issues our members and Institute face, and I am pleased for the opportunity to contribute to the future of both.

My training was through the University of NSW's Manufacturing Management program. This was the first year that UNSW ceased to use the term "Industrial Engineering" – but more about that later. I have been fortunate to work in a number of companies during and post my education – Hoover, Qantas, EOI, Smith's Snackfoods and Comalco. I have practiced Industrial Engineering in the manufacturing, service and mining industries. I am now fortunate to be in a position of leadership in the same discipline as Director of Processes for Telstra's operating division. This provides a great link between my private and public roles.

In summary the full results of election of Directors and Office holders at the AGM are:

Federal President: Daniel Kulawiec

Senior Vice President: Robert Watson

Immediate Past President: Dr Damian Kennedy

Federal Secretary: Lex Clark

Federal Treasurer: Selvarajah Radhakrishnan

Journal Editor: Dr Damian Kennedy

Webmaster: Priyantha Perera

Chairman Membership Committee: Lex Clark

State divisions continue to operate, however some states are not as strong or active as we would like. This is not a situation we would like to be in as one of the roles of the Institute of Industrial Engineers is to foster discussion and debate between like-minded professionals. If anyone wants to know how to contact or catch-up with Industrial Engineers in their local area, please write to me and I will assist in making this happen.

In the modern times, Industrial Engineers face a conundrum. On one hand we should be booming – a growth industry. The need to achieve higher efficiencies and utilization from limited resources remains higher than ever, and practitioners of all sorts are offering their services to companies in this position. Industrial Engineers with their rich tool set and knowledge should be in high demand. However on the other hand, I look at our Universities and other training colleges and find that the term "Industrial Engineering" is no longer in use. How can a professional body like ours seek to grow when new professionals do not associate themselves to the "Industrial Engineering" brand?

Internationally this is not so much an issue as Industrial Engineering remains a popular term in industry, and we are fortunate to have a number of members who originally trained and practiced overseas. On the local front, we have to address this situation.

Another challenge is that there are large sections of the Industrial Engineering community that our Institute is not currently serving. This includes Academics and Learning Institutions, Corporations with strong manufacturing and business processes, and recent graduates from Universities. Imagine how strong our Institute would be if we served all Industrial Engineers in Australia, and imagine what a fantastic resource this would be to our current members.

This is all ahead of us, and I am pleased that the current Federal Council is keen to address these challenges.

As indicated earlier, I am keen to speak with and contact as many members as possible. Please feel free to contact me on the email address below.

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Federal President
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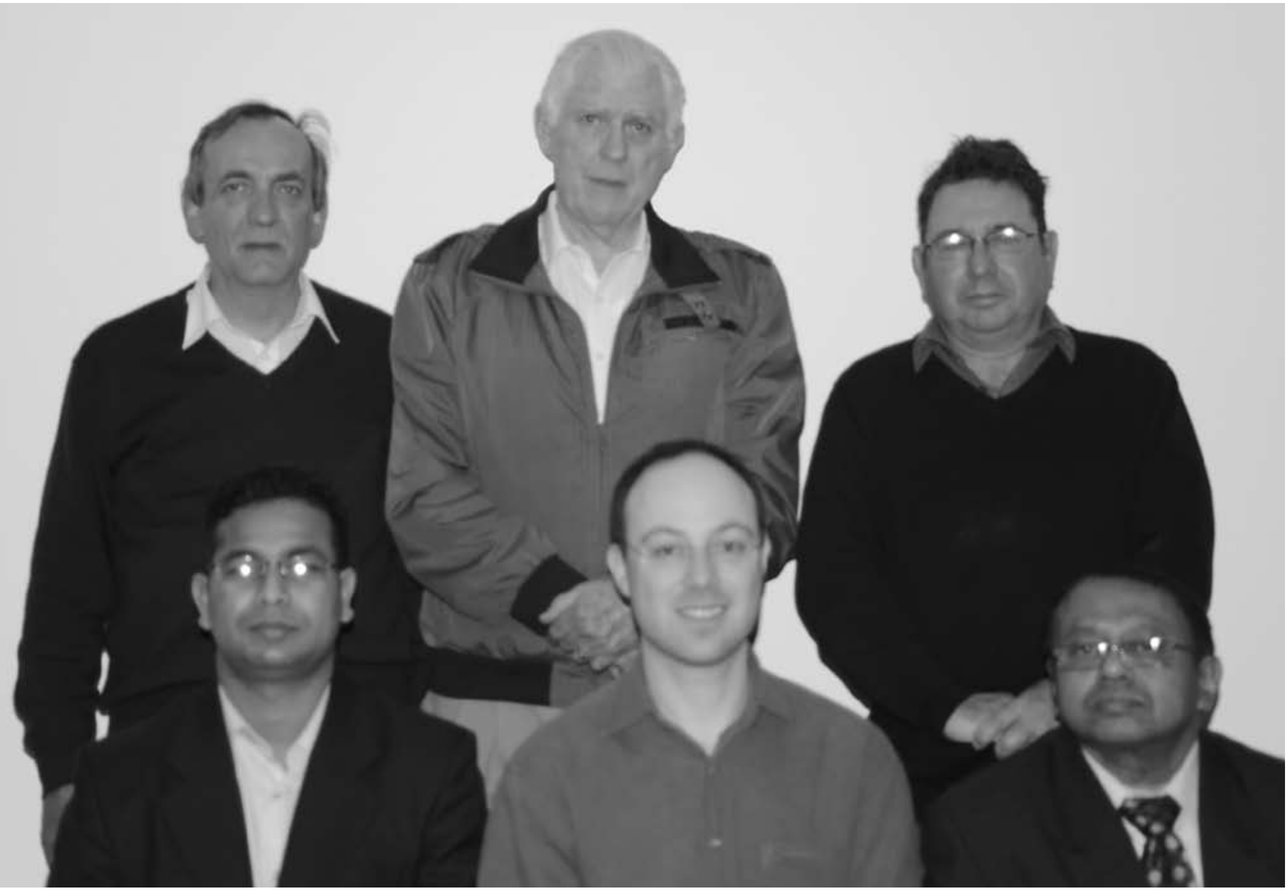

2009-2010 IIE Federal Council: Dr Damian Kennedy, Lex Clark, Robert Watson, Priyantha Perera, Daniel Kulawiec and Selvarajah Radhakrishnan

Application of 5S Productivity Improvement Tools in the Workplace

S. Radha Krishnan FMS UK, MIIE Aust, EuroIEng, Grad DP UK.
Consultant in Industrial Engineering & Productivity Sciences; IIE Director & Federal Treasurer

Introduction

Five S can be used in any environment including the factory floor, warehousing and storage, workshop and the office. Many companies implementing *lean manufacturing* start with a 5S program to remove the workplace clutter and improve workflows between processes.

Basic Principles

The 5S system is based around five Japanese words all starting with the letter 'S'and hence has been given the name "5S".

***Seiri*:** Sort. Asking what is actually needed in an area. If you don't use it, get rid of it or store it in the allocated area. Then, define how much is needed and identify where it should be placed and place what is left in a logical manner.

***Seiton*:** Set in order. Locating where everything is to be used and organized for a smooth workflow. Often quoted, as: 'a place for everything and everything in its place'. This stage includes actions such as colour-coding, labeling and methods of easy identification.

***Seisou*:** Shine or sweep. Developing methods for a clean layout as it is easy to recognize something out of place or a source of defect.

***Seiketsou*:** Standardize or define standards. Ensuring things stay tidy, methodical and clean.

***Shitsuke*:** Sustain. Developing a system of constantly assessing performance, and challenging for improved methods.

While 5S systems have been used by Japanese companies since the 1980s, many Australian companies are only just introducing these concepts into their continuous improvement initiatives.

Predominantly used in the manufacturing sector, they can now be found deployed in diverse industries such as bankin g,mining,contruction,utility and many other industries.

How Does 5S Work?

Lean manufacturing initiatives will often identify bottlenecks in operations and the use of a 5S activity should take place to improve the throughput of that manufacturing or service operations.

A team can be formed to review the Work place layout and workflows following some initial training on traditional Work Study principles. As with all lean tools, 5S is about eliminating waste and maximizing value added work.

5S uses its process to create and maintain an organised, clean and efficient environment setting that enables the highest level of value added performance. This means eliminating search, travel, transporting materials, and inventory.

It achieves its ends by organization and orderliness, eliminating unwanted materials and establishing self-discipline.

Training will often include the completion of a workplace assessment and an audit using criteria of the 5S. Action will be identified during this audit to streamline the workflows. This is often followed by a Priority task-any item not required is removed, or 'tagged' pending a decision where it should be stored.

Excess material/equipment is often sold off, recycled or removed to its rightful place.

This is part of the 'Sort' process. Once any surplus items have been removed, the team can then decide where, how much and how remaining items should be stored. This often includes colour-coding, installation of storage systems, labeling, etc. This is known as 'Set in order'.

A clean up and often a new coat of paint is applied in the next step 'Shine'

This step, if implemented properly, will install a sense of pride in the work place.

The next step is to 'standardise' methods for maintaining the workplace in the new condition-Maintenance standards (no oil leaks or spillages), cleaning standards and frequencies, lubrication standards, storage standards etc. Most organizations neglect to do this stage and often find that their plant/process back to the original state over a period of time.

The final step is to develop a method of 'Sustaining' improvements in the work place.

This is often done through a series of ongoing assessments and audits carried out by the Continuous-improvement Teams supported by management.

Impact on safety

Implementing a 5S program will also improve safety and reduce the risk elements associated with a work place even though 5S does not focus on safety directly.

Many organisations have now included safety into their 5S programs and now call them "6S" or "5S+1" programs.

Conclusion

Many lean companies will use 5S to improve productivity in bottleneck operations and/or to balance workloads between processes. This will often result in lead-time reduction.

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Effective Communications-Effective Industrial Engineering

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Introduction

In order to be able to undertake any activity involving several people or even a larger group, one has to be able to communicate effectively.

Communicating is defined by the Oxford Dictionary as "the imparting, conveying or exchange of ideas or knowledge". What this assumes is that the act of communicating is by two or more individuals (or machines) using various methodologies including speech, writing, pictures or electronic means.

Effective communication can be defined as the ability to be able to pass on information or a request to other personnel (or equipment) and receive an appropriate response. This response can be an indication that the communication was understood or that a task was carried out to the satisfaction of the initiator.

An example of this could be "we were able to make the deadline for the Maxwell report" or "please check on whether the visitors for the 10:30 meeting have arrived".

By specifying the "Maxwell report" implies a knowledge of what the Maxwell report is. Or in the second case what visitors, where they are located and for what reason they are on site.

Getting the Message Across

There is however a major divide between the action of communicating and being able to effectively get the message across such that the message is understood correctly and a desired response or activity in undertaken. For example by requesting an employee to present the projected next quarterly sales figures, the employee has to be:-

- knowledgeable in the sales of products of the organisation
- able to know what sales projections are about
- knowledgeable in historical sales figures for the previous quarter as well as corresponding quarter
- understand the intricacies of accurately gathering sales data
- understand the intricacies of accurately presenting the sales data
- empathetic to the audience, etc.

Thus for the communication to take place effectively, certain conditions or criteria need to be present. These can include:-

- Prior knowledge
- Training
- Experience
- Correct method of input
- Correct method of output
- No internal barriers
- No external barriers
- Attitude

From the above list, some of these conditions or criteria seem very simple and obvious. But are they being undertaken? Let's take a few moments to analyse a bit further.

Prior knowledge – this can include something as basic as being able to speak the same language such as English. There could be something more to it such as knowledge of a process or an event that is essential to the information or activity being understood or undertaken successfully.

Training – people need to be "trained" in undertaking activities or understanding directives. This "training" is based on various factors which include:-

- Acceptable behaviour
- Organisation principles
- Formal or informal focused guidance
- Actual preparation in the task at hand

Experience – this is the ultimate in being able to understand what is required. Many times, especially in the political area, too limited experience or only a basic exposure to the issues, are present. Thus it becomes difficult to be able to get the message out meaningfully in this case. A lack of understanding of the issues can occur without hands on experience.

Correct method of input – this allows for the information to heard, entered or by other means, so as to allow for the communication to be able to be processed accurately.

Correct method of output – on the other hand, the output which could be words, text, deeds, items, etc. can only be produced if precisely understood initially.

No internal barriers – in this case if a person has some challenge such as personal issues or is tired, this can affect the effectiveness of the communication process. Thus there is an additional hurdle to overcome prior to the communication being successfully initiated.

No external barriers – here issues such as physical noise or electrical interference can prevent the required outcome from being achieved.

Attitude – such as acceptance to want to be part of the communication loop allowing for the discourse to be carried out successfully.

Empathy, ESL (English as Second Language) and Context

For effective communication to be undertaken, the above factors need to be considered carefully. Also it depends on particular situations which could require additional effort to improve the communication process. An example is with an individual who is distracted by personal issues. Thus, there maybe a need to show empathy prior to actually undertaking the communication required.

There are other challenges to effective communications, which need to be taken into account. The English language has many words which can have other meanings, or when put in the wrong context can confuse people who would otherwise understand. For example:-

"We need to bear the costs of this operation"

Depending on the context, **"bear"** could mean literally "pay" as in transfer funds to another person or organisation or be "responsible" for the consequences. Another meaning could be the implied anguish of being embarrassed by having to endure something.

Of course the bear could refer to "bare" as in exposing something as "laid bare".

"Costs" could mean an amount of funds or the implied consequences of an action.

The word **"operation"** can have connotations of a medical procedure at a hospital or a series of activities making up a process.

Thus there is a need to have the above sentence put into context such as:-

- a group of work colleagues discussing the issue of an activity that may have gone wrong and thus incurred unplanned expenses or,
- it could be family members commiserating about a relative that is unable to pay for a hospital procedure and thus they need to pay for it or,
- using the word "bare", which could mean make publically known the financial accountability of a particular activity which may have further consequences

News media is very guilty of using quotes out of context.

The above communication example thus needs to be in context. It requires the communicating participants to have prior knowledge and maybe experience in a particular activity. This will thus allow for effective communication and prevent misunderstandings which can lead to further communication issues.

Appropriate Communication Methods

To aid in the communication process, the appropriate communication method should be followed. These options can include:-

- Verbal-face to face
- Verbal-electronic-phone
- Written-letter, newspaper article, book
- Visual-pictures, charts, presentation, billboard, brochure, advertisements, plans, diagrams, documentary, etc.
- Electronic-email, short message service (sms), webpage, etc.

Verbal communication, as mentioned above, can be used well with other communication means. It, however, needs to be considered as an apt form of contact for a large part of an organisation's or individual's communication requirements.

The communicator needs to be aware that verbalisation needs to be articulate, on topic, devoid of personal emotion, and directed at those receiving the communication. Emotion can be used when suitable-such as in the case of important issues or situations where a "do or die" situation exists.

TLAs (Three Letter Acronyms)

The use of suitable language is essential. Acronyms need to be used *very carefully. Never assume* that those being communicated with are familiar with the acronyms being used. As a suggestion, preface the use of an acronym with the full text when first using it. For example **EBIT** should be prefaced with **earnings before interest and taxes**.

Actually the use of acronyms is spawning many new sub-languages within the English language. These acronyms can be industry specific such as financial, engineering or medical as well as within the wider community. On common acronym used is "sms". Most people using the term sms, would not know what is stands for (short message service). SMS is used as a common word within the English language.

Public Speaking

Also when communicating to an audience made up of a cross section of the public, one needs to choose generic words where appropriate. Do not speak too quickly especially when trying to highlight an issue or fact. Repeating the expression has the effect of emphasising what has just been said.

Furthermore when verbalising, one needs to speak clearly and not too rapidly otherwise the message or attention can be lost.

Phone Messages

The use a phone/mobile needs special mention. As per below emails can supersede this means of communication especially in cases when contacting "busy" individuals. If the phone is used, when initiating the call always introduce yourself (depends on familiarity with person being called). If the called person is busy / unavailable and one is leaving a message-state your name, organisation/department, time, short message and contact number/details. Note when providing the contact phone number, vocalise the numbers clearly and slower than normal. For mobile numbers say the first four digits, pause, the next three, pause and then the last three digits. It should be noted that most people can only "record" no more the FOUR digits at a time.

If one is receiving a call especially if it is from an unknown source(assuming using a mobile), on answering, state at least the following:-

- the time of day
- the company/department name
- your name

Answering a phone by saying "hullo" is a situation to illicit a negative response from the caller.

Written Communications

If possible, *always* put the communication in *writing*. The advantage of this method is to allow the communicator to review what information is to be imparted. Also there is a record of the communication. This is important especially in cases where issues can arise. Of course today the written record can very easily be converted into a form of mass communication-the email.

When using the hand written method of communication, the text needs to be legible. In cases where information is sensitive or needs to be accurate, PRINT. This is especially in the case of asking people to write down their email addresses.

Another useful communications practice is to use visual aids. As per the above list, there are many available. Nowadays, with relatively easy to use and affordable software, it is reasonably straightforward to enhance the communication practice with visual aids.

Visualisation can also be used to good effect together with other forms of communication such as verbal communication. The communicator however does need to not overdo the visual aid enhancement and lose the message with too much visualisation. Keep presentation slides simple, do not have information overload and make sure the use of colourisation and text size is suitable.

The Omnipresent Email

Email today to varying degrees has replaced traditional communication means such as the letter, memo, verbal communication and telephone calls. Here there is much to learn about effective communications.

Emails are designed to have a SUBJECT or TITLE line. Here email users need to take care. For example using **"meeting today at 10"** to a recipient who manages several departments and belongs to several service groups will have difficulty understanding which meeting.

Better to use **"HUMAN RESOURCES-NEW STAFF MEETING AT 10 am BOARDROOM"** has a far better impact.

Some comments here:-

- By using uppercase letters there is more clarity
- The department is specified
- The topic, time and location are also identified

One needs to be aware that many people use their mobile phone/personal digital assistant to read their emails, especially when they are away from their primary work area.

Thus the Subject/title of the email is the successful means to communicating the message and getting attention.

Using SMS which is another form of electronic communication or e-communication, one needs to be careful when using "shorthand" or abbreviations, to use suitable text. Otherwise the message will not get through. Even worse the incorrect message or confusion can be created.

Other Tips

There are some other useful techniques to effective communication. These include:-

- Do not use double negatives-it will cause confusion
- Try not to use same sounding words (different spelling) which could be misinterpreted. (This can occur especially when communicating with people whose first language is NOT English)
- Do not use overly long sentences(about 20 words is maximum)
- Do not try to introduce more than one idea into a sentence. One sentence, one idea.
- Try to mix and match people within the organisation. This can occur at common activities such a tea or lunch breaks. Also have company/organisation events which lead to "barriers" being brought down. This leads to better communication.

Conclusion

Thus depending on the nature of the communication, the most suitable communication technique should be utilised. Note there are no right or wrong methodologies, only those that have a higher rate of getting the message across leading to a successful outcome.

Anthropogenic Global Warming ... Fact or Fiction

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Voted one of the top 10 Innovative and Entrepreneural Engineers by Prof Institution of Engineers 2007

The whole world is on the brink of deciding the future of an emissions trading scheme to limit carbon dioxide emissions. The financial and economic consequences of this are so great that it appears beyond accurate analysis.

The existence of greenhouse gases is the reason for life on earth as we know it. Without this blanket of protection the earth's temperature would be minus 19 degrees centigrade not plus 14 degrees centigrade as an average.

Spain has already embarked on an active program of limiting carbon dioxide emissions and the results have been catastrophically bad regarding employment, the economy generally and the standard of living.

Much of the IPCC work and analysis has been based on the Mann Hockey stick graph illustrated below in Figure 1.

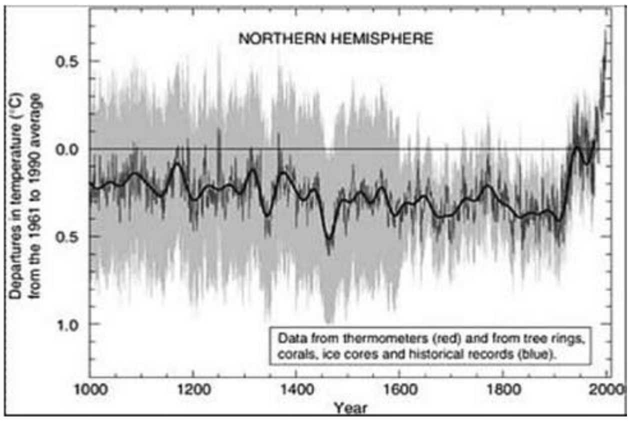


Figure 1. The Mann Hockey Stick Graph (1,2)

Both Al Gore and Tim Flannery used this graph to build an argument that the sudden rise in the earth's temperature was due to human induced carbon dioxide increasing the greenhouse effect and so increasing the earth's temperature. Figure 2 below tells a very different story.

As shown in Figure 2, the trend line for the earth's temperature is certainly increasing. The almost sinusoidal curve superimposed is that due to the 10 year cycle (decadal cycle…the SOHO effect), of sunspot activity. Mann extrapolated the ramping up part of the curve to yield his hockey stick graph. How valid is this extrapolation? Sun spot activity and the natural, changes in the earth's elliptical path, and precession and the change of the angle of tilt alter with

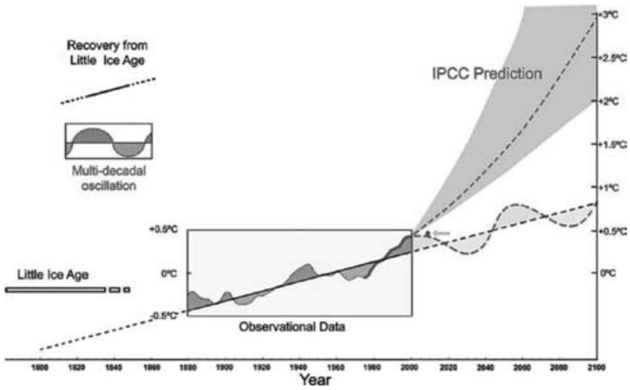
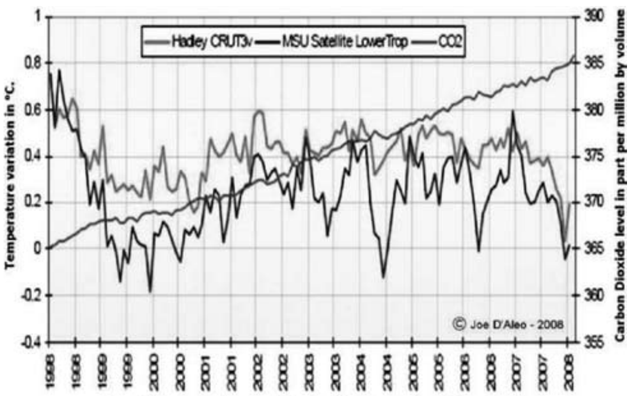


Figure 2

every rotation of the earth around the sun (the Milankovitch effect). and it is most likely that this is the cause of any global warming occurring at the moment. The Mann Hockey stick graph has now been so discredited that it has been taken down from the IPCC website without comment.

The Figure 3 below, shows the relationship between carbon dioxide levels and the earth's temperature. Clearly there is no positive correlation.



http://icecap.us/images/uploads/Correlation_Last_Decade.pdf

Figure 3

There is little doubt that climate change is real and that the earth is probably warming. The main reason for this is that from AD 1300 to AD 2000, we have been in a goldilocks era after the medieval warming period, a mini ice age, and we are now returning to a period as shown in figure 4 below, to temperatures akin to the medieval warming period (AD 600 to AD 1000). This was acknowledged as due to natural causes not carbon dioxide.

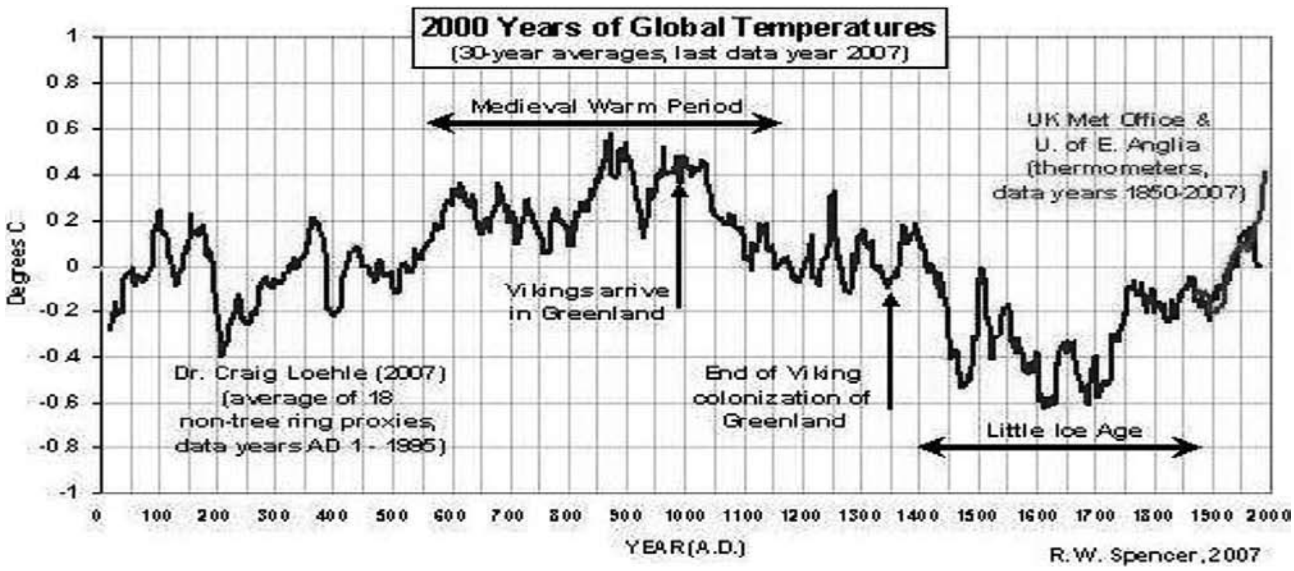


Figure 4

Carbon dioxide is only approximately 3% of the green house gases, 97% is water vapour. An elevation in carbon dioxide concentration in the atmosphere increases plant and crop yields by up to 70%. Carbon dioxide is a clear and harmless gas not a pollutant.

I do not profess to be an expert on climate change but I would like someone to explain to me what is wrong with the above argument.

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4. A. Barrie Pittock "Climate Change"

Expert System for Vibratory Bowl Feeder Tooling

Roger La Brooy, PhD, FIEAust.
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& Chong Jiang, PhD Consultant, Object Orientated Software, Melbourne, Australia.

Preamble

The assembly of a composite product manufactured in large volume is arguably the most costly operation in the manufacturing process. Often, products are designed for functionality alone. At the design stage, if the method of assembly is considered, manufacturing costs can be reduced dramatically by modifying the dessign of the product. Boothroyd [Boothroyd, '05], focuses on assembly as the design criterion, encapsulates the process as a philosophy and ascribes the generic name "DFA" [Design for Assembly] to the procedure. The authors have devised an expert system for designing a product based on DFA. A key feature of the system is its capacity to specify details of tooling used in vibratory feeders to deliver parts at high speed, in a specific orientation to an insertion device. Details of the rules used to effect the above are highlighted in this paper.

1 Introduction

La Brooy, Goodman & Travella ['91] presented details of a conceptual Expert System subsequently written by La Brooy and Jiang ['93]. Details of the data structure employed were tabled in Jiang and La Brooy ['93].

The system requires component drawings to be input from a console using a user-friendly, icondriven graphical user intereface (GUI). The program then analyses the design, recommends changes and identifies part features useful for feeding the part at high-speed. The Expert System finally provides design detail of automatic machinery to feed the parts. The program is written in object orientated language, and contains over fifteen thousand lines of code.

2 Software Design

2.1 Overview

Figure 1 depicts the authors' system conceptually, where a headed stud is used as an example of an assembly component. The System automatically designates the part as b-symmetric and then identifies a key b-symmetric feature (ie its shoulder).

> *The degree of symmetry about a designated axis is defined as the angle through which a part (or feature) must be rotated in order to replicate its initial orientation. b symmetry is measured about the part's insertion axis.*

In this case b =0° for both the part and its key feature. Thsese features are designated as b- symmetric where b =0°.

2.2 Features of the System

Connecting lines drawn by the user in views from the GUI must be interpreted as consolidated 3-d surfaces which in turn determine the most appropriate method of feeding the part. For example, the shoulder of the stud in Figure 1

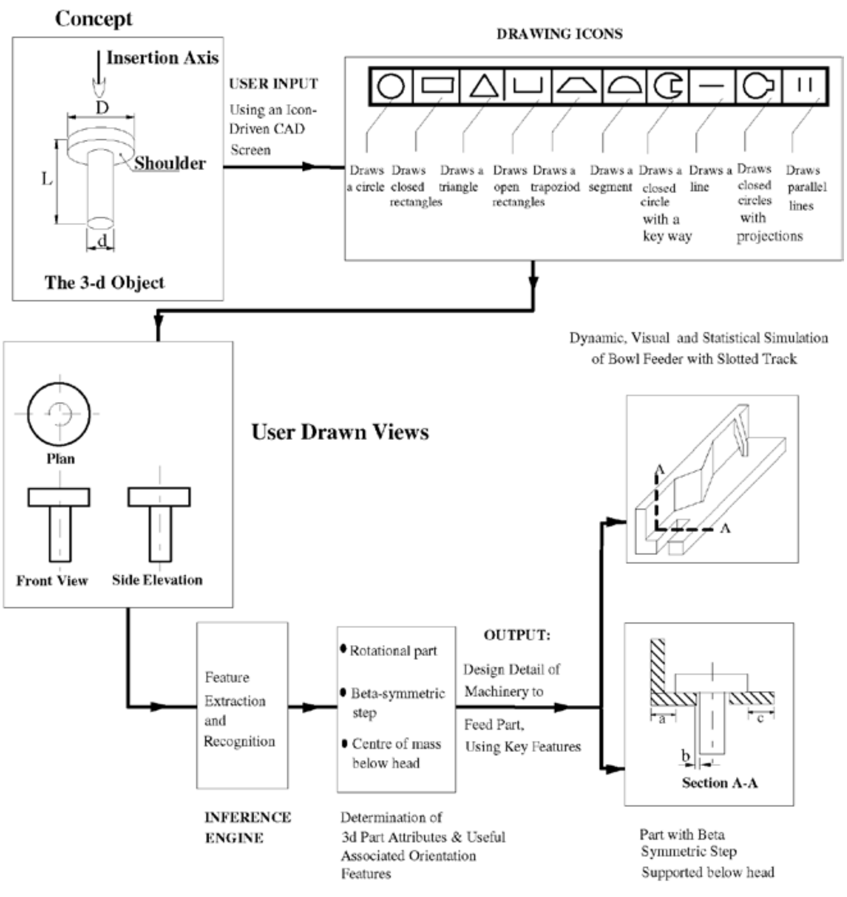


Figure 1. Overview of Data Handling Process

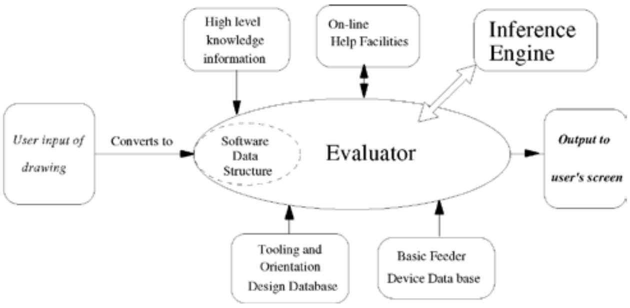


Figure 2 System Architecture

must first be identified as a geometric feature from the three views. The shoulder must then be identified as useful for feeding and finally, a suitable method of feeding the part must be nominated (ie hanging the part in a slotted track of a vibratory bowl feeder, shown in Figure 1). The results must then be presented to the user as a complete solution for feeding the part.

Data from several sources such as the user GUI and an internal knowledge base have to be integrated to form a useful database from which executive judgements must be made. The authors' architecture is depicted in Figure 2.

The Evaluator is the major functional module in the Expert System and is used to extract critical information from the user's drawing. Drawing data is then interpreted and stored in a series of linked lists in the Evaluator's Software Data Structure segment. The Inference Engine then converts 2-d data to 3-d features, identifies critical entities such as flanges and holes and returns crucial information to the Evaluator, described by Jiang and La Brooy ['93].

3 Design Rules for Interpreting User Input

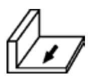
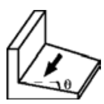
Consider the case where the authors' program detects m part features and provides n separate "inbowl" tools for solving the problem. The authors can then use a fixed mxn matrix [M] devised to enable the system to provide an unique solution to each parts-feeding problem. A specific 20x18 matrix is used to exemplify the scheme, corresponding to Tables 1-3.

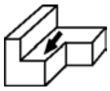
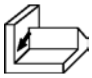
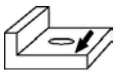
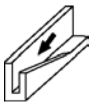
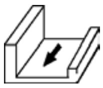
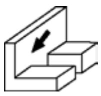
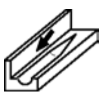
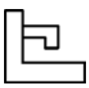
Table 1 depicts 20 key -3d parts features identified by the authors. Table 2 provides general interpretation of suggested bowl feeder tooling whilst Table 3 nominates 18 separate tools and lists their effects within a vibratory bowl feeder.

Table 1. Recognising Key 3-d Features

Item	Key Engineering 3D part features
1	A general part
2	To pass an object whose vertical dimension is less than its maximum dimension
3	Disc
4	Disc with a Beta symmetric step
5	Disc with a Beta symmetric chamfer
6	Disc with a longitudinal side groove
7	Disc with b symmetric projection/s on end surface only
8	Concentric groove
9	Part with a "through hole"
10	Disc with projection on side surface (a symmetric part)
11	Recess on end surface of disc and on surface with largest c/s area for a triangular, square or rectangular prism
12	Cylinder
13	A displaced centre of mass caused by a b symmetric groove, recess step or chamfer
14	Headed parts
15	Flat parts delivered on the surface with longest dimension tangential to the bowl
16	'L' shaped parts
17	Parts with ribs (Parallel to X and Y axis and perpendicular to a mirror plane
18	'T' Shaped parts (symmetry about X axis and step parallel to Z axis)
19	Parts with through groove parallel to X axis or Y axis
20	'U' shaped parts (Groove parallel to Z axis)

Table 2. "In-Bowl" Tooling Primitives

Name	Diagram	Function
Flat Track		Passes all parts: if the rake angle of the track (q) is +ve, items will be pushed towards outer wall,; if -ve will fall into the centre of the bowl.
Negative Rack Track		Refer above: (q<-15°).
Positive Rack Track		Refer above: (q>5°). Normal track; ensures that parts are retained on the track by travelling against the track wall

Narrowed Track		Allows only part orientations when c of g is supported by narrowed surface
Full Step Riser		A discontinuity in the track height perpendicular to the conveyance direction designed to reorientate parts. Note parts can be in an unstable position and must be transported safely in the new position (eg via a discharge hole and tube – see below).
Discharge Hole		An opening in the track with a clearance of ≈10% on external dimensions through which only parts in the desired orientation may pass. Note federates must be slow and pre-conditioning is essential.
Edge Riser		Enables rectangular parts tore-align with longest dimension tangential to the bowl.
Lip		Used to retain a single layer of parts. Usually coupled to a negative rake track. (eg. transportation of flat washers)
Shaped Gap		A discontinuity or opening in the track, perpendicular to the conveying direction, which only accepts particular orientations. Relies heavily on c of g location.
Rail Riser		A raised rib parallel to the conveying direction that is shaped to retain parts in the desired orientation.
Slotted Track		A "through" channel in the track parallel to the conveying direction with parallel sides and an open bottom. Usually equipped with a degree of "lead in".
Grooved Track		Used to transport cylinders longitudinally
Hood		Used to retain parts with their longest dimension vertical.

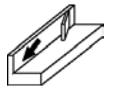
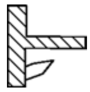
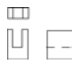
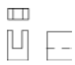
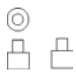
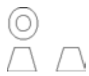
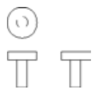
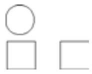
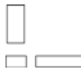
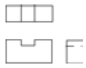
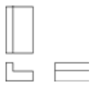
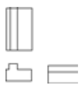
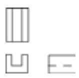
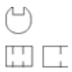
Wall projection		Any protrusion from the bowl wall. (eg. a "wiper" is a convenient method of rejecting parts resting on top of others).
Extend Assist Device		Example: Air jet: Transport Tube: External Rails, etc.

Table 3. Examples and Combinations of Specific "In-Bowl" Tooling Devices

Item	Orientation Devices	Functions of orienting device	Typical Component
1	Pressure break	Prevents jams/ pressure on gate of bowl feeder	NA.
2	Wiper blade & narrowed track	Wiper passes a single layer of components: When coupled to a narrowed track or "cut out", will pass components in a single file	NA.
3	-ve Raked track and lip	Prevents shingling and passes one layer of components	
4	Rail Riser	Used for 'U'-shaped parts delivered by riding on the rail	
5	Wall projection and narrowed track	Projections allows a specific dimension perpendicular to the track to pass	
6	Narrowing of Track or 'cut-out'	Allows only part orientations where c of g is supported by narrowed surface	
8	Slotted track	Provides a hanging position for bolts, headed pins etc.	
9	Scalloped track	Causes cup shaped components travelling open side down to fall off the track and returns to the centre of the bowl	

10	Grooved track with hood	Encourages a single line of cylindrical parts travelling end-to-end	
11	Shaped gap	Ensures a part travelling with its heavy end leading, to drop heavy end first	
12	Edge riser	Enables rectangular parts to re-align with longest dimension tangential to the bowl.	
13	Air jet and scallop	Assists rejection of parts with portion hanging below surface of track blown back to centre. Used with scallop	
14	Hood and narrowed track	Can be used to orientate L-shaped parts with a difference in leg length	
15	-ve Rake track with groove	Orientates parts with ribs	
16	Groove with wiper blade	Ensure a single line of cylindrical parts travelling end-toend	
17	-ve Raked track with Rail	Orientate parts with either an offset or centred groove	
18	Hooded discharge hole	Aligns parts with hood, followed by vertical drop. Large side clearances and slow feed rates needed.	

4 Method of Automatic Tooling Design for Orienting Parts

4.1 Orientation Features

After detection of part features by the Inference Engine, information is passed back to the Evaluator. This information can be described by a (1×m) matrix [F] whose elements are 0 or 1 and correspond to whether one of the m features (see Table1).

By way of illustration, consider an expert system handling 20 features and 18 tools corresponding to the elements of Tables 1 and 3. The authors will apply it to the headed stud depicted in Figure1.

On extraction from the user-input drawings, the Evaluator will detect items 1, 2, 14 in the Table 1 as key 3 d features. Therefore,

$$[F] = (1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0) \qquad (1)$$

4.2 Mapping Between Features and Orienting Devices

The authors have devised a fixed (m×n) matrix [M] mapping parts characteristics to tooling features:

$$[M] = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1(n-1)} & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2(n-1)} & a_{2n} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ a_{(m-1)1} & a_{(m-1)2} & \cdots & a_{(m-1)(n-1)} & a_{(m-1)n} \\ a_{m1} & a_{m2} & \cdots & a_{m(n-1)} & a_{mn} \end{pmatrix}_{mxn}$$

For example [M] can be illustrated from Tables 1 and 3 as:

$$[M] = \begin{pmatrix}
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
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0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{pmatrix} \qquad (2)$$

4.3 Tooling Design

When [F] is returned to the Evaluator by the Inference Engine, the required orientating devices will be specified by taking the cross product:

$$F \times M = \left(\sum_{i=1}^{m} a_{i1} f_i,\ \sum_{i=1}^{m} a_{i2} f_i,\ \cdots\ ,\sum_{i=1}^{m} a_{i(n-1)} f_i,\ \sum_{i=1}^{m} a_{in} f_i \right) \qquad (3)$$

For the headed part in Figure 1, the cross product is rewritten as

$$F \times M = (1, 1, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0) \qquad (4)$$

Where an element $\sum_{i=1}^{m} a_{ij} f_i$ of the row matrix is '1', the column containing '1' nominates the required tool from Table 3. For the stud, the first, second and eighth orientation devices are required.

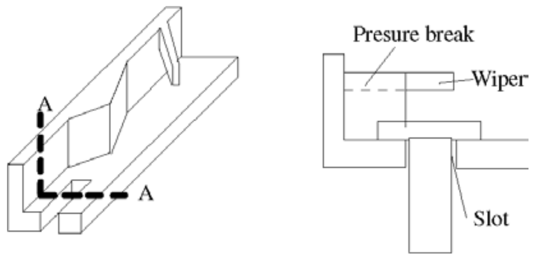

Figure 3. Orienting devices

4.4 Examination of Orientations

Re-consider the headed stud. There are 5 stable orientations as shown in Figure 4.

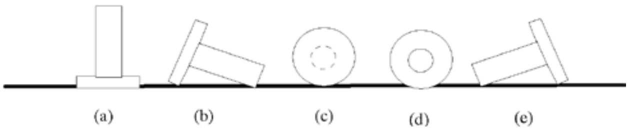

Figure 4. Stable position of the part depicted in Figure 1

A matrix can be constructed thus:

	Tool1	Tool2	Tool 8
Orientation (a)	0	1	0
Orientation (b)	1	1	1
Orientation (c)	1	0	0
Orientation (d)	1	0	0
Orientation (e)	1	1	1

Note all other tools and orientations are null. If the matrix is partitioned thus, a new orientation matrix [O] results, whose elements are themselves matrices o_i:

$$o_1 = \begin{pmatrix} 0 \\ 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}, \quad o_2 = \begin{pmatrix} 1 \\ 1 \\ 0 \\ 0 \\ 1 \end{pmatrix}, \quad o_8 = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 1 \end{pmatrix}, \quad o_i = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} (i \neq 1,2,8) \tag{5}$$

where [O] is defined as:

$$o_i = \begin{pmatrix} o_1^i & o_2^i & \cdots & o_{(k-1)}^i & o_k^i \end{pmatrix}^T \tag{6}$$

The value o_j^i is '1' if the device passes the orientation where k is the number of possible stable orientations.

4.5 Determination of Orientation

For the tool designed by using the formula expressed by eqn. (3), the final orientation distribution can be expressed by:

$$F \times M \times O = \left(\sum_{i=1}^{m} a_{i1} f_i, \ \sum_{i=1}^{m} a_{i2} f_i, \ \cdots \ , \sum_{i=1}^{m} a_{i(n-1)} f_i, \ \sum_{i=1}^{m} a_{in} f_i \right) \times \begin{pmatrix} o_1 \\ o_2 \\ \vdots \\ o_{(n-1)} \\ o_n \end{pmatrix}$$

$$= \left(\sum_{j=1}^{n} o_1^j \sum_{i=1}^{m} a_{ij} f_i, \ \sum_{j=1}^{n} o_2^j \sum_{i=1}^{m} a_{ij} f_i, \ \cdots, \ \sum_{j=1}^{n} o_k^j \sum_{i=1}^{m} a_{ij} f_i \right)^T \tag{7}$$

where the element $\sum_{j=1}^{n} o_k^j \sum_{i=1}^{m} a_{ij} f_i$ corresponds to elements of the [O] matrix defined earlier.

If an element in eqn (7) equals k (here k is the number of possible orientation devices), then this tool can orient a part in one desired position.

The expert system uses the results of the cross products to draw a 3-d diagram of the required tooling for the user and provide a report of expected performance of the feeder.

5 Conclusion

The authors have presented conceptual details of how a comprehensive Expert System for assembly, has been designed. The system requires the user to input three views of parts in an assembly in third angle projection. System outputs are:

(1) generation of bowl feeder attributes to successfully feed the parts and

(2) specifying design detail of those attributes.

On completion of exhaustive trailing, the authors expect to provide a statistical, real-time, visual simulation of part-feeding, to ascertain maximum feed rates and orientation efficiencies.

The key advantage of an Expert System as outlined is that it the user is immunised from the need to understand the intricacies of symmetry. Focus may then be placed on designing more efficient and functional parts.

6 References

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On the Desirable and Undesirable Utility of Resource and Productivity of Process

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Abstract

This paper expands the traditional notion of productivity to include 'bad' and even 'undesirable' productivity, In such cases, the traditional role of the IE in 'improving productivity' should be expanded to include that of "eliminating (or at least minimising) bad and/or undesirable productivity". Simple 'link-models' (to illustrate the interdependencies between productive systems within a simple supply chain/network) and the paradigm shifts associated with the 'New Industrial Engineering' (– an IE based on the utility-productivity performance equation) inform this view. The paper concludes with some combative strategies and action guidelines to elimininate bad and undesirable productivities.

Keywords

Productivity. Desirable Productivity. Good Productivity. Bad Productivity. Undesirable Productivity. Maximising Goal. Minimising Goal. Utility-Productivity Performanne Equation. New Industrial Engineering. Link Model.

Introduction

Traditional industrial engineering has always focused on "productivity" and its continuous improvement. Salvendy (2007) defines productivity as a measure of 'output(s)-to-input(s)'. Hence, productivity can be expressed as:

$$productivity = \frac{output(s)}{input(s)}$$

Now, if *productivity* is represented by the symbol η, the output(s) by the set symbol {*o*}, and the input(s) by the set symbol {*o*}, then:

$$\eta = \frac{\{o\}}{\{i\}} \qquad (1)$$

And, equation (1) can also be shown to have an 'expanded' form as illustrated in Figure 1:

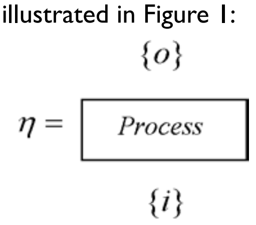

Figure 1. Equation (1) in its 'expanded' form.
[showing the interconnectivity of 'process' in productivity definition, realisation and measurement]

Where, Figure 1 clearly shows the fundamental part played by '*process*' in the definition, realisation and measurement of productivity.

The same equation (1) can also be shown in a 'rolled-over' form. Figure 2 illustrates the 'rolled-over' version of equation (1):

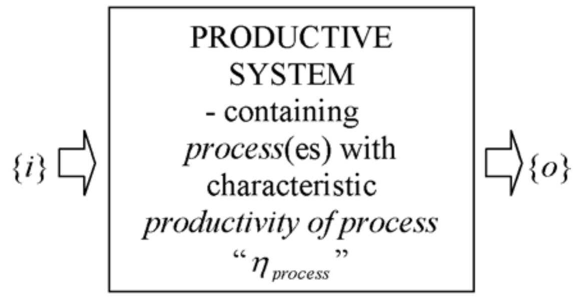

Figure 2. Equation (1) in its 'rolled-over' form.

Figure 2 shows that 'productivity' per se is, in fact the '*productivity of process*' of a productive system where a '*productive system*' is defined as *any system that produces a set of outputs {o} from a set of inputs {i}.*

The productivity of a productive system is, therefore, the productivity of process of that system. This *productivity of process* is given the symbol "$\eta_{process}$" (as in Figure 2) and is the *fundamental characteristic of any productive system.*

The Output-Input Productivity Equation

The fundamental output-to-input (productivity) relationship can now be expressed in the form of an output-input productivity equation of form:

$$\{o\} = \eta\{i\} \qquad (2)$$

This equation, in general, states that the amount of output resource produced by a productive system is a function of the productivity of process and the amount of input resource available to the system.

Productivity of Process

Here, the ***productivity of process*** is to be measured as ***the amount of output resource generated per unit of input resource consumed***.

It is the goal of industrial engineering to MAXimise the amount of this output resource produced per unit of input resource consumed – that is to *MAXimise* the *productivity of process*.

The productivity of process, for a given set of input resources {*i*}, can be MAXimised by employing process(es) most suited to the task at hand. That is, if the best quality ('fit for purpose') process(es) are available and used, then the amount of output resource generated per unit of input resource consumed will be maximised.

The Input-Output Utility Equation

A dual form of equation (2) can now be written and expressed as follows:

$$\{i\} = \mu\{o\} \tag{3}$$

This equation can be interpreted to state that the amount of input resource required is a function of the "utility" of the input resource and the amount of output resource to be produced by the system.

Utility of Resource

In general, "*utility*" is defined as a measure of the "*potential of a unit of resource to become something else*". In particular, from a 'productive system' point of view (where the whole system consists of a set of input resources used to generate a set of output resources), the ***measure*** of ***utility*** is specified to be the ***amount of input resource required to produce a unit of output resource***, and is given by the expression:

$$\mu_{resource} = \frac{\{i\}}{\{o\}} \tag{4}$$

For IEs, it is also the goal to *minimise* this utility by minimising the amount of input resource required per unit produced. That is, by making ***best use*** of an input respurce's potential, the *utility requirement of the input resource can be minimised*. The utility of input resource can be minimised by using input resources most suitable to the task at hand. That is, again, by using the best quality ('fit for purpose') input resources available, a lesser amount of input resource is required per unit of output resource produced.

Quality of Resources (Input and Output)

Resources, either input and/or output, unfortunately also tend never to be fully 100% "fit for purpose". That is, rarely are resources 'perfect' for the 'job at hand'. Either a resource has too limited potential because of the *nature* of the resource itself ('mismatch') and/or of the *quality* of the resource itself (too poor quality) to be 100% useful. For similar "nature and quality" reasons, process(es) resources themselves also are rarely 100% "fit for purpose".

In general, the better the 'fit' between resources available and resources desired, the less utility will be demanded of the input resources themselves, and greater will become both the productivity of process itself and the overall productivity performance of the system.

The Good, the Bad and the just plain Ugly of the Productivities of Process

The simple representation of a productive system (as depicted in Figure 2) suggests that input resource set {*i*} and productivity of process $\eta_{process}$ collectively combine to produce a singular set of output resources "{*o*}".

However, as shown in Figure 3, **three** sets of outputs – one *desirable* set $\{o\}_1$ and two, *undesirable* sets $\{o\}_2$ and $\{o\}_3$ typically emanate from a productive system.

The *desirable* set of output resources $\{o\}_1$ constitutes those products and services expected and *desired* of the productive system. Output sets $\{o\}_2$ and $\{o\}_3$ are, however, **not desirable**. Output sets $\{o\}_2$ and $\{o\}_3$, in practice, represent *undesirable* or "pollution" sets.

While output set $\{o\}_2$ typically represents land and sea pollutants, set $\{o\}_3$ typically represents air-borne pollutants – both *undesirable* sets of outputs.

Figure 3 also shows that the following productivities of process exist:

Desirable productivity is defined as that set of desired output resources $\{o\}_1$ produced from the set of input resources {*i*}. That is,

$$\eta_{desirable} = \frac{\{o\}1}{\{i\}} \tag{3}$$

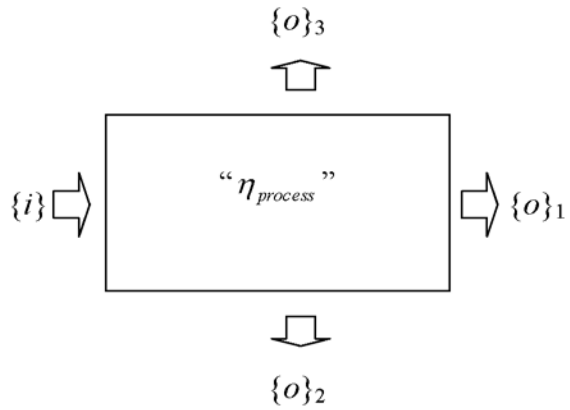

Figure 3. Productive system with one set of inputs $\{i\}_{j=1}$ but three sets of outputs $\{o\}_{k=1,2,3.}$

Contained within $\{o\}_1$, however, are both good {and bad $\{\overline{o_1}\}$ products and/or services. Thus, ***good productivity*** can be defined as:

$$\eta_{good} = \frac{\{o_1\}}{\{i\}} \tag{4}$$

And, ***bad productivity*** can be defined as:-

$$\eta_{bad} = \frac{\{\overline{o_1}\}}{\{i\}} \tag{5}$$

where,

$$\frac{\{o\}1}{\{i\}} = \sum[\, \eta_{good} + \eta_{bad}] = \frac{\{o_1\}}{\{i\}} + \frac{\{\overline{o_1}\}}{\{i\}} \tag{6}$$

Undesirable productivities are defined as those sets of output resources $\{o\}_2$ and $\{o\}_3$ produced from the same set of input resources $\{i\}$. That is, to "complete the threesome", productivities of process associated with pollutant outputs can be defined as follows:

$$\eta_{undesirable} = \frac{\{o\}_2}{\{i\}} + \frac{\{o\}_3}{\{i\}} \quad (7)$$

MAXimising Desirable Productivity and minimising Undesirable Productivity

In order to **MAXimise** *desirable* productivity, strict quality control of all categories, types and quantities of resources contained within $\{i\}$ and strict quality control of *process(es)* is required to eliminate the $\{\overline{O_1}\}$ component of $\{o\}_1$.

Given also that the set of input resources $\{i\}$ consists of both variable and house resources, it is the *variable* resources (direct and support labour, direct materials and consumed utilities) that inevitably end up in generating the bad or unwanted $\{\overline{O_1}\}$. It is through strict conformance to quality standards associated with the above labour, materials and utility input resources and strict adherence to production standards that such outputs can be minimised and, at the limit of '100% fitness for purpose' performance, $\{\overline{O_1}\}$ can be eliminated from $\{o\}_1$.

In order to **minimise** undesirable productivity, however, focus must be shifted to strict conformance to house resource [plant, equipment and indirect (maintenance) materials] standards and again strict adherence to operational standards. It is this *undesirable* component of the input resource set that results in pollution (in all its forms) of land, sea and air. It is through recycling capabilities and strict conformance to recycling standards – associated with the above plant, equipment and maintenance resources, that such outputs can be minimised and, again, at the limit of '100% fitness for purpose' performances, both $\{o\}_2$ and $\{o\}_3$ can also be eliminated.

Responsibilities Associated with the Improvement of Productivities

For productivities associated with a singular productive system, it is a generally accepted (legal) principle that the system as a whole, has sole responsibility to effectively and efficiently manage its own productivities. This can be inferred from a more broad definition of productivity – expressed as "***productivity is a ratio measure of measured effect(s) to known cause(s)***".

That is,

$$productivity = \frac{measured\{effect(s)\}}{known\{cause(s)\}} \quad (8)$$

For a **singula**r (stand-alone) productive system, responsibility for the selection and purchase of all input resources lies with the system itself. And the generation of all its outputs similarly lies with the same system. That is, it has control (authority and responsibility) for the selection and purchase of all its inputs and has similar control (authority and responsibility) for the generation of all its outputs and, hence, responsibility for all its **own** productivities.

That is, in the generation of output resource sets $\{o\}_1$, $\{o\}_2$ and $\{o\}_3$ (from all types and forms of singular productive systems), it is the outputs from such systems that are the individual responsibility of those systems.

For productivity $\frac{\{o\}1}{\{i\}}$, IEs typically employ their well known ('finding the one best way', etc.) skills to boost productivity $\eta_{good} = \frac{\{o\}1}{\{i\}}$ while using their TQC tools and techniques, etc. to (at least) minimise, but hopefully eliminate, respectively *bad* and *undesirable* productivities $\eta_{bad} = \frac{\{\overline{O_1}\}}{\{i\}}$ and $\eta_{undesirable}\ \frac{\{o\}_2}{\{i\}} + \frac{\{o\}_3}{\{i\}}$

However, when it comes to *undesirable* productivity $\frac{\{o\}_3}{\{i\}}$, the situation may not be so "clear cut".

Shared Responsibility?

Undesirable productivity $\frac{\{o\}_3}{\{i\}}$ is often not as visible as (more 'in-house') *undesirable* productivity $\frac{\{o\}_2}{\{i\}}$.

The pollutant output $\{o\}_3$ associated with this type of productivity *may not be from a singular ("*stand-alone'*) productive system*, but rather from a *linked-productive system* or "supply chain".

Figure 4 illustrates this point where Productive System #1 (PS1) effectively "generates air pollutants on behalf of PS2".

This is a typical situation in which several productive systems are, in fact, linked together to form a supply chain or network.

Typically, and unfortunately, one upstream productive system generates not only valuable input resources for other entities downstream within the same supply chain/ network, but also produces pollution sets $\{o\}_2$ and $\{o\}_3$ in so doing:

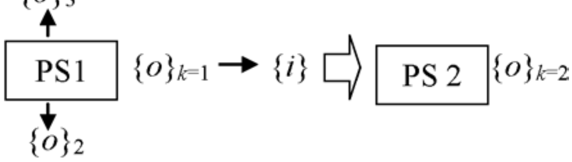

Figure 4. Productive System #1 (PS1) is linked to PS2 by acting as supplier to PS2 in a simple supply chain. [That is, PS1 generates undesirable outputs $\{o\}_2$, $\{o\}_3$ while acting as supplier of resource i to PS2].

In this situation, there appears to be a "joint responsibility" between PS1 and PS2 in the minimisation of *undesirable* productivities $\frac{\{o\}_2}{\{i\}}$ and $\frac{\{o\}_3}{\{i\}}$.

That is, the PS2 in Figure 4 (through its purchase of input *i* from PS1) CAUSES PS1 to produce the pollutant EFFECTS $\{o\}_2, \{o\}_3$. Therefore, in this now increasingly recognised (i.e. globally-common) situation, there appears to be a **joint-responsibilty** between parties (PS1 **and** PS2) in the continuing improvement (in this case, minimisation) of these *undesirable* productivities.

[Note: the cost associated with the 'clean-up' of these pollutants is, of course, today's "hot topic" (pun intended). With global warming seen to be the lead cause of *undesirable* climate change, new systems for the payment of costs in reducing pollutants vary from "user (PS2) pays" to an "all-pay" carbon cap and trade (ETS) system. It is the latter type of control system that recognises the simple fact that few productive systems exist in isolation and that most productive systems are linked and therefore have shared responsibility in the elimination of all undesired productivities.]

The Utility-Productivity Performance Equation and the Improvement of the Utility of Input Resource

The utility-productivity performance equation ($P_{p=\mu,\eta} = \mu\eta$) is a goal-based formulation to measure either the utility of input resource or the productivity of process performance of a productive system (Kennedy, 2009).

Desirable (and good quality) utility: When the performance-parameter (the '*p*' in the P_p) of interest is the *desired* utility $\mu_{desirable} = \frac{\{i\}}{\{o\}1}$, then the utility-productivity performance equation has the minimising-goal form:

$$P_{p=\mu_{desirable}} = \frac{p_{g_{desirable}}}{p_{a_{desirable}}} = \frac{\mu_{g_{desirable}}}{\mu_{a_{desirable}}}$$

$$= \mu_{g_{desirabe}} \eta_{a_{desirable}} \quad (9)$$

- where $P_{p=\mu_{desirable}}$ is the *Performance measure* and where the performance-parameter of interest (or '*performance-metric*') "*p*" is *desired* utility $\mu_{desirable}$.
- $\mu_{g_{desirable}}$ is the desired goal utility value of input resource.
- $\mu_{a_{desirable}}$ is the desired actual utility value of input resource and,
- $\eta_{a_{desirable}}$ is the desired actual productivity of process.

Equation (9) suggests that once goals have been set for the utilities of the input resources, every effort needs to be made to realise a minimum demand on the actual *desirable* utility of these resources. This, in turn, will result in the maximum production of **good** outputs $\{o_1\}$ and help achieve the goal of MAXimising the (*desirable*) utility performance of the productive system.

Desirable (but poor quality) utility:

When the utility of the input resource is of the right nature but not of good quality, then maximising the use of such resource will only maximise the production of desired, but *not good*, units of output $\{\overline{O_1}\}$.

Therefore, to minimise the production of $\{\overline{O_1}\}$ it is required that the performance-parameter of interest *p* becomes the *bad* productivity of process. i.e. $p = \eta_{bad} = \frac{\{\overline{o_1}\}}{\{i\}}$ (Equation 5).

The goal, of course, must be to minimise η_{bad} with the resultant productivity performance measure becoming:

$$P_{p=\eta bad} = \frac{p_{g_{\eta bad}}}{p_{a_{\eta bad}}} = \frac{\eta_{gbad}}{\eta_{abad}} \quad (10)$$

And, the utility-productivity performance equation becoming:

$$P_{p=\eta bad} = \mu_{abad} \cdot \eta_{gbad} \quad (11)$$

- where $P_{p=\eta bad}$ is the *Performance measure* and where the performance-parameter of interest *p* is *bad productivity* η_{bad}
- μ_{abad} is the actual value of the *bad* utility of the input resource caused by the poor quality of the input resource and,
- η_{gbad} is the minimising goal value of the *bad* productivity of process.

Equation (10) suggests that once goals have been set for the *bad* productivity of the process(es), every effort needs to be made to minimise the actual bad productivity of process. This, in turn, will result in the minimum production of bad units $\{\overline{O_1}\}$ and the maximum production of **good** outputs $\{o_1\}$. That is, Equation (10) directly suggests that there is a real need to lower actual bad productivity levels below set goal values.

Equation (11) too says that the actual value of the *bad* utility of the input resource (caused by the poor quality of the input resource) must be minimised. That is, only good quality inputs should be used as these have the maximum potential to be converted into good quality, desirable outputs.

Thus, by taking the above (utility-productivity performance) – informed actions, the twin goals of MAXimising the (*desirable*) utility ***and*** productivity performance levels of the productive system, can be realised.

Undesirable utilities:

When the performance-parameter '*p*' of interest is the *undesired* utility $\mu_{undesirable} = \frac{\{i\}}{\{o\}2}$ or $\mu_{undesirable} = \frac{\{i\}}{\{o\}3}$, then the utility-productivity performance equation must have the MAXimising- goal form:

$$P_{p=\mu_{undesirable}} = \frac{p_{a_{undesirable}}}{p_{G_{undesirable}}} = \frac{\mu_{a_{undesirable}}}{\mu_{G_{undesirable}}}$$

$$= \mu_{a_{undesirable}} \eta_{G_{undesirable}} \quad (12)$$

- where $P_{p=\mu_{undesirable}}$ is the *Performance measure* and where the performance-parameter of interest (or '*performance-metric*') *p* is *undesirable* utility $\mu_{undesirable}$.
- $\mu_{a_{undesirable}}$ is the actual value of the *undesirable* utility of the input resource.
- $\mu_{G_{undesirable}}$ is the MAXimising (G) goal value of the *undesirable* utility of the input resource and,
- $\eta_{G_{undesirable}}$ is the goal value of the *undesirable* productivity of process.

Equation (12), therefore, suggests that once again when goals have been set for the *undesired* productivities of process, every effort needs to be made to realise a MAXimum demand on the actual *undesirable* utility of input resource. This will result in the minimum production of *undesired* outputs $\{o\}_2$ and $\{o\}_3$ and also help achieve the goal of MAXimising the (*undesirable*) utility performance of the productive system. This latter point is further elaborated upon by the following comments:

1. In equation (12), $P_{p=\mu_{undesirable}}$ will be at a superior level (≥ 100%) when $\eta_{a_{undesirable}} \geq \mu_{G_{undesirable}}$ (or when $\mu_{a_{undesirable}} \leq \mu_{G_{undesirable}}$)
2. Any input resource has the potential to be used to produce undesirable output(s). Thus, the resultant actual *undesirable* utility of input resource ($\mu_{a_{undesirable}}$) needs to be increased above MAXimising-goal value ($\mu_{G_{undesirable}}$) in order to realise superior (*undesirable*) utility of input resource performance.
3. It should be the ***overall goal*** of all industrial engineers ***to both design and facilitate the management of superior performance productive systems.*** So, for the focus to be on any one individual utility of input resource measure, and/or any other performance parameter(s) of interest, the overall focus should always be on the attainment of ***superior levels of performance.*** This should be applied in all matters for any organisation and its productive system as a whole.

The Utility-Productivity Performance Equation and the Improvement of the Productivity of Process

Desirable productivity: Assuming that the productivity of interest is now the *desired* productivity $\eta_{desirable} = \frac{\{o\}1}{\{i\}}$, then the utility-productivity performance equation has the following MAXimising-goal form:

$$P_{p=\eta_{desirable}} = \frac{p_{a_{desirable}}}{p_{G_{desirable}}} = \frac{\eta_{a_{desirable}}}{\eta_{G_{desirabl}}}$$

$$= \mu_{g_{desirabl^e}} \eta_{a_{desirable}} \quad (13)$$

where $P_{p=\eta_{desirable}}$ is the *Performance* measure and where the performance-parameter of interest *p* is *desired* productivity $\eta_{desirable}$.

$\eta_{a_{desirable}}$ is the desired actual productivity of process.

$\eta_{G_{desirabl}}$ is the desired goal productivity of process and,

$\mu_{g_{desirabl^e}}$ is the desired goal utility value of input resource.

Equation (13) suggests that once again when goals have been set for the utilities of the input resources, every effort again needs to be made to realise a MAXimum actual *desirable* productivity of process. This will again help to achieve the goal of maximising the (*desirable*) productivity performance of a productive system.

Undesirable productivities: When the performance-parameter of interest is the *undesired* productivity $\eta_{undesirable} = \frac{\{o\}2}{\{i\}}$ or $\eta_{undesirable} = \frac{\{o\}3}{\{i\}}$, then the utility-productivity performance equation has the minimising- goal form:

$$P_{p=\eta_{undesirable}} = \frac{p_{g_{undesirable}}}{p_{a_{undesirable}}} = \frac{\eta_{g_{undesirable}}}{\eta_{a_{undesirable}}} \quad (14)$$

$$= \mu_{a_{undesirable}} \eta_{g_{undesirable}}$$

- where $P_{p=\eta\ undesirable}$ is the *Performance* measure and where the performance-parameter of interest *p* is *undesirable* productivity $\eta_{undesirable}$.
- $\eta_{g\ undesirable}$ is the goal value of the *undesired* productivity of process.
- $\eta_{a\ undesirable}$ is the actual value of the *undesired* productivity of process and,
- $\mu_{a\ undesirable}$ is the goal value of the *undesired* utility of input resource.

Equation (14), therefore, suggests that once goals have been set for the *undesired* productivities of process, every effort again needs to be made to realise a minimum actual *undesirable* productivity of process. This will also help achieve the goal of MAXimising the (*undesirable*) productivity performance of the productive system. This point is further elaborated upon by the following comments:

1. In equation (14), $P_{p=\eta\ undesirable}$ will be at a superior level (≥ 100%) when $\eta_{a\ undesirable} \leq \eta_{g\ undesirable}$ (or when $\mu_{a\ undesirable} \geq \eta_{g\ undesirable}$

2. Recall that any input resource has the potential to be used to produce undesirable output(s). Thus, the resultant actual *undesirable* productivity of process ($\eta_{a\ undesirable}$) needs to be reduced below minimising-goal value ($\eta_{g\ undesirable}$) in order to realise superior (*undesirable*) productivity of process performance.

3. Finally, it is again stated that the ***overall goal*** of industrial engineers and ***industrial engineering*** should be ***to design and facilitate the management of superior performance productive systems.*** And that the overall focus should always be on the attainment of ***superior levels of performance against known and deliberately set goal values*** – not only for the good of the organisation but for society as a whole.

Guidelines for the Improvement of Utility of Input Resource and the Productivity of Process

To realise higher levels of *desirable* productivities, reasonable ('*paid-for*') goal levels ought to be set for the utilities of all categories, types and quantities of input resources and all effort made to realise MAXimum actual productivities of process(es). This approach will MAXimise *desirable* outputs by minimising the actual amount of individual input resource required per unit of *desired* output produced. By meeting or exceeding set utility goal levels, superior productivity performance will always be achieved.

To realise lower levels of *undesirable* productivities of process, *stretch* goals ought to be set for the productivities of process, and all effort made to minimise any undesirable components of utility associated with any category, type and quantity of input resource. This approach will minimise undesirable outputs by minimising the potential utility of any input resource to become or produce undesirable output(s). Again, meeting or exceeding set goal levels will always result in superior system performances.

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