GOONATILAKE S. (1984) Aborted discovery. Science and creativity in the third world. ZED Books pub (57 Caledonian Road London N1 9BV) 191 p.

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[L'auteur, qui était lors de la publication de cet ouvrage Directeur de Recherches à la People's Bank à Colombo, est un lettré d'une immense culture. Il suffit pour cela de lire non seulement son premier chapitre "The colonial science and technology in the third world" qui décrit l'histoire scientifique de l'Asie du Sud, mais aussi le remarquable chapitre sur "European Science".

Toutefois, ce livre ne répond que partiellement à mes questions à cause de ses nombreux partis pris évidents ou moins évidents. Il se présente clairement comme marxiste, mais s'abstient toujours d'appliquer le marxisme à sa propre société. Il annonce une étude sur le 1/3 monde, mais en fait, c'est une étude sur l'Inde et un peu - très peu - trop peu - sur le Sri Lanka son pays. Il montre la brillante école philosophique et théorique indienne, mais ne montre dans cette école, ni d'ailleurs dans l'école européenne, aucune apparition de la preuve, de la démonstration qui sont caractéristiques de la science et la distingue de la spéculation et qui, contrairement à ce qu'il dit, caractérise l'origine hellénique. Il appose la continuité scientifique indienne et insiste sur l'effondrement du Moyen Age en Europe sans évoquer les énormes destructions des invasions toutes venues d'Asie. Il ne s'agissait plus de colonisation, mais de pure destruction. Il accuse la colonisation sans dire que la vie scientifique indienne s'est effondrée sous l'emprise mongol en Inde (XVIe siècle). Il ne discute jamais de la nature de la reprise scientifique en Chine après 1949 (Mao), enfin, et surtout, il ne prononce pas le mot de Japon. Ne parlons pas du monde arabe qu'il évoque surtout comme véhicule de la pensée asiatique en Europe et non comme source de savoir. Quand à l'Afrique (l'Egypte !!) et l'Amérique du Sud, elles figurent au passage. La seule relation intéressante se trouve pour lui entre la civilisation de l'Indus et Sumer.. Un mépris extraordinaire de la cosmogonie chrétienne par rapport au bouddhisme.

Un chapitre vraiment admirable de ce beau livre s'intitule "Modern science and the periphery" (p. 91-119) où il démontre de façon remarquablement forte et juste le caractère dépendant du milieu scientifique national, même dans un pays aussi engagé dans la Science que l'Inde avec, en particulier, les mécanismes du décalage entre les nouvelles idées qui forment l'essentiel du débat mondial et les possibilités de production dans ces nouveaux champs par les scientifiques nationaux. Mais cette critique remarquable - et très sévère - ne s'accompagne pas de solutions. Je pense que s'il avait regardé le Japon, il aurait mieux compris qu'il s'agit moins d'un problème colonial ou post colonial que d'un problème de masse critique intellectuelle, et peut-être de relations entre la science et le savoir qui sont si fortes à l'Ouest (et peut-être aussi au Japon ?].

STRUCTURATION DE LA TECHNOLOGIE - LA TECHNOLOGIE COMME "GENE SOCIAL" (p. 120-139)

Dans le chapitre précédent (la science moderne et la périphérie), j'ai examiné la façon dont la science a été transférée à la périphérie [les P.V.D.I.]. J'ai montré que, là où le transfert est réussi, la science fonctionne comme une routine, mais que la créativité est limitée pour des raisons structurelles [discutables].

Un autre ensemble de savoirs lié intimement à la science est celui de la technologie. En particulier dans le cas des industries actuelles reposant sur la science, ce lien est intime et vital. Au début de la Révolution Industrielle, les domaines scientifiques et techniques n'étaient pas étroitement liés ensemble [ce n'est pas exact : Pascal et les transports de Paris ou la machine à calculer, Lavoisier et l'éclairage public parisien, la pile de Volta, etc ...]. La Révolution Industrielle a été plutôt lancée par des techniciens ayant peu de savoir scientifique formel. La technologie d'aujourd'hui est liée à la science de façon croissante, l'un ou l'autre avançant parfois plus rapidement. Un examen du processus de transfert de technologie vers la périphérie est, de ce fait, un exercice utile - surtout en ce qui concerne ses circonstances et ses conséquences sociales.

Plusieurs études relatives au transfert de technologie ont souligné le fait qu'une technologie est souvent transférée comme une enclave sans lien préalable et ultérieur avec l'infrastructure technologique existante. Cela se produit habituellement dans de petits pays [et les "dragons" ?], mais des liens préalables et ultérieurs ont été établis dans des pays comme l'Inde grâce à des programmes majeurs d'industrialisation. Toutefois, ce n'est pas cet aspect des connections internes que je souhaite examiner dans ce chapitre. Ce que je veux décrire, c'est le processus de production de la technologie dans les conditions socio-économiques qui sont celles du pays du "centre", son adoption par la "périphérie" et les conséquences qui en découlent [Il est curieux qu'en 1982, un Asien aussi distingué n'évoque pas la technologie produite au Japon, dans les petits "dragons" : Corée du Sud, Taïwan, Hong-Kong et Singapour et de façon plus générale dans les N.P.I. (Nouveaux Pays Industrialisés). Il ne se pose pas non plus la question du transfert de technologie de l'Inde vers les P.V.D.I.; or, plus de 10% des exportations de l'Inde sont des machines ...].

La perspective large que je prends ici est que la technologie n'est pas seulement une question d'outils, de machines et de science appliquée. La technologie est essentiellement un intermédiaire dans l'interaction de l'homme avec son environnement, un outil qui, - à la fois, - l'aide à conquérir la nature et a un effet direct sur sa vie sociale [toujours l'attitude abstraite de Goonatilake et plus généralement de la pensée indienne]. Depuis l'époque de l'usage des outils de pierre pour la chasse jusqu'à l'utilisation d'outils de bronze ou de fer dans le cadre d'une civilisation agricole sédentaire, la technologie a été une variable essentielle dans la structuration des sociétés humaines. Je vais décrire la relation de la technologie à la société du centre et à la périphérie dans 3 domaines.

PROPOSITIONS GENERALES SUR LE TRANSFERT DE TECHNOLGIE ET LA SOCIETE

La première proposition large est que les technologies n'influencent pas seulement la forme et la structure de la société, mais que ces technologies (plus particulièrement les technologies complexes des 150 dernières années), sont également très influencées par les systèmes socio-économiques [Il s'agit là d'une des contradictions de Goonatilake qui se dit ainsi marxiste, mais est en même temps persuadé du caractère permanent de la supériorité intellectuelle indienne; il ne connaît pas le travail des anthropologues marxistes qui combinent une approche structuraliste anthropologique et culturelle avec une certaine forme de marxisme qui montre l'influence des conditions économiques et sociales dans l'évolution historique de ces mêmes structures].

Ainsi, il n'y a pas de technologies "universelles", mais seulement des technologies particulières qui sont le produit de prémices socio-économiques particulières. Ainsi, les technologies apparaissent comme un assemblage, dans des conditions particulières, du savoir disponible sur les propriétés de la matière pour produire des effets particuliers (En l'absence de savoir, cela comprend également la recherche préalable). Ces forces sociales sont propres à une époque, à une région et à d'autres facteurs limitatifs. Les technologies particulières peuvent - de ce fait - être considérées comme le produit de configurations de forces socio-économiques particulières à une époque donnée [Il est difficile d'être plus abstrait à propos du concret].

La technologie porte donc les traces du système socio-économique dans lequel elle est née, d'une histoire particulière. En ce sens, la technologie est de l'Histoire congelée dans un objet ou un savoir. Etant les produits d'une époque particulière, les technologies portent les traces des conflits, des compromis et des solutions sociales particulières réalisées dans une société particulière. Ainsi, la technologie reflète en général les relations de classe d'une société particulière, la nature de son système économique, de ses conflits propres. [Cette généralisation hypermarxiste est discutable, à quelle classe appartiennent l'électricité ou la réfrigération ? Pourtant, l'idée initiale est juste].

La technologie qui nous intéresse surtout, est celle qui s'est développée au sein de la civilisation européenne au cours des 150 dernières années, en particulier depuis la première révolution industrielle britannique [dans ce cas, il faut remonter à plus de 200 ans]. Cela ne veut pas dire seulement "technologie industrielle", mais aussi la technologie associée à une forte augmentation de la production agricole. La technologie a accru le surplus disponible des sociétés qui lui ont donné naissance et a accru à la fois la quantité et la qualité des biens disponibles pour la population. C'est le succès de la technologie comme fournisseur potentiel d'une quantité inépuisable de biens qui a attiré l'attention passionnée des pays extérieurs à la zone d'origine. Ainsi, des pays aussi différents que l'Union Soviétique du début du XXe siècle et l'Inde du milieu du XXe siècle (et la plupart des pays du 1/3 monde depuis la décolonisation politique) l'ont considéré avec admiration et envie et ont tenté de diverses façons de l'utiliser comme ressource pour leurs populations. Dans le processus d'adoption, la technologie particulière [ou plutôt l'ensemble particulier de technologies] qui s'est développée en Europe a été perçue comme universelle, et non historique par les retardataires dans le processus de développement [Cette remarque est vraie et fausse. D'abord, il y a bien longtemps, entre 100 et 150 ans, que le développement industriel n'est pas seulement européen, mais aussi américain et il y a 100 ans que ce développement est aussi japonais et russe. Or, ces 4 centres de développement industriel ont le même fond scientifique et technique, même s'ils le développent un peu différemment. En fait, comme beaucoup d'auteurs tiermondistes, mais Goonatilake le fait mieux que d'autres, il y a confusion entre la civilisation industrielle qui est totalement internationale - elle a été rejointe par la Chine, l'Inde et les petits dragons - et la civilisation occidentale. La question qu'il pose - mal - avec une pensée pourtant forte - est double : peut-on produire une autre civilisation industrielle? Pour moi, plus que jamais avec l'effondrement du communisme, la réponse est non. Peut-on garder sa propre civilisation avec l'industrialisation, la réponse est oui car, contrairement à ce que pense l'auteur, même en Europe, il n'y a pas une seule culture mais plusieurs très marquées et très vivantes].

La seconde proposition générale de ce chapitre est que l'absorption de la technologie moderne par les retardataires ne doit pas être considérée comme l'adoption d'un système universel. Au contraire, l'absorption est perçue ici comme ayant les caractéristiques de la dépendance culturelle et du colonialisme culturel. La technologie qui est transférée ailleurs depuis le centre de la civilisation européenne, peut ainsi être considérée comme un transfert au sein d'une relation évidente (ou plus souvent cachée) de dépendance ...

Il faut toutefois noter que les remarques ci-dessus au sujet du transfert de culture et de technologie s'appliquent tout particulièrement dans la situation coloniale et, de ce fait, peuvent apparemment ne pas s'appliquer strictement aux pays tels que l'Union Soviétique ou la Chine qui ont acheté ou achèteront de la technologie occidentale comme un aspect de la modernisation. Dans ces derniers cas, la demande de transfert de technologie ne vient pas d'une classe de collaborateurs créé par la présence coloniale, mais de l'avant garde révolutionnaire qui poursuit la "modernisation". [Ces dernières considérations sont d'une dialectique particulièrement comique quand on connaît l'effet désastreux du retrait brutal des soviétiques de Chine après la grande crise des années 50-60 entre les deux pays. En fait, l'URSS et la Chine étant de grands pays scientifiques et techniques peuvent assimiler les techniques achetées, la preuve en est leur succès dans le domaine militaire, spatial et nucléaire, mais cela ne change en rien le caractère étranger des technologies importées et de l'effet de "civilisation étrangère qu'elles comportent"].

La troisième proposition générale à propos de la technologie et de la société est que la technologie, parce qu'elle porte les cicatrices de l'histoire de sa société d'origine est, en fait l'histoire encapsulée, agit comme un gêne social, c'est-à-dire comme vecteur de relations sociales d'une société dans une autre. Le transfert du système social d'où elle est issue dans un autre contexte social, conduit une technologie particulière à jouer un rôle de gêne social qui tend à recréer divers aspects du système social initial. [Il s'agit d'un très vieux débat que Goonatilake reprend d'ailleurs très bien à la fin du chapitre. Faut-il croire les japonais qui pensent maintenir la tradition en présence des technologies modernes ?]

La technologie est, de ce fait, un transmetteur de relations sociales entre systèmes sociaux. Au cours de l'adoption par son nouvel hôte, la technologie prend des éléments de son nouvel environnement - matériel, intellectuel, - aussi bien que les opérateurs humains et les recombine de telle sorte que non seulement elle remplit sa fonction technique, mais encore qu'elle recrée le système social d'origine. [En fait, il s'agit de la reprise de l'idée de Lenine sur le rôle de la technologie et, plus généralement, de l'industrialisation comme transformateur social. Mais, en fait, il a fallu créer l'anthropotechnologie pour montrer comment réunir les conditions nécessaires pour la réussite de la nouvelle technologie car, dans la plupart des cas, on essaie de faire marcher le nouveau système sans rien transformer].

LA COMPOSANTE SOCIALE DU PROCESSUS MANUFACTURIER

[Ce sous-chapitre est une description brillante des diverses conceptions du travailleur et du travail cours du XIXe et du XXe siècle.].

En résumant ce qui vient d'être dit sur la technologie et le système socio-économique avec une référence spéciale à l'industrie automobile, il est clair que la technologie a été changée en réponse (cachée ou évidente) aux changements socio-économiques. L'environnement socio-économique extérieur et l'idéologie associée furent reproduits au sein de l'entreprise du début du XIXe siècle dans les périodes ultérieures. Des étapes importantes de la réponse de la technologie aux changements socio-économiques peuvent être analysées grâce aux travaux de Babbage, de Taylor, de l'école des Relations Sociales et des tentatives plus récentes de restructuration consciente de la technologie. La première représentation technologique de l'environnement socio-économique fut créée au temps de la suprématie du propriétaire alors que les dernières sont la réponse à la démocratisation croissante de monde occidental ... La dernière technologie, celle des robots, répond à de nouveaux critères socio-économiques qui marginalisent le travailleur dans le processus de production.

L'ADAPTATION DE LA TECHNOLOGIE INDUSTRIELLE

Si la technologie est si étroitement en rapport avec le contexte social de son histoire, que se passe-t-il quand une telle technologie est absorbée par un système extérieur au milieu d'où elle est sortie ? Pour illustrer quelques-unes des conséquences, je ne prendrai pas l'exemple d'un pays du 1/3 Monde, mais celui de l'Union Soviétique, pays qui a cherché à écarter quelques uns des aspects négatifs des relations de classe de l'Occident capitaliste et à construire un nouvel ordre social. [En fait, si l'URSS au sommet de sa réussite a fort bien réussi la technologie de pointe nécessaire pour l'Espace et la Défense, dans le domaine industriel et surtout manufacturier, ce grand pays n'a fait guère mieux que l'Inde où le Brésil, les N.P.I. (Nouveaux Pays Industriels) alors que son histoire industrielle est très ancienne (dernier tiers du XIXe siècle).

L'absorption par l'URSS de la technologie qui s'est développée avec la croissance socio-économique de l'Ouest doit être considérée à l'aide des vues soviétiques sur la technologie.

Dans la représentation marxiste, la technologie, comme partie du processus de production, joue un rôle important dans le système social. La technologie est la substratum dont dépendent les relations de production donc la structure de classe. Selon le paradigme marxiste, le développement des forces de production conduit à une production toujours croissante. Dans le schéma marxiste, l'Europe capitaliste fut considérée par l'URSS comme le sommet du développement technologique. Ainsi, en achetant la technologie occidentale et en rattrapant l'industrie de l'Ouest, l'URSS ne fait pas qu'une démarche souhaitable mais répond à une nécessité historique.

Lénine se faisant l'avocat d'une telle nécessité après la révolution définissait le socialisme comme le pouvoir des soviets et l'électrification des campagnes. [J'ai vu en 1972 , ce slogan en lettres lumineuses sur la Centrale Electrique située au centre de Moscou sur les bords de la Moskowa près de la Place Rouge]. De même, selon les vues de Lénine, la direction soviétique devait utiliser ce qu'il y avait de mieux dans les techniques de direction comme s'il s'agissait d'un outil neutre.

C'est ainsi qu'à cette époque - la période après la Révolution - "L'organisation Scientifique" décrite par Taylor aux U.S.A. fut considérée par Lénine comme faisant partie de "ce qu'il y a de mieux dans le capitalisme" (Il est intéressant de noter qu'à l'époque où le chef du premier Etat socialiste du monse se faisait l'avocat du système taylorien, les travailleurs américains, en particulier leurs syndicats, s'opposaient activement à leur influence deshumanisante.

Ainsi, dans les années 1930, l'Organisation Scientifique était présentée en URSS comme scientifique et progressiste. L'un des groupes intellectuels qui émergèrent en URSS fut la Ligne des Temps dont les buts déclarés étaient de contrôler et de règler le travail y compris le travail ménager de façon à économiser le plus de temps possible. Les réformes staliniennes telles que l'introduction du paiement aux pièces, de même que la création de titres d'honneur comme celui de "Héros du Travail" poussèrent le Taylorisme aux extrêmes.

Alors que les systèmes tayloriens étaient célébrés, il y avait aussi des facteurs d'atténuation. Dans les années 50, un certain degré de consultation syndicale fut organisé au niveau de l'entreprise. Dans certains cas, les prérogatives patronales ont été atténuées au profit du comité syndical d'entreprise. Il apparaît ainsi un certain degré de participation originale des travailleurs.

Cependant, la zone d'action des travailleurs était limitée : la masse salariale de l'entreprise était décidée au plan national (dans le cadre du centralisme démocratique) ...Les discussions limitées à la productivité et à la sécurité ne portaient pas sur l'esprit même de la technologie ...

Mais l'absence de discussion significative sur ces facteurs au niveau de l'entreprise ne veut pas dire que les implications de la technologie et les considérations sociales et psychologiques associées n'étaient pas perçues par les travailleurs ni même discutées dans les entreprises soviétiques. Que les travailleurs soviétiques soient très concernés par le contenu du travail, largement prédéterminé par une technologie particulière, est fortement suggéré par les résultats d'une recherche sociologique faite dans 25 usines de Léningrad (1966). L'étude demandait aux ouvriers de classer par ordre un ensemble de variables. Les résultats furent les suivants :

1) contenu du travail, en particulier ses aspects créatifs;
2) paie
3) la possibilité d'améliorer ses compétences
4) variété du travail
5) organisation des travailleurs
6) intérêt de la direction pour le travail
7) effort physique ....

INTRODUCTION D'UNE TECHNOLOGIE PREDETERMINEE SOCIALEMENT : L'INDUSTRIE AUTOMOBILE

L'URSS et d'autres pays de l'Est de l'Europe ont, au cours de la dernière décade, décidé que le transport individuel représentait un important bien de consommation pour leurs populations , et ont, pour cela, construit de grandes usines automobiles. Tous ces pays avaient des capacitiés propres limitées pour l'industrie automobile (Moskovitch, Skoda). Pour ce nouvel élan considérable de l'industrie automobile, ils ont dû presque tous importer de vastes usines venant de l'Ouest et, en particulier, de l'italien Fiat. La plupart des pays de l'Europe de l'Est commencèrent au début des années 1970, à produire diverses versions de la Fiat 120 (L'importation d'usines pour l'industrie automobile s'est étendue à la production des camions comme le montre la grande usine de technologie Mack installée en URSS [Cette extension est plus surprenante car l'URSS produisait certainement depuis longtemps de grandes quantités de camions militaires. Pourquoi ne pas avoir étendu cette production au secteur civil ? S'agit-il d'un retard technologique ou de la séparation rigide entre la Défense et la vie civile ?].

Ces usines importées ont une production importante, l'usine Fiat soviétique devait produire au début 700.000 voitures par an [En fait quand, en 1972, j'ai participé au premier congrès ergonomique du COMECON (groupement économique des pays alors socialistes), une psychosociologue soviétique m'a interrogé sur la faible productivité de cette usine (70% de l'usine italienne), je me suis demandé si cette faible productivité était liée à des cadences plus faibles (plus humaines ?) ou à l'incapacité de réussir le transfert de technologie du fait de la composition et des habitudes de la société industrielle soviétique].

La raison pour ces usines importées est essentiellement économique : une technologie pour produire des automobiles à grande échelle existe à l'Ouest, il est plus simple d'acheter plutôt que de créer cette technologie (une telle avidité pour acheter la technologie remonte aux toutes premières années de l'Union Soviétique).

Nous avons vu plus haut que le développement de la technologie était le produit de facteurs sociaux et techniques et que, dans la substance même de la technologie et de l'organisation de l'industrie automobile, se trouvaient intégrés un vaste ensemble de conceptions sur la nature de l'homme et des relations humaines en relation avec l'expérience particulière du développement capitaliste à l'Ouest. Quelques-unes des idées sur l'homme intégrées historiquement dans la technologie sont celles vis-à-vis desquelles Marx était le plus critique. Ainsi, Marx parle d'Adam Smith, un ancêtre intellectuel de l'industrie automobile, de la façon suivante : "Adam Smith pense au travail comme à une course, le "repos" lui paraît un état de choses vague analogue à la "liberté" et au "bonheur" (Mc Lellan D. , 1973, Marx Grundrisse). Les vues de Taylor sur l'homme, en parrticulier sur le travailleur de l'industrie automobile, étaient encore plus extrêmes que celles d'Adam Smith. Que se passe-t-il dans les relations sociales des usines soviétiques quand celles-ci sont achetées clés en mains avec toutes ces idées exprimées dans la technologie ?

La technologie Fiat achetée, appartient à l'époque classique de la production de masse avant les changements apportés sous la pression des travailleurs dans les années 1970 (En fait, les travailleurs italiens de Fiat qui appartenaient à des syndicats communistes, se mirent en grève au début des années 70 contre la technologie inhumaine à peu près au même moment où le premier état socialiste achetait toute cette technologie). L'usine soviétique est essentiellement la même que celle qui fonctionnait dans l'Italie capitaliste. Le processus de fabrication ne subit que des altérations mineures qui ne touchent pas à l'essentiel. Des éléments en matière plastique difficiles à obtenir sont remplacés par de l'acier. Les ressorts sont renforcés pour tenir compte de l'état des routes soviétiques ... Le divorce radical entre la pensée et l'action, la préprogrammation étroite de l'activité des travailleurs par un groupe d'experts de la direction, la fragmentation des travaux individuels à un niveau excessif, toutes ces caractéristiques d'un capitalisme rampant remontent, en particulier au temps où l'effet du mouvement syndical sur la direction était très faible. Exprimées sous la forme de la science de l'organisation, elles sont présentes dans la technologie soviétique de Fiat. Les activités des travailleurs comme des cadres étaient fortement structurées par la technologie, les relations sociales capitalistes sont de ce fait reproduites au niveau industriel. Dans un sens très réel, le fantôme du capitalisme hante les machines de l'Usine Fiat soviétique et guide les actions des humains qui y vivent.

[Goonatilake fait ici une analyse brillante, mais je crois que son idéologie l'égare. Je crois que les savoirs de l'humanité, techniques et sociaux, s'expriment sous forme de technologie à un moment donné et que l'on ne peut condamner ces réalisations au nom de savoirs que nous avons maintenant et que nous ignorions alors. Ce qui est à discuter, c'est plutôt de savoir quel état de la technologie ancien ou plus récent est le meilleur à transférer. Est-ce que la technologie Fiat vendue à l'URSS n'était pas plus utilisable à cette époque plutôt qu'à celle qui allait apparaître à la fin des années 70, compte tenu de l'état peu avancé de la société soviétique de l'époque. Le milieu dirigeant soviétique n'était-il pas plus à l'aise avec la représentation ancienne du travailleur fort et pas très intelligent qu'avec la représentation plus moderne du travailleur cognitif ? Goonatilake aime baucoup attaquer le capitalisme, mais on peut se poser 3 questions majeures à propos de son excellent texte.

1) Pourquoi un grand pays industriel comme l'URSS n'était-il pas en état de produire une technologie manufacturière de l'automobile en 1970 ?

2) Pourquoi les dirigeants soviétiques ont-ils préféré une technologie pessimiste vis-à-vis des capacités intellectuelles des travailleurs ? N'est-ce pas en relation avec une vue réactionnaire des capacités intellectuelles des divers niveaux sociaux ?

3) N'est-ce pas ce dernier mécanisme qui préside aussi à des choix faits par certains PVDI ?]

Le système soviétique de participation des travailleurs ne change pas de façon significative les relations prévues dans la technologie. Dans les réunions régulières à l'usine, les travailleurs discutent de la sécurité, des salaires, le salaire des dirigeants et les bonus, mais la combinaison centrale des comportements dans l'entreprise a été établie par la technologie importée. Qui fait quoi et comment ? Quand ? A quelle vitesse ? A toutes ces questions, les réponses sont données dans une proportion très élevée par la technologie. En fait, l'insistance des participants ouvriers soviétiques sur la production et les motivations tend à renforcer la technologie reçue et les relations sociales qui en découlent dans la perspective d'une meilleure production.

Il n'y a pas d'étude disponible sur des comportements de protestation (baisse de l'attention, absentéisme, sabotage, etc ...) dans l'industrie automobile soviétique comme il en existe à l'Ouest. Cependant, si l'on considère l'insistance soviétique sur la participation des travailleurs et les efforts de soutien de la motivation; on peut supposer que de tels comportements de protestation sont plus faibles qu'à l'Ouest (bien que, comme nous l'avons mentionné plus haut, les études des scientifiques soviétiques montrent que les préférences des travailleurs ne vont pas dans le sens du type de technologie et d'organisation industrielle que représente l'industrie automobile. Le résultat en est une représentation biaisée des travailleurs qui ne peuvent percevoir la réalité de leurs relations sociales au travail et la deshumanisation de la situation. [Cela s'appelle soit "idéaliser" soit "sublimer"]. Une fausse conscience technologique est paradoxalement créée au nom de la conscience socialiste. Les travailleurs (et la direction) tombent ainsi dans un piège technologique et social en absorbant comme universelle la cristallisation de plusieurs décades de développement industriel [Oui, mais ... étant donné l'énorme retard technologique soviétique dans l'industrie automobile - qui est la vraie faute grave - que peut-on faire d'autre qu'acheter la technologie étrangère et la faire marcher au mieux si l'on veut produire rapidement des voitures. Ne pas répondre à ce type de question est la faiblesse du livre de Goonatilake qui n'a pas de caractère constructif] .... Une détermination partielle du système social par les "gênes" technologiques n'implique pas que l'Union Soviétique retourne au mode capitaliste de production en achetant une telle technologie [et si, en fait, le contraire était vrai et que l'échec relatif de la production automobile soviétique a été un des nombreux déterminants de la chute du communisme et du rétablissement du capitalisme en URSS ?]

TECHNOLOGIE AGRICOLE ET ORGANISATION SOCIALE

La Révolution verte au Centre et à la Périphérie (PVDI) correspond à la conjonction de nouveaux hybrides, d'un haut degré de mécanisation, de l'usage de quantités importantes d'engrais et de biocides et d'une irrigation développée. Le résultat en est une production élevée ...

Il y a beaucoup de diversité génétique dans les céréales, de telle sorte que l'on peut obtenir des variétés de blé ou de riz ayant une tige longue ou courte, un gros épi ou un épi plus menu, des grains blancs ou bruns (pour le riz). On peut produire des espèces résistant à la sécheresse ou exigeant beaucoup d'eau, résistant aux maladies ou moins l'importance du doute et de la preuve dans la pensée occidentale, ce qui est très regrettable puisque le doute et la preuve sont des éléments centraux de cette pensée, et les ressorts du progrès scientifique et technique. Cela correspond également à ses positions philosophiques orientées vers l'assertion et non la dialectique. Pour lui, la Science et la Technologie sont des idées et non des faits. Or, l'esprit même du progrès scientifique et technique, c'est l'apport de faits].

Citons la conclusion de l'auteur, "le monde de l'intelligence est celui de l'imagination, de l'incertitude et du jeu". Ce livre porte sur l'entrée dans un tel monde, le monde de la créativité scientifique. Il exprime la conviction que les scientifiques du Tiers Monde devraient s'engager dans la conception, à se plaire à jongler avec les idées et à essayer de promouvoir leurs propres vues sur la réalité physique derrière les voiles qui la cachent.

Asian Design Originality
Its Role in the 21st Century Lifestyle Revolution

Kenji Ekuan
ICSID Senator and chairman of GK group Japan

Discours inaugural prononcé lors du Congrès international de Design Industriel, ICSID' 95 à TAIPEI, ROC , en Septembre 1995.

I wish to extend my congratulations to this exciting event of International Council of Societies of Industrial Design. The occasion has very important meaning, because this is held in the capital of the People's Republic of China.

As you are well aware, this international congress was held twice, in 1973 and 1989, in Japan, at the far edge of Asia. In 1973, I acted as chairman of the executive committee for the event, and at that time I said, «Now design has made the globe round.» We have exerted all our efforts toward learning modern design that had gotten its start in Europe and went to the United States for further development.

This congress in the People's Republic of China is even more significant than that former rounding of the globe, when the center of modern design was firmly rooted in the West.

But will the centrality of modern design persist in the 21st century as well?

Frankly speaking, I am convinced that 21st century design will establish a new base in Asia which will send out the new design to the rest of the world. In other words, Asian civilization may come to beam a light to the world. Thus today, I wish to make it clear that Asia will become a vigorous sender of design message for many, many years to come.

In this sense, the congress in Taipei is surely a harbinger of this emerging trend. Japan, situated on the far edge of Asia, has acted as a forerunner of Asia in bringing to reality of the stance of Asian design. She has served as catapult for the swift spreading of this new source of light that is Asian design throughout Asia.

It has a broad range of colors that will serve to increase its brilliance in the 21st century. Thus I envision in my mind that in the 21st century this fountain will create a gorgeous display such as has never been seen before. When I say, a gorgeous fountain such as has never before been seen, I am actually forgetting the history of Asia, for from the 14th to the 17th century, Asia was the center of the world's civilization. The ceramics of China; the weaving and dying culture including the cottons of India and Java; the Silk Road that left its name as the conduit for the silk trade,—and these ultimate handicraft works were greatly admired by Europe.

The 18th and l9th centuries were the age of the industrial revolution in Europe. The 20th century was the age of modern design with its home base in the West. For the first time in three centuries,however, Asia is joining the mainstream of design activities.

To begin with, I wish to establish a clear placement in the context of the history of civilization for Western design as an element of the culture that was produced by the modern civilization of Western Europe. It was an aesthetic that was born of the modern civilization of Western Europe that was supported by the materialistic logic of functionalism and rationalism. After being conquered by the world of design that was initiated in Europe, the United States succeeded in popularizing material culture through the principles of mass production and commercial design. And this was eagerly learned and imitated in Asia. Even I myself was one who went to the United States as soon as the War was over to learn Western design. And all the other founders of the GK Group also went abroad to study western design at the same time.

Asia has a great number of civilizations that stand shoulder-to-shoulder with Japanese civilization. In Asia there are charming design cats that are covered with tri-colored spots like a calico cat. Asia possesses a multipolarized civilization that is color-coded in stripes like a seven-colored cat. Here I would like to take a close look at the stance of the multipolarized civilization design. The design will spread throughout Asia during the 21st century with Japanese civilization as its point of departure.

We must approach straight on the problem of the design of the future. It will stand upon the convenient and comfortable material culture. It was created by Western civilization to find a way to give form to a spiritual richness. Herein I see within the world that has reached the «limit of growth» a direction for rising above this dilemma to bring salvation to global culture.

Modern design was a high-Culture in Europe including United Kingdom. It was the United States that popularized modern design. Success was achieved in the popularization of design in the United States through development of a design method in accordance with the mass-production system. The system determined the stance of things in which the shape of things was manipulated for the purpose of motivating behavior. But even in the United States, lovers or believers of modern design were rather limited quantity-wise.

What is about to take place here is a evolution in the design aesthetics. It is a trend toward going beyond the design aesthetics provided by Western civilization. And it was brought through the universalization of the material culture that began with the modern design movement.

I would like to stop here to define for the moment the five terms, civilization, culture, design, modern design, and Asian design.

Civilization is a universal artificial method for adaptation to the global environment to make it for the human race to survive on this planet Earth. In other words, civilization is a universal system for survival in the global environment.

In this context, culture means the method for adaptation of the common universal civilization to the differences in regional environment conditions, as well as the present-tense form of historical inheritence, change, and development.

In contrast to the idea that there is only one universal civilization on the earth, there is also a pluralist theory that maintains that in the varied environment of different parts of the world, different tribes gave birth to mutually exclusive and separate civilizations. These include the temperate island civilization of Japan; the more compact island civilization of Taiwan; the great continental civilization of China; and the subcontinental civilization of India.

In this case, civilization is a common global system that contains a number of elements that are commonly acknowledged by most ethnologist. These include religion, language, history, tribes, specially recognized world features (such as view of nature, view of human beings, view of life, and view of technology), and special philosophical methodologies.

Since the modern Western civilization that came into being after the industrial revolution has come to be considered the global civilization, it has become the yardstick for dividing the world into civilized and non-civilized or barbaric regions. In this context, the modernization that Japan and the other Asian nations have been aiming for was an attempt to overcome an un-civilized condition.

The view of civilization that I have explained thus far maintains that there are such other coexisting civilizations in the world. They are medium-size civilization of Asia, and the small-size island civilizations of Japan and Taiwan. It is this interpretation of civilization that was explained by Dr. Tadao Umezao in his keynote speech for the ICSID international convention. It was held for the first time in Asia in 1973.

Meanwhile, culture is an expression of values shared by the people of a region, an identity system as opposed to survival system of civilization.

Modern design was an expression of the values of the Western machine civilization in the European region.

In this manner, the defining of the various terms that I mentioned earlier is actually the skeletal framework of my main theme for today.

Design that did not comply with modern design which was the expression of values of European civilization after the industrial revolution was considered nondesign or unrefined design. What I am speaking today is aimed toward conversion of this implicit value judgement.

Once, there was a rich Asian design. The industrial revolution in United Kingdom began with conversion of the thoroughly delicate and beautiful textiles of the weaving and dying techniques of Indian cotton known as Saint Thomas into a British national product. This fact has been pointed out by many economic and social historians who were influenced by the ecology of Professor Kinji Imanishi, teacher of Dr. Umezao. Spinning and weaving machines were developed in order to accomplish the longed-for purpose of British nationalization of these products.

And the Jacquard system of codification of thread-color groups was carried out. Even so, the mass-produced products manufactured in Manchester and other British mills could not hold a candle to the highly refined textiles of India in terms quality and decorative allure. But machine spinning became the mainstream. And subsequent cultural history shows that the high quality handicraft products lost to the low quality level that prevailed under the name of industrialization.

Pre-17th century Asia enjoyed an multi-civilization age. However,the single-civilization that was modern Western European civilization encouraged «modernization» equal Western Europeanization in all the areas of the rest of the globe including Asia. However, now as we approach the end of the 20th century, the entire world is welcoming the advent of a period of multilateral change and restructuring.

The industrial revolution developed a new civilization that was stimulated by the scientific revolution that was supported by the possibilities of technology, and the energy revolution brought about by the use of coal. That new civilization set out to conquer the world, bringing along with it the advent of modern design that was based upon the aesthetic. It found beauty in doing away with extraneous decoration to keep in line with functional form.

William Morris is known as the founder of the modern design movement. He was a critic of the poor quality of the flood of industrial products. They inundated the world as a result of the industrial revolution during the latter half of the l9th century.

Then as the modern design movement shifted from United Kingdom to Germany, the ascetic aesthetic was brought clearly to the fore. Thus modern design with its intellectually brilliant pursuit of function and logic was born.

The thesis of modern design that was established in Germany has prevailed to this day. In this manner, the various peoples of Europe have developed design separately as a system of expression of the unique characteristics of their individual civilizations based upon their differences in climate and ethnicity.

Japanese designers work in accordance with their own individualities, as a result of which some of them remain firmly faithful to British design; others take German design as their starting point; others are totally involved in Scandinavian design; others are totally steeped in Italian design; and yet others have settled completely into Catalonian design, each of them remaining absolutely dedicated to their own stance.

In any case, however, the style of design that was an expression of the values of modern Western European civilization, and its purpose of promoting ascetic functionality and rationality and its totally unified methodology has prevailed throughout the world as the mainstream.

Tokyo can be referred to as an imitation modern design city where the only way that you can discover where you are even on the Bullet Train Shinkansen Line is to read the name of the station on its signs.

If the world were to become totally dominated by this kind of unification, global culture would be dead.

Even so, to us Asians, modernization has always meant the attempt to achieve the modern civilization of Europe.

The world products found their origin in United Kingdom where the design concept of dailylife comfort by means of mechanization was invented; Germany gave it form through the ascetic aesthetic; and the United States popularized it. A design technique was evolved for creation of purchase motivation. But there is a limit to formulation of a daily life system through the pursuit of commercial values in the realm of dismantling the daily life system into products.

In 1972, the Club of Rome reported the «Limits of Growth,» and the first oil crisis took place in 1973. It was shown,then,that the modernization movement that aimed toward expansion of efficiency in order to create a new Western civilization had its own limit.

Just what is the reason for this? There is a limit to growth in terms of material civilization, but I think that there are no limitations to cultural development and deepening of cultural quality.

Even in Japan, the modernization theory of material civilization growth continued on the road toward «growth» until the end of the 1980s, but then it met with the catastrophy of the «bursting of the bubble.» However, while the waves of «civilization growth» continued active on the surface, the «culture deepening» movement continued to flow independently beneath the surface. Thus when the bubble disappeared, this undercurrent came to the surface.

And in the midst of this period of global change, Japan is also being buffeted about by the angry waves of de-structuring and re-structuring of its industrial, its economic, and its educational establishments. And since the world of Japanese design is deeply involved with industry, the same sort of restructuring and de-structuring has begun in the establishment of our world of industrial design that has prevailed up to the present.

Up to this time, Japanese industrial designers have had a tendency to occupy themselves with the design of concrete things. But design must express the «matters» desired by the heart; it must design these «matters» in order to give concrete shape to «things . « In order to be complete, a design must bring together the three elements of «heart,» «matters,» and «things.»

One of the most straightforward manifestations of Japanese design as a converter for changing civilization into culture. It is seen in the karaoke phenomenon. No matter how much one may insist that Europe is the cultural inventor of music, the karaoke machine was developed in Japan to become a product of original Asian design for the enjoyment of music that has spread throughout Asia.

The «heart» of karaoke is the desire to enjoy music together with others. as well as the desire for self-expression, and the desire for self-intoxication. Until this desire of the «heart» is not grasped, it is impossible to bring a new «matter»—that consists here of friends jostling each other for possession of the microphone to sing their hearts out—into visible form. And the quick chosing of one's favorite repertory piece and setting the accompaniment in motion is the «matter» of karaoke. When this «matter» is clearly understood, it is easy to design the «thing» which in this case is the hardware of the karaoke set.

Sound equipment technology is civilization, but it is only when the «heart» of karaoke is grasped in such a way. The «matter» of karaoke is realized at a «thing,» only when these three elements are brought together. Then it becomes culture that stands as expression of human values, that it becomes design.

Now, as the next step, I wish to share my thoughts on what must be done to develop designs with attractive Asian originality as expressions of cultural values.

Originally, design could have no allure unless it was a cultural expression that came from within the various civilizations. When the multipolarized civilization complex of Asia comes to possess cultural expression related to the civilizations of its various regions, it will become possible to carve out a pleasant world where design exchange and cultural exchange will provide mutual stimulation and influence that will continue to deepen limitlessly.

The growth of civilization has ended. The deepening of culture is beginning. For the first time in three centuries, the time for the appearance of Asian design woven from the multipolarized Asian civilization complex will come at the end of this century.

Through history, Japanese civilization has received the influence of a large number of surrounding civilizations. Meanwhile constructing a unique civilization of its own. And it sends out its own cultural expression to the rest of the world that has continued to enthrall the world market.

After World War II, Japan was strongly attracted to the highly developed civilization of America, and from that time forward, it was introduced into Japan. But to Japan that had always been behind in the race toward modernism, American household electric products were American culture itself.

American household electric products were introduced into Japanese daily life as a condensed symbol of cultural values for daily life modernization that went beyond their function and efficiency. .

The household electric appliance—the idea for dismantling daily life activities and making products out of them belongs most certainly to the West. Then, Japanization of that original idea took place, bringing about a world of unlimited cultural pleasure in the field of electric and electronic products. Such mobile sound equipment as transistor radios, casette tape recorders, radiocasette players, headphone stereos, and CD players have been created one after another. In a mere ten years, the Japanese-language word processor has been developed from the large desk model to the small laptop type. And the fact that the tabletop electronic calculator has been reduced to calling-card size.It is the result of culture as an expression of civilization values, in other words, of design.

As we approach the end of this century, the European and American civilizations are faced with the limits of growth. Is it not Asian original design that derived from the complexity? Is it not the design that will bring salvation to the 21st century industrial style and carve out a new lifestyle that will save the globe?

Remarkably in common with the all rest of Asia, Japan partakes of the world of pantheism. In Japan there innumerable deities, as expressed in the term «yaoyoro-zu. It is believed that a deity dwells in everything in the entire universe including plants, trees, insects, and fish.

When traveling in Asia, one comes into contact with numerous dwellings of the gods. At the same time, there are an equally large number of evil deities and their vassal demons, as a result of which there are symbols and signs to ward them off everywhere.

The act of design gives form to innumerable hearts. The giving of shape to things is also the creation of hearts for them. Is this not the spirit of creation of things that is common to all of Asia?

In this world overflowing with innumerable deities, one must never treat thinghs without due respect. And, even more so, when one is in the position of creating things, one must not be reckless or sloppy in the process of creation. It is through creating things will deep feeling that they are imbued with a soul. It is believed that this is the point of departure of Asian design originality.

The role of Asian design will be to utilize the Asian view of the order of things to link hearts and things in the world of the spirit. It will be achieved through creation of a reason for living for people in cœxistence with things. And it will be re-structuring the world of human beings in the 21st century. It is in this context that it can be said that Asian design is a new and original design. And the design will take the place of modern design.

The viewpoint that things possess hearts and life has no relationship to capitalism. And this was the lifestyle of artisans who made things in the world before the advent of capitalism. I believe that this world of people who make things will be revived in Asia. And in Asia numerous deities dwell from the midst of the movement toward multi-re-structuring of the present social establishment.

Even in the West, in the Greek and Roman ages, there existed a multi-deity world that was very similar to that of Asia. The mythologies of northern, middle, and southern Europe are all overflowing with rich tales. The deities of southern Europe are particularly human-like. And I think that this has some relationship with the uninhibited shapes of modern design in southern Europe.

Just as Aegean civilization was an inland sea civilization. That embraced a mixture the differing deities through exchange with disparate civilizations. I am convinced that the sea of 21st century Asia will be a sea of civilization exchange where numerous differing deities come and go freely.

In Asia, modernization equal material civilization was pursued. Meanwhile, though many gods were killed, many other continued to live on to inhabit the things born of the material civilization.

The tasks of the 21st century is to let these deities live and prosper forever.
Herein lies the key to the emergence of Asian desgin. The ecologically valid environment in which all living things can live happily should be the best environment for the deities to survive and flourish. But, this is nothing but the environment which modernization has disrupted.

In order to restore this well-being in our age, however, we have to establish a new rule of doing things. This is the very thing I strongly want to pointout. Modernization has founded nation states and created extreme specialization of all human activities including design, that I think has made it difficult to solve the problems, including those of environments, the aged, and the handicapped. This state of things must be overcome at all costs.

But, fortunately, in the face of the arrival of a global age, it appears that the national boundaries of life culture are now beginning to waver and disappear. Even in the various fields of learning, technology, and industry, boundaries are beginning to merge, and new territories are beginning to appear. This is truly the emergence of a borderless society. The problem facing design is how to respond to the demands for collaboration among the various design genres to go beyond the extant vertical specialist design territories.

Today design is entering a period of new challenges that include changes and regeneration of design itself.

The aim of design has always been to perceive the signs of the civilization that is about to appear, while effecting a crystallization of the sense of values and the view of technology of each passing age into a culture of things. And it is bringing fresh quality into life culture. It can be said that today when astounding changes are taking place in everything, design must bear the torch for creation of new prototypes for the culture of things. Design is to solve both stimulating and challenging problems that never before existed. The swift development of such new technologies as biotechnology, multimedia, and artificial intelligence serves as capital for activity for design. And design is hard at work to solve the thrilling problem of intuitively grasping a new lifestyle image from the midst of these new technologies and giving it expression.

In order to efficiently answer many social problems, cooperation of many professional fields centered around design is urgent necessity. The cooperation will need an unprecedently merged and intimate solidarity among the various technology, sociology, humanities, and natural science fields. And further, in answer to the linkages achieved among these fields, a new system of activity must be formulated in administration, education, and vocation related to design. What was impossible for the vertical track that was born of modernization to accomplish can be accomplished by constructing a horizontal track. This is the new culture of things for the global age that must be carved out in the future. And I want design as integrating force to serve as the starting point for the movement toward creation of this culture of things. And I sincerely hope that this will give rise to a new type of international collaboration and subsequently serve to disseminate this theory. I believe that ICSID '95 Taipei will play the role of a true springboard in this direction, for, after all, Asia contains half of the population of the entire world.

The entire world has an intense interest in what sort of new culture will be created. And it will be achieved through the employment of the civilizations of the various regions of Asia that go together to for a mosaic pattern. And it goes without saying that the entire world is also particularly interested in what view of technology will be taken on. And the world is also interested in the new civilization by the view of culture that has been structured and deeply rooted in the various regional cultures for the past several thousand years.

Design can create cultural systems. Culture must not lack the full workings of the spirit. I find myself becoming extremely excited when I think about the original design and the culturalization of civilization. The civilization will come along with the spiritual repletion of the people of the various regions of Asia.

I sincerely hope from the bottom of my heart that ICSID '95 Taipei will become the eye of the typhoon of this design movement.

WORKSHOP ON
APPLIED ERGONOMICS IN SPECIFIC REAL LIFE WORK SITUATION AND THEIR LOW COST SOLUTIONS

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Chapter 1

Introduction

The word *ergonomics* comes from the Greek *ergo* (work) and *nomos* (law). It was used for the first time by Wojciech Jastrzebowski in a Polish newspaper in 1857 (Karwowski, 1991). In the USA, *human factors engineering* or *human factors* have been close synonyms. European 'ergonomics' has its roots in work physiology, biomechanics and workstation design. 'Human factors', on the other hand, has its origin in experimental psychology and the focus is on human performance and systems design (Chapanis, 1971).

There are common problems in the workplace where it is necessary to take a broad approach. Despite the differences between human factors and ergonomics in the type of knowledge and design philosophy, the two approaches are coming closer. For example, the introduction of computers in the workplace presents a variety of design problems (see Table 1.1). We can illustrate the problem as shown in Figure 1.1. Here a human operator is perceiving information on a display. The information is then interpreted and an appropriate action is selected. The action is executed manually as a control input, which in turn effects the information status on the display.

The environment may also affect the human operator. Here it would be appropriate to analyse factors that are external to the task and yet may have a great effect on performance and job satisfaction, for example:

- Noise and vibration.
- Heat and cold.
- Work–rest cycle.
- Organizational factors.

To effectively solve a problem related to VDT workplaces, an ergonomist must be able to recognize and analyse a variety of problems and suggest design solutions. This leads to our first maxim: *the primary purpose of ergonomics is design*.

Table 1.1 Design problems arising from the introduction of computers in the workplace

Problem	Knowledge required to solve problem
Work posture	Biomechanics
Keying	Biomechanics
Size of screen characters	Perception, vision research
Layout of screen information	Cognitive psychology, cognitive science
Designing new system	Systems design and cybernetics
Environmental factors	Noise, heat stress, cold stress

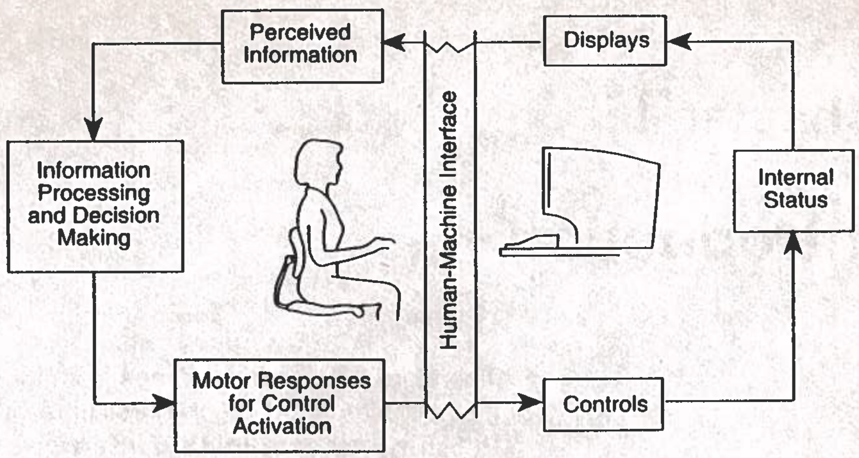

Figure 1.1 Analysis of the human–machine interface requires interdisciplinary knowledge of biomechanics, cognitive psychology and systems design methodology

The existing situation must, therefore, first be analysed, design solutions must be generated and these design solutions must be analysed. The design work can be described using a control loop, as shown in Figure 1.2.

It follows from Figure 1.1 that interdisciplinary knowledge is required: (1) to formulate systems goals; (2) to understand the functional requirements; (3) to design a new system; (4) to analyse the system; and (5) to implement the system. From the feedback loops shown in Figure 1.2 it also follows that design is a never-ending activity. There are always opportunities for improvements or modifications.

A common scenario for the work of an ergonomist could be the following: Imagine that the system shown in Figure 1.1 could be redesigned. Maybe there could be two displays, or perhaps part of the human information processing could be done by a computer, or maybe the manual input to the computer system could be made by computer voice recognition. In the redesign of the system the ergonomist would have to consider many constraints. There will be constraints in allocating tasks (who does what), economic constraints, company constraints, and sometimes labour union constraints. The ergonomist will obtain information from those who use the system or

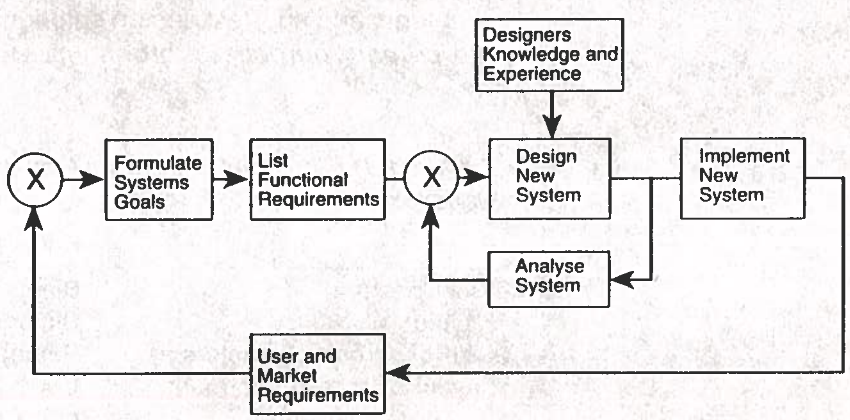

Figure 1.2 Procedure for design and redesign of a system

from another similar system. It will be necessary to consult textbooks and scientific articles, and in the end it may be necessary to evaluate several design options by using rapid prototyping or by performing an experiment with users as test subjects. This scenario leads to our second maxim: *a systematic, interdisciplinary approach is necessary in system design and analysis*.

1.1 Brief History of Ergonomics

In the USA, human factors emerged as a discipline after World War II. There were many problems encountered when using sophisticated war equipment such as aeroplanes, radar and sonar stations, and tanks. Sometimes these problems caused human errors with grave consequences. For example, during the Korean War, more pilots were killed during training than in war activities (Nichols, 1976). This finding focused the interest on the design of controls and displays in aircraft. How could information be better displayed, and how could controls be redesigned and integrated with the task so that they were easier to handle? Many improvements were implemented, such as a pilot's joystick which combined several control functions and made it easier to handle the aeroplane and auxillary combat functions (Wiener and Nagel, 1988). As a result of these improvements and new pilot training programmes, the number of fatalities in pilot training decreased to a fraction (5%) of what they had been previously. Ever since, most of the research in human factors in the USA has been sponsored by the Department of Defense. Consequently, the information available in textbooks on human factors is heavily influenced by military rather than civilian applications of ergonomics.

Some federal agencies have sponsored research on civilian applications: the Federal Highway Administration (design of highways and road signs), NASA (human capabilities and limitations in space, design of space stations), the National Highway Traffic Safety Administration (design of cars, including crash worthiness; effects of drugs and alcohol on driving), the Department of the Interior (ergonomics in underground mining), the National Bureau of Standards (safe design of consumer products), the National Institute of Occupational Safety and Health (ergonomic injuries at work, industrial safety, work stress), the Nuclear Regulatory Commission (design requirements for nuclear power plants), and the Federal Aviation Administration (aviation safety).

In the USA, applications in manufacturing are fairly recent. Eastman-Kodak in Rochester, New York, was probably the first company to implement a substantial programme around 1965. Their approach has been well documented in two excellent books (Eastman Kodak Company, 1983, 1986). At IBM Corporation, interest in manufacturing ergonomics started around 1980. At that time IBM had many human factors experts, but most of them worked on consumer product design. Currently they have turned their interest to computers and software systems. Most of the manufacturing ergonomics has been undertaken by industrial engineers and company nurses. Ergonomics is also discussed in 'quality groups', which comprise a mix of engineers and operators (Helander and Burri, 1994).

In Europe, ergonomics has had a different history. The discipline is particularly well established in the UK, France, Germany, Holland, Italy, and the Scandinavian countries. In the former USSR, just as in the USA, the interest was focused primarily on Department of

Defence activities. There have been few applications on the industrial side, but interest is quickly growing.

In many European countries, labour unions have taken an active interest in promoting ergonomics as being important for safety, health, comfort and convenience. The labour unions are particularly strong in the Scandinavian countries and in Germany, where they can often dictate what type of production equipment is purchased.

One may argue that ergonomics is nothing new. Even during the Stone Age individuals were designing hand tools to fit the user and the task (Drillis, 1963). During the Industrial Revolution there were efforts to apply the concepts of a 'human centred design' to tools such as the spinning-jenny and the spinning-mule. The concern was to allocate interesting tasks to the human operator, but let the machine do repetitive tasks (Rosenbrock, 1983). At the beginning of the 20th century, Frederick Taylor introduced the 'scientific' study of work. This was followed by Frank and Lillian Gilbreth who developed the time-and-motion study and the concept of dividing ordinary jobs into several small micro-elements called 'therbligs' (Konz, 1990). Today there are sometimes objections against Taylorism, which has been seen as a tool for exploiting workers. Nonetheless, these methods are useful for measuring and predicting work activities. The time-and-motion study is a valuable tool if used for the right purpose!

It was not until the 1950s that ergonomics became an independent discipline. In the UK, the Ergonomics Research Society was formed in 1950. In the USA, the Human Factor Society was established in 1957. In 1961 the first meeting of the International Ergonomics Association was held in Stockholm, Sweden (Chapanis, 1990). Today, this umbrella association represents about 15 000 ergonomists in 40 countries.

1.2 The Interdisciplinary Nature of Ergonomics

Ergonomists come from a variety of professional fields. This mixed background is well demonstrated by the membership of professional societies which typically consists of engineers, psychologists, and individuals from the medical profession.

To successfully implement ergonomics in manufacturing design and planning, it is often an advantage to be an engineer. Psychologists, medical doctors and industrial nurses can certainly diagnose many ergonomics problems, but sometimes have an insufficient technical background to suggest how a technical system can be redesigned. Engineers with a background in ergonomics are ideal, as they can analyse different design alternatives for machinery and processes, make trade-offs in the selection of equipment, and arrive at a better solution. Ergonomics is often implemented by work groups where the members have expertise in different areas. Groups composed of workers, engineers, managers and nurses can propose new design solutions. The establishment of such groups is typical of the complex decision-making found in modern manufacturing.

1.3 Ergonomics for Productivity, Safety, Health and Comfort

In many industries ergonomics is implemented primarily as a means of reducing high injury rates and high insurance premiums. In the USA, a worker's compensation premiums often amount to 15% of the salary. This is because there are many back injuries due to materials handling and injuries to the joints in the arms, shoulders and neck due to poor work posture.

During the past 5 years many injuries due to cumulative trauma disorders, carpal tunnel syndrome and tenosynovitis have been reported. At the same time, the number of back injuries remains high, and is still the main cause of industrial injury. It is estimated that the actual cost of musculoskeletal disease in the UK exceeds £25 billion. The reporting of injuries is affected not only by the actual injury, but also by psychological and sociological factors. A study by Hadler (1989) compared disabling back injuries in France, Switzerland and The Netherlands. He observed that not only are the legislative programmes in the three countries different, but the pattern of reported injuries is different. The conclusion was that, in addition to actual injuries, there are several psychological, attitudinal and ethical factors which determine what is reported as an accident or injury and what remains unreported. Individuals will sometimes report particular symptoms because they are 'recognized' by the country's legislation or by society. Different countries might pool injuries under different names. One interesting difference is between VDT operators in the Scandinavian countries and the USA. In the USA there is a prevalence of injuries due to cumulative trauma disorder and tenosynovitis of the hand and of the wrist. These types of injuries are more rare in the Scandinavian countries, where operators complain more about pain in the neck and the shoulder. Certainly there must be a connection between the two, but the prevalent ethic of one country is different from that in the other.

While the reduction of injuries and improved health of workers is a very important reason for implementing ergonomics, it is a fairly negative one. Management is forced to implement ergonomic measures to reduce the injury rate. The author is concerned that this 'negative' message will dominate, so that industry leaders will ignore what could be a much more important driving factor for ergonomics, namely increases in productivity. Ergonomic improvements in workstations, industrial processes, and product design can be undertaken from the point of view of productivity, and there can be tremendous gains. Management is often unaware of poor working conditions, and what types of improvement could improve productivity. Workers in plants and in offices usually adapt to the poor conditions – but the cost is increased production time, lower quality of production and, of course, increased injury rate. The two case studies in Chapter 2 illustrate the potential of ergonomics to improve productivity.

Ergonomics is also highly related to industrial safety. If workers can perceive hazards, if there are relevant warning signs, if controls are easy to use, if work postures are acceptable, if noise and other environmental stressors are reduced, if there is collaboration between workers and management based on mutual understandings, and if there is good housekeeping, then safety will improve. Ergonomics measures regarding safety are somewhat different from the conventional, somewhat mechanistic approach often taken in industrial safety. Ergonomics can improve safety through worker's attitudes, perception, decision-making, and risk-taking behaviour.

Figure 1.3 summarizes how an ergonomics systems analysis can be undertaken with at least three different objectives in mind: (1) ergonomics, (2) production, and (3) quality of manufacturing.

In the design of any complex system it becomes necessary to apply many criteria simultaneously. All these criteria must be at least partially satisfied or, to use Simon's (1969) terminology, multiple criteria must

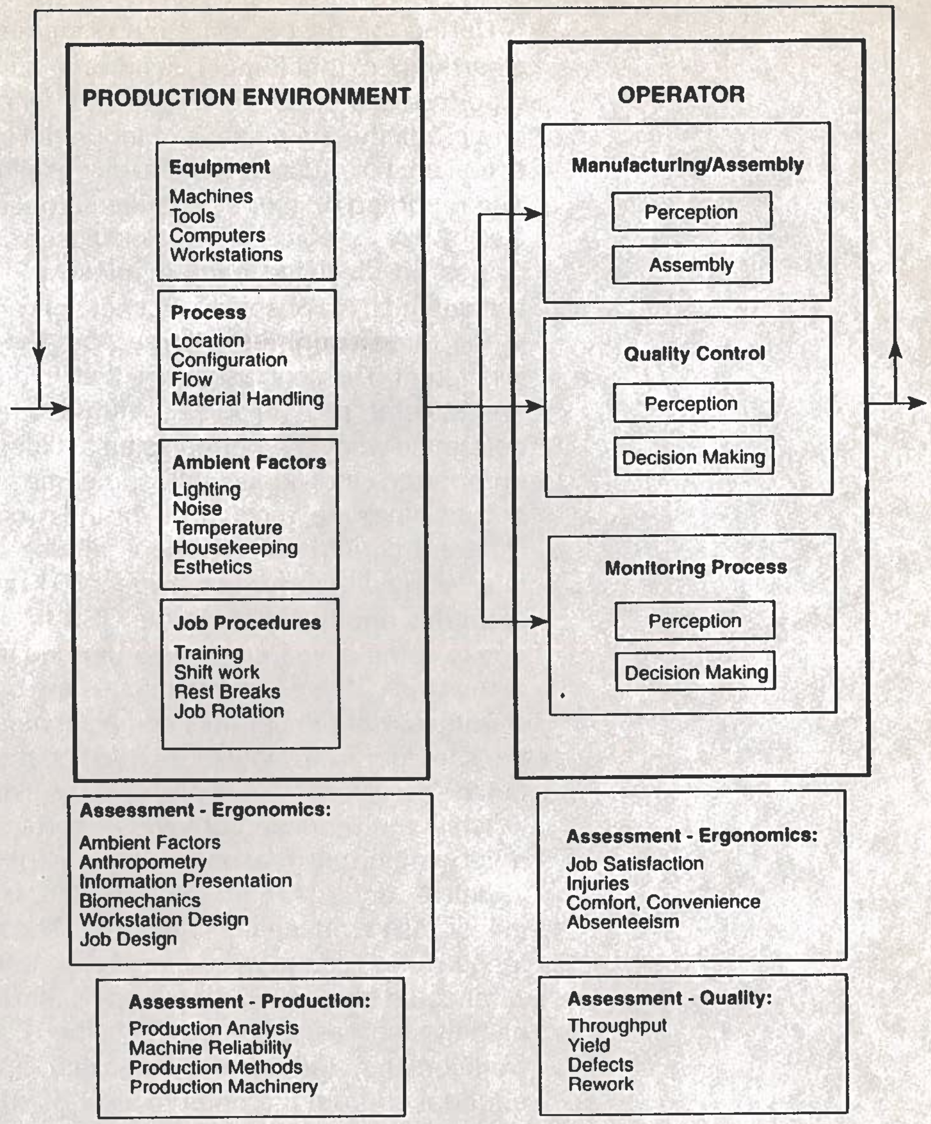

Figure1.3 A production environment / operator system. There are three broad criteria for assessment: ergonomics, production, and quality

be 'satisficed'. In other words, one cannot accept a manufacturing situation where either the production process, ergonomics, or quality of manufacturing are substandard. All assessment criteria must be at a certain minimum level to be acceptable.

The two case studies in Chapter 2 illustrate how ergonomic improvements can be implemented in manufacturing. The ergonomic improvements improved all aspects of system performance. There were no (obvious) conflicts between ergonomics and productivity – a win–win situation, as they say.

ERGONOMIC APPLICATIONS

FOR PEOPLE AT WORK

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Introduction:
Ergonomics is a multidisciplinary subject embracing the optimum use of human resources through balanced interactions between man, machine and milieu (the environment).

The word 'Ergonomics' originated from the word 'erg', which means 'work'. 'nomos' means 'rules'. So, Ergonomics deals with rules of work. However, I prefer to define Ergonomics as the Science, Technology and Art of Man at Work (1). The word 'Man' includes women and children.

The different disciplines which form the basic frame-work of 'Ergonomics' comprise Work and Industrial physiology including Environmental physiology and Industrial Hygiene, Work Psychology, some aspects of Anatomy and Physical Anthropology, Engineering Sciences, Bio-mechanics, Psychophysics, Biostatistics, Management and Human Sciences (2,3).

Scope and Application of Ergonomics:
The subject received great importance during the Second World War when the need for research on various problems arising out of the defence requirements of the country was felt. It was found that many defence problems concerning interactions between defence personnel and equipment required an ergonomic approach for their solution. Since the industrial revolution, the importance has always been placed more on engineering or material technology. It is now-a-days considered, however, that a subject which deals with the problems of man at work involves both the basic and applied sciences.

The multidisciplinary approach of solving a problem was found to be very useful and the subject developed very much during the Second World War, when many of the limiting problems concerning performance and safety of bomber pilots, control and operation of radar, aircraft tracking system, high speed aircraft and other intricate military equipment were tackled by specialists working on Ergonomics.

The aim of Ergonomics is to enable man to work with optimal physical and mental comfort, to use his senses with best effect and to get the best productivity with minimum physiological cost. The subject allows a practical approach to the problem of fitting Man to the Machine and Machine to the Man. Ergonomics is applied in various ways such as (i) improvement in productivity through reduction of work load and improvement in a variety of other factors that cause human discomfort, (ii) improvement in quality and quantity of production through better and simpler working methods, (iii) improvement in working condition(making the work more humane) and (iv) reduction of hazards and improvement in the safety, health and welfare of Man to work.

Historical Background and Modern Development

The term 'Ergonomics' is said to have been first coined by the members of the Human Research Society was later on designated as the Ergonomics Society of United Kingdom, when a good number of accidents of a very similar nature were found to be due to the incompatibility of the controls and displays of aeroplanes and the capability of the pilots, the ergonomists came to the rescue because they could tackle some of the problems of man, the operator, from the view points of physiology and psychology and the performance of the machines from the engineering points of view in the different environmental conditions. All the problems emphasized that the technical developments had reached the stage at which the capacities of the operator rather than the potentialities of his equipment were setting limits to the performance of men and machines working together. To make further progress it was, therefore, necessary that these human limits should be studied and machines should be designed in relation to them. This new approach to the applied aspect concerning man and machines with special reference to environment has made tremendous development in some western countries in various fields such as Agriculture, Industry, Mining, Defence, Sports, Household and Office work, etc.

India being the second in the world with respect to her human resources, it is quite natural that Ergonomics has great potentiality in the utilization of valuable human resources in agriculture, industry, both in the organized and unorganized sectors, in home and in offices , in various other situations in our country. Fortunately enough, the University of Calcutta started a post-graduate course specializing on Ergonomics and Work Physiology with limited resources, as late as 1971-72 and still of remains the only University in India teaching this subject in the post-graduate level.

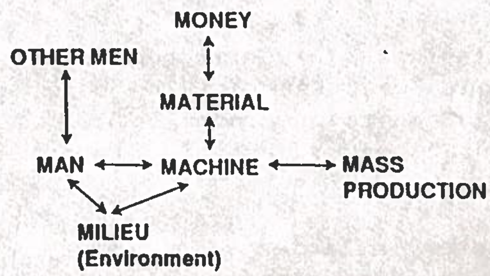
The Indian Society of Ergonomics has also been formed only recently to promote and enhance Ergonomics and allied studies, research and training in India, for the benefit of people at work to improve their welfare and quality of life.

Application of Ergonomics:

In these lectures, an attempt would be made to give some examples regarding the application of Ergonomics in different industrial and other sectors for improving efficiency, productivity, work methods, working conditions, occupational health, safety and working life.

Ergonomics deals with widely differing situations, such as a secretary engaged in typing work, a man working with a hoe or a hammer, a worker controlling a complex machine, an astronaut in a spaceship, a house -wife operating the washing machine and even a boy playing with an electronic toy.

The interactions between the different components of the Man-Machine -Environment System can be depicted easily by the diagram below:



MACHINE
Displays
(Visual) Dials, Counters, Gauges, Lights.
(Auditory) Bells, Buzzers, Hooters, Horns.

Controls
Switches, Knobs, Levers, Joysticks, Cranks, Pedals.

ENVIRONMENT
Fumes, gases, Smoke, Heat, Cold, Glare, Dimness, Noise, Vibration, Altitude & Underwater in mines.

All these components of the Man, Machine, and Environment are taken into account in the **proper** management of particular work with a particular machine in a particular working condition for optimum results of manufacturing a product.

Illustrations of different ergonomically designed implements and equipment for Indian people at work in agriculture, e.g.,"Desi Plough", Sickles for greater productivity and safety, "Float-seat" to reduce back-ache during transplanting, "Head-Gear" for protection against solar radiations and rains, "Leg-Guard" against snake-bites and infections while working in knee-deep water, Overalls for protection against mosquitoes and other insects, "Double Handled Shovel", "Combined Shovel and Hoe", newly designed spade, etc., were given.

Similarly examples with illustrations of different new, ergonomically designed implements and equipment for Indian people at work in industries, e.g., electrode holder for better productivity, welding screens for protection against UV and thermal radiations for manual metal arc welders, blow and gathering pipes for the glass workers against thermal radiations and injuries; safety shoes, protective clothing, face-shield, thermal barriers, etc., for the furnace workers working in hot industries; etc., ergonomically designed cabins with controls and displays for the drivers of railway locomotive, fork-lift and platform trucks and overhead cranes, etc., were presented.

Some Control measures:

1. Anthropometry and Design:

1) The application of static and dynamic anthropometry and other methods in the design of factory buildings, shop-floor layout, design of machine, equipment (controls and displays), tools, safety guards, good house-keeping maintenance, etc.

2. Heat stress and controls:

i) Evaluation of heat stress indices- (a) Corrected Effective Temperature (b) Predicted 4 hour Sweat Rate (c) The belding and Hatch Index (d) Wet-bulb Golbe Temperature Index, etc., to assess the effects of environmental heat stress and protection from such stresses.

ii) Evaluation of thermoregulatory efficiency, acclimatization and heat disorders of workers, comfort zone, upper tolerable levels, maintenance of body fluids and ion balance for excessive sweating control measures, Work-Rest Cycle (Rest pauses)

iii) Control of natural and artificial ventilation, local and other exhaust systems,circulating fans, or man coolers, floor-fans, etc. Insulation of hot surfaces, thermal barrier, shielding against radiant heat, personal protective equipment (segregation or isolation, substitution, etc).

3. Measurement and control of illumination level - adequate natural and artificial lighting, improve poor illumination levels, avoidance of glare, maintain proper colour and contrasts between foreground (task) and adjoining background and environment in the ratio 5:2:1 to a maximum of 10:3:1; Advantage of Human pattern recognition.

4. Acoustic Noise and Control:

Measurement of levels and characteristics of noise-noise level meter,noise dosimeter, Speech Interference level, Octave band analyzer, continuous and interrupted noise, hearing loss; annoyance; performance deterioration; sound isolation (enclosure), insulation barrier; deflector; space absorber; personal protectors ear defenders, ear muffs, etc.

5. Vibration and control:

Measurement of the frequency and intensity of vibration; type of vibration- impact and rhythmic; effect on binocular acquity (25 to 40 Hz) and (60 to 80 Hz), reflex action, fatigue, nervous and circulatory and excretory systems.

6. Chemical factors and control:

Similarly the chemical environmental factors may consist of dusts, fumes, smokes, vapors etc., for which various measures are necessary to eliminate or at least to minimize these occupational hazards.

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GENERAL ERGONOMICS

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Ergonomics is known as the scientific discipline studying the 'man-at-work' systems with work it it most large content as possible including work, home and play.
It emerged as a modern discipline during World War II when the human operator became increasingly the weakest link in modern sophisticated military systems. After the .var, the discipline continued to grow to meet the challenge of civilian applications.
The emphasis in the early days was on human productivity and work physiology. As the discipline matured, other fundamental objectives were recognized, such as the provision for safer and healthier working environments and the improvement of the quality of working life.
Today the discipline encompasses a diversity of interests including cognitive science, human-computer interaction, organizational design and management. The potential of ergonomics is becoming widely recognized by industry, goverment, labour and the general public.
Ergonomics has contributed to the development of industrial workplaces, transportation, aerospace systems, office design, computer hardware and consumer products.

In practice, ergonomics studies the impact of worksystems on man, tries to develop improvement measures which are necessary to bring a balance between workload and human capacity. The aim is to improve health, safety, well being and efficiency of production systems, because in performing jobs, disbalances threathening human integrity may occur..
The main elements in the study objects includes three elements: man, work and at.

Man at Work
(1) (3) (2)

1. Man

Man represents the active males and females; for this presentation the workforce in industry is focussed. The 'man-system' is a cybernetic psycho-somatic feed back system which is oriented to action. It is build similar to an information processing system with the classical elements input, processing and output, the results being used again as input.
Input: man systems has 2 main sources of information:

a) contacts with the environment (sensorial input: vision, hearing, tactile, smell and taste)
b) endogenuous information (fundamental changes in chemistry, pressure and heat balance in the body recorded by appropriate receptors (chemo- baro- and thermoreceptors).

Processing:

All information from both sources is transformed into digital (activated/non activated) signals and send to the processing unit (brain) where several processing systems handle the incoming information.

To the main processes belong: storing information in appropriate memory cells (immediate memory (few thents of a second), short term memory (seconds) and long term memory (undefined). The information can be handled abstractly and modified (eg. adding, multiplying, etc) and mainly a subjective value is given to the incoming information (which information is important, pleasant, annoying, painful etc...).
Action is prepared within the processing unit and the necessary signals (again under coded form) is send to the different systems (organs, muscles, brain, etc...) of the system.

In between input-processing and output, there is a filtering process. The total amount of all incoming information is too aboundant and can not be handled simultaneously. Therefore two systems become active:

a) a passive system. A latent period has been build in in order to process as efficient as possible the information. The hardware capacity is limited sue to the restricted transmission speed in nerves (eg baudrate);
b) an active system, steered by the processing unit. It is known now that for an important part this type of filtering is based on cognitive and non cognitive processes, with the **subjective** value assignment as steering mechanism.

Output:

Concerns all the psycho-mental, intellectual and physiological, voluntary and unvolutary actions of the body.
As in any sophisticated feed back system, the actions are used as input information again, closing the cybernetic model.

Of course for each individual there are particular capacities as well as at the input side, the processing as for the output.

2. Work

Work has different content depending of the meaning and application: phylosophical, physical, mechanical, physiological, economical etc... but in ergonomics it can be defined as a '*sustained physical or mental effort to overcome obstacles and achieve an objective or result*'. Or '*the labor, task, duty, function or assignment that is one's accustomed means of lifehood*'.
Work can be classified in 4 main categories, which are closely linked to the evolution of industrial activities, namely:

- manual work,
- mechanized work,
- automized work,
- robotics.

The evolution from manual work up to the other types is mainly the result of economic strategies focussing the profitmaking of processes (demand-supply principles) by increased quantitative and qualitative productivity.

New and more products are (were) boosting the industry towards higher employment and/or to bring some of the activities to machinery. Undeniable, this policy has been influenced partly by the effects of workload on the human factor.
The higher required efforts revealed the man's weakness: fatigue, inaccuracy, low output quality, biased risk perception, etc.. making of man the unreliable element in a man-at-work system. A fundamental reason why more functions have been allocated to machinery.

The evolution of work has been categorized by Bright and Teanni who recognized 17 different steps of which:

- manual work : phase 1 = activities without tools
  phase 2 = activities with handtools
- mechanization: phase 3 = machine powered tools first use of natural energy, then produced energy
  phases 4 - 7 = development of instrument machines with starting feed-back
  phases 8 - 11 = machines start upon introduction of products and machine starts to pick up information)
- automation: phases 12 - 15 = machine changes workingregime by measuring and interpretes single parameters
  phase 16 = start of autoregulation
- robotics: phase 17 = machine extrapolates incoming data, controls its functioning by interpreting the observed information

- Manual work (fases 1 and 2)
  In the evolution the longest period of lifetime. Since the origin of humankind man used his physical capacity to survive in a hostile world. In producing goods (first limited to own use later, in the development of trading, goods were spread to a wider users'population) the relation between man, product and natural environment was very close.

  Man Materials

  The immediate relation between observation, task and result (eg in pottery where manipulating clay and water allowed to produce a useful utensil with also the impact of the climate) steered closely the input-processing-output system. The intellectual capacities and creativity developed- first slowly, then faster and faster- the design and production of other goods, materials, products and tools using energy from natural and animal ressources.
  Each step of development made the system more complex due to the increasing number of interrelations:

  Man Materials Environment

  Man Tools Materials Environment

However, the main energy is produced by man and the limitation in productivity is the physical capacity: muscular and cardiorespiratory fatigue.

- Mechanization (phases 3 - 11)

In the policy of increasing productivity with the weak 'man' element, in a first phase the most elementary and repetitive movements have been allocated to very simple machines (steam-powered).
The interrelation man-machine became more complex, because of an added element which widens the man-operator from the direct contact with materials and goods: namely the designer. Furthermore, workers' intervention capacity has been limited too (man-operator cannot change machinery).

The impact on man changes too: the highly dynamic activities (cause of muscle fatigue) are allocated now to the machine, but creates a new kind of physical fatigue, namely static muscle contractions due to postural load (eg standing/sitting permently at the machine, using commands often designed at a level which requires hand and arm positions higher than shoulderlevel, etc...). In addition, processing speed is often imposed by the machine (Chaplins' Modern Times) where before work-rest schedules were decided by the employee him/herself.
Instead of solving the problems for the workers, another even more annoying aspect, appeared with consequences for the physiological functions, especially an increased cardiovascular load. The energy produced by machinery, not used efficiently with an overspill of energy, is liberated under form of noise, vibrations and heat. These factors influence the human psycho-somatic information processing system (sensorial system, endogenuous changes as thermoregulation, muscle chemistry etc..). The increasing physical workload as well as the increased mental load (filtering of unnecessary information) and the alienation from the production processes makes from man again the weakest element in the production chain.

Man machine designer

Man machine environment

- Automation (phases 11 - 16)

In order to protect cq to eleminate the weakest element in the system and with regard to the increased production requirements, more and more functions are allocated to machines and the role of the human operator became mainly a 'controlling' function. As such the physiological overload is solved. Moreover, the environmental effects are reduced technically (climate by airconditioning, noise and vibrations by using appropriate absorbing materials) with as a final result that 'man' has to face a reduced 'input' information.

In a cybernetic system input is of prior importance and this is also the case in automized systems. Jobs became boring, without solliciting the physical capacities, without challenging the operator and without any possibility to feed the creativity and independancy. Hence an increasing gap between job and man leading to the alienation from the work.

Man system designer

Man machine designer

Man automate machine - environment

- <u>Robotics</u>: (phase 17)

The final aim in producing without human factor problems is to increase the capacities of machinery, bringing them close to the 'man'-system. The number of functions increased drastically and all negative effects from mankind disappears. Robotics, phase 17. Only a happy few, highly qualified experts are occupied and the system creates a mass unemployment for lower educated and skilled workforce.

- system design
- workrprocess design
- workprocess

Man Robot

- self controlling aspects
- self steering
- self maintaining

The evolution of working systems moved rather slowly in the industrialized world (about 300 - 400 years- 6 to 7 generations) and allowed to build up a kind of industrial culture in which human kind learned to coop with the positive and negative effects of the evolution. In newly industrializing countries the same evolution takes place in a much shorter time (from a few years to a few months). This creates specific problems concerning

a) the development of an own industrial culture as an outcome of the combining working culture and socio-religious backgrounds,
b) the technology transfer from a population (in industrialized countries) for which the design has been made, to the industrializing countries where anthropometric, biomechanic and anthropologic specificities, sometimes completely different than these used in the design phase.

3. Man AT Work

The mutual interactions of an active worker, whatever the kind of work he or she is performing is determined by the external work factors and the individual capacities.
In whatever system the activities take place (manual, mechanized, automized), the external parameters (in principle the same for all performing the same job) are composed by the elements: task, organisation and environment.

Task:	(duty, function) is an assigned piece of work to be finished within a certain time, now usually an 8 hours shift. Factors affecting tasks are: quantitative and qualitative aspects; used tools, equipment, materials (size, weight, grip, ...); intensity of effort, etc.
Organisation:	administrative and functional structure of a job: eg. work-rest schedules, working time, shift work, job-rotation, provisioning materials and goods, team work, etc...
Environment:	to be splitted into physical environment: climate, noise, vibrations, lighting, air quality, dust, ... and biomechanical environment which refers to the anthropometric aspects, dimensions, reaching distances, working heights, etc..

All the different factors are somewhere interacting between each element and the totality of workload (also called 'stressors') affects the exposed workforce.
In case the external parameters are demnading for the different 'man' functions, workload is characterized as overload, in case there is a too low challenge of workers capacities, it is called underload and depends of the design of the worksystem.
Badly or imperfect designed systems offer a wide range of negative consequences as well for man for the industry (factory) as for the society.
For example:

- for man it affects his psycho-mental integrity (accidents, diseases, psychologic strain as burn out syndromes), the evolution may increase the risk for unemployment or indicate that the individual in question is not fitted for the job anymore(eg. Low back pain and material handling), resulting in a lower income (social security, social compensation), a loss of confidence etc...
- For the company: a reduced productivity and efficiency cause a direct financial loss, but also indirect cost may not be underestimated. Increase of absenteism and loss of experience, increasing insurance costs, loss of quality and high drop outs, more important risks for technical breakdowns, higher salary costs to maintain a peaceful social climate, etc...)
- For the society the total cost for the social security system will increase and in combination of higher levels of unemployment it will lead to a lower quality of life.

Reasons the over to develop an efficient riskmanagement in which is tried to find an acceptable balance between workload and the individual capacities of the exposed workforce.

Riskmanagement and ergonomics methodology

Three bodies are determining the risk levels in industry: governmental organisations and institutional bodies, the industry and companies and the working population.
The first could collect all necessary statistics about occupational issues and about social compensations. The inspection teams (labour, occupational health) could give complementary information and departments responsible for standardization and legislation can put a framework within some of the activities must be performed.

Industry and management determine the risks closer to the workfloor by the decisions about working systems, investments in machinery and equipment and in establishing guidelines and procedures (eg safety rules) following which the jobs must be performed.
Workforce is the final link in the chain by acting following the task requirements, the environmental and organisational conditions. The decisionmaking in behaviour is based on experience in the job, on the reliabaility of formal guidelines and rules and in using protective devices.

In this structure and in preventing the negative effects as well as in the persuit of improving the quality of working life, next steps and techniques should be taken into consideration:
1. Screening techniques
2. Selection of critical worksituations, stations and jobs
3. Analysis of the problems and establishment of proposals for improvement
4. Conclusions in setting priorities of actions
5. Reporting and follow up

1. Screening techniques

- Statistics
  The basic rules to set up an efficient risk management depends on the knowledge of the problems, without which no actions can be undertaken.
  As a first and major source, statistical information about incidence, prevalence and gravity of accidents, diseases and direct and indirect economical compensations should be known. This however requires the registration and collection of all data at whatever level of the industrial system: governmental and national or professional organisations, insurance companies, factories etc.
  In the registration procedure, there should be made reference to the working system thus offering absolute necessary information about:
  - frequency and gravity of accidents, occupational diseases, absenteism
  - industrial activity
    - task,
    - organisation and
    - environmental conditions.
  With this information a risk-distribution can be made and the industrial activities which exceed the average riskfactor should be tackled by priority. The same principle can be used to find the most critical companies in an industrial activity, the most critical department in a company, etc...

- The second stept is to screen the most riskful activities cq industries and several techniques can be used to make an objective picture of the problems.
  Observations, check-lists and questionnaires are quite common in use and extremely useful.
  Special attention should be paid to well established questionnaires because many observations and control lists require a basic knowledge of the workprocedures, techniques and equipment as well as an in-depth knowledge about risks, injuries and diseases. As such, the operator is, by experience, the most qualified expert in knowing risks and dangerous aspects of his task. His experience is often a necessary complement to the assessment of external, neutral observers.

2. Selection of the critical workstations.

Based on statistical evidence and on local observations, a selection is made of those stations which should be studied with priority.
Once the jobs are selected a reliable sample, taking into account the workforce's particularities (eg general health status, anthropometric biomechanic characteristics, age, sex, experience, etc), should be chosen in order to be studied about the disbalance between workload and capacities and the number of observations as well as the objectivation criteria will be determined. The revealed risks then could be representative for the total population.

3. Analysis and proposal for improvement.

- Ergonomics methodology

In the ergonomics analysis model, it is tried to find the causes of the problems as well as information which is necessary to sollicit and to convince workforce and management. Because management is mainly interested in objective and abstract criteria (figures) about frequency, gravity, thresholds, legislative directives and standards (if any) these data must be measured and collected. For workforce however, the convincing information has a more subjective character and aspects about annoyance, fatigue, discomfort and pain are much more appreciated than figures and standards.
Both aspects should be taken into account.

The consequences of the 'at' factor, reflected in overload, underload or a balanced load is of prior importance but in starting with the external stressors, normally the most easy to observe and to measure, the evaluation is extremely difficult. There are almost no standards and tresholds referring to 'workload'. In most cases only the health standards are known, but there are really minimal requirements. The standards and directives refer to merely one single factor (eg asbestos) and have no particular interest in other related factors (as for example lung ventilation as a consequence of heavy/moderate.light physical work).
Another essential comment is that a human beings life is extremely difficult to split in professional and private leisure activities. It is therefore important to allocate the workload to the exposure time, the shift and these aspects ar in most cases not available in the assessment of the stressors.
The multifactorial interrelations between task, organisational and environmental factors are too complex to assess the external workload in an easy and simple way. For example: light intensity is expressed in Lux-values and some levels are advised with regard to the visual acuity of a task.

But not with work-rest periods, not with environmental physical parameters as dust, humidity of the air, nor with aspects of reflection and glare which may vary depending of sun incidence etc... In ergonomics the 'Lux' has no meaning, because the 'eye' observes only reflected light which is expressed in candelas per square meter.

The only valid factor is the human being who integrates all work related factors, develops a behaviour which is a resultant the ratio between his maximal capacities and the rest level.

In an ergonomics approach it is tried to measure and to evaluate, besides the external stressors, also the operators reactions, objective and subjective reactions, to the exposed workload. In fact, the human operator is used as a dosemeter, integrating all work load related factors.
In summary the ergonomics methology encompass next factors:

Ergonomics methodology

External factors:
- Task aspects: qualitative and quantitative requirements, speed, repetitivity, tools and equipment, weight, dimensions, grip-facilities etc...
- Organisation: working time, work-rest schedules, shift work, team work but also material supply and evacuation etc..
- Environment:
  - physical environment: climate, noise, vibrations, lighting, air quality, dust, ...
  - biomechanical environment and anthropometrical aspects such as reaching distances, working heights, etc.

The internal or functional load: reactions of workforce to the stressors
- objective data:
  - physiological reactions: heart rate, body and skin temperature, weight loss, muscle tension (EMG), ...
  - psycho-motoric strain: reaction time, accurancy tests, ...
  - psycho-mental strain: attention and vigilance tests
  - behavioural aspects: errors, mistakes, drop outs ..
  - functional aspects: eg. handgrip force, ...
- subjective data:
  - questionnaires about experiencing workload, eg Subjective Workload Index (SWI)

In a first phase, the results obtained for a whole shift are compared to thresholds (ratios between the maximal allowable limits and the rest values) in order to assess in a practical way 4 categories:
- an acceptable load which could be seen as without specific risks
- an attention level: at which some improvement measures should be developed in order to anticipate to the present risks but for which no urgent priority is requested
- a riskful level, at which improvement measures are required within a short term (or almost immediate) and
- a level which is not acceptable in normal working conditions because the risks are quite obvious. Work is not allowed and should be stopped at once, unless immediate appropriate measures are taken to reduce the risks.

From level 3 up, a detailed feed-back analysis of the workforce is carried out in referring to the external parameters (projection of the strain data and measured stressors on the external task and organisational analysis). I most cases, some risk-factors are revealed as critical (responsible for the high average workload) and then the conclusions are quite obvious.

Task
Organisation
Environment - physical
- biomechanical

Physiologic response (***)
Psycho-mental (*)
Psycho-motoric (**)
Behavioural (*)

(***) level 3 - requires short term actions
(**) level 2 - requires long term actions
(*) level 1 - no actions required

In most cases this method is satisfactory to indicate in what way the improvement should be realized. Management and staff know all essential details in the technical structure of the production process which, for the external observer, would take a long time to understand and comprehend all details.
However, when needed, detailed technical and organisational solutions are prepared to remediate the risks following the terms indicated by the used thresholds.

4. Conclusions:
In the conclusions is indicated which measures should be tackled by priority in making reference to the observed risks. The conclusiosn will be supported by the collected data.

5. Reporting
A written and illustrated report is prepared to present the results to management and to workforce or their representatives. The report contains, besides the observed risks, a description of the studied sample, the used methodology and methods (equipment), the evaluation of the data (with graphs) and the conclusions. The proposals for improvement are funded on the data and the way to realize (pro- and contra) will be discussed during the presentation to the participants.

In the evolution of ergonomics as described, some problems occur which put a hypothec on an efficient output of ergonomics actions:
- a first problems is the difference in risk perception between managers and workforce. Managers have more interest for the external factors where legislative and normative aspects are predominent. If the law is respected, the situation for management is estimated as risk-free, and there is no need to change the working methods and procedures.
  However, it is observed at many occasions that workforce adapt an informal way of realizing the job, mostly the easiest way in which, for a neutral or inexperienced observer, quite a lot of risks occur. Sometimes there are, sometimes there are not, but within the formal policy of the company (and possibly also for labour- and health inspection) the behaviour of workers is not acceptable. Both, formal and informal behaviour could be a source of conflicts;

- the second aspect is the fundamental difference between the hierarchic levels. If a risk is known (eg injuries a the fingers/hands; or hearing system) protective measures are foreseen normally in the law or in good working practice and guidelines. (eg circular saws, knifes, and noise) namely using gloves and in the example earplugs. In many cases, for management the problems is estimated as solved when the protective devices are made available. The responsibility of using them, is then put on the shoulders of the operator. However, the practical use is determined by the practicability and comfort in use: if the workers characteristics of hands and the specific needs of the task does not fit with the quality of the glove, he/she never will use it. The same if the earplug is not designed for the specific noise characteristics (frequency) and because no offering a profit (and expecially not when they give annoyance, as heat and dust) the plugs are used in practice ;
- the fast evolution in working systems makes it difficult to calculate the pay-off of the investment and to anticipate in existing working conditions. Within a very short time, machinery and equipment may change drastically, which could be an obstacle to make important investments in modifying the actual existing situation. The aspects of this paralizing situation is stronger when the emphazis is put on productivity rather then on efficiency;
- maybe the most important issue is the establishment of an efficient structure and policy.
  - on what should given the first priority? Short term or on medium or long term actions?
  - who is organizing inspection? Private or government? On which matter? Occupational health or safety?
  - what kind of registration and statistical processing should be established?
  - what kind of guidelines, standards or directives must be adopted and implemented? This issue is of prior importance since previous studies have shown that the standards (mainly established in industrialized countries) are not always representative for people in industrializing countries;
  - what methods, tools and equipment are necessary to realize field research projects;
  - what training is necessary, etc...

In conclusion:

Though ergonomics offers quite a lot of advantages in the strategies for the improvement of working conditions, there is still a long way to go. The major issue seems to be a lack on knowledge and experience about a series of problems. One of the problems in industrializing countries is that they face a huge amount of technology transfer from the industrialized.

Linked to the development of working systems, mainly oriented to mass production in using a high amount of workers (skilled and unskilled) with 'productivity' as the key issue.
However, the evolution in the social security, as observed in the industrialized world, and soon or later implemented in the industrializing world, will bring quite similar problems as those which are faced now in the Western world: increased labour cost and an almost unbearable social security cost. This due to neglecting the micro- and macro-economical aspects of badly designed and redesigned working systems. Occupational diseases and accidents cost an awful lot of billions to the society and the situation will become worse and worse if unemployment, absenteism and turn over have to be added to the social security cost. It comes into a negative spiral evolution of companies offering employment move to other, cheapier and less social evolved countries, making a perfect copy of the problems in the industrialized world.

The way to escape it to anticipate by 'preventive' measures. The disadvantage of a fast growing industrialization is an advantage too: renewal of machinery and equipment, economic growth offers possibilities for ivestments, etc. allow to do so. But only when serious and reliable arguments can be given to management and to workers, because a non used investment due to low quality assessment and inaccurate proposals, can be missed as a hole in the head.
The need for high skilled and qualified teams, well equiped and having the opportunity to work in a progressive open social and political structure, will offer guarantees for an efficient preventive policy.
To develop such a strategy, emphazis should be put (urgently) on following aspects:

1. Training and education at different levels, bringing a qualification an 'expert' levels:
   - general introduction on ergonomics and prevention (2-4 days)
   - technician in Ergonomics (2-4 weeks)
   - academic level - postgraduate (2 - 4 months)
     - M.Sc, Ph.D in Ergonomics and Human Ecology (2 - 4 years)
2. Consulting missions in industry. Organisations with expertise able to tackle problems occuring in man-at-work systems. Short (scientific based) interventions (1 - 2 weeks) which are ver practical oriented and going through the sequence 'problem definition' up to 'reporting' about key issues and proposals for solutions.
3. Research. Applied and fundamental research will be needed for specific problems having an impact on a large part of the population and/or specific for the region. In these projects it should be tried to use a common methodology in order to combine theory and practice.

That is the challenge for the fortcoming decennia and ergonomics with its philosophy, its methodology in combining science and practice, and with its techniques could be an essential discipline in order to coop with the arising problems.

The purchase of a foreign production system
The role of Ergonomics and Anthropotechnology
Synopsis of the Tutorial given in New Delhi on the occasion of the 11th Indian Ergonomics Seminar (November 1996)

A. Wisner *

The technology transfer

The technology transfer is an activity that is very old. But it has taken on considerable dimensions over the last 50 years. What is actually involved is an exchange. Although India is a major importer of technology, it is also a major exporter, hence its membership of the exclusive club of the New Industrialized Countries (N.I.C.) distinguished some 20 years ago by MacNamara. Here, we shall only mention the problems raised in India by imports of foreign technology.

Cultural machines and the Art of the Engineer

Although science is universal, the technology transfer raisers particular problems due to the fact that machines, and even more so machine systems, are cultural in as much as the engineers and technicians who design them think of the companies, managers and workers of their own country when they design a new technical system. Furthermore, the engineer who designs a system imagines it working in the industrial environment of his own country.
More often, a good engineer works through analogy with the situations he knows or thinks he knows according to his own engineering logic - the logic of design - which is unfortunately different from the logic of use which will be that of the users in the real situation of the installed technical system.

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<u>Diversity of technology installation situations</u>

Numerous aspects separate the conditions of use of a technical system in the buyer country from those that exist in the seller country. These differences are due to various parameters:

- geographical: climate, seismic risks, ports, road and rail networks, water resources, electricity supply, etc.
- technical competence: engineers (India trains a large number of top-level engineers), technicians, skilled workers, technical and university centres and experts.
- social resources: housing, schools, nourishment, health system, the extent of endemic parasitic or infectious diseases.

The countries, and sometimes the provinces in a country as large as India, differ from each other both historically and culturally. The age and the level of traditional craftwork and the constitution of a relatively dense industrial fabric are the main elements which play an important part in the success of a technology transfer.

<u>Criteria for a successful transfer</u>

The success of technology transfers can vary considerably depending on diverse criteria.

- <u>Quantity of production</u>. Without aiming to achieve nominal-level production - which is dangerous from the viewpoint of keeping the production system in good working order - there can be deceptions in the field of production volume.

- <u>Production quality</u>. In certain cases, the production quality does not reach a level necessary for it to be exported. This is a situation which leads industrialists to claim protectionism which - in time - is dangerous for industrial expansion. To obtain international-level quality, the technical system must not be <u>downgraded</u> or, worse still, <u>atrophied</u>.

- <u>Keeping the technical system acquired in good condition</u>, often at the price of considerable financial and human effort. Keeping the production system in good condition and preventing its deterioration or its atrophy not only means that great attention must be paid to <u>maintenance</u> - which is not always part of the culture of regions that are little industrialized - but also necessitates customs regulations and financial resources which enable acquisition of the necessary raw materials and spare parts. Sometimes, such a practice is too expensive. But since maintenance remains a major concern in order to achieve a good level of quality and endurance of the installations, it is necessary to search for local supplies of replacement raw materials and to discover the processes for local production of the necessary spare parts. As such, the main demand is that of maintenance, requiring an effort that is sometimes considerable but well within the reach of a country as educated and industrialized as India.

All these considerations show that the purchase of a technical system is not enough to overcome all the difficulties which this purchase is expected to solve. A transfer is only successful if it is active. Therefore a theoretical framework and a methodology must be available in order to achieve the success of this active transfer.

Accompanying the foreign technological system. Comprehension of the system whose purchase is planned requires a considerable amount of work, not only from the technical viewpoint, but also from the viewpoint of the resources used in the country of origin: quality of raw materials, water supply, electricity supply, the extent of use of subcontracting, the maintenance done by suppliers of measuring and analysis equipment, the frequency of use of experts of all levels and the degree of initiative of managers and operators.

Negotiation of the specifications

After this considerable work of comprehension, the buyer is ready to negotiate the specifications so that the system can be adapted to the particularities of the region of India where it should be installed. The modifications requested may be important for the workers, but negligible for the manufacturer. For example: the dimensions of the workstation intended for operators who, on average, are 10 cm smaller than the "standard" operators for whom the system was originally designed. The modifications may be minor relative to the alphabet or the symbols used to guide operators, while bearing in mind that, in all probability, very few of the workers can read English.

The modifications which appear necessary are sometimes more extensive when the raw materials used in India are different from the country of origin and where the water or electricity supplies raise particular problems in the region of India where the system is installed. The reluctance or refusal of the seller to satisfy these modification requests is linked to the fact that, where it agrees to an excessive amount of modifications, it could lose all its profit on the operation which mainly comes from reuse of the hours of study and drawings that were necessary to design the system offered for sale.

It can be seen that this phase prior to purchase is of great importance. It should include:

1) A specific definition of the reason why the system is purchased

2) An in-depth study of the resources of the Indian region where the installation is planned and the difficulties that could be encountered when the system is used in the planned installation. The best way to find out future difficulties is to carry out ergonomic work analysis (E.W.A.) in a similar company in the planned region or a neighbouring region. It is dangerous to imagine that all difficulties, or combinations of difficulties, can be envisaged through a top-down approach. It is much safer to carry out a bottom-up approach in which an in-depth analysis is made of the activities of operators in some key jobs in the company and where the origin of the difficulties of these operators can be found.

3) A study of the technical system whose purchase is planned. This should be done either in the seller country where the system was designed, or in a country similar to the buyer country. It would be wrong to blindly assume that the system works perfectly well in the seller country and that any difficulties that could arise in India are necessarily linked to the transfer. They could quite simply be linked to the inherent weaknesses of the technical system itself.

When one thinks about the questions raised as such, it is obvious that the purchase of a technical system by persons who have no knowledge of its industrial use could have disastrous consequences. As I see it, the Carbaryl plant in Bhopal was a terrible illustration of this. The determination of certain areas of India to industrialize and the search for arrangements that are apparently advantageous from the financial viewpoint, can lead to unfavourable and inextricable economic situations, the result of which can be tragic or, at least, negative.

The place of organization of the company and the work

In favourable cases which, luckily, are the vast majority, the result is only obtained by paying the greatest possible attention to the organization of the work and the company that will be created to adapt the technical system to Indian society. In a way, the organization is the bridge that links the machines coming from another country and another culture to the situation of the buyer country, to India and, more particularly, to the part of India where the plant will be installed. From the viewpoint of the theory of contingency, the fact that the company is located in India should be included as a dominant contingent element of the situation. However, when it is a foreigner who has to produce and take the data into account, there is a risk of the situation being complicated even further due to the superficial representation which this foreigner could have of Indian culture.

Therefore, it appears vital for the organization of the work and the company to be done by a team which includes a majority of Indians. However, we now know that a successful import is that of a system whose various technical elements are compatible and where - even more so - the organization corresponds to the requirements of the system. Therefore, there are two contributions which, in a way, are contradictory. Firstly, the ideal organization according to the designers and, secondly, the organizational characteristics that best correspond to Indian culture, more particularly to that of the region where the installation is planned.

This is only a question of principles, as demonstrated by the Finnish school of engineers with Engestrom following the work of the Russian school of Leontiev. For these authors, activities are performed through actions that can be broken down into operations. In a stabilized system, the actions then the activities themselves take place in a regular way and, to an extent, become automatic, taking on the status of an operation regardless of the complexity of human functioning. But if an anomaly disturbs the situation, the operator, once again, has to break down his activity into actions, or even operations. Yet, in transferred systems, such anomalies often arise. Perrow proposed the means of evaluating this complexity which can provoke defective operation, or even deterioration of the system. The transferred system can suffer from the very difficulties of the transfer which provoke an increased complexity of the task for the operator and, due to this, require an operation that is different from the one planned by the designer that worked rather well in the seller country or in similar situations.

Start-up of the transferred system

It is not simply a matter of forming a mixed seller-exporter team before the transfer. Such a team to be maintained during the installation period of the new technical system and also during the period of normal operation.

The normal character of operation conditions should be stressed since optimal conditions e obtained artificially for the limited period of the test-run by cutting off the water and electricity supplies of the neighbouring town and by doubling the number of specialists. Of course, this is a normal situation and, once this period is over, the dissociated installation team and the I operators can be faced with problems that are impossible to solve.

Often, the possible seriousness of the difficulties encountered with installation of the technical system on a particular site cannot be reduced without the aid of the national, regional or local authorities. The insufficiency of electricity and fresh water supplies, insufficient dimensions or poor equipment the port, not to mention the poor quality of the roads linking the plant to the port or the state, limits of the education or social system, are generally questions which the company cannot solve on its own. Sometimes, they are the subject of tough negotiations with various authorities and company cannot be satisfied with promises.

Conclusion: the technology transfer is a difficult operation

As such, the technology transfer is always a difficult operation, even if the supplier is Indian and located in a major industrial region and when the new system is to be installed, for example, agricultural region which has a less reliable social and industrial fabric. But, as we have seen systematic approach is possible ... and efficient.

Chapter 4

Physical Work and Heat Stress

4.1 Physical Workload and Energy Expenditure

In most Western countries physical workload is no longer as common as it used to be. In manufacturing, hard physical labour has been taken over by materials handling aids, mechanized processes and automation. Legislation has also put limits on the workload that employees can be exposed to. Yet, in some occupations such as construction work, commercial fish netting and logging, workers still perform much physical work. Such work generally involves less structured tasks, and they are difficult to mechanize.

Although physical work activities have become less important in Western countries, they are still common in industrially developing countries, where mechanization does not yet pay off. For example, in the construction industry materials are typically carried by workers. Eriksson (1976) estimated that 200 workers at a road construction site in Bangladesh could move as much dirt manually as one Caterpillar, and the costs were equivalent. Under such circumstances, the national economy as well as the workers' private economy will gain by using manual labour. Although the physical work demands in manufacturing have been reduced, there are still situations which require ergonomic analysis. Many individuals are less capable of physical work, and we are particularly interested in individual differences due to gender and age.

4.1.1 Metabolism

Metabolism may be defined as the conversion of foodstuffs into mechanical work and heat (Åstrand and Rodahl, 1986). In order to be useful to the body, the foodstuff is converted into a high-energy compound adenosine triphosphate (ATP). ATP serves as a fuel transport mechanism. It can release chemical energy to fuel internal work in the various body organs. The ATP conversion process is only about 50% efficient, so that half of the total food energy is lost as heat before it can be used. The ATP energy is used in three different processes. First it maintains chemical processes, such as the synthesis and maintenance of high energy bonds in chemical compounds. Second, it is used to fuel neural processes and muscular contractions to maintain the body functions, such as blood flow and breathing. Finally, some of the ATP energy is used for muscular work. At most, 25% of the energy that enters the body in the form of food can be used for muscular work. This is the upper limit of the energy efficiency for the human body, and it is typically achieved for the large muscles in the body, such as the leg muscles. The 25% efficiency exceeds that of a steam engine and is about equal to the efficiency of a combustion engine (Brown and Brengelmann, 1965). For the smaller muscles in the arms and shoulders an efficiency of about 10–15% is fairly typical.

The amount of energy expenditure associated with a task can be assessed by measuring the amount of oxygen used. The *oxygen uptake* is calculated by measuring the volume and oxygen content of exhaled and inhaled air. This analysis is performed using special instruments. The oxygen uptake is then converted into kilocalories of energy expenditure; one litre of oxygen generates 4.83 kcal of energy. Measurement of oxygen uptake therefore provides an exact assessment of energy expenditure, but it is an elaborate procedure. A much easier, but approximate, method is to measure heart rate. Heart rate gives a fair estimate of energy expenditure in the intermediate range. Heart rate is less suitable for assessing small and very high rates of physical work.

Maintaining the basic body function at rest requires about 1200 kcal/day. This is referred to as the basic metabolic rate (BMR). It includes functions such as the heart (215 kcal/day), brain (360 kcal/day), kidney (210 kcal/day), and muscles at rest (360 kcal/day). On top of maintaining the basic body functions, people usually engage in some minimal activity. This is referred to as leisure activity and does not include work activities. Together the BMR and leisure activities give an average energy consumption of 2500 kcal/day.

Different occupations incur different energy consumption rates. For an 8-hour work day the following values are typical:

- Seated office work, 800 kcal/day.
- Light assembly work, 1680 kcal/day.
- Ocean fish netting, 4800 kcal/day.
- Lumberjacking, 6000 kcal/day.

Ocean fish netting and lumberjacking are unusual because of their very high energy requirements.

Total energy requirements are obtained by adding together the BMR, leisure activities and the occupational rates. A total energy requirement of less than 4000 kcal/day is considered moderate, between 4000 and 4500 kcal/day as heavy, and above 4500 kcal/day as severe.

4.1.2 Individual Differences

As noted above, one of the main reasons for taking an interest in work physiology is to consider variations in work capacity between individuals. One important difference is physical condition (Figure 4.1). A highly trained individual (such as a marathon runner) can sustain 50% of the maximal aerobic capacity for an 8-hour work day, an average individual can sustain 35%, and an untrained individual 25% (Michael *et al*., 1961).

Chronological age is a fairly poor determinant of work capacity. One sure conclusion is that the variability between individuals increases with age. Figure 4.2 shows the maximal oxygen uptake for two individuals from the age of 35 years onwards (Miller and Horvath, 1981). The two curves represent two professors of work physiology (who else would have their maximal oxygen uptake tested so frequently?). From the figure we observe that by the age of 65 years individual A was as fit as ever, whereas individual B had a maximal oxygen uptake of 65% of his high value at the age of 35 years.

4.1.3 Metabolism During Work

Once work has begun, it takes some time for the metabolism to 'catch up' with the energy expenditure of the muscles that are engaged in

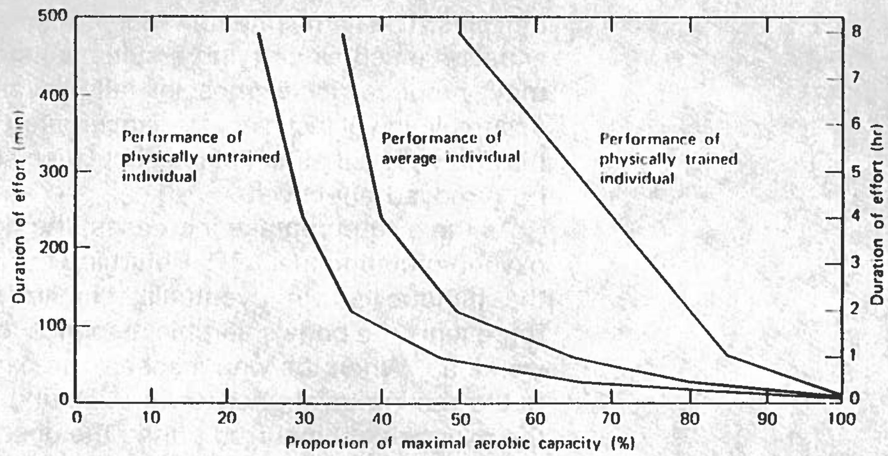

Figure 4.1 The capacity for sustained physical work depends upon the amount of physical conditioning

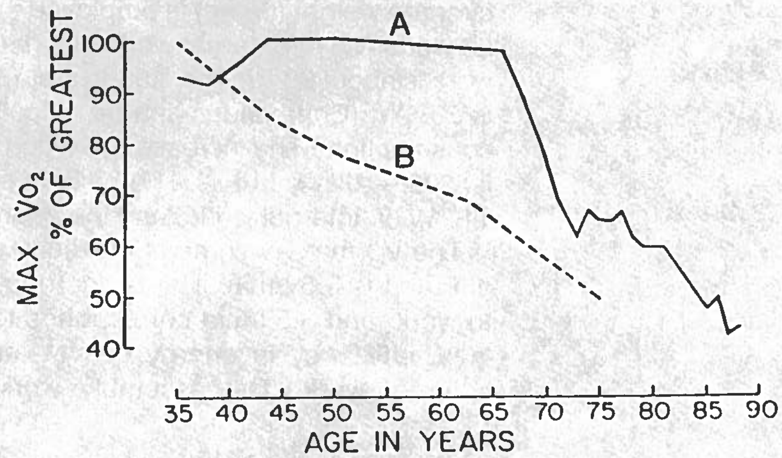

Figure 4.2 Volume of maximal oxygen uptake $\dot{V}O_2$ as a function of age for two individuals. The oxygen uptake is given as a percentage of the greatest value attained for that individual

work. In fact, metabolism does not reach a stable level until several minutes after work has begun. The amount of time taken depends upon how hard the work is, but is typically about 5 minutes. Thus, the metabolic activity (or oxygen uptake) does not increase suddenly at the onset of work. Rather, there is a gradual, smooth increase in oxygen uptake (Figure 4.3). During the initial portion of work, the muscles use a type of energy that does not require oxygen. This type of energy production is known as 'anaerobic' (without oxygen) metabolism. A brief task, such as a 100-m sprint uses primarily anaerobic energy.

Anaerobic metabolism is inefficient. It uses nearly 20 times more food fuel than does the aerobic process. It also produces a waste product (lactic acid) which may accumulate in the working muscles rather than being carried away by the blood. Eventually, lack of available energy supplies, lack of fuel, and accumulation of lactic acid in the muscles involved lead to fatigue and cessation of work. It is generally believed that the accumulation of lactic acid results in aching muscles. The same phenomenon is also noted for static work. In this situation (such as carrying a suitcase) static contraction of muscles may produce local muscle fatigue and aching muscles. The accumulation of lactic acid is exacerbated by swelling muscles, which may partially cut off the blood circulation so that the lactic acid cannot be removed effectively.

As the oxygen uptake increases, the body can use the aerobic or oxygen-requiring fuel ATP. Returning to Figure 4.3 it can be seen that the metabolic rate eventually stabilizes. This steady-state level represents the body's aerobic response to the demands of increased workload. When the work ceases, the oxygen uptake returns slowly to the resting level prior to work. During this slow return after work the oxygen debt incurred during the onset of work (area A) is repaid (area B).

4.1.3.1 Example: Calculation of Relative Workload

With a general understanding of the internal energy conversion processes, an example of the calculation of human work efficiency can be discussed. A 30-year-old man of average height (173 cm) and average weight (68 kg) is employed in packaging. This task imposes 23 watts (W) of external work. His resting metabolic rate just prior to work is about 93 W. The steady-state energy expenditure for this task is 209 W. (Both values can be calculated by measuring his oxygen consumption.) The increase in oxygen uptake due to the imposed task is: 209 − 93 = 116 W. The 23 W of external work therefore imposes 116 W of 'internal work', and the energy efficiency is 23/116 = 20%.

The Vo_2max. (volume of maximal oxygen uptake) for this 30-year-old man is 3.5 l/min. The oxygen uptake can be converted directly to work, and 3.5 l/min corresponds to 1179 W of work. Assuming a 20% efficiency in energy conversion, this translates to 236 W of external work. The assembly work therefore corresponds to a

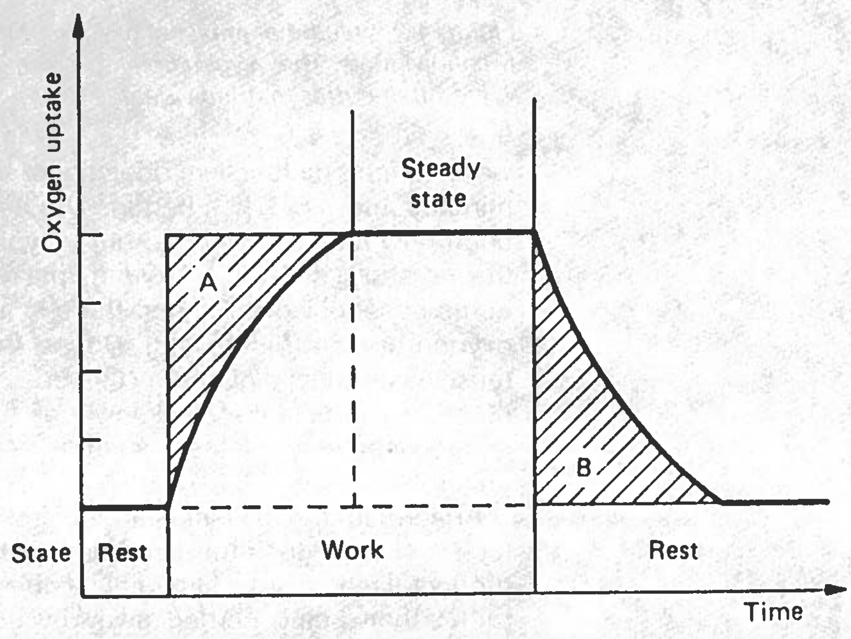

Figure 4.3 Oxygen uptake at the onset of, during and after work. A, oxygen debt; B, repayment of oxygen debt during rest. A = B

23/226 = 9.7% relative load. Compared with Figure 4.1, this is much below 25%, and is not excessive.

This calculation example can be expanded by analysing other individuals with a lower maximal oxygen uptake. For example, a 60-year-old female has a Vo_2max. of 2.2 l/min (Åstrand, 1969). This translates to 134 W of external work and a relative workload of 17%. For an untrained individual with a maximum workload of 25% (see Figure 4.1) this value would be on the high side.

4.1.4 Measurement of Physical Workload

As we have previously noted, it is mostly impractical to use oxygen uptake to assess workload in a manufacturing situation. Heart rate (pulse rate) is a far easier measure. However, heart rate is a good predictor only of workloads of intermediate intensity (about 100–140 beats/min). Simple measurements of heart rate can be useful to estimate if there are any problems with the current level of physical workload. This is illustrated by the following example.

4.1.4.1 Example: Fatigue Due to Physical Workload

The author once visited an automobile assembly plant. There was a female assembly worker who seemed physically exhausted. She was about 45 years of age and of small stature (about 150 cm (5 ft)). The type of work did not seem to put overly great demands on any of her co-workers. However, I stepped up and asked to take her pulse rate. It was running at about 135 beats/min, clearly excessive for an 8-hour work day. She was moved to another, less physically demanding task.

4.2 Heat Stress

Heat stress is often a serious problem in industrially developing countries where work is conducted outdoors or manufacturing facilities lack insulation and/or cooling. Surprisingly, it is often also a problem in southern Europe and the USA. In this section I briefly review the standards on heat stress that have been issued by the International Standards Organization. In no other field of ergonomics are there as many detailed regulations.

4.2.1 Thermoregulation

There are several physiological mechanisms for regulating body temperature. These are under involuntary control by nerve cells in the hypothalamus (a structure in the lower brain), and they maintain the body temperature within a narrow range (about $37 \pm 0.5°C$). This process is known as 'thermoregulation'. As illustrated in Chapter 15, the body temperature exhibits daily variations. It peaks in the late afternoon and reaches its lowest level in the early morning. In order to keep the body temperature within a narrow regulated range, the amount of heat gained and lost by the body over the short span of time must be equivalent. If the body gains an excessive amount of heat, there could be excessive sweating, dehydration, heat stroke and, finally, death may occur.

There are two major ways of adapting to a hot environment: through acclimation and acclimatization (Miller and Horvath, 1981). *Acclimation* refers to physiological changes, such as sweating, in response to temperature. *Acclimatization* refers to more enduring changes in physiological mechanisms that enable an individual to work in extremely hot environments. Repeated exposure to hot environments leads to an improved tolerance to the heat load. During acclimatization there are progressive increases in body temperature, working heart rate and sweat rate. These processes can be completed in 1–10 days of exposure to a hot environment. The time required for acclimatization is reduced when people actually perform physical work in the heat. However, acclimatization to a hot environment can be lost over a period as short as a weekend. People who work outdoors and spend the weekend in an air-conditioned environment will have to acclimatize again. Recovery to the prior level will take about a day. Acclimatization is usually completely lost after 3–4 weeks in a cool environment.

4.2.2 Measurement of Heat Exposure

In addition to the ambient temperature, there are several other factors that effect heat exposure. In order to calculate their effect, the thermal balance of the body may be expressed in the *thermal balance equation*. A somewhat simplified version of this equation is (in $W\ m^{-2}$):

$$M - W = C + R + E + S$$

where M is the metabolic power, W is the effective mechanical power, C is the heat exchange by convection, R is the heat flow by radiation at the skin surface, E is the heat flow by evaporation at the skin surface, and S is the heat storage.

As explained above, the metabolic processes are only partially effective. For the most effective muscles only about 25% of the metabolism (M) can be used for work (W), the rest being used to produce heat and maintain the basic metabolic processes. By expressing the metabolic power in watts per square metre, it is possible to compensate for the body size of individuals. For the calculation of an average individual, one can assume a body area of 1.8 m^2.

Heat transfer by convection (C) refers to the temperature exchange produced by moving air. The amount of convection depends on the difference between skin temperature and air temperature. The radiated heat (R) may be heat radiated by the human body (in the infrared light spectrum). The human body can also absorb radiated heat from external sources. The evaporated heat loss (E) occurs primarily at the skin surface. Moisture is present on the skin because of sweating, and when the moisture evaporates heat is taken from the body surface. The evaporation is a function of air speed and the difference in vapour pressure between the sweat (at skin temperature) and the air. In hot, moist environments, evaporated heat loss is limited by the low capacity of the ambient air to accept additional moisture. In 100% humidity there is no evaporation, which limits the cooling of the body (Miller and Horvath, 1981). In a hot, dry environment, however, evaporated heat loss is limited only by the amount of perspiration that can be produced by the worker. The maximum sweat production that can be maintained by an average man throughout a day is $1\ l\ h^{-1}$. The heat storage (S) should in essence balance at around zero. If S becomes large there is a risk of heat stroke. There are obviously many ways to reduce S – stopping working is one way. Several additional methods are mentioned below in Section 4.2.4.

The metabolic rate for different tasks can now be classified as in Table 4.1 (International Standards Organization, 1989a).

4.2.3 Wet Bulb Globe Temperature

One common method of evaluating heat stress is to record the wet bulb globe temperature (WBGT) (International Standards Organization, 1989b). This index takes into account four basic parameters: air

Table 4.1 Classification of industrial activities in terms of workload and metabolic rate

Activity	Workload	Metabolic rate ($W\ m^{-2}$)
Seated, relaxed	Resting	58
Standing, light industry	Low	93
Standing, machine work	Low	116
Heavy machine work	Moderate	165
Carrying heavy material	High	230

temperature, mean radiant temperature, air speed, and absolute humidity. There are two different formulations for WBGT.

(1) Inside buildings and outside buildings where there is no sunshine:

$$WBGT = 0.7\,T_{NW} + 0.3\,T_G$$

(2) Outside buildings with solar load:

$$WBGT = 0.7\,T_{NW} + 0.2\,T_G + 0.1\,T_A$$

where T_{NW} is the natural wet bulb temperature, T_G is the globe temperature, and T_A is the dry bulb temperature.

These measurements are easy to obtain using the instrumentation illustrated in Figure 4.4. The values of WBGT can now be used to classify the amount of work and to suggest limits for exposure to heat stress (International Standards Organization, 1989) (Table 4.2).

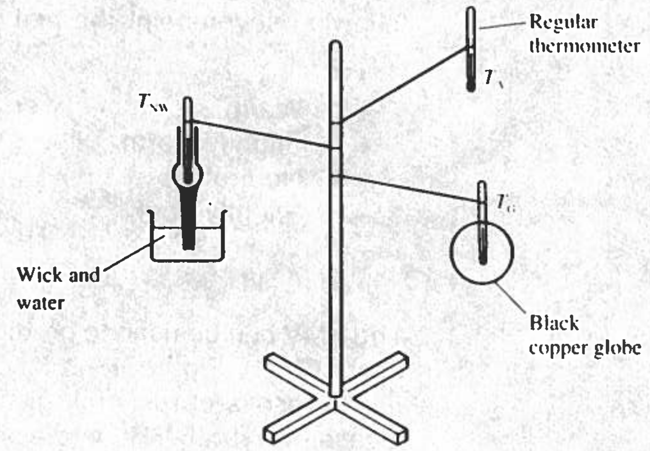

Figure 4.4 The globe temperature (T_G) is measured with a thermometer inside a black painted copper globe; the wet bulb temperature (T_{NW}) is measured with a thermometer put in a wick, the lower part of which is immersed in a reservoir of water; the dry bulb air temperature (T_A) is measured using an ordinary thermometer

4.2.4 Heat Stress Management

A number of ways of reducing heat stress in the work environment are listed below. Note that in each case the practicality of measures must be evaluated.

- Reduce the relative humidity by using dehumidifiers.
- Increase air movement by using fans or air conditioners.

- Remove heavy clothing; permit loose-fitting wide clothing.
- Provide for lower energy expenditure levels.
- Schedule frequent rest pauses; rotate personnel.
- Schedule outside work so as to avoid high-temperature periods.
- Select personnel who can tolerate extreme heat.
- Permit gradual acclimatization to outdoor heat (2 weeks).
- Supply cool, refrigerated vests (containing cooling elements).
- Install local cold spots, e.g. refrigerated rooms for rest breaks.
- Maintain hydration by drinking water and taking salt tablets.

Table 4.2 Reference values of the WBGT heat stress index (adapted from International Standards Organization, 1989)

Workload	Metabolism, M ($W\ m^{-2}$)	Reference value of WBGT (°C)	
		Acclimatized	Not acclimatized
Resting	<65	33	32
Low	65–130	30	29
Moderate	130–200	28	26
High	200–260	26	23
Very high	>260	24	19

4.2.5 Comfort Climate

During the past 20 years there has been increasing debate concerning the maintenance of a pleasant climate in office environments. In order to measure the *thermocomfort* under these circumstances, an index called the predictive mean vote (PMV) is used. The PMV is an index that predicts the mean value of the votes that would be obtained if a large group of persons were asked to evaluate the climate. The following seven-point thermal sensation scale is used:

+3 Hot
+2 Warm
+1 Slightly warm
0 Neutral
−1 Slightly cool
−2 Cool
−3 Cold

The PMV can be used to predict the percentage of dissatisfied office users (PPD) (Figure 4.5).

The results of research gives credence to the saying: 'You can't please everybody'. Regardless of the temperature setting in an office there is always at least 5% of the office workers who are going to be dissatisfied. The International Standards Organization suggests that the temperature be chosen so that the PPD is less than 10%, that is 90% of office users like the climate. During the winter season this translates to an indoor temperature of 20–24°C, and during the summer season to an indoor temperature of 23–26°C. Both these temperature ranges assume sedentary activities, such as are common in an office environment. The reason for the lower temperature range during the winter is that thicker, more insulating clothes are worn during winter time. The ISO 7730 points out that there is not sufficient information available to establish comfort limits for activities that are more physically demanding than seated office work (International Standards Organization, 1984).

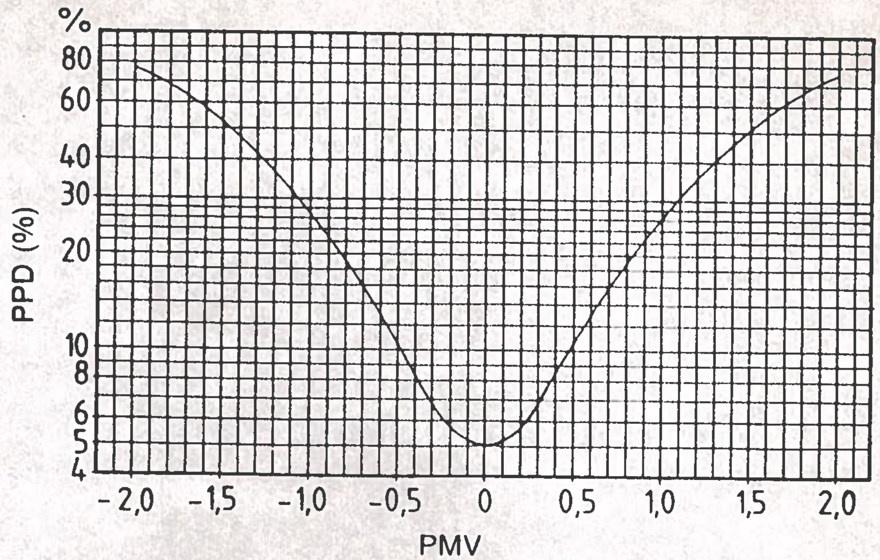

Figure 4.5 The predicted percentage of dissatisfied (PPD) users as a function of the predictive mean vote (PMV) (International Standards Organization, 1984)

4.2.5.1 Example: Discussion of Heat Stress Measures

Discuss the different measures listed under section 4.2.4 that can be taken to reduce heat stress. For each one factor, indicate what entity in the thermal balance equation is being affected.

'Low cost high tech' thermal models.

Can they contribute to ergonomics solutions in industrially developing countries ?

by

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‘Low cost high tech’ thermal models.
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Introduction

Industrially developing countries are developing in the context of the 1990’s and comparisons with the industrial revolutions of the industrially developed countries are limited and will be misleading. The information technology revolution of the 1980’s provides the opportunity for the introduction of ‘new technology’ into both developed and developing countries. The challenge is to ensure that this is both appropriate and effective.

While the philosophy of ergonomics has not changed, information technology has provided new methods and tools for the ergonomist as well as new problems for applied ergonomics to solve. Computer aided ergonomics design and assessment tools are becoming integrated and established as experience in their practical use is gained. Computer models of human thermoregulation are now at a stage of development to allow use in practical application and are routinely used by some ergonomists as their role is established. When under development, the costs involved in providing research data and usable software were large. As the cost of the supporting technology has dramatically decreased and the availability of low cost software has dramatically increased, thermal models have become available to ergonomists world-wide. Just as the question of whether models are valid and usable was and is raised in developed wor d applications, so the same questions and opportunities are appropriate for their use in industrially developing countries.

Thermal Models

Thermal models can be regarded as representations that can indicate the thermal stress imposed upon a worker and the consequent thermal reaction or strain. Simple physical models such as the wet globe (temperature - WGT) or a wet bulb globe temperature (WBGT) instrument are able to provide an index value that can, with experience. be interpreted to provide likely thermal strain. Empirical models have related thermal conditions to the ‘actual’ thermal strain (heart rate, sweat loss, rectal temperature) measured on human subjects. The most extensive model of this type has been developed to predict the responses of US soldiers (Pandolf,1996). This USARIEM (United States Army

Research Institute of Environmental Medicine) model has been developed over many years but, as with all empirical models, it will not necessarily transfer beyond the context in which it has been developed.

Rational computer models of human responses to thermal environments vary in complexity from representations of the heat balance equation for the human body (Parsons, 1992,1994), simple dry heat transfer models of a black sphere (Humphreys, 1974), or cylinder, to complex representations of the human body, its thermoregulatory system, clothing and environment, (Gagge et al. 1971; Stolwijk & Hardy, 1977; Haslam and Parsons, 1988; Werner and Buse, 1988). Parsons (1993) suggests that 'Thermal models are often considered to be those which provide a rational representation of the human body involving both heat transfer between the body and the environment, the anthropometry and thermal properties of the body and a dynamic representation of the human thermoregulatory system". Wissler (1988) notes that models are characterized by the representation of the temperature field within the body, thermoregulatory responses and garments and boundary conditions. These aspects are presented below using, as an example, a modified version of the thermal model of Stolwijk and Hardy (1977). The computer model is dynamic and integrated, however, for convenience, it is presented in terms of its component parts.

The Human Body

The representation of the human body is termed the 'passive' or 'controlled' part of the model. It represents that part of the system upon which the thermoregulatory system operates. The passive (controlled) system of the model is represented by five appropriately sized cylinders, representing trunk, arms, hands, legs and feet, and a sphere, representing the head. Each of these has four concentric layers or compartments representing core, muscle, fat and skin layers, and an 'additional central blood compartment, representing the large arteries and veins, exchanges heat with all other compartments via the convective heat transfer occurring with the blood flow to each compartment' (Stolwijk and Hardy, 1977). The model assumes that the body is symmetrical to reduce the number of calculations, i.e. one cylinder represents each pair of hands, arms, feet and legs. The values are doubled later (Figure 1).

The six segments (five cylinders and one sphere), four compartments per segment and the central blood compartment make a total of 25 nodes. To define further the passive system, the dimensions and thermal properties of each of the nodes are provided from reviews of previous studies. The model presented is based on a standard 1.72 m, 74.4 kg man with a volume of 74.4×10^{-3} m^3. The quantities which define the passive system as used by Stolwijk and Hardy are presented in Parsons (1993). It is emphasized that those values should be replaced for predictions for humans of different sizes .

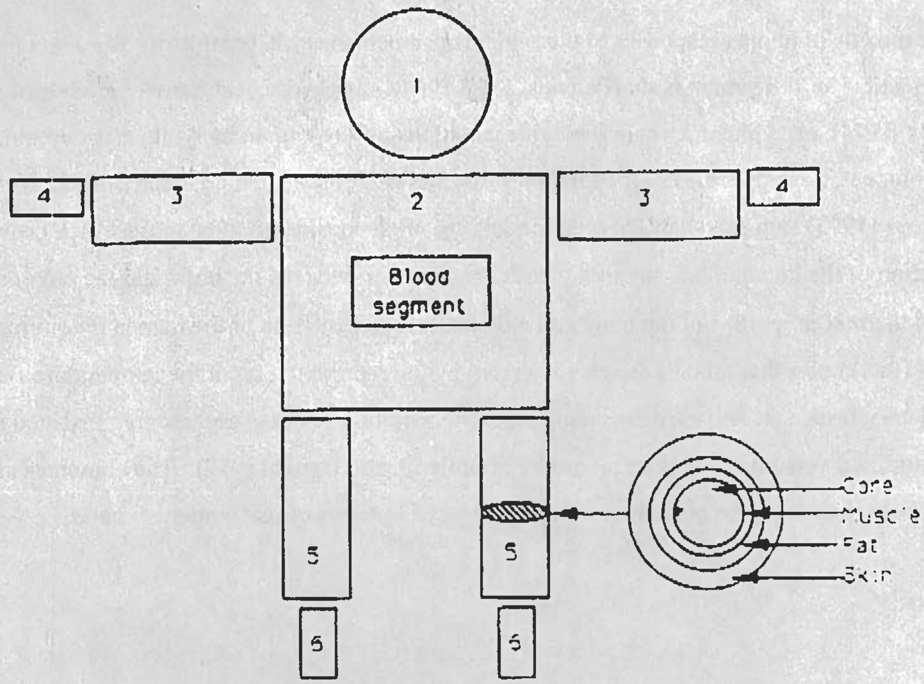

Figure 1. Representation of the passive (controlled) system of the 25-node model of Stolwijk and Hardy(1977). (6 body segments x 4 layers + 1 blood compartment= 25 nodes)

Human Thermoregulation

The human body responds to external stimuli to 'attempt to' maintain internal temperature within some optimum range (around 37°C). If the body tends to become hot then it attempts to lose heat by first vasodilation then sweating. If the body becomes cold then it first attempts to preserve heat by vasoconstriction and then generates heat through shivering. In effect, the system of thermoregulation controls the state of the (passive or controlled) body and is therefore known in the model as the controlling system.

The controlling system consists of a temperature sensing system , an integrating system and an effector system. It is a simple representation of the human thermoregulatory system based on 'set' points. The system is defined in terms of controlling coefficients to determine the strength of vasodilation, sweating and other thermoregulatory effector mechanisms. (see Parsons,1993)

Clothing

The representation of clothing over the passive system of the body can vary in complexity. In its original form Stolwijk and Hardy (1977) proposed a nude model. This is useful for studying human thermoregulation but not representative for practical applications. Haslam and Parsons (1988) added clothing to the model using equations for dry insulation and vapour resistance properties. This 'two parameter' model quantifies properties of clothing in terms of intrinsic (or basic) clothing insulation and intrinsic resistance to clothing vapour transfer where intrinsic values for clothing are theoretically independent of external environmental conditions. It should be noted that a number of assumptions (absence of thermal inertia, pumping, water transfer etc.) are made using this model, and that more sophisticated models of clothing may be required for some applications. The parameters of the clothing model are often represented in terms of 'clothing indices' (e.g. the 'moisture' permeability index, i_m - Woodcock, 1962; or the permeation efficiency factor, Fpcl - Nishi and Gagge, 1970). The resistance of the environment (air or boundary layer) and the increase in surface area due to clothing, are also considered in the equations for heat transfer. How much of the body is covered by clothing is also a consideration, however as a first approximation, the clothing resistance properties are often assumed to be distributed evenly over the body. For a more detailed description see Parsons (1993) and ASHRAE (1993).

Heat Transfer between Human Body and Environment

The heat transfer between the human body and the environment is usually considered as four components. **Metabolic heat** is generated within the body and is transferred to the skin surface. **Dry heat** is transferred from the skin, through clothing to the clothing surface, through the boundary layer to the environment. The environment is defined by the four environmental parameters, air temperature, radiant temperature, air velocity and humidity. Dry heat loss or gain (i.e. by convection and radiation) is 'driven' by differences between skin temperature and the environmental temperatures and involves the first three parameters above. **Evaporative heat** loss is driven by differences between partial vapour pressure at the skin and that in the environment (i.e. related to humidity). The fourth component is heat transfer by **respiration** where both dry and evaporative heat is exchanged within the lungs (core) of the body and transferred directly to the environment.

Inputs and Outputs

Inputs to the model define the model, its starting and 'running' conditions. Outputs from the model are selected from the numerous parameters that define the model at any time after its start. Inputs to the model include definitions of passive and controlling systems and their parameters. In addition, 'starting' (t = o) temperatures and conditions are required. Often an average man is assumed with initial (starting) body temperatures at those that would produce thermal comfort. To predict the response to any thermal conditions the 'user' of the model will be required to input the environmental parameters of air temperature, mean radiant temperature, air velocity and humidity as well as activity level and the thermal properties of clothing. From the data the model can predict human physiological responses (temperatures, sweat rates etc.) over time. The user will have an exposure time of interest and will also determine how often responses are required to be observed. That is, printing data every one second may not be of interest and reporting every ten minutes over two hours for example may be sufficient.

The user will also select which of the model's outputs may be of interest. These are practical points as printing large amounts of data may not be useful. An example of the thermal model, in terms of inputs and outputs, is presented below.

Example of Model 'Run'

Consider a hot environment where men working in the iron and steel industry are performing machine molding and pouring off castings. This would provide a metabolic rate of 125 Wm^{-2} (BS EN 28996, 1994, Parker and Parsons, 1990). Clothing is light with a light jacket with normal vapour permeation properties. This provides an estimate of basic clothing insulation of Icl = 0.8 Clo (0.124 m^{2}°C W^{-1}), and estimated vapour permeation of i_m = 0.4 (ISO 9920, 1994, Parsons, 1993). Measurement of environmental conditions provide the inputs and predicted responses (selected outputs) shown in Tables 1 and 2 respectively. Note that exposure time is for two hours and responses are 'observed' every fifteen minutes.

Table 1: Inputs to Thermal Model : Hot environment,medium work, light clothing

Air Temperature	30°C
Mean Radiant Temperature	50°C
Air Speed	0.25 ms^{-1}
Relative humidity	50%
Intrinsic Clothing Insulation	0.8 Clo
Clothing Permeability index (im)	0.4 ND
Total Metabolic Rate	125 Wm^{-2}
External Work	0 Wm^{-2}
Output Time internal	15 mins
Exposure Time	2 hours

Table 2: Outputs from Thermal Model : Hot environment,medium work,light clothing

Time (mins)	Head core (°C)	Mean skin (°C)	Hand (°C)	Foot (°C)	Skin wettedness (ND)	Metabolic heat Wm^{-2}	Convection + radiation Wm^{-2}	Evaporation Wm^{-2}
	Body Temperatures					Heat Gains		
0	37.0	34.0	35.2	35.0				
15	37.1	35.9	36.6	36.5	0.58	125	25.8	- 74.3
30	37.5	35.4	36.4	36.4	0.95	125	27.8	-112.7
45	37.7	35.7	36.3	36.3	0.98	125	26.9	-118.1
60	37.9	35.9	36.5	36.2	1.00	125	25.7	-122.8
75	38.1	36.2	36.8	36.4	1.00	125	24.5	-125.7
90	38.3	36.4	37.0	36.6	1.00	125	23.5	-128.0
105	38.4	36.6	37.2	36.8	1.00	125	22.5	-130.0
120	38.5	36.8	37.3	36.9	1.00	125	21.7	-131.7

Interpretation

For the conditions defined by the inputs (Table 1), the predicted physiological responses are provided in Table 2 in terms of selected temperatures, skin wettedness and heat gains. Consideration of heat gains (and losses) provides a thermal audit (Parsons, 1992) and explains the physiological responses. Metabolic heat shows a constant heat gain of 125 Wm^{-2}. Because the environment is hot it can be seen that there is an additional heat gain, after 15 minutes of exposure, of 25.8 Wm^{-2} due to dry heat transfer by convection and radiation. Thus there is a heat gain to the body of around 150.8 Wm^{-2}. This is 'offset' against an evaporative loss of 74.3 Wm^{-2} (due to a skin wettedness of 0.58), making a net heat gain (body heat storage) of 76.5 Wm^{-2}. This is reflected in continued increased head core temperature, and skin temperatures (although there are small dynamic adjustments). As exposure time increases the net heat storage continues but at a slower rate as heat gains by convection and radiation show a small decrease due to increasing skin temperatures and evaporative loss greatly increases due to increase in skin wettedness.

In terms of acceptable strain, exposure time could be restricted to 60 minutes as head core temperature approaches 38°C, World Health Organization limits for internal body temperature (WHO, 1969). Dehydration is also related to evaporative loss and could be used in interpretation. Based upon what is physiologically acceptable therefore, the model has been used as a tool for evaluating the clothing risk. This would be appropriate where clothing, activity and environmental conditions were 'fixed'. Where they were not, then helpful adjustments to the working conditions could be used to select clothing and design the work for acceptable risk. Such conditions could then be defined and used as controls.

Application to Industrial Developing Countries

The rational model described above is a typical example of a lumped parameter model and has been specified in terms of an 'average' US male. This need no necessarily be the case. The model could be defined to simulate responses of Indian workers, for example. Changes in anthropometry could be made as well as in thermoregulatory response and tolerance if thought appropriate. Interpretation of responses could also be adjusted. Although this model would be of use to the applied ergonomist, just as in the developed world, the context, culture and behaviour of workers will be important. In particular, models of human behaviour are needed for both developed and developing countries.

Conclusion

Thermal models are a potentially 'low cost high tech' methodology that could be usefully developed and used in industrially developing countries to suit the culture of those countries and in parallel with their use in developed countries.

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ERGONOMIA

WWDU'94

WORK WITH DISPLAY UNITS
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AULA MAGNA, UNIVERSITY OF MILAN
OCTOBER 2- 5, 1994

In copertina
"Santi". Scultura di Letizia Minotti, foto di Santi Caleca.
Con le nuove tecniche sopravviverà lo spirito?

Sommario

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Work with display units in perspective. To the better or worse?

Bengt Knave and Per-Gunnar Widebäck

In a broader development perspective, with all our efforts lasting more than twenty years, we now bring forward the question: Does the VDT working environment show real progress? We can realize some improvements, for sure. but at the same time changes for the worse do appear. These are the questions on which the paper will focus:

- Does society take its responsibility in desired action programmes?
- Does education in school reflect the work requirements and the society we want to live in?
- Have only the machines improved and not the working routines and environments?
- What are the major research areas. of yesterday. today and tomorrow?

Back to the 1970's

Twenty years ago VDTs became the symbols for interactive work with computers. The new technology was scarcely spread over the workplaces. Applications were studied within military projects. In offices we could find clusters of programmers and operators with tasks like data entry, word processing. and data base interactions.

The VDT operator became a specialist worker. How was the new tool to be used efficiently? The curiosity of what the new technique could do for you engaged developers. Experience was exchanged and gathered to manuals and other guidance. Already in the mid-seventies standardization efforts. especially within Germany, were substantial.

The implementation of the VDTs to the offices, however, brought complaints from the operators. often going to the company health officers. Therefore. VDTs sonn began to be a problem area within occupational health services. The hardware problem dominated: keyboard design. image quality. lighting and vision aids for the operator: and also radiation. Breakdowns and respond times of the system were discussed. Ergonomic measures were taken but not enough to ensure good working conditions.

Conferences in Milan 1980 and Turin 1983

Around 1980 the interest was more directed toward work posture, work organization. stress and monotony. Postural discomfort of the neck. shoulders and upper parts of the back. neck-back disorders related to viewing axis, head position and furniture height, were in focus. In Turin different solutions of work postures were items that caused vivid discussions. The discomfort among men and women and the accommodation of the eye during and after longer periods of VDT work attracted attention in large field studies.

WWDU '86

The planning for the conference in Stockholm started in summer 1983. The long marketing period of three years was evaluated as necessary for running a new large conference. The aim was to concentrate efforts on gathering knowledge to state and solve problems: to inspire research within special field as well as interdisciplinary attacks. We also found that one conference is not enough because you need subsequent conferences to reach scientific results. The conference in Stockholm and the following 1989 in Montreal and 1992 in Berlin gathered attendees with a professional interest in occupational health. occupational hygiene. image quality and vision. work physiology. work place design. work organization. or human computer interaction. The scientific heritage of the wwdu conferences is kept in the Selected Papers published a year after each conference.

Typical for the event - above all the rest - was the amount of large-scale and important field studies that were presented and discussed. The political interest was bound to electromagnetic fields emitted by the VDTs. Image polarity was treated in both image quality and lighting sessions. Alternative display technologies to CRTs and functional disabilities were sessions that were brought in at late a stage. Sedentary work and physical inactivity imply the importance of work organization when designing the work and work place. Reported postural discomfort. eye discomfort and stress manifestations were often found to be related to work organization problems. Also in the relay to Montreal there was a demand for continued research: pregnancy outcome, skin disorder, alternative VDT technologies and human computer interaction.

WWDU '89
Work with VDTs as causing a higher risk of adverse reproductive outcomes could not be confirmed after the discussion of several epidemiological studies and some research hypotheses. The research on electromagnetic fields continue however, and we now know that we definitely have to go for more a complicated relationship between variables! The conference featured reviews in different areas. Still the central issues concerning health are on visual and other ergonomics factors, job design and work organization. Ageing as well as VDTs in developing countries became important areas. VDT in schools became a new topic. Quality of life was addressed.

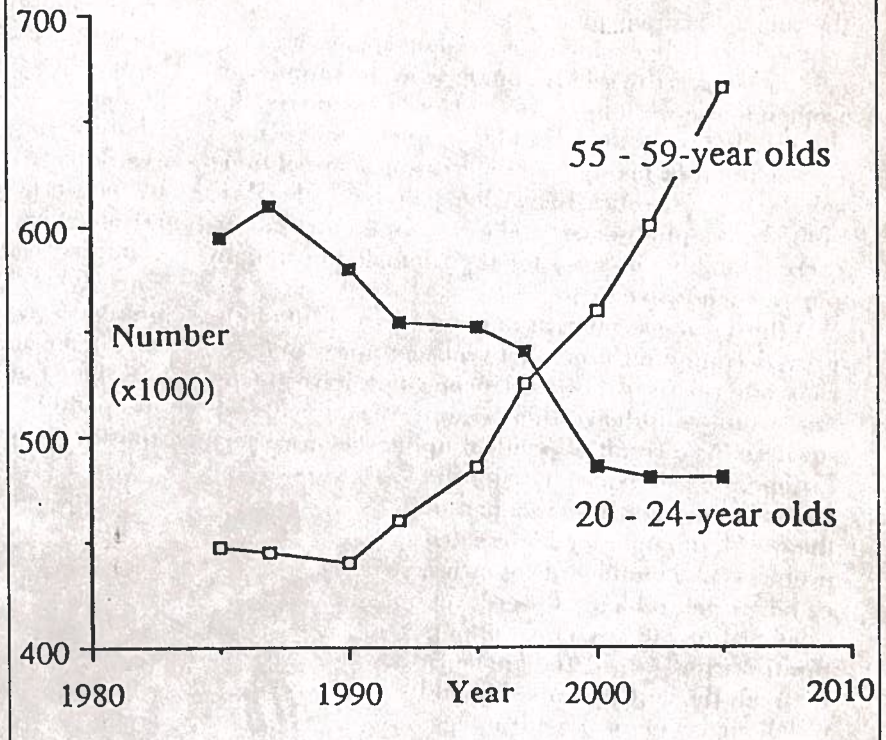

Fig 1. Supply of labour for 1990-2005

WWDU '92
In Berlin topics connected with the new technique appeared as video and hypermedia for communication within group, Kansei engineering and multimodal interfaces. This meant that analysis of relations of variables in complex situations were now standard. The reviewing sessions were frequent. Strategies for prevention and some other sessions indicated recommendations which could ensure better guidance. And in the year "Europe 1992" the interest in regulations and standards was not less than before.

WWDU '93 Tokyo Seminar
Last year WWDU had two technical meetings in Tokyo: "Human sciences on virtual environment" and "Hypermedia". A round table of Japanese scientist ended up with recommendations of agenda topics for wwdu conferences, as for instance forecast and evaluation of influences of new technologies, evaluation of handwritten input, ethics standards, ethical and cultural differences in research and evaluation of electronic publication and virtual environment.

WWDU '94
Now in Milan we expect new items and statements. It is obvious that we are looking at characteristics connected with the vdt worker. his task, equipment and environment, and their interactions. The complex situation of the worker is now mapped. So. the health and well-being effects may be calculated.

There are still clusters of operators with an intensive VDT work load. Some of the monotonous jobs have diminished in frequency. however. or are distributed as a natural part of the job. Nowadays. it is a real problem to get a suitable control group of non-VDT users for field studies because of the widespread use of VDTs.

More elderly people, fewer young people, more women and more migrants in the work force
Age changes in the general population obviously affect the supply of labour. Population trends in Sweden, with corresponding changes also taking place in other parts of Europe, have been unambiguous. There will be a major increase in the number of older people in the work force by the end of the 1990s and a corresponding decline in the number of young people in working life (Fig. 1). There have been speculations about whether this means that the work force will acquire more people with handicaps and chronic diseases and that employers will be forced into fierce competition with one another for the dwindling supply of young employees. This is valid under the presumption that the unemployment rate is low, but unfortunately this is not the case for the time being.

We know that young people in the future will be increasingly better educated than was previously the case. Recent attitude studies have shown that young people have heightened expectations about work and are more critical in their perception of work hazards. The studies have also shown that the work environment, and not just the work itself, is an important factor in the choice of employment.

Another change which has become apparent in recent decades is the relative increase in the number of women in the work force. In the Nordic countries, the increase has been considerable, to some extent because men are now taking on an increasing share of household responsibilities. In Sweden, men have a legal right to leaves-of-absence to take care for their children, thereby making it easier for their female partners to pursue their own careers.

A third change concerns migrants. As a result of improved communications between countries and various other parts of the world, people now have greater opportunities to leave their countries and settle elsewhere. As a result of political upheavals in eastern Europe, we can expect a major increase in migrants from that part of the world. Immigration has created problems in a number of countries, eg language problems, lower levels of education etc. Increased opportunities for a better balance between the supply and demand of labour is one of the advantages conferred by immigration. In the long run, the advantages are likely to outweigh the disadvantages.

So, to state that computer systems should be adapted to users' level of knowledge is not enough. A challenge for the society is that it should be able to educate its members up to levels qualifying them to participate fully in worklife and in society. Education in school for children is as important as for adults.

"Winners and losers"

As the psycho-social effects of computerization the concept of "winners and losers of computerization" was introduced. Some people will benefit from the "new" technique (new stimulating work tasks, better paid than before) and others won't. The "losers" will instead get the monotonous, dull, low-paid jobs.

In Sweden data processing know-how has been traditionally regarded as a "technical" subject for math teachers and students primarily interested in learning how computers work. The courses still cover operative systems and programming. An effect of the Swedish system is that an "A-team" of compulsory school students with computer and program experience acquired at home or elsewhre developed. But many other students, girls in particular, may enter working life or higher education with virtually no knowledge of computers as working tools. This could relegate such students to the labour market's "B-team". Of course, we have to be on the alert to avoid the segregation of winners and losers starting already in school.

Criteria for acceptable work load

The development of equipment and systems is important. We have to develop better standards and also anticipate continuous competition between producers. However, criteria for acceptable work load for different human functions are a challenge under development.

Mental stress has been shown to be associated with what is called high and low mental workload, where "workload" is defined in terms of the demands made by the work task and the capacity with which workers are able to accommodate these demands. Mental stress can arise as the result of "overloading" (demands > capacity) or "underloading" (demands < capacity). Cognitive aspects of software and the user interface and the organizational design of systems and networks are capable of affecting the mental health and well-being of operators and represent factors to which attention must be devoted.

Work postures, tasks and design are closely related to work organization and work tasks. A recent study of VDT work and sickness absenteeism showed that groups with a low degree of control over their work and few opportunities for obtaining new skills have higher rates of absenteeism than people with greater skills, greater control and more varied tasks. Analysis has also demonstrated the existence of a relationship between the time spent on VDT's and rates of absenteeism.

The risk presented by excessive sedentary work should also be noted. We now know that musculoskeletal disorders develop both when the physical workload is too great and when the physical workload is too little. Computerized work must be modified to reduce sedentary components.

Conclusions

It is clear from what have been stated above that there is more to be done as to information and action programmes where the society takes responsibility. A good example of this is student education at school, where the risk of segregation into winners and losers is imminent. It should be said, however, that machines and working routines have improved during the years, but we still face problem areas, e g eye discomfort, electromagnetic fields and health problems, and mental work load and work organization. Here we have the major research areas of today - and possibly also of tomorrow.

A conclusion is: we need the Work With Display Units conferences as a forum to discuss all this in a perspective which stresses the health and well-being of the VDT worker. ●

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Electric and magnetic fields and health outcomes – an overview

by Bengt Knave, MD[1]

KNAVE B. Electric and magnetic fields and health outcomes — an overview. *Scand J Work Environ Health* 1994;20 special issue:78—89. In recent years interest has increased in the biological effects and possible health outcomes of weak electric and magnetic fields. Studies have been presented on magnetic fields and cancer, reproduction, and neurobehavioral reactions. Epidemiologic studies on childhood leukemia and residential exposure from power lines seem to indicate a slight increase in risk, and excess leukemia and brain tumor risks have been reported in "electrical" occupations. In spite of a large number of experimental laboratory studies, however, no plausible and understandable mechanism has been presented by which a carcinogenic effect could be explained. International guidelines state that the scientific knowledge on magnetic fields and cancer does not warrant limiting exposure levels for the general public and work force down to the low levels of everyday exposure. Study results on reproduction, including adverse pregnancy outcomes, and neurobehavioral disorders are generally considered insufficiently clear and consistent to constitute a scientific basis for restricting exposure.

Key terms — cancer, environmental exposure, neurobehavioral reactions, occupational exposure, pregnancy outcomes, restriction of exposure, review.

In recent years research interest has increased in the biological effects and possible health outcomes of low-frequency electric and magnetic fields. In Soviet studies of substation operators certain effects of electric fields on health were already reported in the 1960s, neurasthenic symptoms, cardiovascular and gastrointestinal disorders of a functional nature, and temporary changes in blood cell composition (1—3). Follow-up research in other countries, however, did not verify the Soviet findings, and interest in electromagnetic fields diminished. (For a review, see reference 4.)

At the end of the 1970s and beginning of the 1980s interest was reawakened with the publication of American studies linking childhood leukemia to magnetic fields from power lines (5) and leukemia and brain tumors to workers in "electrical" occupations with exposure to low frequency magnetic fields (6). In 1979 the first reports were published — also in the United States — about clusters of adverse pregnancy outcomes among women working at video display terminals. (For a review, see reference 7.) Suspicion was cast on the magnetic field emitted by the screens of the terminals, as, in some studies on laboratory animals, teratogenic effects were reported if animals were exposed to magnetic fields similar to those of video display terminals.

Other possible health effects related to exposure to low-intensity electric and magnetic fields have also been reported. Nonspecific skin problems and neurasthenic and neurobehavioral disorders (called "hypersensitivity to electricity") were described for "sensitive" persons in the vicinity of video display terminals and other electric and electronic office equipment, electrical machines, and power lines (8).

During the past 15 years a vast number of experimental and epidemiologic studies on biological effects and possible health hazards has been published. The studies have been reviewed and evaluated for regulations on exposure restriction (9—12). This overview presents relevant background information and recent scientific studies, and also criteria for and discussions on restricting exposure.

Low-frequency electric and magnetic fields

Physically, electric and magnetic fields can be defined as part of the low-frequency electromagnetic radiation spectrum. The photon energy available is proportional to radiation frequency and is thus inversely proportional to its wavelength (ie, the higher the frequency or the shorter the wavelength, the higher the energy). At the high-frequency end of the spectrum, with wavelengths <200 nm, the photon energy is so high that it suffices to break chemical bonds and thereby ionize chemical compounds (ionizing radiation). Wavelengths of >200 nm are known as nonionizing radiation, which may also give rise to biological effects, but then due to other mechanisms.

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Radiation of wavelengths between 400 and 800 nm can, for example, be detected by special receptor cells in the retina of the eye (rods and cones), and it is experienced as visible light. Longer waves, like infrared waves, microwaves, and radio frequency waves, are biologically active in one way or another in relation to their thermal energy (ie, molecular vibration).

The low-frequency electromagnetic fields that are referred to in this context have such low frequencies and such long wavelengths that their low photon energy contents can in no way elicit any biological effects through the aforementioned mechanisms. As far as is known today, there are no special receptor cells or structures that form a missing link between the fields and possible biological effects — with the possible exception of the very recently demonstrated special magnetite crystals in different human cells (13, 14).

The low-frequency fields have two components, an electric field (proportional to the voltage) and a magnetic field (proportional to the strength of the current). Strictly speaking, there are no "electromagnetic" fields, but, instead, there is an electromagnetic force effect that is the sum of the forces of the electric and magnetic fields. The electric field strength is measured in volts per meter, and the magnetic field strength (magnetic flux density) is recorded in teslas.

The low-frequency fields can also be divided into two subgroups as regards frequency. By definition the 50 to 60 Hz frequencies are called ELF (extremely low frequencies) and the higher frequencies in the kilo-Hertz domain are called VLF (very low frequencies). Most often, though, the ELF fields occupy the center of attention because the electricity net frequency is 50 to 60 Hz. Residential exposure is more or less always in the ELF domain, occupationally however the fields sometimes vary in frequency. In front of a video display terminal, for instance, the operator is normally exposed to 50—80 Hz fields (ELF) and 15—20 kHz fields (VLF).

Exposure to electric and magnetic fields

Exposure to electric and magnetic fields occurs throughout society: in the home, at work, in schools, and by electrically powered means of transport. Wherever there are electric wires, electric motors, and electronic equipment, electric and magnetic fields are created.

At home

There are many sources of electric and magnetic fields in the home; television sets, refrigerators, electric stoves and ovens, microwave ovens, electric razors, hairdryers, clock-radios, electric wires, radiators and electric blankets form magnetic fields in their immediate environment. A feature of these fields is that exposure falls very rapidly with distance from the source. If one uses an electric razor, for instance, there is a strong magnetic field in the immediate vicinity of the machine, but it is hardly detectable a few meters away. As only low voltage is used in the home, electric fields from household appliances are negligible. In some houses stray currents occur due to an imbalance in the electrical grounding system of the building, and this occurrence might give rise to increased magnetic fields in limited areas of the house.

If the house where one lives is under or near an overhead power line, it is exposed to both electric and magnetic fields. The outer walls of the building screen off the electric field, and therefore there is no indoor exposure to the outdoor field. A magnetic field cannot be screened out, and because of its wide dispersal (several hundred meters from the power line), the level of the magnetic field remains more or less the same irrespective of where one is in the house.

At work

Certain occupational groups are more exposed than others. The following list presents "electrical" occupations in the order roughly corresponding to the degree, from highest to lowest, of exposure to magnetic fields during a workday: welders, linesmen and substation operators (electric power industry), electronic engineers and technicians, locomotive engineers, train conductors and railway station workers, radio and television repair men, foundry and furnace workers, miners, and telephonists, telephone repairmen and installation engineers.

A welder is thus more exposed than a linesman who works with power lines. Naturally people in other occupations can also be exposed, for example, exposure to both electric and magnetic fields in the proximity to a video display terminal. To reach the levels in the list one would, however, have to be within decimeters of the screen. From occupational studies in which dosimetry has provided exposure information, 0.1 μT has been found to represent an average magnetic field level for a workday.

Electrical vehicles

As the preceding list indicates, locomotive engineers and other railway and railroad staff are among the occupational categories exposed. Passengers on long-distance and commuter trains are also exposed to magnetic fields when in transit, if trains are run on alternating current.

Induction of current in the body

Both electric and magnetic fields induce current in the body. For a person standing under a 50- or 60-Hz power line, the current induced in the body by the magnetic field is much less than the current induced by the electric field. In addition, the current induced in the body by magnetic fields is considerably weaker than that occurring in the body in connection with normal heart and brain activity (ie, 10 mA · m^{-2} and 1 mA · m^{-2}, respectively).

Health effects under study

Cancer

The discussion of possible health risks of low-intensity low-frequency electromagnetic fields started in the 1970s with interest mainly on the electric component of these fields. At the end of the 1970s, and in the 1980s, scientific interest shifted towards the magnetic fields, especially their relation to carcinogenesis. The reason for this shift was the appearance of several epidemiologic reports presenting data indicative of an increase in the incidence of leukemias in children (5, 15—17; for a review, see references 11, 12, 18, 19) and adults (20—24) living in the vicinity of power distribution lines and of leukemias (6, 25—37) and brain tumors (29, 34, 31, 38—42) in "electrical" occupations.

Residential studies. Of the possible cancer risks discussed today, leukemias in children living close to power distribution lines are best documented. The "early" studies between 1979 and 1991 showed increased leukemia risk ratios only when using surrogates for exposure (eg, the Wertheimer-Leeper code) (5). Field measurements of the magnetic fields did not relate to cancer risk.

Very recent case-referent studies from Sweden and Denmark with improved techniques for exposure assessment have — in an overall perspective — strengthened the evidence of a possible cancer risk for residential exposure (43—45). The Swedish study found a doubled risk for childhood leukemia above a calculated historical level of 0.2 µT. The Danish study found a positive association for all major types of childhood cancer combined above an average exposure level of 0.4 µT. At 0.25 µT, and above, no statistically significant increases were found; the odds ratio for leukemia was 1.5 [95% confidence interval (95% CI) 0.6—4.1]. A Finnish residential cohort study (46) found no excess risk, however, of overall cancer, leukemia, lymphoma, or nervous system tumors in children exposed to residential magnetic fields close to transmission power lines. The standardized incidence ratio was 1.6 (95% CI 0.3—4.5) for leukemia above an exposure level of 0.2 µT. Therefore there are apparent differences between the results of the Scandinavian studies. On the other hand, the leukemia risks found do not necessarily need to be contradictory. The Danish and Finnish studies had a lower precision than the Swedish study because of differences in study population sizes.

The Scandinavian residential studies referred to may indicate a doubled leukemia risk above 0.2 µT, corresponding to a distance within 50—100 m from an overhead power line. The number of childhood leukemia cases under power lines are few, however, and the risk is therefore low compared with that of other environmental hazards in society. It has been calculated that each year in Sweden there are two cases of childhood leukemia under or near power lines. One of these cases is attributable to the magnetic field risk, if any.

Occupational studies. During 1993 three occupational studies were published, from Sweden (47), Denmark (48), and the United States (49). In the Swedish case-referent study, in which the exposure assessment was made by individual dosimetry measurements, a magnetic field strength above 0.2 µT gave a double risk for leukemias and brain tumors, for the latter for younger men only. Of the leukemias, chronic lymphocytic leukemia was in excess, but not acute myeloid leukemia. In the Danish cohort study men with continuous, but not those with intermittent, exposure had an excess risk for leukemias, with equal contributions from acute and other leukemias. In the American study on electric utility workers (nested case-referent study), fields were measured for the exposure assessment. No risk increases in leukemias or brain tumors were found; however, the risk and interval estimates were limited by low precision. No distinction was made between the leukemia subtypes.

Occupational exposure to magnetic fields is generally higher than residential exposure, and calculations of leukemia and brain tumor risks also give higher values for exposed workers than for children living close to power lines. From calculations on the attributable risk in the Swedish study approximately 20 cases of leukemias and 20 cases of brain tumors could be attributed to the magnetic fields each year. These figures are to be compared with the total number of 40 000 annual cancer cases in Sweden, of which 800 have been calculated to have an "occupational" origin.

If the cancer effect is real, there are, however, unclarities as to exposure characteristics (eg, magnetic field frequency and exposure intermittence) and not much is known about confounding or effect-modifying factors. As a matter of fact, it is only the Floderus study (47) that has considered confounding; exposure to benzene, solvents, ionizing radiation, pesticides, and some behavioral factors did not essentially influence the odds ratios. Furthermore, most of the occupational studies have indicated one special form of leukemia, acute myeloid leukemia. A few, on the other hand, have found higher incidences for another form, chronic lymphatic leukemia. The reasons for this discrepancy in results are not known. In several studies brain tumors have been reported, and the evidence for an association is considered stronger (11) than for leukemias because of the duration-in-employment effect noted in some studies.

Excess breast cancer among men has also been reported in association with exposure to magnetic fields (36, 50—52). Almost all of the occupational studies have been made on male study populations. Breast cancer among women has been reported in two recent studies, however. In the Danish register cohort study (48) no excess risk was found. In an American case-referent study (53) it was reported that women in traditionally male-dominated "electrical" occupations had 40% higher breast cancer mortality than other women in the labor force. Since breast cancer is such a common cause of morbidity and mortality among women, even a small excess relative risk implies many cases attributable to the fields.

Animal studies. Only a few animal studies on magnetic fields and cancer have been reported, and therefore they are little help in the risk assessment of the fields. (See references 54 and 55 for reviews.) If the fields are truly associated with cancer, laboratory studies have indicated that they do not initiate cancer; instead they promote it. For instance, a co-promotional effect was reported for mouse skin with exposure to a continuous field (56, 57). Another research team did not find any promotion with a continuous field (58), but with an intermittent field the results differed (59). It is clear that the results of additional, ongoing large studies in Canada, Sweden, the United States, and Australia must appear before it can be determined whether or not the fields promote cancer in animals.

Mechanism studies. In contrast to the sparse animal cancer studies, there is a vast number of in vitro studies in the search for possible field-induced cancer promotion mechanisms. (See, eg, references 9, 10, 55, and 60.) Several candidate models have been presented on changes in the cell surface and in the cell membrane transport of calcium ions, the disruption of cell communication, the modulation of cell growth, the activation of specific gene sequences by modulated RNA (ribonucleic acid) transcription, the depression of pineal melatonin production, the modulation of ornithine decarboxylase activity, and the possible disruption of hormonal and immune-system antitumor control mechanisms. Each of these mechanisms has features applicable to explaining reported magnetic field cancer effects; however, none has been free of problems and essential objections (61).

There are two mechanism candidates which deserve special attention, the reduction of nocturnally produced melatonin induced by exposure to magnetic fields (62) and the discovery of magnetite crystals in human tissues (13, 14).

It is known from animal studies that melatonin, indirectly via an effect on circulating sex hormone levels, has an oncostatic effect. It is also known that magnetic fields suppress pineal melatonin production, which, for example, provides a theoretical mechanism for the increase in breast cancer reported in relation to exposure to magnetic fields. Recently, an alternate explanation for the increased cancer risk has been proposed (62). Melatonin has been found to be the most potent hydroxyl radical (-OH) scavenger discovered, and consequently the free radical damage to DNA (deoxyribonucleic acid) is markedly inhibited by melatonin. If melatonin is suppressed (eg, by magnetic fields) the DNA is left more vulnerable to oxidative attack. This theory explains how the depression of melatonin by magnetic fields could result in a higher incidence of cancer in any tissue. But do human melatonin blood levels diminish when individuals are exposed to weak magnetic fields? In an experimental study Graham et al (63) recently reported that this occurrence was possible in a subgroup of healthy young men with low melatonin base levels. It is apparent that further research along the "melatonin track" will be well worth following.

For some years it has been known that the seasonal migrations and orientation ability of birds are mediated via magnetite crystals in cells responding to the earth's magnetic field. Now, as has already been mentioned, magnetite crystals have also been demonstrated in human cells (13), in some cells in a concentration high enough theoretically to respond to the weak magnetic fields in residential and occupational exposures (14). It is possible that magnetite crystals may be a missing link explaining some of the biological effects under discussion.

Effects on reproduction with special reference to adverse pregnancy outcomes

High-voltage utility and laboratory workers. Towards the end of the 1970s results of Swedish studies were presented which indicated that there was a greater risk of miscarriage and having children with congenital malformations in families in which the husband worked in the electric power industry (64). The same research group also found chromosome damage in lymphocytes of switchyard workers (65, 66), and more recently a Norwegian study reported chromosome breaks in high-voltage laboratory cable splicers (67), indicating a possible risk increase of genotoxic effects in these workers. However, in a German study no chromosome aberrations were found in lymphocytes of 380-kV utility workers (68). In another, earlier Swedish study, family size and fertility among utility substation workers differed between the exposed and unexposed men. However, these differences were apparent before utility employment, and for this reason the authors interpreted the study as negative (4).

Electric blankets. In 1986 and 1989 Wertheimer & Leeper (69, 70) reported possible adverse pregnancy effects after the use of electric blankets and electrically heated water beds. Later, in a Chinese case-referent study that adjusted for drug usage, exposure to chemicals, and noise (71), an increased risk of spontaneous abortion was reported for women using electric blankets during early pregnancy. Other studies have not found increases in malformations (72, 73). It has been convincingly documented that users of electric blankets have higher magnetic field intensities than nonusers (74), and several large-scale epidemiologic studies are in progress in which the possible confounding by temperature increase will hopefully also be considered.

Residential exposures. A Finnish case-referent study found an increased incidence of early pregnancy loss among women exposed to 50-Hz magnetic fields in their homes (75). The early pregnancy losses were determined by hormone analysis in a group of women attempting to become pregnant. The 50-Hz magnetic fields were measured in the homes of 89 cases with early pregnancy loss and 102 referents. A cut-off score of 0.6 μT resulted in an odds ratio of 5.1 (95% CI 1.2—21). A study of birth defects in some municipalities through which high voltage power lines pass did not, however, find any increases in congenital malformations (76).

Late effects (childhood cancer) after parental exposure to electromagnetic fields. In a study of childhood cancer and maternal field exposure from electric blankets during pregnancy, brain tumors were found in excess (77). In two studies the incidence of brain tumors was elevated among children to men occupationally exposed to the fields (78, 79), while in a third it was not (80). As to childhood neuroblastoma, one study reported an association with presumed paternal exposure (81), while two others did not (82, 83). The results of these late-effect studies are contradictory, and a prerequisite for a true association is field-induced genetic or chromosome damage (11, 12, 84, 85).

Video display terminals. As has already been mentioned, operators of video display terminals are exposed to both ELF and VLF electric and magnetic fields. Since the middle of the 1980s, several well-designed epidemiologic studies have been published in which pregnant women who worked with a video display terminal during pregnancy were compared with pregnant women who did not. Although the results showed some variations, these studies essentially failed to demonstrate any differences between the two groups (86—99). (For a review, see references 100 and 101.)

Two of these studies have, in addition to examining possible differences between work with and without video display terminals, also utilized data on the emission of or exposure to low-frequency magnetic fields from the terminals (96, 98). In the study by Schnorr et al (96), in which the magnetic fields were measured at a selection of the actual workplaces, there were no associations between levels of magnetic fields and miscarriages. In the study by Lindbohm et al (98), there was no association between VLF magnetic fields, as measured in a laboratory, and miscarriages, but a significant association was found between ELF magnetic fields and miscarriages. A comparison between the results of these two studies is given in table 1. Caution is recommended when the comparison is interpreted because of the considerable differences in the methods used (workplace versus laboratory measurements, instrumentation, etc). Regarding the positive results of the Lindbohm et al study, issues have been raised concerning (i) the appropriate comparison group (within video display terminal comparison or not), (ii) exposure

Table 1. Associations between miscarriage and extremely low-frequency magnetic fields in two studies. (VDT = video display terminal)

Study	No VDT use	VDT with low field	VDT with high field
Schnorr et al (96)			
Magnetic field[a]	0.036 μT	0.046 μT	0.050 μT
Odds ratio (in a comparison with a group unexposed to video display terminals)[b]	1.00	0.98 (0.58—1.64)	0.92 (0.58—1.47)
Lindbohm et al (98)			
Magnetic field[c]	Not measured	<0.13 μT	>0.3 μT
Odds ratio (comparison within a VDU group exposed to video display terminals)[b]	·	1.00	3.4 (1.4—8.6)
Odds ratio (in a comparison with a group unexposed to video display terminals)	1.00	0.4 (0.2—0.8)	1.6[d]

[a] Measured at random in a selection of workplaces, value assigned to type of VDT, measured in fetal position with operators present.
[b] 95% confidence interval in parentheses.
[c] Measured in a laboratory for appropriate type of VDT, at 50 cm from screen center, here recalculated into root-mean-square.
[d] Not significant.

misclassification since workplace measurements were not made (nondifferential or not), and (iii) variation of exposure levels between companies (confounding or not).

To summarize, the epidemiologic studies that have been performed have not been able to demonstrate an association between work with a video display terminal during pregnancy and increased risks of miscarriage, giving birth to a malformed child, or growth retardation of the fetus. Regarding the possibility of specific subgroups of women at risk, groups to be considered are those that can be defined by exposure to VLF or ELF magnetic fields. For VLF fields, the two epidemiologic studies that have provided data have not been able to demonstrate such an excess risk for miscarriages. For ELF magnetic fields (ie, frequencies about or somewhat above the net frequency (50 or 60 Hz), one epidemiologic study has indicated an excess risk of miscarriage. The absence of a similar response in a second study, as well as some methodological considerations in both studies, do however detract somewhat from the strength of this positive finding. No experimental data seem to support the existence of such an increased risk in association with 50- or 60-Hz fields. (See the following discussion.) Nevertheless, the positive association noted in the study by Lindbohm et al (98) warrants an attempt at replication.

Animal teratogenicity of low-frequency magnetic fields. In 1982 a Spanish research team reported on the possible teratogenic effects of low-frequency magnetic fields (102) from their observations of chick embryos exposed to pulsed magnetic fields. Subsequently several other groups have tried to repeat these results, with varying success. The most concerted effort was the "Henhouse project," in which six laboratories attempted to verify the Spanish results by using identical equipment and standardized procedures. The outcome, however, was indicative of the involvement also of other, uncontrolled factors (103, 104). Studies of rats and mice have not resulted in adverse pregnancy outcomes that could be related to 50- or 60-Hz sinusoidal or pulsed magnetic field exposure (105—111). Experiments have also been performed on rats or mice with sawtooth-formed 15- to 20-kHz magnetic fields similar to those of video display terminals, with varied results (table 2). This variation could be due to (i) inappropriate statistical analyses (some of the effects have been noted when the statistical analysis was based on the fetus, not on the litter), (ii) incomplete study protocol (eg, lack of documentation as to control for 20-kHz noise), (iii) different species of rats or mice being used.

A combination of these differences between the studies could probably explain the different results noted. Only one of them — the species difference — is fully indicative of a real biological effect of magnetic fields on pregnant rodents, and then only for certain rodent species. This situation makes extrapolation to human risk evaluation rather difficult (84, 116).

"Hypersensitivity to electricity" and neurobehavioral reactions

In the 1980s the occurrence of skin symptoms and signs among operators of video display terminals was studied by different investigators in Sweden. Consistently an increase in some mild nonspecific skin symptoms was found, but, as to objectively diagnosed skin changes, there was no similar consistency in the findings (117—119). In a case-referent study on subjective skin disorders and work video

Table 2. Results of teratogenic studies with rodents and 18—20 kHz saw-tooth magnetic fields.

Study	Experimental conditions[a]	Results[b]		
		Malformation	Resorption	Other outcomes
Tribukait et al, 1987 (107)	C3H mice, 20 kHz, 15 µT, fetus analysis	yes/no[c]	no	no
Frölén et al, 1993 (112)	CBA mice, 20 kHz, 15 µT fetus and litter analysis	no	yes	[d]
Huuskonen et al, 1993 (113)	Wistar rat, 20 kHz, 15 µT	yes[e]	no	yes[f]
Stuchly et al, 1988 (114)	SD rat, 18 kHz, up to 66 µT, litter (and fetus) analysis	no[e]	no	no
Wiley et al, 1992 (115)	CD-1 mice, 20 kHz, up to 200 µT, litter analysis	no	no	no

[a] Reporting on species used, magnetic field frequency, peak-to-peak field level(s), and basis for statistical analysis.
[b] yes = significantly increased occurrence among exposed, as compared with unexposed, animals, no = no significant differences at any field level.
[c] The study consisted of two series.
[d] The study consisted of several series; fetal mortality increased in the first series only.
[e] Minor skeletal deformations found.
[f] Increased implantations, leading to (?) increases in the number of fetuses and uterus weight.

display terminals, certain risk factors were identified, gender (women), atopic skin reaction, work load and psychosocial factors, and the handling of paper. After low-frequency electric and magnetic fields were measured at workplaces, it was also found that the electric fields in the offices and the magnetic fields in front of the screens of the terminals were higher among the cases than among the referents (120). In another, comparative prospective study of skin disorders, it was possible to verify the connection with work load and psychosocial factors, but there was no association with the electromagnetic factors (121).

During the past four or five years attention has been paid to a minor group of persons, mainly operators of video display terminals, with more severe skin symptoms, often in combination with other symptoms (eg, from the nervous system, sense organs, upper respiratory tract, gastrointestinal tract, etc) (8). The symptoms are not exclusively related to contact with video display terminals; vicinity to outdoor and indoor electrical power and distribution lines, electrical motors and machines, household appliances, fluorescent lamps, and the like can also provoke symptoms. The persons affected have themselves defined the condition as "hypersensitivity to electricity," since a common denominator to them appears to be nearness to things that have something to do with electricity. There are several thousands of persons today in Sweden with this hypersensitivity.

The hypersensitivity is a phenomenon of late date; more than half of the examined patients have fallen ill in 1986 or later (8). A great variety of symptoms and discomforts has been put forward, mainly of the skin and the nervous system. Most of the persons state diffuse skin complaints on the face, such as flush, rosiness, ruddiness, heat, warmth, pricking sensations, ache, tightness, and the like. Symptoms from the nervous system are also stated, such as headache, dizziness, fatigue and faintness, tingling and pricking sensations in the extremities, shortness of breath, heart palpitations, profuse sweating, depression, and memory difficulties. No characteristic organic neurological disease symptoms have been presented.

Symptoms can be severe and then give rise to sick leave. The prognosis varies with the type of symptoms. Symptoms of the nervous system persist more often than skin symptoms. Most persons with this hypersensitivity can go back to work, however, after simple measures to reduce exposure at the workplace. A reduction of the time spent working with video display terminals is the most common recourse, and the most effective means of alleviating symptoms — skin symptoms especially.

The hypersensitivity is believed to be multifactorial in origin. It is not clear whether electrical or magnetic fields are involved or not. In a recent laboratory provocation study from the United States the authors presented evidence that hypersensitive persons were able to detect and identify weak fields (122). Well-controlled and similarly designed Swedish provocation studies could not confirm this phenomenon, however (123—125). Chemical, ergonomic, stress, and work organization factors have been proposed to contribute to the etiology, and it seems as if a mismatch between company organization and possibilities for an individual career at work definitely play a role in the development of symptoms (126). Hypersensitive persons were also found to produce higher levels of stress hormones at work with video display terminals than referents were, a finding which, together with the clinical picture, led the authors to diagnose "technostress" in these persons (127). It is generally agreed that the phenomenon of hypersensitivity to electricity should be further studied. From laboratory studies on healthy volunteers it has been shown, for instance, that combined exposure to an electric ($9 \text{ kV} \cdot \text{m}^{-1}$) and magnetic field ($20 \mu\text{T}$) can give rise to more physiological changes, such as slowing of heart rate and changes in late components of event-related brain potentials (128). Slowing of the heart rate has also been reported among workers and volunteers under power lines (129), and in a study on volunteers electroencephalographic changes were found after exposure to magnetic field strengths similar to those near household appliances (130).

Of interest in this connection is the altered melatonin cycle in response to weak magnetic field exposure, and it is known that altered diurnal rhythmicity in the pineal gland and melatonin production can be linked to depressive illness in humans ("seasonal affective disorders"). Recently a well-designed epidemiologic study was presented in which depressive symptoms and headaches were found to be associated with proximity of residence to high-voltage transmission lines (131). The association was not explained by demographic variables associated with depression and headaches or by attitudes about power lines or other environmental issues. Similar results on headaches and migraine were described some years ago in another study of populations residing near overhead power lines (132). Efforts are already in progress to relate changes in pineal melatonin to the described neurobehavioral reactions, including hypersensitivity to electricity.

Regulations and guidelines on limits of exposure

The discussions on regulation of exposure are based entirely on the cancer reports. As mentioned earlier, the exposure levels found in the epidemiologic studies are very low. Average field strengths of 0.2–0.4 μT for a workday appear to be the level above which there could be an increased risk, and similar levels have been calculated for annual averages for people living under or near power lines.

Many people are similarly exposed above these levels, though for shorter periods, in their homes (electric radiators, household appliances, razors, hair-dryers, and stray currents in the plumbing system), at work (in certain industries and in offices near electric and electronic equipment), or while traveling in trains and other electric conveyances. The importance of such intermittent exposure is not known. There are animal studies indicating that it could be important; on the other hand, there are epidemiologic studies stressing an even, continuous exposure as more essential for cancer development. There are other uncertainties in the epidemiologic studies as to exposure (eg, the importance of field frequency, other modifying or confounding factors, knowledge of the total exposure day and night) and effect (inconsistencies in findings as to type of cancer) which make a risk assessment difficult. The animal experiments presented thus far, on cancer promotion, are few, and the results of ongoing studies are awaited. To this situation can be added the lack of a plausible and understandable mechanism by which the carcinogenic effect can be explained. Recently, however, exciting and promising results have been presented on possible melatonin mechanisms, and the magnetite crystals identified in the brain and in some blood cells inspire considerable interest for the future.

In studies on other possible health effects related to electric and magnetic fields (eg, reproductive and neurobehavioral disorders), the results are generally considered to be insufficiently clear and consistent to constitute a scientific basis for restricting exposure.

In international guidelines, limits for restricting field exposure are several orders of magnitude above what can be measured from overhead power lines and found in "electrical" occupations. The International Radiation Protection Association (IRPA) issued *Guidelines on Limits of Exposure to 50/60 Hz Electric and Magnetic Fields* in 1990 (133). These guidelines have been adopted in many national standards. Since important new studies were published thereafter, an addendum was issued in 1993 by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) (134). Furthermore, in 1993, risk assessments in agreement with that of IRPA were also made in the United Kingdom (135).

These documents emphasize the facts that the state of scientific knowledge today does not warrant limiting exposure levels for the public and the work force down to the microtesla level and that further data are required to confirm whether or not health hazards are present. The IRPA and ICNIRP guidelines are based on the effects of field-induced currents in the body, corresponding to those normally found in the body (up to about 10 mA · m^{-2}). Occupational exposure to magnetic fields of 50 or 60 Hz is recommended to be limited to 0.5 mT for all-day exposure and to 5 mT for short exposures of up to 2 h. Exposure to electric fields should be limited to 10 and 30 kV · m^{-1}. The 24-h limit for the public is set at 5 kV · m^{-1} and 0.1 mT.

However, there is concern among some standard setters, and reference has been made to the concept of "prudent avoidance" (136), which could be summarized as the *future* avoidance of unnecessary exposure in the absence of scientific certainty. A systematic strategy has been presented on how future power lines should be routed and designed in order to minimize residential and occupational exposure, and on how household appliances should be designed to reduce or eliminate the fields they generate.

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Chapter 2

Case Studies of Implementation of Ergonomics in Manufacturing

In this chapter two case studies are presented. Both studies illustrate how traditional ergonomics improvements were implemented. The first study was in an electronics plant. In this case the economic benefits from improved productivity far exceeded any other benefits accrued from worker comfort or reduced injury rate. This implementation of ergonomics was very successful, and the quality in manufacturing improved significantly.

The second case study took place in a plant that manufactured printers. Both manual labour and automation were used for assembly, and this study illustrates the difficulty in allocating tasks between automation and human operators. The surprising outcome was that, after a few years, the very expensive automated manufacturing was discarded. The work is now done manually.

2.1 Ergonomic Improvements in Card Assembly

At IBM in Austin, Texas, printed circuit boards for computers were manufactured. The boards consisted of multiple layers of copper sheet and fibre glass with etched circuitry. Holes were drilled through the circuit board for insertion of components. Much of the component insertion was automated. However, there were many tasks which could not be automated, including quality control and inspection of component parts and finished products.

One important measure of quality in the manufacturing of boards is the percentage production yield. In this case, plant management had observed that the yield was consistently 5–10% below target (Burri and Helander, 1991a). Most of the quality problems were described as 'internal', which means that there were defects inside the circuit board, which could have occurred at several different locations in the manufacturing process. It was therefore difficult to isolate problems as occurring in any specific department. In this study, we focused on one department called 'Core Circuitize'. This was located just prior to the determination of the percentage yield, about half-way through the manufacturing process. Altogether 132 individuals, mostly operators, worked at this location, consisting of 59 workstations.

To collect information and evaluate the manufacturing scenario, information was collected from five different sources:

1. Discussion with management.
2. Plant walk-through, inspection, and note taking.
3. Discussion with operators.
4. Discussion with first-line supervisors.
5. Field measurements of illumination, noise, and workstation design.

Through these discussions and measurements, data were gathered on the effectiveness of the operation. This provided the basis for a comprehensive assessment of both the system and the individual tasks, which revealed significant opportunities for improvements.

Most of the 59 workstations were different and it is not meaningful to summarize the data collected; we instead focus on the recommendations. Based on the information, we identified 14 design improvements (see Table 2.1). Some of these were conventional ergonomic measures, and some required redesign of the manufacturing process.

2.1.1 Design Improvements

2.1.1.1 Illumination Level

The improved illumination turned out to be the most important of all the measures. Several operators were performing a relatively simple task by placing circuit boards into machines for automatic insertion of components (so-called 'card-stacking machines'). The managers thought of the operators as supervisors of the automatic machines. However, interviews with the operators disclosed that they regarded themselves more as quality inspectors than as machine tenders. They would inspect cards and components that were placed in the machine and they inspected the finished product as it was removed from the machine. One of the most critical aspects of this task was to inspect the magazines containing the electronic components that were put into the card stacking machines. A common problem was that components were turned in the wrong direction in the magazines.

The average ambient illumination level was about 500 lux, which is inadequate for inspection work. In some areas the illumination was as low as 120 lux. It was decided to increase the illumination to 1000 lux throughout the department. This was achieved by installing fluorescent light tubes, switching on lights that had been turned off for energy-conservation reasons, and lowering light fixtures from high bay ceilings to a location closer to the workstations.

2.1.1.2 Special Lighting for Inspection

In addition to the above measures, some polarized lights were installed to make it easier to see imperfections and quality defects. Many examples of special illumination systems for inspection are presented in Chapter 9.

Table 2.1 Ergonomic improvements at the IBM plant in Austin, Texas

1. Uniform illumination level at 1000 lux
2. Installation of special lighting for inspection
3. Job rotation to avoid monotony
4. Personal music was distracting and was discontinued
5. Ergonomic chairs certified for clean rooms
6. Improved communication
7. Materials-handling guidelines
8. Automation of monotonous jobs
9. Metric to decimal conversion charts
10. Housekeeping improved
11. Noise reduction
12. Ergonomics training
13. Continuous flow manufacturing
14. Use of protective gloves

2.1.1.3 Job Rotation and Shift Overlap

Visual inspection is often monotonous, and there are problems in sustaining the attention throughout an entire work shift. To break the monotony, job rotation was incorporated so that operators could split their time between two jobs (Grandjean, 1985). Existing rest-break patterns were evaluated, but it did not seem necessary to increase the length of the rest break. The time overlap between shifts was reduced from 30 to 12 minutes. The shift overlap is generally used to transfer information between shift crews on the status of machines and processes. However, the existing overlap of 30 minutes was excessive.

2.1.1.4 Personal Music

An experiment was performed to introduce personal music in the workplace. However, the music was distracting to the work and it was therefore discontinued.

2.1.1.5 Ergonomic Chairs

New ergonomic chairs were provided to increase comfort. This also seemed to increase productivity, for operators could remain seated during inspection. The chairs were manufactured to be used in a clean-room environment. There were several adjustabilities including seat height, back-rest angle and seat-pan angle. For some operators, sit/stand types of chair were also provided for occasional use.

2.1.1.6 Operator Communication and Feedback

In order to enhance verbal communication and feedback between operators, openings were installed between some of the workstations. The openings improved communication significantly, particularly with respect to quality control (Bailey, 1982).

2.1.1.7 Materials Handling

Guidelines were established to limit the heights of storage racks. For example, the lowest shelf in the storage racks was removed. This made it impossible for anything to be put on the lower shelf, which reduced the amount of bending and back injuries. In addition, a guideline for a maximum weight of parts was established.

2.1.1.8 Automation of Monotonous Jobs

Some operations were converted from manual work to robot/automation. One of the jobs involved a task where a protective Mylar peel tape was removed from a board. This was a highly monotonous and repetitive task and did not provide any job satisfaction. The operator now supervises the robot, and in addition performs several other tasks, which provides for a more varied and interesting job.

2.1.1.9 Metric to Decimal Conversion

The conversion between metric and decimal measurements was confusing to several operators, and a conversion chart was provided for each workstation.

2.1.1.10 Housekeeping

Through collaboration with management, an example of good housekeeping was set up in part of the plant. The area was cleaned up and organized. This inspired operators in other areas as well, and housekeeping improved. As part of the housekeeping effort, the manufacturing facility was converted to a 10 000-type clean-room facility. Clean-room clothing and smocks were evaluated and their use recommended.

2.1.1.11 Noise Reduction

The noise levels were well within the 85 dBA stipulated by NIOSH. However, to enhance verbal communication, sound insulation covers were installed for several processes. The ambient noise level at the workstations was reduced from about 75 to 60 dBA, which greatly enhanced verbal communication between operators as well as their comfort.

2.1.1.12 Ergonomics Training

An ergonomics training and awareness programme was provided during departmental meetings. This was a 4-hour programme and addressed a variety of problems, very much similar to the contents of this text.

2.1.1.13 Continuous Flow Manufacturing

Continuous flow manufacturing was implemented at several locations in the plant. The main purpose was not to enhance ergonomics, but to reduce the amount of space required for manufacturing. There were important side benefits in that the distance between nearby operators decreased and verbal communication became possible.

2.1.1.14 Evaluation of Protective Gloves

For several of the operations, anti-laceration gloves were used to protect the operators from sharp edges and the corners of the boards. However, some types of glove reduced tactile sensation so that it was difficult to manipulate components. Several different gloves were tested, and the type of glove selected maximized tactile sensation.

2.1.2 Specific Problems

In addition to the general problems there were specific problems at several workstations. For the 'drills' operation, operators had to bend over the machine to replace drill bits that were used to drill holes in cards (see Figure 2.1). On the old machine, operators had to bend very carefully otherwise the drill bits would stick in their stomachs. In the new machines the drill bits were relocated, reducing the operator's reaching distance and improving the work posture. Using time-and-motion studies, time savings were calculated to be 1.5 minutes per set-up. This translated into a yearly saving of $270 000.

2.1.3 Cost Efficiency of Improvements

Based on our experience gained in previous ergonomic field studies, we had projected a 20% improvement in process yield, a 25% improvement in operator productivity, and a 20% reduction in injuries. Actual improvements were close to our predictions and resulted in a cost reduction of $7 375 000 (see Table 2.2). The cost of materials for ergonomic improvements (such as improved illumination) was $66 400. The labour costs for the implementation were about $120 000. The benefit/cost ratio for these improvements was approximately 40:1 for the first year or, phrased differently, the payback time was about 1 week (Helander and Burri, 1994).

Reductions in injury costs were fairly minor compared with the improvements in productivity and yield, demonstrating that improvements in productivity are sometimes extraordinary. We can conclude that ergonomics is important in improving the quality in production. Management was impressed by the results and hired two ergonomists with an industrial engineering background to continue the improvements.

There were also improvements in operator comfort, convenience and job satisfaction. Informal interviews were held with a large number of operators and with management. They showed that there were no

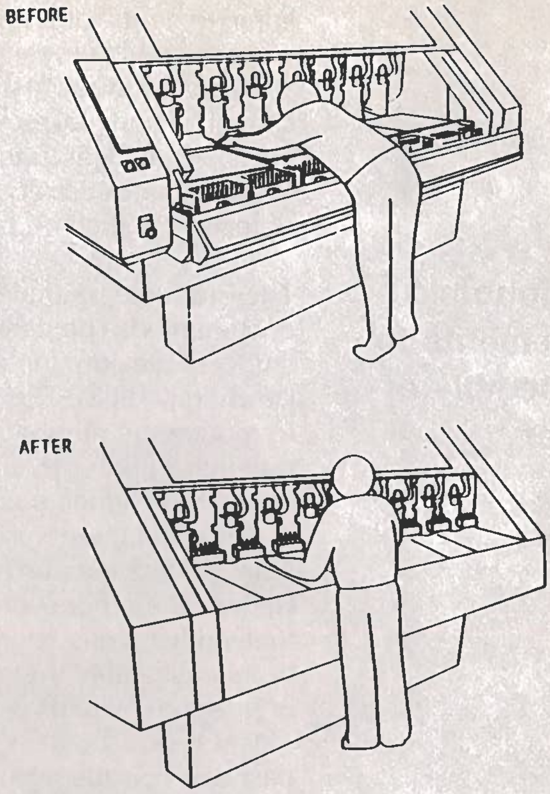


Figure 2.1 The location of the drill bits forced excessive reaching and required great caution. After the modification, drill bits were located close to drills, thus reducing reach

Table 2.2 Projected and actual improvements

	Improvement (%)		Cost reduction ($)	
	Projected	Actual	Projected	Actual
Yield improvement	20	18	2 268 800	2 094 000
Operator productivity	25	23	5 647 500	5 213 000
Injury reduction	20	19	73 400	68 000
Total			7 987 700	7 375 000

negative effects of the new system. Operators generally appreciated what had been done and were happy with the new system. These types of improvement are more tangible and difficult to quantify in terms of cost savings than are improvements in productivity and safety.

From a scientific point of view, this study is very unsatisfactory, for there was no control group for comparison. Such is often the case in industry. It is usually very difficult to find an identical control group, and for 'core circuitize' with 200 operators it was impossible. We are therefore restricted to selective evaluation methods without statistical significance testing. In our study, 26 managers and engineers were interviewed. They agreed that approximately half of the savings could be attributed to ergonomics, while the remaining half was attributed to other improvements such as the continuous flow manufacturing. Management were extremely positive about the ergonomic improvements, and particularly the increased illumination levels for visual inspection.

This case study also demonstrates that ergonomic improvements cannot be undertaken in isolation of the manufacturing process. There must be a clear understanding of technological alternatives for improving productivity and how ergonomics is affected by the choice of technical system, process layout and equipment.

2.2 Ergonomic Improvements in the Assembly of a Printer

The Proprinter manufacturing line at IBM in Charlotte has been well documented. The design of the printer presents an interesting case study of design for automation (DFA) concepts (Boothroyd and Dewhurst, 1983). The printer was redesigned several times in order to reduce the number of parts and to make it possible to assemble the entire printer by using automation. For example, only one type of screw fastener was used.

Altogether there were 18 workstations (4 manual and 14 automated). Total automation – an engineer's dream – turned out to be impractical. Rather, the production line was designed with flexibility in mind, so that workstations could be switched between manual or automatic. In this assembly there was no materials handling such as carrying or pushing. All parts were automatically delivered to the workstations.

The task allocation between automation and manual labour was based on considerations of what a robot (or automaton) could do, given the constraints of the manufacturing tasks. Manual tasks were typically tasks that were 'left-over', since they were either difficult to automate (such as cable routing), too costly to automate, or would take too much time to automate. The time to set up the automation is not much of a restriction, but the delivery time of automated production machinery can be excessive.

From the ergonomics perspective, the challenge was to design a product that was compatible with the requirements of the workforce. Most of the engineers at this location were familiar with ergonomics design principles and had participated in ergonomics training offered by the company. Several ergonomic design measures were taken and these are summarized below in Tables 2.3–2.5.

2.2.1 Task Considerations

Several measures were taken to improve task design (Table 2.3). To balance the assembly line, a 30-second cycle time was used. However, the implementation team increased the task duration time for the human operator from 30 seconds to 2.5 minutes. This was accomplished by integrating several manual tasks. Such longer, and

Table 2.3 Task design measures taken to improve ergonomics and job satisfaction

1. Increased assembly cycle time from 30 seconds to 2.5 minutes
2. Conveyor storage to reduce operator pacing by assembly line
3. Flexible schedule for rest breaks
4. Job rotation – two jobs per day
5. Buddy system for robotic safety
6. Physical proximity to enhance verbal community
7. Performance feedback to operators
8. Career path established for operators

more comprehensive tasks are considered more satisfying, since there is both less boredom and less fatigue due to the one-sided strain.

Job rotation is a technique that has been widely used to increase the competence of workers and to reduce monotony. In this facility, operators changed workstation twice per day going 'upstream'. Thereby the operators did not have to check on their own work from the previous operation, and they could feel free to report quality defects.

Several operators maintained robotics workstations. For maintenance and repair it is necessary to work close to the robot. To improve safety there was a buddy system with two individuals, one doing the maintenance and the other watching the robot. If something went wrong, it was possible to shut off the system very quickly.

Physical proximity is essential to promote team work between operators, engineers and management. To facilitate communication, the line manager's office was moved from a remote area to the manufacturing line. Support engineers' offices were located close by.

Performance feedback is important for all production. In this case task performance data were summarized and made available to the operator for evaluation, recognition and possible corrective action.

For this manufacturing operation several different job titles were established: assemblers, set-up operators, quality and process auditors, and automated equipment operators. This formalization of the job titles was intended to facilitate a career path and discussions between management and operators. It could also reinforce teamwork.

2.2.2 Workstation Ergonomics

Table 2.4 summarizes the measures that were taken to improve the workstation.

The worksurface height was made easily adjustable by using a motor drive. Thereby both the small and large operators could fit at the workstations.

Vacuum suction cups were attached to the worksurface and used to hold the kit in a comfortable position for assembly.

The roller ball transfers were used to facilitate the movement from the conveyor line to the workstation. Thereby the operator could push and pull the unit into the workstation and did not have to lift it.

Ergonomic chairs were acquired. The seat height and seat-back angle were adjustable. Thus operators could either sit or stand in the workplace.

Each workstation was equipped with tack boards for personal items, such as photographs. A lockable drawer served as personal storage for private items.

Table 2.4 Ergonomic design of the workstation

1. Work-table height electrically adjustable
2. Vacuum suction cups used to hold the unit in different positions
3. Roller ball transfer from conveyor line to workstation
4. Ergonomic chairs for sitting or standing work posture
5. Tack boards for personalization of workstation
6. Lockable personal storage
7. Use of low-noise equipment and enclosure of noise sources
8. 1000 lux ambient illumination and optional task illumination
9. Heat and ventilation optimized for comfort

Many researchers have reported the adverse affect of noise on job satisfaction. With the high degree of mechanization in the area, there was a great risk that conveyors, pneumatic devices and motors would create too much noise. Consequently, special attention was given to procure low-noise equipment and acoustic covers to enclose the sound at the noise source. For one operation (frame serialization), the noise was practically eliminated by using laser etching rather than stamping.

One very important factor is to provide adequate lighting at the workstation. Precision tasks typically need at least 1000 lux. In addition, moveable task lights were provided for each workstation.

Heating and ventilation requirements were established in accordance with IBM facility practices, to ensure comfortable climatic conditions.

2.2.3 Design of Tools and Controls

Measures were taken to procure ergonomic handtools, controls, and displays (Table 2.5).

The power tools used in the operation were lightweight and more delicate in appearance than common heavy-duty power tools typically used in manufacturing. This increased the efficiency and comfort of the operator (Hasselquist, 1981).

Some of the controls on the control panel were removed as they were unnecessary for the operation. This reduced the number of possible actions, which simplified the task. In addition, schematic lines were drawn to identify control sequences. Logical groupings of controls were enhanced by using contrasting colours.

One common problem in maintenance is the lack of adequate lighting. To simplify maintenance, permanent light fixtures were installed inside equipment panels.

2.2.4 Discussion

The ergonomic design took place during the preliminary system design phase. Because these features were implemented at a very early stage, they were inexpensive.

All the parties involved (operators, managers and engineers) were very enthusiastic about the ergonomic design. The operators appreciated the design of the workstation, including the flexibility of the adjustable worksurface, and the convenient layout of the items on the workstation. Managers appreciated the flexibility of the workstation, which could be used for a variety of purposes. This particular workstation became the plant standard. Finally, the company medical doctors indicated that the use of ergonomics had eliminated most complaints of back and shoulder strain.

There is one interesting aspect about this case study which we have not addressed, namely the allocation of tasks between automation and manual labour. When the printer assembly was first planned, it was envisioned that the manufacturing would be totally automated. However, it was soon obvious that a few manual workstations were

Table 2.5 Ergonomics of handtools, controls, and displays

1. Use of lightweight power tools
2. Reduction of number of controls on robot control panel
3. Schematic lines on panels to identify the required control sequence
4. Use of colour coding and colour contrast
5. Light fixtures inside control panels to simplify maintenance

necessary for tasks that were difficult to automate. These were workstations where intricate assembly work was performed – 'leftover' tasks which were too complicated for robots to perform.

Several years later, after several product modifications, this assembly is almost totally manual. Most of the automated workstations have disappeared, because of product modifications that were introduced in later models. It was difficult to reprogram the automation and time consuming to acquire new process machinery.

The printer had been designed for ease of assembly, implying that a minimum number of parts are used. It turned out that not only did this simplify the automatic assembly but also the manual assembly. In the end, it became so simple to assemble the printer manually that the cost of automation was not justified.

This case study serves as an example of task allocation between people and automation. The automation failed, which must have disappointed many engineers. There are certainly other less intricate jobs that are easier to automate. For example, in the automobile industry, welding and painting are mostly performed by robots. However, assembly work, with its intricate movements, is more troublesome to automate.

Chapter 17

Design for Manufacturing Assembly

Ergonomics professionals working for manufacturing companies have in the past specialized in two areas: design of industrial workstations and design of products to improve functionality and usability. In this chapter we propose a new field of activity: the study of the effects of product design on the types of job created in the assembly of the product. The basic concept is that, through product design, jobs are created in manufacturing. It is then important to design products so that they are easy to assemble and do not create safety hazards. One must also distribute the manufacturing tasks between manual labour and automated processes. This distribution of tasks or 'task allocation' must be productive for the company, and it must create satisfying jobs for the employees.

17.1 The Desire to Automate

During the 1980s, manufacturing engineers vigorously pursued opportunities to automate, and sometimes the results were very disappointing. During this time, General Motors invested $80 billion in automated manufacturing, but at least 20% of their spending on new technology failed (*The Economist*, 10 August, 1991). Other major companies had similar experiences. In many cases the surprising reason was that manual labour, with its greater flexibility and adaptability, can outperform automation. The focus on automation has not been serving our interests. Automation does not by itself increase productivity and job satisfaction. Unfortunately, automation is what engineers take an interest in. Modelling of human work is difficult, and principles of allocating work functions between humans, machines and computers are not well understood by the engineering community.

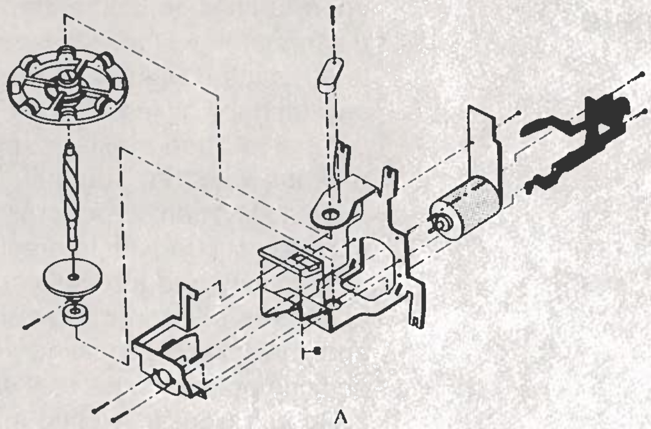
Robots were first used in industry for fairly simple tasks such as welding and painting. At the beginning of the 1980s there was increasing interest in using robots for assembly. Early on there was a realization that robots can only be used for fairly simple assembly tasks which are easy to describe and program. In order to enhance the utility of robots, assembly had to be simplified, and it became necessary to redesign products so that they were easy to assemble by automation. In the last 10 years many design guidelines have been published, which prescribe the design of parts that are easy for a robot to assemble. This type of product design is referred to as 'design for automation' (DFA) or 'design for manufacturability' (DFM) (Boothroyd and Dewhurst, 1983). However, sometimes the redesign of a product leads to a very surprising outcome, as we illustrate in the following example.

Example: The Assembly of a Paper Picking Mechanism
In the early 1980s, IBM Corporation was manufacturing copy machines at the plant in Boca Raton, Florida. The paper picking mechanism

in the copy machine had 27 parts (Helander and Domas, 1986) (Figure 17.1).

One problem was that individual parts require individual feeding mechanisms, which standardize their presentation so that they are easy for the robot to grip. Twenty-seven parts were simply too many, because the entire work envelope would be filled with part-feeding mechanisms. After the redesign the paper picking mechanism had 14 parts, 13 of which could be assembled by robots and automation. The fourteenth part required a complex insertion motion and had to be put in place using manual labour (thereby creating a highly repetitive task). The surprising outcome of the redesign was that manual assembly of the mechanism became so simple, that the cost of using robots could no longer be justified. This product is still assembled manually.

From our perspective it is ironic that only the introduction of automation has compelled engineers to investigate the principles of manual assembly. Throughout the history of manufacturing, engineers have taken for granted that workers can adapt to any situation. Engineers have ignored opportunities for ergonomic improvements, which could increase productivity as well as operator comfort. Only in the last 10 years, through the advancement of automation have



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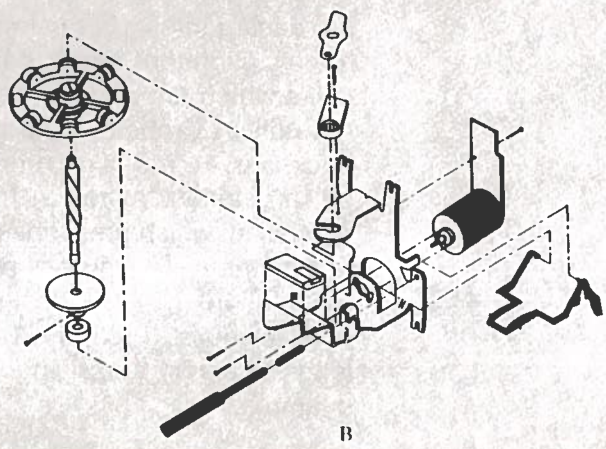

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Figure 17.1 (A) The origin design of the paper picking mechanism had 27 parts. (B) The redesigned mechanism has 14 parts engineers been forced to consider alternative production methods – in this case manual labour.

One may question under what circumstances automated devices are actually more productive than human labour. Within the IBM Corporation there are several similar cases of product redesign, where manual labour has ultimately proven more cost-effective. One case study is the printer manufactured at IBM in Charlotte, North Carolina, which is mentioned Chapter 1 (see also: Genaidy *et al.*, 1990; Mital, 1991). In these cases manual assembly was faster and the introduction of automation could not be justified. Could it be that design for human assembly (DHA) is a viable method, and we do not need robots? As usual in ergonomics, it depends on the task.

In the rest of this chapter we provide an overview of guidelines that may be used in product design in order to simplify both automated assembly and manual assembly. The information is collected under four headings:

(1) What to do and what to avoid in product design.
(2) Boothroyd's method for the redesign of products.
(3) Use of predetermined time systems to diagnose product design.
(4) Human factors design principles applied to product design.

17.2 What to Do and What to Avoid in Product Design

In this section we provide examples of product design features that simplify assembly. Many of them are used for automation and have been published in guidelines for DFA. They apply equally well to manual assembly (Helander and Nagamachi, 1992).

17.2.1 Using a Base Part as the Product Foundation and Fixture

Design the product with a base part as the foundation and fixture for other parts. It should be possible to assemble the other parts from one direction, preferably from above (Figure 17.2). It is also advantageous to use fasteners which are inserted from one direction, either from the front or from above. The base part should also serve as a fixture. If this arrangement is not feasible, pins can be used so that the base part can be easily positioned on a fixture as in Figure 17.2. If this is not possible, a specially designed fixture is used.

To make the product easy to transport, it should have a flat bottom and a simple shape.

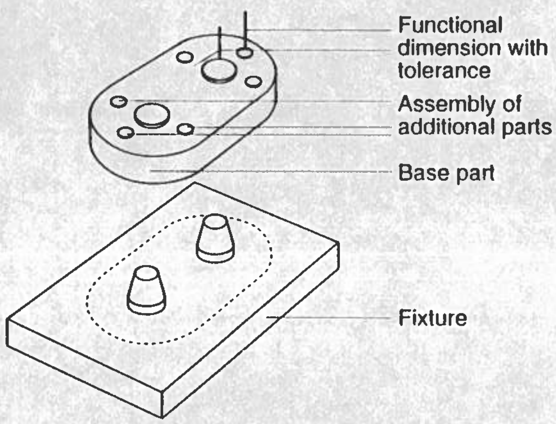

Figure 17.2 Provide a simple and reliable fixture for the base part. If possible the base part should also serve as a fixture

17.2.2 Minimizing the Number of Components and Parts

1. Integrate or combine parts, since they take less time to organize and less time to assemble. In some cases an entire subassembly can be replaced by a single part (compare with modular design in electronics). Integrated parts may be complex to handle, but they reduce the number of operations (Figure 17.3).

   Holdbrook and Sackett (1988) noted that it is *difficult* to combine parts if:

   - Parts move relative to each other.
   - Parts are required to be of different materials.
   - Parts must be separate for maintenance and sevice reasons.
   - Parts are necessary to enable the assembly of remaining parts.

   Combined parts can often be fabricated using plastic injection moulding. Another advantage with plastic parts is that they can easily be provided with chamfers, notches, and guides which are helpful in assembly. Metal parts can also be moulded or mounted into plastic parts. The elastic property of thermoplasts (e.g. nylon) can be used to form snap joints, integral springs and integral hinges. Thermoplasts can also be used to straighten other parts and to eliminate clearances.

2. Eliminate or minimize different types and sizes of fasteners:

   - Use snap and insert assembly. If possible, design integral fasteners and clips into parts so that no screws are required, as in Figure 17.4.
   - Minimize the various types and sizes of screws (Figure 17.5). Fewer number of parts decrease the number of part bins, which saves space. A smaller number of bins will also decrease the operator's choice-reaction time between bins. In addition, fewer

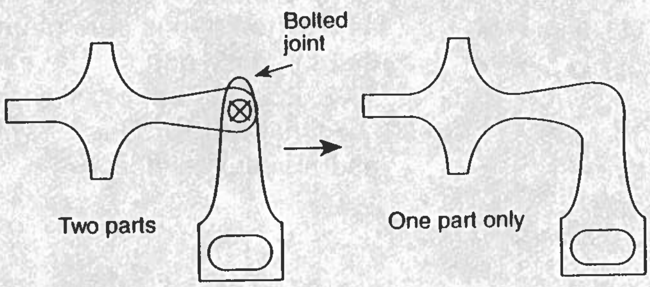

Figure 17.3 Integrate or combine parts

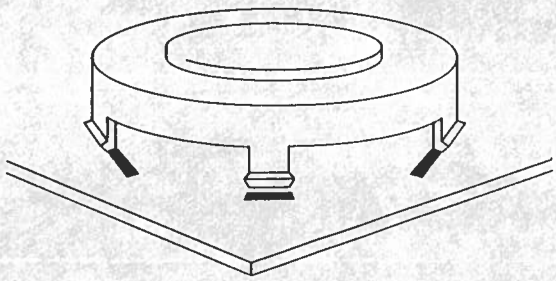

Figure 17.4 Use snap and insert assembly

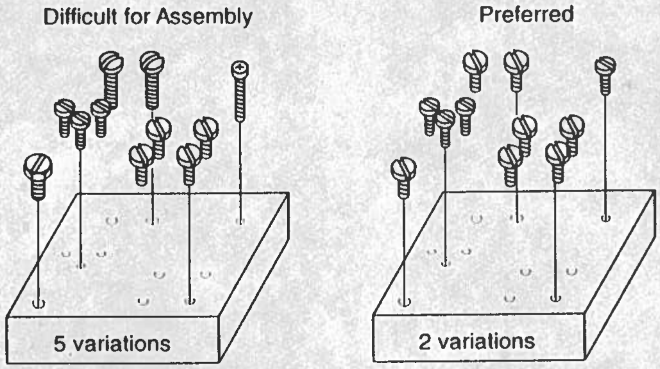

Figure 17.5 Minimize the various types and sizes of screws

parts will reduce the number of hand tools, which in turn decreases handling time and space requirements.

3. Do not use small parts such as washers. This requirement which is mandatory for robotic assembly, also simplifies manual assembly (Figure 17.6). The use of washers increases the manual handling time. Their use may also make it necessary for the operator to use pinch grips, which have been implicated as a cause of cumulative trauma disorder.

17.2.3 Facilitating Handling of Parts

1. Improve parts handling by using parts that are easy to grip (Figure 17.7).
2. Avoid using flexible parts, such as wires, cables and belts, because they are difficult to handle. Sometimes components can be plugged together in order to eliminate the use of connecting wires.
3. Avoid parts which nest or tangle. Close open ends and make part dimensions large enough to prevent tangling. For example, use springs with closed ends rather than open ends (Figure 17.8).

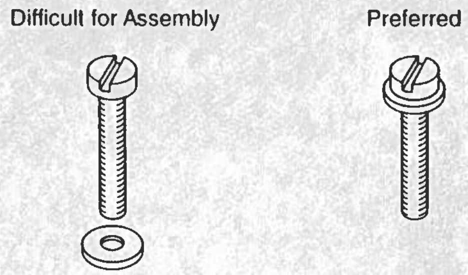

Figure 17.6 Do not use small parts that are difficult to handle, such as washers

Figure 17.7 Improve parts handling by making parts easy to grip

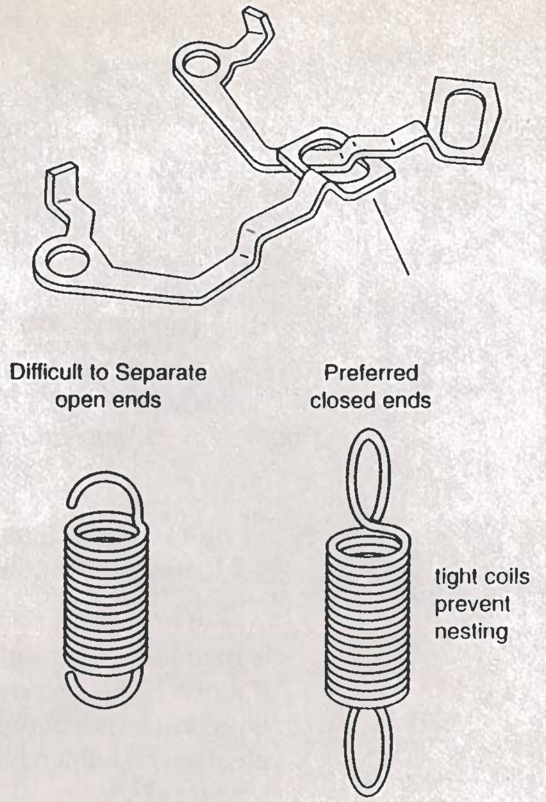

Figure 17.8 Avoid parts that nest or tangle

17.2.4 Facilitating Orientation of Parts

1. Use symmetrical parts, because they are easy to orient (Figure 17.9). The use of symmetrical parts reduces information processing, since the operator does not have to decide whether to turn the part round. It also reduces manual handling time.
2. If asymmetric parts are used, provide visual aids for orienting parts (e.g. colour coding or shape coding). If asymmetric parts are used, it may be advantageous to exaggerate the asymmetry to improve visual cues (Chhabra and Ahluwalia, 1990). Colour coding of parts

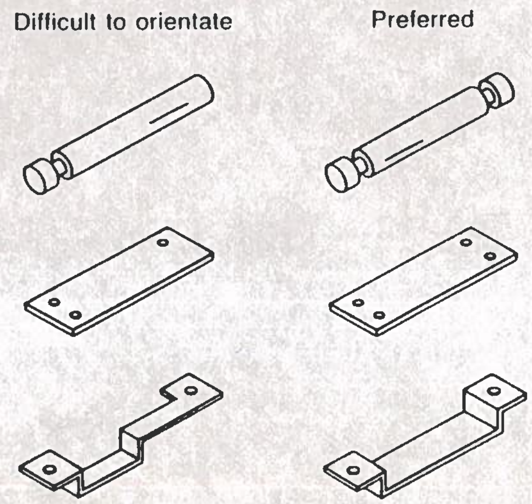

Figure 17.9 Use parts that are easy to orientate, such as symmetrical parts

may be used to form *families of parts*, i.e. parts which belong together in a subassembly. Colour coding will enhance stimulus-response compatibility in assembly. This results in reduced reaction time and better eye-hand coordination (Figure 17.10).

3. Consider feeding parts. The use of vibratory bowl feeders or other types of electromechanical feeder simplify the presentation and grasping of parts (Figure 17.11). Alternatively, magazines for parts or trays of parts can be used by the operator. These devices were conceived for use in automated assembly. However, they are equally practical for manual assembly.

17.2.5 Facilitating Assembly

1. Use self-locating parts. Parts with chamfers, notches and guides for self-location simplify assembly (Figure 17.12). The use of chamfers, for example, reduces the amount of manual precision required to insert the part. (The insertion time with and without chamfers can be modelled using Fitts' law (Fitts and Posner, 1973).
2. Reduce tolerances in part mating. Figure 17.13 illustrates how a slotted hole may be used to simplify positioning and relax accuracy requirements.

17.2.6 Consideration of Stability and Durability

Parts that are weak or easily bent are difficult to assemble (Figure 17.14). These parts often cause extra work in quality control, visual inspection, and replacement. Grossmith (1992) noted that many

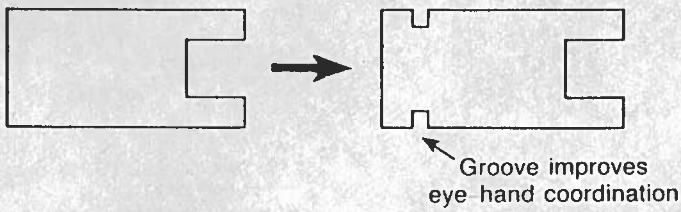

Figure 17.10 Exaggerated asymmetry may enhance stimulus-response compatibility

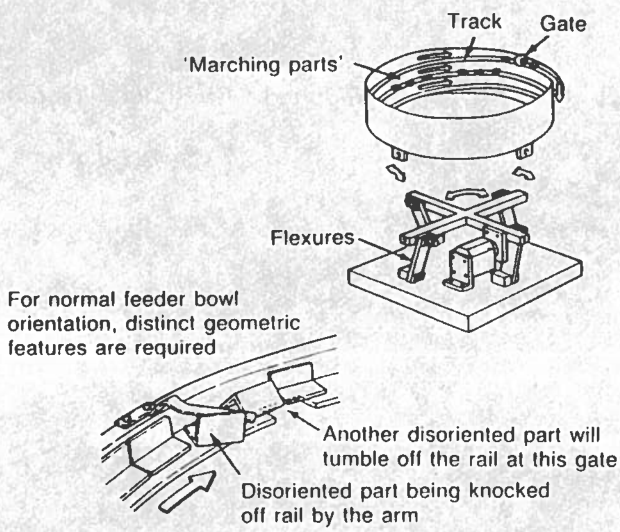

Figure 17.11 Use of a vibratory bowl feeder simplifies manual (and automatic) grasping of parts

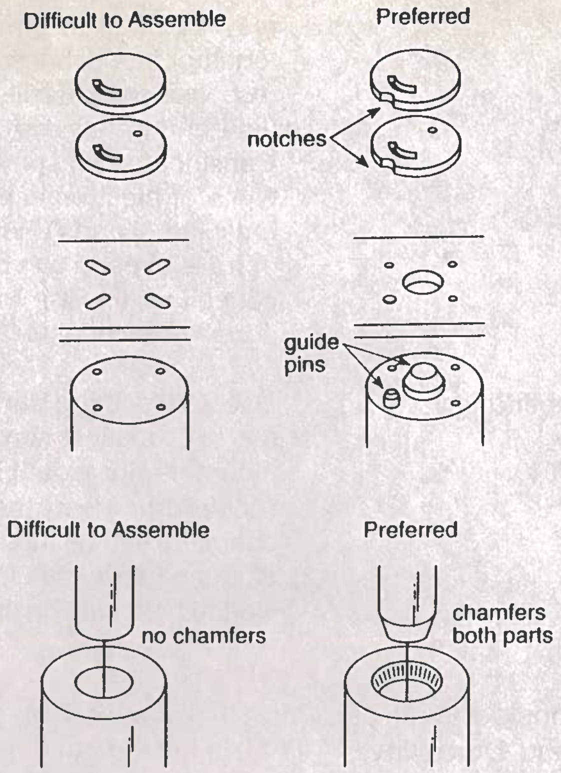

Figure 17.12 Facilitate assembly by using self-locating parts

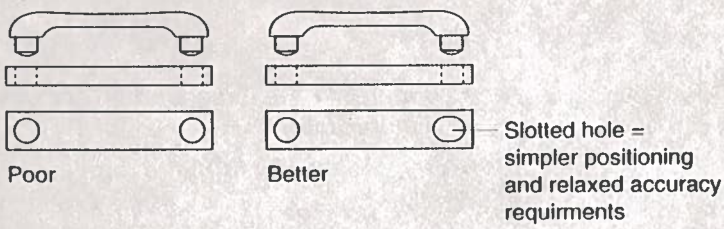

Figure 17.13 Reduce tolerances in part making

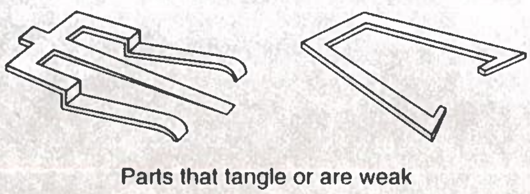

Figure 17.14 Avoid parts that are easily bent or parts that crack or chip

microscope inspection tasks can be avoided if product designers chose materials that are less likely to chip or crack.

17.3 Designing Automation Using Boothroyd's Principles

The design principles formulated by Boothroyd and Dewhurst (1983, 1987) have been extremely influential in industry. Several companies, including Hitachi, Black & Decker, General Electric, General Motors, IBM and Xerox, have used these principles to develop corporate guidelines (Gager, 1986; Holbrook and Sackett, 1988).

In Boothroyd's technique an existing product is disassembled. The necessity of each part is then analysed. First one must decide if a part is necessary for assembly or disassembly. If not, it may be possible to eliminate a part or integrate it with a mating part if:

1. There is no relative motion between the two parts.
2. The materials of which the two mating parts are composed do not have to be different.

For each part the assembly time is measured. Boothroyd then makes the assumption that an 'ideal' time for a part is 3 s. This is reasonable for a part that is easy to handle and insert. A measure of the manual assembly design efficiency (E_m) is then obtained using the equation:

$$E_m = \frac{3N_m}{T_m}$$

where N_m is the minimum number of parts, and T_m is the total assembly time. If $E_m < 1$ then the design is inefficient, and if $E_m > 1$ the design is efficient. An example of this methodology is given in Figure 17.15 and Table 17.1.

The value of E_m is, however, not always conclusive. Complex electromechanical products that require extensive wiring tend to have low design efficiencies, even when well designed. On the other hand, simple products with few parts can have a high design efficiency. In their handbook, Boothroyd and Dewhurst (1987) provide many examples of successful redesigns where productivity gains of 200–300% were obtained.

17.4 MTM Analysis of an Assembly Process

Boothroyd's technique is useful for redesigning existing products, but it cannot be used in the design of new products at the conceptual stages of design. Predetermined time-and-motion studies (PTMS) can be used for this purpose. As a basis for our analysis, we use motion time measurement (MTM) (e.g. Konz, 1990).

In MTM, an assembly is broken down into several constituent tasks including: reach, grasp (pick-up and select), move, position part, and insert. MTM specifies the amount of time it takes for a trained worker to do each of these elemental tasks. However, the asembly time depends very much on how the product is designed. Table 17.2 illustrates time savings for a 'best design case' as compared with less efficient designs. For example, reaching to a fixed location is the 'best case' and takes about 30% less time than reaching to a variable location or to small and jumbled parts. 'Grasping' of easily picked up parts is 75% faster than for parts that are not easily grasped.

Hence the design engineer should design parts that are easily reached and easily grasped. Luszack (1993) presented several methods which simplify the grasp of a part to be assembled

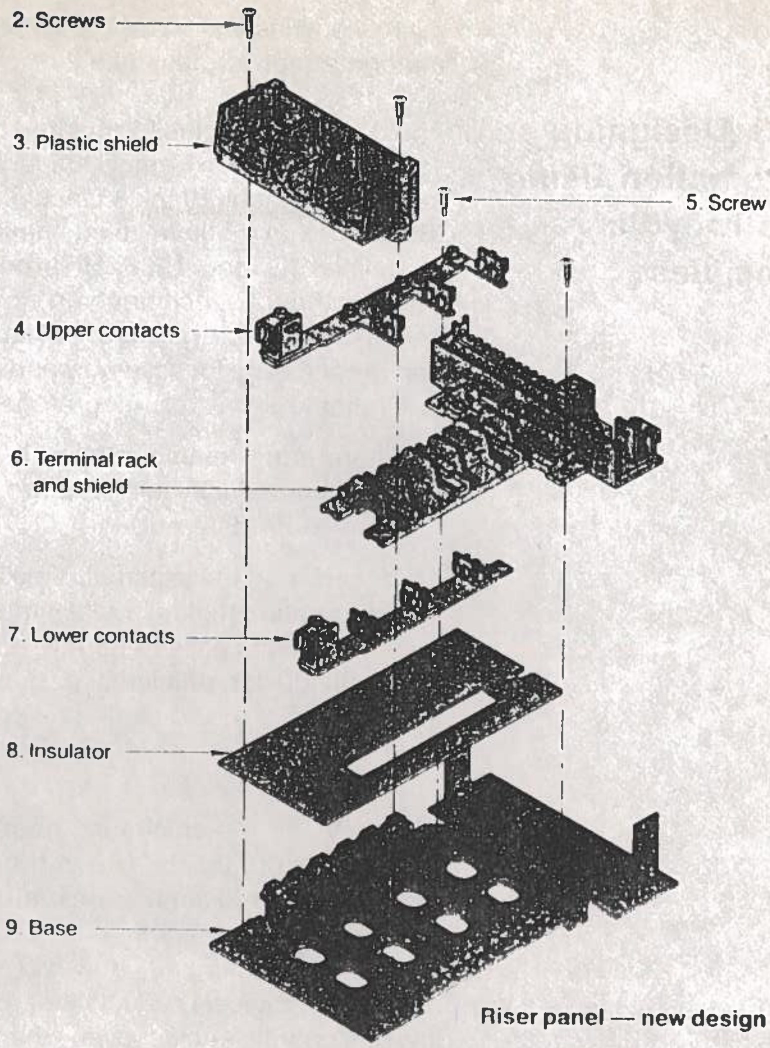

Figure 17.15 Example of product redesign for ease of assembly. The new design of the riser panel has only 10 parts, compared with 18 in the old design. Further reduction would be possible if screws 2 and 5 could be replaced by integral fasteners. The calculated assembly times are given in Table 17.1

(Figure 17.16). This is a complementary approach. Here, the parts are not redesigned to be easier to grasp, rather the process (of grasping) is redesigned. The process is redesigned for the purpose of improving the interactivity of products and processes so that (in this case) manual assembly will be easier. Process design is typically more abstract than product design, and hence more difficult to implement.

The parts should be presented at a fixed location. This can be accomplished by using part feeders (Figure 17.11). Much research has been performed to develop part feeders for robots (Boothroyd, 1982). These can also be used for manual assembly. A cost–benefit calculation can easily determine whether parts feeders for a manual assembly are cost-efficient. Simply calculate the time savings for assembly and compare to the cost for parts feeders.

Following the 'pick-up' the part has to be transported and positioned for the final insertion step. Table 17.2 illustrates that moving a part against a stop (case A) requires about 15% less time than when a

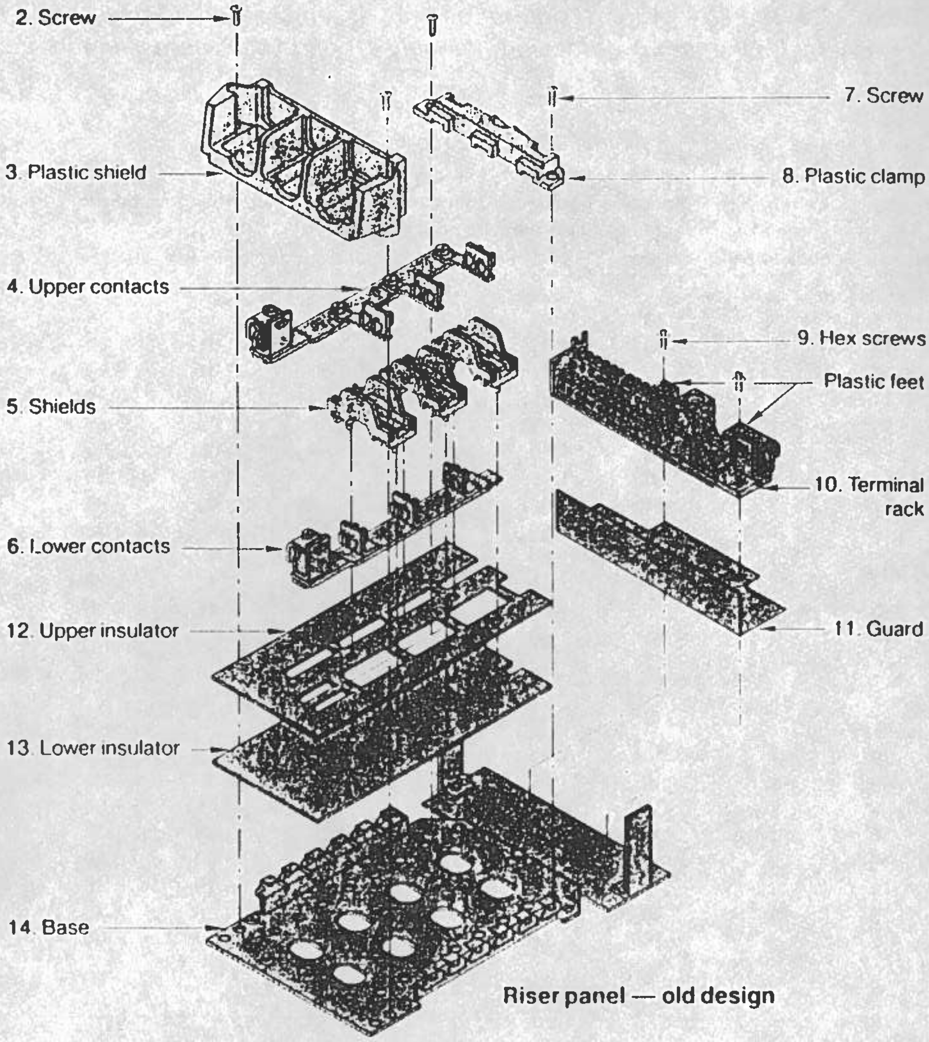

Figure 17.15 cont.

part is moved to a location without a stop (case B). In the latter case the absence of tactile feedback requires greater manual control. Ironically, most products are assembled as in case B. One objective of good design must therefore be to incorporate stops which provide tactile feedback (Furtado, 1990).

In MTM, parts insertion or mating is described using a position element composed of three complex motions; align, orientate and engage. 'Align' is the time required to line up the insertion axes of the two parts, like a pen into a cap. 'Orientate' describes the basic motions required to geometrically match the cross-sections of the two parts, like a key into a lock. 'Engage' consists of motions required to insert a part. Alignment is effected by asymmetry of the part. Table 17.2 illustrates that the use of symmetrical parts gives a time saving of 20%.

17.5 Human Factors Principles in Design for Assembly

In MTM and other PTMS methods we predict the time for manual assembly. These methods do not consider the time required for information processing. Yet there are many design features that can affect the information processing time. Table 17.3 lists several human factors principles that are applicable to design for human assembly

Table 17.1 Worksheet for design for manual assembly; the old design had 18 parts and required 136.3 s for assembly; the improved design has only 10 parts with an estimated assembly time of 51.7 s

1 Part ID No.	2 Number of times the operation is carried out consecutively	3 Two-digit manual handling code	4 Manual handling time per part	5 Two-digit manual insertion code	6 Manual insertion time per part	7 Operation time (s): (2)x[(4) + (6)]	8 Operation cost ($): 0.4x(7)	9 Figures for estimation of theoretical minimum parts	Name of assembly
Old design									
14	1	30	1.95	00	1.5	3.45	1.38	1	Base
13	1	33	2.51	00	1.5	4.01	1.60	1	Lower insulator (< 2 mm)
12	1	33	2.51	06	5.5	8.01	3.20	0	Upper insulator (< 2 mm)
11	1	30	1.95	08	6.5	8.45	3.38	0	Guard
10	1	30	1.95	08	6.5	8.45	3.38	1	Terminal rack
9	2	10	1.50	49	10.5	24.00	9.60	0	Hex. screws (8x16 mm)
8	1	30	1.95	00	1.5	3.45	1.38	0	Plastic clamp
7	2	11	1.80	49	10.5	24.60	9.84	0	Screw (9x14 mm)
6	1	30	1.95	08	6.5	8.45	3.38	1	Lower contacts
5	3	20	1.80	00	1.5	9.90	3.96	0	Shields
4	1	30	1.95	02	2.5	4.45	1.78	1	Upper contacts
3	1	30	1.95	02	2.5	4.45	1.78	1	Plastic shield
2	2	11	1.80	49	10.5	24.60	9.84	0	Screw (9x14 mm)
						$T_m = 136.3$	$C_m = 54.5$	$N_m = 6$	Design efficiency = $\frac{3N_m}{T_m} = 0.13$
New design									
9	1	30	1.95	00	1.5	3.45	1.38	1	Base
8	1	30	1.95	00	1.5	3.45	1.38	1	Insulator (> 2 mm)
7	1	30	1.95	00	1.5	3.45	1.38	1	Lower contacts
6	1	30	1.95	00	1.5	3.45	1.38	1	Terminal rack and shield
5	2	10	1.50	38	6.0	15.00	6.00	0	Screw (9x20 mm)
4	1	30	1.95	02	2.5	4.45	1.78	1	Upper contacts
3	1	30	1.95	00	1.5	3.45	1.38	1	Plastic shield
2	2	10	1.50	38	6.0	15.00	6.00	0	Screw (9x20 mm)
						$T_m = 51.70$	$C_m = 20.68$	$N_m = 6$	Design efficiency = $\frac{3N_m}{T_m} = 0.35$

(DHA), including design features that reduce human information processing time.

Much of this chapter has addressed *ease of manipulation*, which will enhance productivity in manual assembly.

An example of *tactile feedback* is the use of physical stop barriers. When a part is moved against a stop there is a sensation in the fingers – tactile feedback which indicates that the task has been completed. *Auditory feedback* is helpful not only with parts but also for hand tools and controls and for hand tools operating on parts. In this case a sound is produced that indicates task completion. For example, the clicking sound of a switch, or the ricketing noise of a hydraulic screwdriver, indicating that the task was completed.

Visibility and *visual feedback* play an important role in assembly. Everything that is used in the manufacturing task should be fully visible. Hidden or invisible parts, cannot be pointed at. They become difficult to think of and are more abstract. When a task has been completed, there should be visual feedback – in other words something should look different. Sometimes in automobile assembly a piece of tape is put on top of a part to indicate it is finished.

Spatial compatibility has to do with the spatial layout of a workstation and has been addressed previously (see Figure 11.4). Part bins can be located in sequential order so that the operator can pick parts from

Table 17.2 Examples of time savings obtained with the 'best case' as compared with less efficient alternatives

	Best case	Comparison	Approximate time saving for best case (%)
Reach	To fixed location (case A)	To variable location (case B)	30
		To small or jumbled objects (case C)	40
Grasp			
Pick-up	Easily grasped (case 1A)	Object on flat surface (case 1B)	75
		Small object, 1/2 in. (case 1C2)	400
Select (for jumbled objects only)	Large jumbled objects (case 4A)	Object smaller than 1x1x1 in. (cases 4B, 3C)	50
Move	Against a stop or to other hand (case A)	To exact location without a stop or physical barrier (case C)	15
Position part			
Symmetrical part	Symmetrical, e.g. round peg in round hole (code S)	Semi-symmetrical 45° turn typical (code SS)	20
		Non-symmetrical, 75° turn typical (code NS)	30
Depth of insertion	No depth	4 in. insertion	100
Pressure to fit	Gravity, no pressure (code 1)	Light pressure (code 2)	210
		Heavy pressure (code 3)	500
Disengage (two parts)			
Class 1 fit	Loose	Tight	500
Ease of handling	Easy	Difficult	40

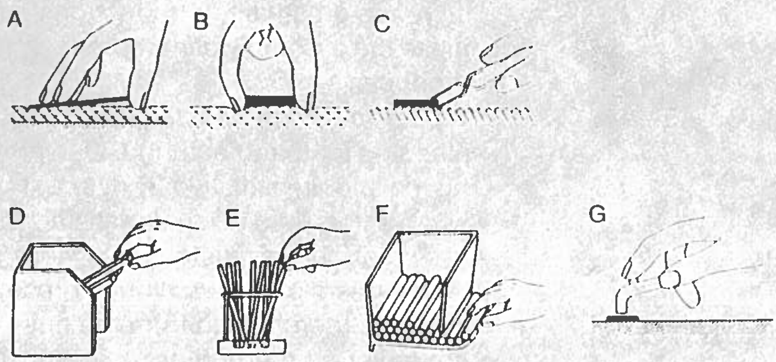

Figure 17.16 Gripping aids for an assembly workstation. (A and B) Gripping against a soft surface. (C) Tweezers or tongs used against a rippled table surface. (D) Container with inclined opening. (E) A ringholder with smaller bottom diameter. (F) Self-feeding container. (G) Use of vacuum gripper. From Luczak (1993)

Table 17.3 Human factors principles in DHA

Design for ease of manipulation
Design for tactile and auditory feedback
Design for visibility and visual feedback
Design for spatial compatibility
Design to enhance the formation of a mental model
Design for transfer of training
Design for job satisfaction

left to right in the same order as used in the assembly. Part bins can also be arranged so that their location mimics the product design. This could, for example, be used with components that are inserted in an electronic board. The best arrangement depends on the product design and the number of parts used. Obviously product design should consider spatial compatibility. One should also consider the locations of hand tools and controls. Typically items that belong together in task execution should be physically close.

Workers develop *mental models* of the task they are performing, i.e. they think of an assembly in a certain way. The concept of mental models has been used extensively in human computer interaction. Software programmers have a different mental model than do users of the same software. Therefore, programmers fail to consider the needs of the user. Similarly, in manufacturing the product designer may fail to consider mental models other than his or her own. There are, indeed, many different tasks that impose different mental models (Baggett and Ehrenfeucht, 1991). A person assembling a product would have a different mental model than a person responsible for the quality control of the same product. They look for different things and they do different things, and the priorities are different. This observation is contrary to the notion that assembly operators should exercise their own quality control; it may be difficult to change a person's mindset (Shalin *et al.*, 1994).

Transfer of training applies when a new product has only small modifications compared with the old product. A worker can then apply his skills to the new product. However, differences in product design and workstation layout may create confusion, and assembly times can increase drastically. Product designers have a responsibility here to make the assembly of new products similar to the assembly of previous products.

Design for job satisfaction is probably the most difficult aspect in planning for manufacturing. One problem is that people have different needs and are satisfied by different factors. We may understand better what factors lead to job dissatisfaction, and it could be easier to 'design to avoid job dissatisfaction'. More research is needed here.

Designers of manufacturing processes, facilities, and products must evaluate their design from the point of view of job satisfaction. There are several criteria (Locke, 1983). The design of a job should allow operators to:

- Collaborate.
- Talk to others.
- Receive performance feedback.
- Have control over their own work pace.

Chapter 7

Repetitive Motion Injury

Repetitive motion injury, or the more-or-less synonymous term 'cumulative trauma disorder', has become important in ergonomics during the last 10 years. There are many other terms such as 'overuse disorder', 'regional musculoskeletal disorder', 'work-related disorder', 'repetitive distress or strain', 'motion injury', and 'osteoarthrosis'. They are caused by repetitive motions, for example of a hand, and there is a cumulative affect so that a repetitive motion injury may develop over an extended period of time (Putz-Anderson, 1988). In this chapter we use the terms repetitive motion injury (RMI) and cumulative trauma disorder (CTD) synonymously. There are many different types of syndrome; Table 7.1 gives both medical and popular names of some of the more common disorders.

These types of injury have long been recognized in the literature. In the 18th century Ramazzini (1717) described CTD among office clerks, and he believed that these events were caused by repetitive motions of the hand, by constrained body postures, and by excessive mental stress. Liberty Mutual estimated that in 1989 the annual cost in the USA for insurance premiums for CTD cases was $563 million (Webster and Snook, 1994b). This may underestimate the current problem, since during the last 5 or 6 years the reporting of these injuries has increased rapidly.

7.1 Carpal Tunnel Syndrome

The carpal tunnel is an opening in the wrist delimited by the bones of the hand and the carpal tunnel ligament (Figure 7.1). The carpal tunnel is a tight space containing several tendons, some blood vessels and the median nerve. This crowded space is reduced in size even further when the hand or fingers are flexed or extended or bent to

Table 7.1 Some common repetitive motion injuries

Disorder name	Popular names
Carpal tunnel syndrome	Telegraphist's wrists
Cubital tunnel syndrome	Clothes wringing disease
De Quervain's disease	Tennis elbow
Epicondylitis	Golfer's elbow
Ganglion	Bible bump
Shoulder tendonitis	Space invader's wrist
Tendonitis	Slot-machine tendinitis
Tenosynovitis	Pizza palsy
Thoracic outlet syndrome	
Trigger finger	
Ulnar nerve entrapment	

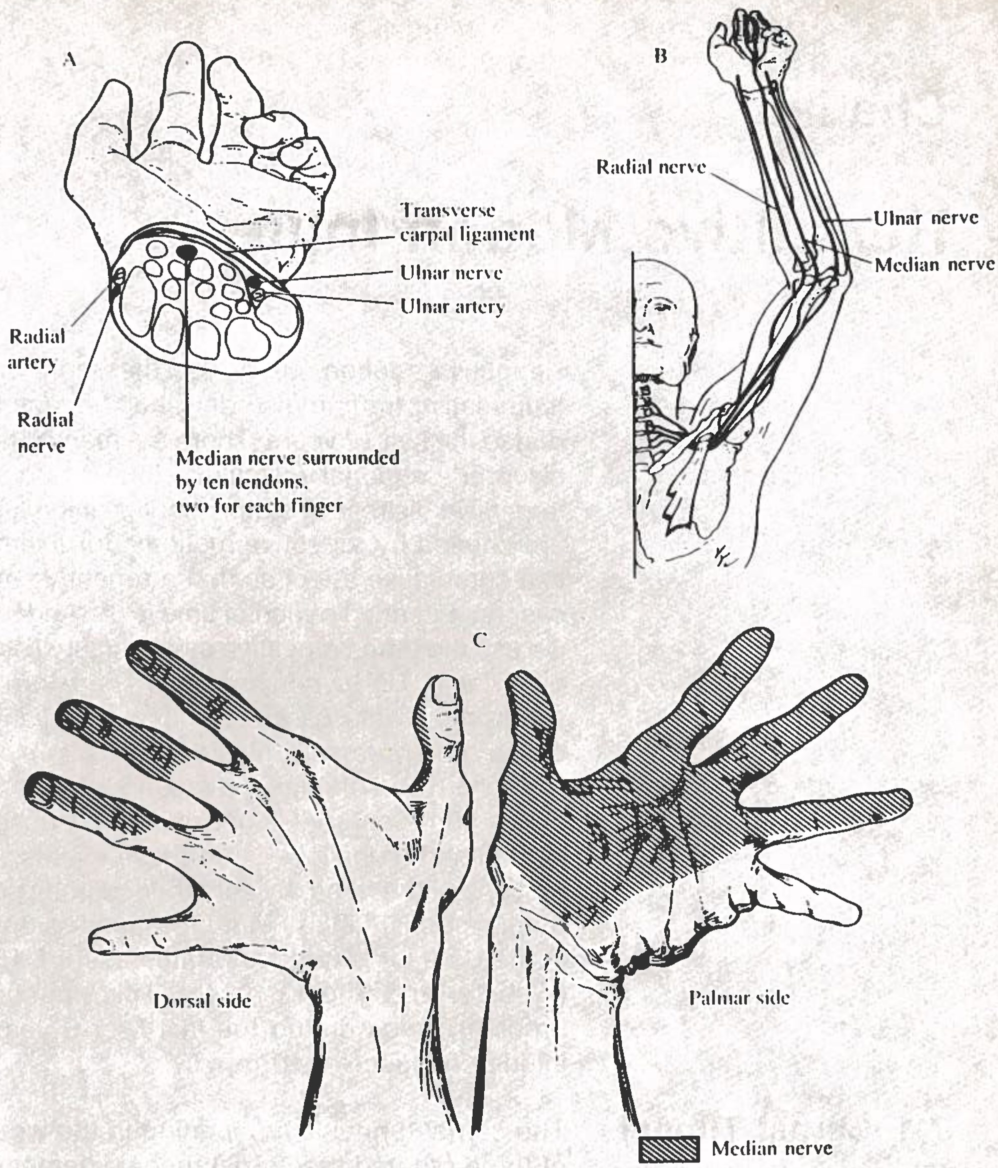

Figure 7.1 (A) Cross-section of the wrist showing the carpel tunnel, which is formed by the five bones on the one side and the transverse carpal ligament on the other. (B) Pathway of the three major nerves that originate in the neck and feed into the arm. (C) Enervation of the hand of the median nerve. The shaded areas indicate where numbness would occur in carpal tunnel syndrome (adapted from Putz-Anderson, 1988)

the side - ulnar deviation and radial deviation. These different postures of the hand are also explained in Figure 7.1(A).

The median nerve enervates the index and middle fingers and the radial side of the ring finger. If there is a swelling inside the carpal tunnel such as would occur if a tendon was inflammed, or if there is external pressure, the median nerve can get squeezed and nerve conduction is no longer efficient. The symptoms of carpal tunnel syndrome are numbness, tingling, pain, and clumsiness of the hand - very much the same as when a foot falls asleep.

Carpal tunnel syndrome has been reported for many occupations in manufacturing (Silverstein *et al.*, 1987). It is particularly significant for meat packers (Brogmus and Marko, 1990) and automobile workers (White and Samuelson, 1990). But it has also been observed among supermarket cashiers (Margolis and Kraus, 1987) and a variety of occupations in manufacturing (Table 7.2).

7.2 Cubital Tunnel Syndrome

This is a compression of the ulnar nerve in the elbow. The ulnar nerve enervates the little finger and the ulnar side of the ring finger, and this is where tingling and numbness will occur. It is believed that cubital tunnel syndrome can be caused by resting the elbow on a hard surface or a sharp edge.

Table 7.2 Repetitive motion injuries reported in manufacturing (adapted from Putz-Andersen, 1988)

Type of job	Disorder	Occupational factors
1. Buffing/grinding	Tenosynovitis Thoracic outlet Carpal tunnel De Quervain's	Repetitive wrist motions, prolonged flexed shoulders, vibration, forceful ulnar deviation, repetitive forearm pronation
2. Punch press operators	Tendinitis of wrist and shoulder	Repetitive forceful wrist extension/flexion, repetitive shoulder abdunction/flexion, forearm supination
3. Overhead assembly (welders, painters, auto repair)	De Quervain's Thoracic outlet Shoulder tendinitis	Repetitive ulnar deviation in pushing controls. Sustained hyperextension of arms. Hands above shoulders
4. Belt conveyor assembly	Tendinitis of shoulder and wrist Carpal tunnel Thoracic outlet	Arms extended, abducted, or flexed more than 60°, repetitive, forceful wrist motions
5. Typing, keypunch, cashier	Tension neck Thoracic outlet Carpel tunnel	Static, restricted posture, arms abducted/flexed, high speed finger movement, palmar base pressure, ulnar deviation
6. Small parts assembly (wiring, bandage wrap)	Tension neck Thoracic outlet Wrist tendinitis Epicondylitis	Prolonged restricted posture, forceful ulnar deviation and thumb pressure, repetitive wrist motion, forceful wrist extension and pronation
7. Bench work (Glass cutters, phone operators)	Ulnar nerve entrapment	Sustained elbow flexion with pressure on ulnar groove
8. Packing	Tendinitis of shoulder wrist Tension neck Carpal tunnel De Quervain's	Prolonged load on shoulders, repetitive wrist motions, overexertion, forceful ulnar deviation
9. Truck driver	Thoracic outlet	Prolonged shoulder abduction and flexion
10. Core making	Tendinitis of the wrist	Prolonged shoulder abduction and flexion. Repetitive wrist motions
11. Stockroom, shipping	Thoracic outlet Shoulder tendinitis	Reaching overhead. Prolonged load on shoulder in unnatural position
12. Material handling	Thoracic outlet Shoulder tendinitis	Carrying heavy load on shoulders

7.3 Tendonitis (or Tendinitis)

This is inflammation of a tendon. The symptoms are pain, burning sensation and swelling. One special case is shoulder tendonitis or bursitis at the rotator cuff (Figure 7.2). Irritation and swelling of the tendon or of the bursa may be caused by continuously keeping the arm elevated or raising the arm (Kroemer *et al.*, 1994).

7.4 Tenosynovitis (or Tendosynovitis)

This is an inflammation of tendons and tendon sheaths. It frequently occurs in the wrist and ankle where tendons cross tight ligaments. The tendon sheath swells which makes it more difficult for the tendon to move back and forth inside the sheaths. Like any inflammation, the symptoms are pain, burning sensation, and swelling.

There are many special cases of tenosynovitis such as De Quervain's disease. This is tenosynovitis of the tendons of the thumb at the wrist. It may occur due to forceful gripping and twisting of the hand, such as using a screwdriver. It has also been called 'clothes wringing disease'. Another special case of tenosynovitis is 'trigger finger', which occurs in the flexor tendons of the finger. The tendon can become nearly locked up so that the movement of the finger is sudden and jerky.

7.5 Thoracic Outlet Syndrome

This is a disorder that results from compression of the three nerves of the arm and the blood vessels (see Figure 7.1(B)). The blood flow to and from the arm is reduced and the arm becomes numb and difficult to move.

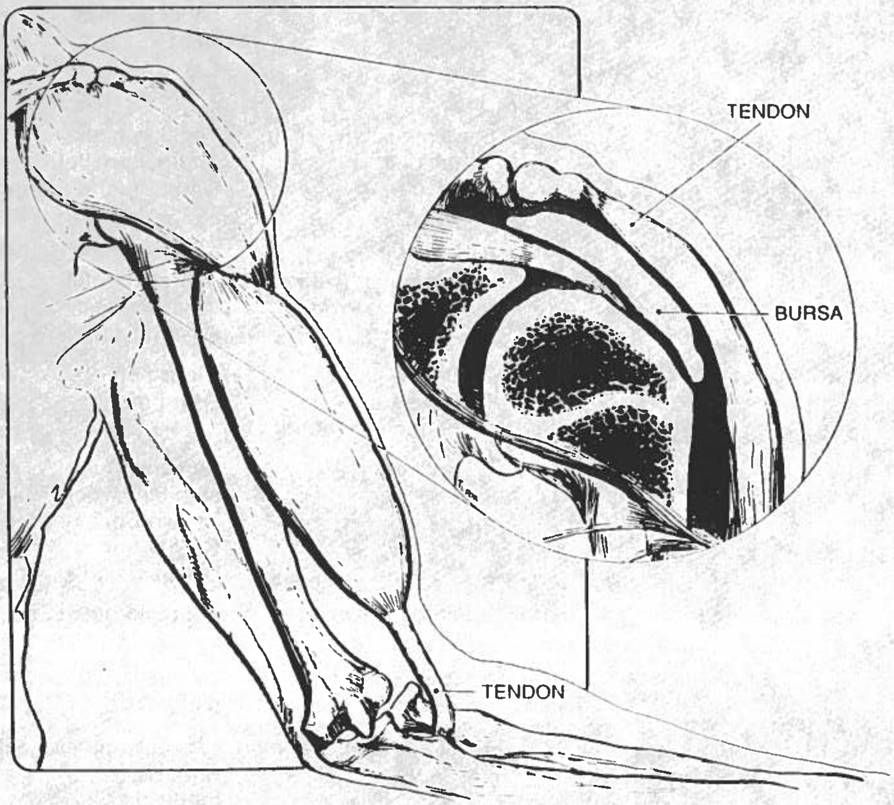

Figure 7.2 A view of the muscle-tendon-bone unit illustrating the relationship between a bursa and a tendon in the shoulder. (From Putz-Anderson, 1988)

7.6 Cause of Repetitive Motion Injury

There are several different factors that may play a part in causing cumulative trauma disorder. For the individual case, it is often impossible to pinpoint a primary cause. One must take a comprehensive look at all the various manual activities that may have contributed to the RMI. It is not just a matter of inappropriate or aggressive work methods, but also what type of activities are performed off work. Leisure activities such as knitting, carpentry and tennis playing will also impact the likelihood of developing RMI. Some of these factors are listed in Table 7.3 (Armstrong and Chaffin, 1979; Eastman Kodak Co., 1986; Putz-Anderson, 1988).

In addition, there may be psychological 'causes' of cumulative trauma disorder. One well-known incidence is the so-called 'RSI epidemic' in Australia. During 1984 the repetitive motion injury rate increased by a factor of 15 (from 50 to 670) among employees of the Australian Telecom. But then the injury rate decreased, and by the beginning of 1987 the injury rate was back to normal (Hadler, 1986; Hocking, 1987). This sudden increase and subsequent drop in injury rate must be attributed to psychological factors. It may have been the case some operators heard that colleagues were having problems and would interpret their own symptoms as being serious manifestations of RMI.

In the last couple of years the RMI rate has increased tremendously in the USA and in Europe, and it would be natural to assume that some of the reported injuries are psychological in nature. But there is also a real problem, and the increased injury rate may be due partly to the situation where it has become accepted in society to report RMI, whereas this was not an accepted work injury in the past. Indeed, Hadler (1989) reported on the types of back injuries reported in Switzerland, Germany and Holland. The legal definitions of back injuries are different in these countries, and as a result different types

Table 7.3 Causes of cumulative trauma disorders (note that many of the listed causes have not been reconfirmed by research, since they are difficult to investigate, and it takes a long time to accumulate epidemiological data)

Inappropriate work methods:
- Repetitive hand movements with high force
- Flexion and extension of hand
- High force pinch grip
- Uncomfortable work postures

Lack of experience of manual work
- New job
- Back from vacation

Inappropriate leisure activities
- Insufficient rest due to working in a second job
- Knitting, playing musical instruments, playing tennis, bowling, home improvements

Pre-existing conditions
- Arthritis, bursitis, other joint pain
- Nerve damage
- Circulatory disorders
- Reduced oestrogen level
- Small hand/wrist size

of back problem are reported. Society norms and acceptance seems greatly to affect the type of occupational injuries that are reported.

Another example is for VDT workers. In the Scandinavian countries complaints of pain in the neck and shoulder are common (Hagberg and Sundelin, 1986), but RMI have been rare (Winkel, 1990). In the USA the situation is different, and carpel tunnel syndrome is frequently reported among VDT operators (National Institute for Occupational Safety and Health, 1992). The shoulders and hands are connected by the three nerves (see Figure 7.1(B)), and there may be a possibility that the aetiology of the injuries is the same, although the manifestation of complaints are different, so as to conform to the local norms.

Whatever reason employees may have (physical or psychological) one must take complaints seriously. There are often simple modifications and additions to workstations that can alleviate some of the problems. For example, VDT operators often ask for a soft wrist

Table 7.4 Guidelines for reducing RMI through product design, process engineering, workstation design and use of appropriate handtools

Guidelines for hand posture

- Watch out for sudden flexion or extension of the hand or fingers
- Avoid extreme ulnar deviation and radial deviation
- Avoid operations that require more than 90° wrist rotation
- Keep forces low during rotation or flexion of the wrist
- For operations that require finger pinches keep the forces below 10 N; this represents 20% of the weaker operators' maximum pinch strength

Guidelines for handtools

- Cylindrical grips should not exceed 5 cm (2 in.) in diameter
- Avoid gripping that spreads the fingers and thumbs apart by more than 6 cm (2.5 in.)
- Use handtools that make it possible to maintain the wrist in a neutral position (see Figure 8.2)

Guidelines for workstation design

- Keep the worksurface low to permit the operator to work with elbows to the side and wrists in a neutral position
- Avoid sharp edges on the work table and part bins that may irritate the wrists when the parts are procured
- Keep reaches within 20 in. from the work surface so that the elbow is not fully extended

Guidelines for process engineering

- Allow machinery to do repetitive tasks and leave variable tasks to human operators
- Provide fixtures that hold parts together during assembly and which can present the assembly task at a convenient angle to the operator
- Minimize time pressure or pacing pressure by allowing operators to work at their own pace

Guidelines for product design

- Minimize the number of screws and fasteners used in the assembly
- Minimize the torque required for screws
- Locate fasteners and screws at 'natural' angles so they are easy for the operator to insert
- Design a product with large parts to permit gripping with fingers and palm instead of pinching

rest, a split keyboard, a lower typing surface, or a footrest. These are inexpensive modifications, and one should not question the utility of such measures.

7.7 Design Guidelines to Minimize Repetitive Motion Injury

Table 7.4 illustrates several engineering guidelines that can be used to minimize RMI. The assumption for presenting these guidelines is that the working environment, the task, and the workstation can be improved or redesigned by using various measures.

Participatory ergonomic improvements in small enterprises in some countries in Asia

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Introduction

For the last several years, ergonomic improvements in small enterprises have been promoted in collaboration with occupational safety and health institutions in some countries in Asia. This has led to the development of an inter-country network for improving the health of small enterprise workers. Participatory steps based on the exchange of positive local experiences have proven to be effective in various socio-cultural settings.

These experiences have shown the special need for utilizing practical intervention tools for identifying workplace needs and available solutions. These tools are effective when they can facilitate the participatory process of local people. They point to the importance of (a) building on local practice and practical workplace improvements and (b) promoting participatory processes.

Building on local practice

The advantage of building on local practice, in particular learning from locally achieved improvements, was apparent throughout these experiences. Despite large differences in socio-economic and cultural conditions among the participating countries, the key for successful interventions was to learn from local positive examples. The presentation of locally achieved improvements could facilitate new interventions from occupational health and ergonomics points of view. These local improvements had strikingly similar features despite large between-country differences in local situations. This facilitating role of local good examples was also clear from the positive experiences through the application of the Work Improvement in Small Enterprises (WISE) methodology developed by the ILO for enabling small enterprises to carry out improvements.

Collected local good examples of workplace improvements could be used in various ways. Examples were: discussion of such examples in orientation meetings; encouraging voluntary initiative; case study sessions; clues for the identification of multiple problem areas; discussing available solutions; and support for prioritizing action. Thus such examples could be used in a number of phases in field interventions. The role of local good examples could be summarized as a practical means of information-sharing with a view to:

(a) identifying local needs;
(b) understanding benefits of interventions;
(c) motivating local people for taking action; and
(d) focusing on available solutions.

Our experiences confirmed the common types of improvements conducive to field interventions. Interventions tended to be successful when improvements aimed at were: (a) relatively simple; (b) available at low cost; (c) multifaceted; (d) combined with visible benefits; (e) flexibly adjusted to local situation; and (f) accessible by using local material and skills. Low-cost improvements were usually simple and this simplicity apparently helped create opportunities for action and achieve immediate results. The multifaceted nature of achieved practical improvements seemed particularly important. Main types of such improvements were typically seen in materials handling, workstation design, physical environment, welfare facilities and work organization.

Promoting participatory processes

In organizing ergonomic interventions, a special attention was paid to their participatory nature. In view of the many constraints, particularly in developing countries, taking practical steps for finding locally workable solutions was crucial. This was because occupational health and ergonomic interventions had to be a local procéss responding to the particular needs of local people. Our experiences also showed that the best way to facilitate participatory processes was to focus on group work aimed at solutions.

To sustain active initiative of local research staff and workplace people, direct support was needed for group work in sharing experiences and identifying workable solutions. The practical steps commonly used for facilitating participatory interventions included:

(a) group discussion and subsequent group action based on locally achieved examples;
(b) prioritizing different elements of the workplace by group inspections; and
(c) identifying simple improvements first with a view to learning-by-doing.

Good local examples and workplace assessment results were useful inputs so as to help the participants identify locally available solutions.

Based on the successful experiences of group work processes in pilot intervention studies, we could jointly organize a series of participatory action training workshops for workplace improvements. A workshop of 2-3 days could usually motivate trainees to learn form local good examples, examine their own workplace conditions by means of a checklist, and identify feasible low-cost solutions in multiple aspects. This training approach was similar to the WISE methodology. It was particularly interesting to see that such participatory training could motivate both research staff and workplace people together.

This experience led to the recognition of the importance, within the network, of developing participation tools that could facilitate the assessment of workplace needs and the identification of practical workplace improvements. The use of "action checklists" listing feasible actions, combined with small group work, was considered to be extremely effective in prioritizing different workplace aspects and focusing on available solutions. As the most essential tools the following may be mentioned:

(a) audio-visual materials of local low-cost improvements;
(b) action checklists that list locally available simple solutions;
(c) action manuals providing guidance as to how to implement improvements;
(d) practical methods to animate group work (such as brainstorming, games, etc.);
(e) work sheets for group work and presentation (photo-sheets, flip-charts, etc.).

It should be noted that, in order to initiate an effective participatory process, providing a forum of discussion by local people was by no means sufficient. Participants had to be given an opportunity to do the planning and implementation of improvements. Thus, it was very important to enable participants to base their judgement on information on local achievements and locally available solutions. The above-mentioned tools were closely coupled with this idea of direct participation

Conclusions

Our experiences of several years in developing a small network for field interventions promoting practical improvements of workers' health and ergonomics demonstrated the importance of building on local practice as well as promoting participatory action. Particularly important was a combination of (a) presenting locally achieved improvements; (b) group work methods; and (c) using participatory tools. A clear focus on identifying and implementing low-cost improvements was always essential.

Workplace Checklist

How to use the checklist

1. Define the work area to be checked. In the case of a small enterprise, the whole production area can be checked. In the case of a larger enterprise, particular work areas can be defined for separate checking.

2. Read through the checklist and spend a few minutes walking around the work area before starting to check.

3. Read each item carefully. Look for a way to apply the measure. if necessary ask the manager or workers questions. If the measure has already been applied or it is not needed, mark **NO** under "Do you propose action?" If you think the measure is worthwhile, mark **YES**. Use the space under **REMARKS** to put a description of your suggestion or its location.

4. After you have gone through the whole items, look again at the items you have marked **YES**. Choose a few where the benefits seem likely to be the most important. Mark **PRIORITY** for these items.

5. Before finishing, make sure that for each item you have marked **NO** or **YES**, and that for some items marked **YES** you have marked **PRIORITY**.

Materials storage and handling

1 Clear and mark transportways.

Do you propose action?

O No O Yes O Priority

Remarks

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____
____

2 Keep transportways wide enough and even, with ramps of a small inclination where necessary.

Do you propose action?

O No O Yes O Priority

Remarks

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____
____

3 Use carts, hand-trucks, rollers and other wheeled devices when moving materials.

Do you propose action?

O No O Yes O Priority

Remarks

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____
____

4 Provide multi-level shelves or storage racks near the work area for tools, raw materials, parts and products.

Do you propose action?

O No O Yes O Priority

Remarks

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____
____

5 Use mobile storage racks for storing and moving materials, tools and semi-products, using (if necessary) pallets or small containers.

Do you propose action?

O No O Yes O Priority

Remarks

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____
____

6 Use hoists, conveyers or other mechanical means for moving or lifting heavy materials.

Do you propose action?

O No O Yes O Priority

Remarks

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7 Instead of carrying heavy weights, divide them into smaller light weight packages, containers o r trays, all provided with good grips or holding points.

Do you propose action?

O No O Yes O Priority

Remarks

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Work-stations

8 Adjust working height for each worker at elbow level or slightly lower than elbow level. (If necessary, use foot platforms for small workers and work item holders for tall workers.)

Do you propose action?

O No O Yes OPriority

Remarks

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9 Put frequently used tools, controls and materials within easy reach of workers.

Do you propose action?

O No O Yes O Priority

Remarks

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10 Use jigs, clamps, vices or other fixtures to hold items while work is done.

Do you propose action?

O No O Yes O Priority

Remarks

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11 Provide a conveniently placed "home" for each tool.

Do you propose action?

O No O Yes O Priority

Remarks

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12 Change work methods so that the workers can alternate standing and sitting while at work.

Do you propose action?

O No O Yes O Priority

Remarks

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13 Provide chairs or benches of correct height (with the feet comfortably and flatly placed on the floor) with a sturdy back rest.

Do you propose action?

O No O Yes O Priority

Remarks

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14 Attach labels and signs easy to read in order to avoid mistakes.

Do you propose action?

O No O Yes O Priority

Remarks

Low-cost Hazard Control

15 Attach proper guards to dangerous moving parts of machines and power transmission equipment.

Do you propose action?

O No O Yes O Priority

Remarks

16 Use mechanical devices or magazines for machine feeding to avoid hazards and increase production.

Do you propose action?

O No O Yes O Priority

Remarks

17 Make emergency controls clearly visible and easy to reach.

Do you propose action?

O No O Yes O Priority

Remarks

Physical environment

18 Add skylights and paint ceilings and walls in light colours.

Do you propose action?

O No O Yes O Priority

Remarks

19 Provide good lighting by re-positioning lamps or by adding local task lights.

Do you propose action?

O No O Yes O Priority

Remarks

20 Ensure safe wiring connectors for supplying electricity to equipment and lights.

Do you propose action?

O No O Yes O Priority

Remarks

21 Isolate or screen the sources of dust, hazardous chemicals, noise or heat.

Do you propose action?

O No O Yes O Priority

Remarks

22 Increase natural ventilation and introduce or improve local exhaust ventilation.

Do you propose action?

O No O Yes O Priority

Remarks

Welfare facilities

23 Provide an adequate supply of cool, safe drinking water and a separate, hygienic place for eating.

Do you propose action?

O No O Yes O Priority

Remarks

24 Provide regularly cleaned toilets and washing facilities (with soap) close to the work area.

Do you propose action?

O No O Yes O Priority

Remarks

25 Provide resting corners, apart from work areas, with comfortable sitting arrangements.

Do you propose action?

O No O Yes O Priority

Remarks

26 Provide enough fire extinguishers and first-aid equipment within easy reach and be sure that workers know how to use them.

Do you propose action?

O No O Yes O Priority

Remarks

27 Provide at least two unobstructed ways out of every floor or every big room and make sure that workers know how to evacuate in an emergency.

Do you propose action?

O No O Yes O Priority

Remarks

Work organization

28 Combine tasks so that each worker can perform varied and interesting work.

Do you propose action?

O No O Yes O Priority

Remarks

29 Set up a small stock of unfinished products (buffer stock) between different work-stations in order to keep work flow constant while allowing self-paced work.

Do you propose action?

O No O Yes O Priority

Remarks

30 Provide opportunities to take short breaks for strenuous work or work requiring continuous attention.

Do you propose action?

O No O Yes O Priority

Remarks

___

___

___

ERGONOMICS CHECKPOINTS

CHECKPOINT

1 - Clear and mark transport routes.

2 - Keep aisles and corridors wide enough to allow two-way transport

3 - Make the surface of transport routes even, not slippery and without obstacles

4 - Provide ramps with a small inclination of up to 5 to 8 per cent instead of small stairways or sudden height difference within the workplace.

5 - Improve the layout of the work areas so that the need to move materials is minimized

6 - Use carts, hand-trucks and other wheeled devices, or rollers, when moving materials

7 - Use mobile storage racks to avoid unnecessary loading and unloading

8 - Use multi-level shelves or racks near the work area in order to minimize manual transport of materials

9 - Use mechanical devices for lifting, lowering and moving heavy materials

10 - Reduce manual handling of materials by using conveyers, hoists and other mechanical means of transport

11 - Instead of carrying heavy weights, divide them into smaller lightweight packages, containers or trays

12 - Provide handholds, grips or good holding points for all packages and containers

13 - Eliminate or minimize height differences when materials are moved manually

14 - Feed and remove heavy materials horizontally by pushing and pulling them instead of raising and lowering them

15 - Eliniate tasks that require bending or twisting while handling materials

16 - Keep objects close to the body when carrying

17 - Raise and lower materials slowly in front of the body without twisting or deep bending

18 - When carrying a load for more than a short distance, spread the load evenly across the shoulders to provide balance and reduce effort

19 - Combine heavy lifting with physically lighter tasks to avoid injury and fatigue and to increase efficiency

20 - Provide conveniently placed waste containers

21 - Mark escape routes and keep them clear of obstacles

22 - Use special-purpose tools for repeated tasks

23 - Provide safe power tools and make sure that safety guards are used

24 - Use hanging tools for operations repeated in the same place

25 - Use vices and clamps to hold materials or work items

26 - Provide hand support when using precision tools

27 - Minimize the weight of tools (except for striking tools)

28 - Choose tools that can be operated with minimum force

29 - For hand tools, provide the tool with a grip of the proper thickness, length and shape for easy handling

30 - Provide hand tools with grips that have adequate friction or with guards or stoppers to avoid slips and pinches

31 - Provide tools with proper insulation to avoid burns and electric shocks

32 - Minimize vibration and noise of hand tools

33 - Provide a "home" for each tool

34 - Inspect and maintain hand tools regularly

35 - Train workers before allowing them to use power tools

36 - Provide for enough space and stable footing for power tool operation

37 - Protect controls to prevent accidental activation

38 - Make emergency controls clearly visible and easily accessible from the natural position of the operator

39 - Make different controls easy to distinguish from each other

40 - Make sure that the worker can see and reach all control comfortably

41 - Locate controls in sequence of operation

42 - Use natural expectations for control movements

43 - Limit the number of foot pedals and, if used, make them easy to operate

44 - Make displays and signals easy to distinguish from each other and easy to read

45 - Use markings or colors on displays to help workers understand what to do

46 - Remove or cover all unused displays

47 - Use symbols only if they are easily understood by local people

48 - Make labels and signs easy to see, easy to read and easy to understand

49 - Use warning signs that workers understand easily and correctly

50 - Use jigs and fixtures to make machine operation stable, safe and efficient

51 - Purchase safe machines

52 - Use feeding and ejection devices to keep the hands away from dangerous parts of machinery

53 - Use properly fixed guards or barriers to prevent contact with moving parts of machines

54 - Use interlock barriers to make it impossible for workers to reach dangerous points when the machine is in operation

55 - Inspect, clean and maintain machines regularly, including electric wiring

56 - Train workers for safe and efficient operations

57 - Adjust the working height for each worker at elbow level or slightly below it

58 - Make sure that smaller workers can reach control and materials in a natural posture

59 - Make sure that the largest worker has enough space for moving the legs and body easily

60 - Place frequently used materials, tool and control within easy reach

61 - Provide a stable multi-purpose work surface at each workstation

62 - Provide sitting workplaces for workers performing tasks requiring precision or detailed inspection of work items, and standing workplace for workers performing tasks requiring body movements and greater force

63 - Make sure that the workers can stand naturally, with weight on both feet, and perform work close to and in front of the body

64 - Allow workers to alternate standing and sitting at work as much as possible

65 - Provide standing workers with chairs or stools for occasional sitting

66 - Provide sitting workers with good adjustable chairs with a backrest

67 - Provide adjustable work surface for workers who alternate work between small and large objects

68 - Use a display-and-keyboard workstation, such as a visual display unit (VDU), that workers can adjust

69 - Provide eye examination and proper glasses for workers using a visual display unit (VDU) regularly

70 - Provide up-to-date training for visual display unit (VDU) workers

71 - Involve workers in the improved design of their own workstation

72 - Increase the use of daylight

73 - Use light colors for walls and ceilings when more light is needed

74 - Light up corridors, staircases, ramps and other areas where people may be

75 - Light up the work area evenly to minimize changes in brightness

76 - Provide sufficient lighting for workers so that they can work efficiently and comfortably at all times

77 - Provide local lights for precision or inspection work

78 - Relocate light sources or provide shields to eliminate direct glare

79 - Remove shiny surfaces from the worker's field of vision to eliminate indirect glare

80 - Choose an appropriate visual task background for tasks requiring close , continuous attention

81 - Clean windows and maintain light sources

82 - Protect the worker from excessive heat

83 - Protect the workplace from excessive outside heat and cold

84 - Isolate or insulate sources of heat or cold

85 - Install effective local exhaust systems which allow efficient and safe work

86 - Increase the use of natural ventilation when needed to improve the indoor climate

87 - Improve and maintain ventilation systems to ensure good workplace air quality

88 - Isolate or cover noisy machines or part of machine

89 - Maintain tools and machines regularly in order to reduce noise

90 - Make sure that noise does not interface with communication, safety and work efficiency

91 - Reduce vibration effecting workers in order to improve safety, health and work efficiency

92 - Choose electric hand lamps that are well insulated against shock and heat

93 - Ensure safe wiring connections for equipment and lights

94 - Protect workers form chemical risks so that they can perform their work safety and efficiently

95 - Provide and maintain good changing, washing and sanitary facilities to ensure good hygiene and tidiness

96 - Provide drinking facilities, eating areas and rest rooms to ensure good performance and well-being

97 - Improve welfare facilities and services together with workers

98 - Provide a place for worker's meetings and training

99 - Clearly mark areas requiring the use of personal protective equipment

100 - Provide personal protective equipment that gives adequate protection

101 - Choose well-fitted and easy-to -maintain personal protective equipment when risks cannot be eliminated by other means

102 - Ensure regular use of personal protective equipment by proper instructions, adaptation trials and training

103 - Make sure that everyone uses personal protective equipment where it is needed

104 - Make sure that personal protective equipment is acceptable to the workers

105 - Provide support for cleaning and maintaining personal protective equipment regularly

106 - Provide proper storage for personal protective equipment

107 - Assign responsibility for day-to-day cleaning and housekeeping

108 - Involve workers in planning their day-to-day work

109 - Consult workers on improving working-time arrangements

110 - Solve work problems by involving workers in groups

111 - Consult workers when there are changes in production and when improvements are needed for safer, easier and more efficient work

112 - Reward workers for their help in improving productivity and the workplace

113 - Inform workers frequently about the results of their work

114 - Train workers to take responsibility and give them the means for making improvements in their jobs

115 - Provide opportunities for easy communication and mutual support at the workplace

116 - Provide opportunities for workers to learn new skills

117 - Set up work groups, each of which collectively carries out work and is responsible for its results

118 - Improve jobs that are difficult and disliked in order to increase productivity in the long run

119 - Combine tasks to make the work more interesting and varied

120 - Set up the small stock of unfinished products (buffer stock) between different workstations

121 - Combine visual display work with other tasks to increase productivity and reduce fatigue

122 - Provide short and frequent pauses during continuous visual display work

123 - Consider worker's skill preferences in assigning people to jobs

124 - Adapt facilities and equipment to disabled workers so that they can do their jobs safely and efficiently

125 - Give due attention to the safety and health of pregnant woman

126 - Take measures so that older workers can perform work safely and efficiently

127 - Establish emergency plants to ensure correct emergency operations, easy access to facilities and rapid evacuation

128 - Learn about and share ways to improve your workplace from good examples in your own enterprise or in other enterprise

An Ergonomic Approach to Job Design & Hazard Abatement

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Background

Ergonomics is the scientific study of human work.[1] It has been around for a long time, and formally recognised since World War II. It is also called "human engineering," or "human factors engineering," and essentially tries to apply scientific information concerning human beings to the design of objects, systems and environments for human use.[2]

The objective of ergonomics is to try to match the job to the worker, and/or the product to the user, and thus covers both those who make the product and those who ultimately use it. And it tries to adapt the job or product to the environment in which it is used. We are not good at this -- we adopt the ideas of others in slavish fashion, not noting that the environment in which we use a tool or machine may be substantially different from that where it came. We use trucks and automobiles which were designed for a cold climate and frequently don't take into account that a hot climate may require concerns about cooling or ventilation which did not rank as importantly where the machine or product was developed. Third-world countries may be particularly affected by this problem.

There is no such thing as a single discipline called "ergonomics." It is multi-disciplinary, and may include medical practitioners, psychologists, engineers, human resource people, nurses, managers, and a wide variety of others. It is only by pooling the information available concerning people or jobs that we can be helpful when it comes to bad job design and elimination of the physical, psychological, and emotional problems that can result.

Bad job design costs money and eats up human beings. But because we are the kind of creature we are, we tend to accept as job, for what it is, good or bad. If suffering or risk is part of the situation, we accept it more often than not, as something that cannot be changed. In countries where labour is cheap, a decision may be made to simply ignore job design problems at a tremendous cost to the working population.

Bad job design interferes with achievement of high productivity and good quality of product and services. Unfortunately, solutions to job design problems are too often viewed as simply a way to eliminate hazards and not also as a means to get people to change their ways of doing their job, working smarter, not harder, and leaving work at the end of the day feeling better and more productive.

Another regrettable problem relates to the typical engineer's and supervisor's lack of understanding of basic human physiology and the limitations of the human body. Just a little knowledge of what kind of work damages tendons and soft tissues would go a long way toward development of working procedures which are kinder to the human body.

When we invent a new machine, process, chemical compound, or work method, we tend to concern ourselves more with the production purpose and not enough with potential problems that may be built into the original design. Engineers or inventors design the equipment attain a production goal, not because they know what effect their innovation will have on others. It is not until it is out in the workplace that its flaws become visible.

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[1] Stephen Pheasant, *Ergonomics, Work and Health, Macmillan Press, Ltd. London, 1993, p.3*
[2] Pheasant, *op cit*, p. 4

Typical manifestations of job design problems

There are a number of clear signals that problems exist when any of the following are found:[3]

- Work-related pain, fatigue, or psychological stress
- Acute muscle injuries
- Tendonitis, tendon injuries, spasms
- "Home-made" job redesign (pads, cushions, blocks, or other worker changes)
- Back pain or injuries
- Postural deformities
- Long-term degenerative changes to extremities or back
- Worker avoidance of certain jobs or tasks

In the United States, nearly half of all injuries are, one way or another, related to job design, improper working procedures, or lack of training. Repetitive strain injuries, which are only recently (in the last 25 years) getting attention, are directly related to work method and stress from overuse. In some countries including Australia, repetitive strain injuries have assumed epidemic proportions since 1980. Why weren't they spotted earlier? Perhaps because of mis-diagnosis or because employees didn't realise they were job-related.

Causes of RSI or Chronic Trauma Disorders

To a significant degree, much of the applied ergonomics work is based on principles of scientific management, or "Fordism" as it is sometimes called, Just like the assembly line produced a new system for manufacturing and processing work, the system of *job analysis*, a critical part of the process of investigating causes of CTD and RSI problems in the workplace.[4]

There are six work activities that are directly related to causes of CTD problems. While the jobs may be designed in different ways, once the key problems are know, it becomes easy to assess a workplace and identify causes of injuries. These are:

1. **Application of force** - If the job requires application of mechanical effort in pressing, pushing, pulling, twisting, lifting, other physical activities

2. **Posture (Motion)** - If working procedure require performing tasks in an awkward posture, then injury is likely to result. This includes bending, working with the shoulders or back in an off-center position, reaching beyond the normal length of the arm repetitively or behind.the trunk of the body. Motion can result in , negative effects from acceleration, deceleration, weightlessness, disorientation resulting therefrom, and Chronic Trauma Syndrome or injury is likely to result.

3. **Repetition** - If the same activity has to be done over and over again, hundreds or, thousands of times, then this can be related to CTS (Chronic Trauma Syndrome). In general it becomes a major problem when combined with one of more of the previous factors shown.

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[3] Pheasant, Stephen, *op cit*, chapters 2-5.
[4] Torsten Björkman, "The Rationalisation Movement in perspective and some ergonomic implications," *Ergonomics*, Spring, 1995, pp. 111-117

4. **Duration** - This refers to the time elapsed when a specific exertion is performed or a posture is assumed. In more detail, duration is the movement or exertion time for a specific muscle-tendon group or body region, (eg. right hand and wrist). The assumption is that the longer force is exerted on a particular part of the body, the more likely that problems will occur if posture is bad or there are job design problems of other types.

5. **Vibration** - The last major cause of CTS is related to vibration, and sound. Short-term exposure causes little physiological effect, but long-term exposure can possibly cause damage to the back, internal organs, nervous, and circulatory systems.

6. **Temperature** (Cold especially) - Low temperatures can expose body parts to musculoskeletal disorders, but injury results from cutaneous sensory sensitivity, manual dexterity, and grip strength, which in turn results in injury.

Human error as a cause

To some safety and health people, human error has a connotation of *blame*.[5] Instead it should be looked at as an incident whose cause has to be investigated. And they may be due more to the nature of work to be performed or equipment, or a combination of human behaviour and work surroundings, as to human failure. The categories of human error include:

- Errors of omission - where a worker fails to do something
- Errors of commission - where an act is performed incorrectly
- Sequence error - where a step or task is done out of sequence
- A timing error - where a person fails to perform the action within the allotted time

The Process for Working with Ergonomic Problems[6]

It has to be recognised that cumulative trauma disorders are associated with multiple work- and non-work-related factors, including work processes, methods, equipment, tools, materials, schedules, incentives and other aspects of work organization. Any program that intends to look into eliminating the hazards associated with these factors should include the following:

Assumption of responsibility by management - to control work-related CTDs by establishing procedures to identify and control recognised risk factors. These include education & training of employees in signs of CTDs, employee procedures from reporting problems, helping to survey through job analysis and design functions, protect employees from reprisal for reporting injuries or potential CTD risk factors, or access to a health care provider. Provide job incumbents with opportunity to become familiar with jobs and tasks, modify jobs and /or accommodate employees who have functional limitations secondary to CTDs as determined by Health Care Providers, and ensure employee privacy and confidentiality regarding medical conditions identified during the assessment.

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[5] Mark S. Sanders & Ernest McCormick, *Human Factors in Engineering & Design*, Seventh Edition, McGraw-Hill, New York, 1993, pp. 655-656.
[6] From: National Safety Council, *Control of Work-Related Cumulative Trauma Disorders, Part 1: Upper Extremities*, Itasca, IL, 1996, Section 4-2 - 4-6.

Employees - Should follow applicable workplace health & safety rules and work cooperatively with management to identify and help correct ergonomic and work procedure problems.

Develop a written document describing program - Specify objectives, tasks, schedule, personnel to handle program, those who will oversee program, identify key players, training necessary, resources needed, mechanism for communicating, and how program evaluating will be handled.[7]

1. **Provide employee and manager training** - Train people to handle medical management, job analysis and design of medical management components of the program.

2. **Seek employee involvement** - To control work-related CTD problems, employee involvement is a powerful tool, since they need to understand and contribute to the overall components of the work to be done. These activities can be carried out through joint committees, a hazard surveillance and reporting system, or turned over to an ergonomics team for them to work on.

3. **Identify exposed and injured employees and work-related risk factors** - Through assessment of medical records, injury reports and use of employee survey methods.

4. **Evaluate affected employees** - Perform medical assessments to determine health condition, determine whether work-related, make conclusions about possible treatment or necessary actions to remove the employee from the source of the problem.

5. **Evaluate identified jobs** - Identify forceful, repetitive or sustained postures inherent in the job by direct observation or from job descriptions, weights of work objects and tools, production standards, if any, and length of the workday. Look for insufficient rest, pause or recovery times. Identify extreme, repeated or long exposure to vibration from available information, and look for cold temperatures if they are present in elements of the job.

6. **Develop and implement workplace interventions** - Essentially, this means to re-design the job as best can be done to remove the causal factors resulting in ergonomic and CTD problems that are causing multiple or severe injury to employees.

7. **Implement the ergonomic control program** - By establishing priorities for prevention and control activities, and following through on each of the steps described in preceding sections.

Working with employees and the union

Building an ergonomics program into the high performance work organization, such as are being tried in the United States, makes sense in three ways. First, it suggests to employees that the organization is not solely focused on improving the way the company functions but is also concerned about worker welfare. Second, it removes a major roadblock to organisational change -- it helps to persuade workers that change can be beneficial, or at least better than the current status quo. And third, the changes help make the organization more efficient as individual work stations are re-designed in the interest of worker well-being and productivity.

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[7] National Safety Council, *op cit*, pp.

Joint Committees - Joint committees have been around since the 1930s. Initially they were intended to provide employees with a voice by which they could make their safety concerns known while the employer retained a veto on any proposal which they did not choose to fund and or implement. In some workplaces they functioned well, but in many they didn't, simply because workers quickly determined that little was going to happen as a result of their efforts. During the 1970s, however, they became more important as employers discovered that employees would go to the government with a safety complaint if they didn't give their concerns a fair hearing first. And the federal government of the United States encouraged joint labor-management participation in hazard abatement. The proposed ergonomic standard currently being considered includes a joint participation component.

The committee complement - Who should serve on a joint ergonomic committee? Certainly the employer's safety officer, members of the union's safety committee, and key supervisors whose departments have reported high levels of Chronic Trauma Disorders. It is important that the union, if one represents employees, has some input into appointing or electing worker representatives. Whoever is chosen, they should be interested in safety and health and capable of learning how to deal with ergonomics problems.

Training - What kind of training will the committee members need? They need training in the basics of ergonomics, what the key work activities that cause CTDs are, where injuries are most prevalent in the workplace, how to work cooperatively on a committee, typical solutions to ergonomic problems, and how to conduct a hazard investigation. And depending upon how much authority the committee is given, they may need some training in work physiology, engineering controls and working procedures designed to reduce exposures to CTDs (job rotation, use of breaks, revision of production standards, etc.). In general, a one-week training program, plus occasional refresher training, is sufficient to get an ergonomics committee or team going.

Committee responsibility & authority -What should the responsibilities of the ergonomics committee be? They should be given considerable responsibility for hazard assessment, design of jobs to eliminate hazards, and coming up with solutions to ergonomic problems. And they will need a budget and some authority to spend money on solutions. This last is one that upper management gives up reluctantly. The interesting thing is that ergonomic committees tend to be more thrifty about spending funds than the managers themselves, and the risk of over-spending can be guarded against by setting up a review system. But, under no circumstances should the committee feel that it does not have the responsibility to carry out their functions.

The safety officer -The employer's safety officer, instead of being the person responsible for coming up with solutions to problems identified by the committee, should instead be a *facilitator* whose role it is to help the ergonomics committee carry out its function. He should encourage the committee to brainstorm solutions, come up with unorthodox possibilities, and focus their attention on the most serious problems first.

Positive feedback - When an ergonomics committee is functioning well, the feedback in terms of the organization quickly becomes apparent. Those workers who have benefited from improvements in job design take on a more positive attitude toward management, and almost always are able to improve their productivity. The Union as an organization begins to develop support among its members for cooperation with managnent as they see positive changes occur.

Chapter 15

Shift Work

Shift work is not a new phenomenon. Scherrer (1981) reported that in Ancient Rome, transportation of goods had to be performed at night in order to reduce traffic congestion. However, it is only during the last century, after Edison's invention of the lamp, that shift work has become widely adopted in industry. This is concomitant with several trends in industry and society:

1. *Process industries*. Many modern industries such as power plants and steel works cannot close at night.
2. *Economic pressures*. Companies often prefer to introduce a second and a third shift because production machinery is expensive and cannot be duplicated. In addition, shift work makes it possible for individuals to work overtime, which is less expensive and is often perceived as less risky than recruiting additional employees.
3. *Service sector demands*. In the service sector there are many types of job where people are needed around the clock (nurses, physicians, policemen, transportation workers, and restaurant employees).

In this chapter we take a broad definition of shift work as being anything outside the hours of 7.00 am and 6.00 pm (Monk and Folkard, 1992). With this broad definition, approximately 20–30% of the workforce participates in shift work. A later study found that 22% of the working population were shift workers: 16% of full-timers and 47% of part-timers (Mellor, 1986). Similar figures have been estimated in the UK and Sweden (Monk and Folkard, 1992). In the USA, Tasto and Colligan (1977) estimated the percentage of shift workers in several job categories (Table 15.1).

Table 15.1 Percentage of shift workers in various industries in the USA

Type of industry	Shift workers (%)
Postal workers	45.8
Food workers	42.7
Hospitals	36.9
Rubber/plastic	35.0
Railroad	32.7
Tobacco	32.8
Printing	28.5
Welfare	21.8
Chemical	19.7
Education	17.0

There are two types of operation: around-the-clock, usually involving three shifts; and operations involving fewer hours. The around-the-clock operation, and in particular the hours from 12 midnight to 4.00 am cause severe problems in terms of health, fatigue, and lost productivity, and these problems are the major focus of this chapter.

Shifts are usually designated as 'morning shift', 'afternoon shift' and 'night shift'. There are other common names: 'day shift', 'swing shift', and 'graveyard shift', or simply 'shift 1', 'shift 2' and 'shift 3'. In this chapter we use the first designation, as illustrated in Table 15.2.

15.1 Example: How Not to Schedule Shift Work

In 1981, the author visited an underground metal mine in the southern USA. During interviews with the workers it was obvious that many of them suffered fatigue from participating in shift work. It turned out that there were only two shifts, and the working hours had a beautiful symmetry:

Shift 1: 7.00 am–3.00 pm.
Shift 2: 7.00 pm–3.00 am.

We asked a manager why there were 4 hours of non-work starting at 3.00 pm. He gave the following explanation: the work procedures were identical for both crews. At first when they arrived they would transport ore and rocks which had just been blasted by the previous shift. Then they would start drilling holes for blasting, and at the end of the shift they would blast. Many years ago it used to be that blasting agents produced lots of smoke, and it was necessary to ventilate the mine for 4 hours before the next crew could come in. However, with modern types of blasting agent ventilation is no longer necessary. We told the manager that the problems with shift work would be eliminated if the second crew could work from 3.00 pm to 11.00 pm. But they did not even want to try: 'We would hate to renegotiate the contract with the union!'

15.2 Circadian Rhythms

The basic physiological problem with shift work is that the body establishes a 24-hour rhythm which is difficult to change. Figure 15.1 illustrates the so-called 'diurnal' or 'circadian' changes in oral temperature over 24 hours. The temperature is at a maximum at about 4.00 pm and at a minimum at about 4.00 am. Many other body mechanisms (heart rate, breathing rate, body temperature, excretion of many types of hormones, and urine production), follow the same sinusoidal pattern (Chapanis, 1971). Assume that a person starts working the night shift (10.00 pm–6.00 am) instead of the morning shift (6.00 am–2.00 pm). It would then take about 1 week to flatten out the sinusoidal curve and about 3 weeks to reverse the waveform. However, as illustrated in Figure 15.1 the pattern is never quite reversed. The circadian changes are smaller for a person who works the night shift as compared with those for a person who works the morning shift.

Table 15.2 Typical working hours in shift work

Name of shift	Typical working time
Morning shift	6 am–2 pm (6.00–14.00 h)
Afternoon shift	2 pm–10 pm (14.00–22.00 h)
Night shift	10 pm–6 am (22.00–06.00 h)

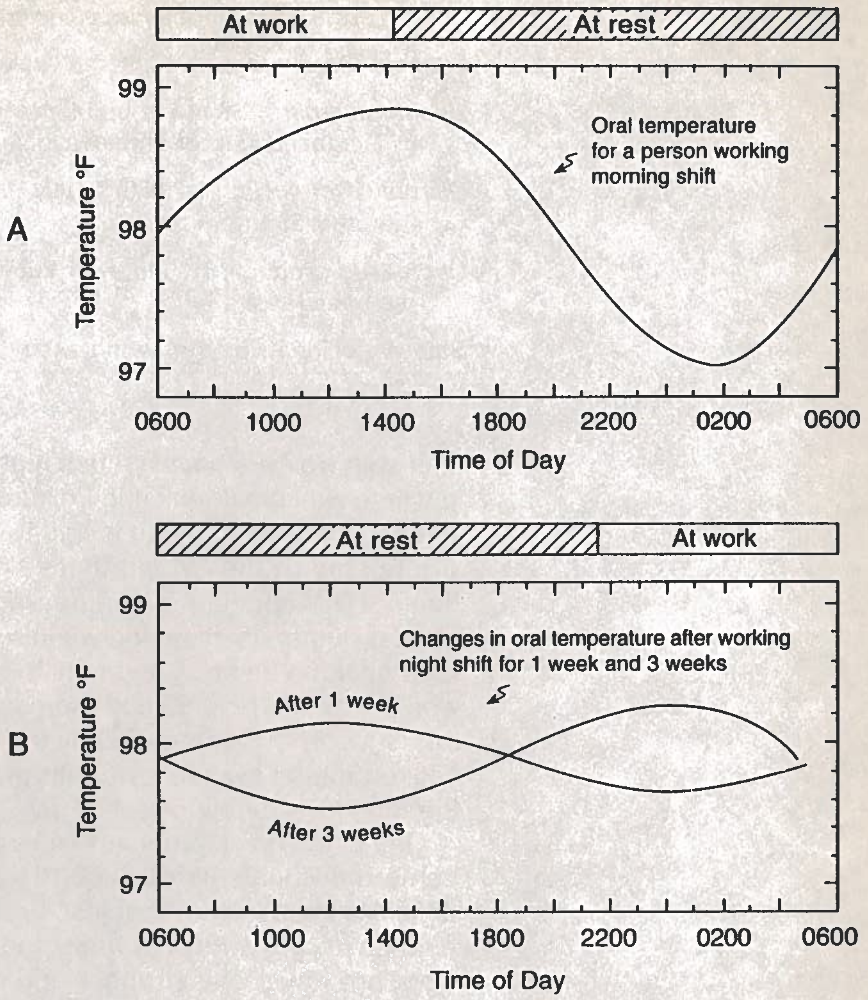

Figure 15.1 Diurnal (or circadian) rhythm of oral temperature. (A) The normal pattern for day work. (B) There is a flattening after one week and reversal of the curve after 3 weeks of working on the night shift

In other words, it seems to be impossible to adjust totally to night-time work.

There are many reasons for this lack of adjustment. The most important component may be daylight. Daylight is a very forceful cue in indicating the time of day. In German, this phenomenon is referred to as a *Zeitgeber* (literally, time-giver). Some recent research has shown that exposure to daylight levels (more than 2000 lux) of illumination increases alertness during night shifts, and suppresses the production of melatonin (a sleep-inducing hormone). But there are also many environmental and social *Zeitgebers* (Monk and Folkard, 1992). It is easier to sleep during the night-time because there is less disturbing noise and there are no social activities. On the other hand, a night worker suffers more from daytime noise and daytime activities, and family and friends also disturb the sleeping pattern.

15.3 Problems with Shift Work

There are many problems with working the night shift. Some of these problems have been well documented, whereas others have been suggested but not yet verified by research (Table 15.3). Some of the items listed in the Table 15.3 warrant some comment. It is evident

Table 15.3 Typical problems associated with working the night shift

Fatigue. On average a night-shift worker sleeps 1.5 h less
Health disorders. Stomach problems, digestive disorders, and possibly an increased rate of cardiovascular disease
Disruption of social life. With family, friends, labour unions, meetings, and other gatherings
Decreased productivity. More for knowledge-based tasks than skill- and rule-based tasks
Safety. Accident rates may increase

that shift workers have a much higher rate of stomach problems than daytime workers (Monk and Folkard, 1992). Part of the problem is that the sensation of appetite is tied to the circadian cycle. Shift workers are hungry at the 'wrong times', and go to the toilet at the 'wrong times'. The appetite is suppressed while people are asleep and is greater during daytime. Individuals starting on the night shift will carry their daytime habits along until they have adjusted. In addition, shift workers eat more junk food than do daytime workers. One reason for this may be that the company cafeteria is closed and there are no cooked meals available. A shift of the circadian cycle also disturbs the digestive functions.

One of the basic problems with research on shift work is that, while some individuals like it, about 20% of the population has severe difficulties and will never adjust. Perhaps their constitution is not robust enough to cope with shift work, and perhaps those who remain in shift work are physically stronger and have better health. Therefore the population of study may be biased to start with, and there cannot be a fair scientific comparison.

The possibility of an increased rate of cardiovascular disease in shift workers has been suggested, but this is difficult to verify. The most convincing study of increased heart disease was performed in Sweden (Knutsson *et al*., 1986). This study involved 50 workers in a paper mill. It showed that after 10–15 years of exposure to shift work, the risk of heart disease was doubled compared with a population of workers on day shift. But there were many uncontrolled factors. In addition to shift work there might have been differences related to life-style, diet, and so forth, although some of these factors were taken into account in the study. To draw firm conclusions more research is necessary.

The disruption of social life is another important consequence of shift work. Night work can make it impossible to participate in gatherings of family and friends and other social functions. This is one of the major reasons why several countries in Europe propose a fast rotating shift-work schedule, with 2 or 3 days at most on each type of shift (Table 15.4).

15.4 Effects on Performance and Productivity

It has been difficult to establish in research whether productivity is reduced during the night shift. One of the problems is that the type of work tasks are often different, so there cannot be fair comparisons with daytime work. For example, some plants schedule maintenance work during the night shift, whereas in other plants maintenance work

Table 15.4 The effect of shift work on social activities and leisure activities (adapted from Knauth et al., *1983)*

Not enough time for	Shift workers (%)	Day workers (%)
Social events	87	22
Cultural events	72	11
Friends	80	13
Family	72	11
Hobbies	67	17

is performed during the day shift. There is also a lack of supervisors and managers during the night shift, which means that group morale can suffer.

The consensus from the research is that simple skill-based and rule-based tasks do not suffer as much during shift work. Cognitive, knowledge-based tasks requiring ‘deep thinking’ are more affected. A study by Bjerner and Swensson (1953) evaluated records of error frequency in reading meters at a gas company. The error frequency was greatest at 3.00 am. Browne (1949) evaluated the speed of switchboard operators. The slowest responses were obtained between 3.00 am and 7.00 am.

Several studies have pointed to the effect of circadian rhythms on accidents. Folkard *et al*. (1978) showed that the frequency of minor accidents is the greatest at 5.00 am. Harris and Mackie (1977) investigated accidents involving US interstate truck drivers, due to falling asleep. They found that the accident rate was 20 times as high at 5.00 am as at 12 noon.

One of the most quoted, although least conclusive, events is that the Three Mile Island nuclear accident occurred during the night shift. The occurrence of this event was traced to human error and may not have occurred during daytime (Monk and Folkard, 1992).

15.5 Improving Shift Work

Guidelines that can be used for scheduling shift work and for selecting individuals to participate in shift work are listed below.

15.5.1 Type of Work

The length of the shift should be related to the type of work. For light work a 12-hour shift could be contemplated. In fact, most workers like 12-hour shifts (Miller, 1992). There is better job satisfaction, improved morale, and reduced absenteeism. But alertness and thus safety may decline, and workers may work at a slower pace.

For heavy physical or complex mental (knowledge-based) work shifts should be no more than 8 hours, and may be only 6 or 7 hours, during the night.

Visual inspection and visual monitoring is extremely difficult during the night time. This is a low vigilance task. The arousal level is low even during daylight hours and at night time many operators simply fall asleep. Rohmert and Luczak (1978) investigated operators sorting letters in the German Post Office. After working for only 2 hours on a night shift the fatigue became overwhelming. In addition, during the critical hours of 3.00–5.00 am the error rate in sorting letters increased significantly. Due to the problems with fatigue and because missorted letters are extremely costly for the postal system, it was decided to abolish the night shift – a radical solution for any operation. For these reasons visual inspection and quality control should not be scheduled for the early morning hours.

Miller (1992) suggested that the number of hours could be reduced for the night shift. It might be advisable to use a shift schedule of 8-hour morning, 9-hour afternoon, and 7-hour night (8M–9A–7N) or, alternatively, 8M–10A–6N or 9M–9A–6N. This may allow the worker to deal more appropriately with the greater amount of stress experienced during the night shift.

15.5.2 Shift Work Schedules

There is an infinite number of ways of arranging a shift-work schedule. Here we restrict ourselves to the most difficult case: 7 days of operation using four shift crews. Knauth *et al*. (1979) pointed out that the 40-hour working week is cumbersome and limiting, and that a 42-hour week allows an even distribution of worktime across workers on all shifts, because:

$$7 \text{ days/week} \times 24 \text{ hours/day} = 168 \text{ hours/week}$$

$$42 \text{ hours/crew} \times 4 \text{ crews} = 168 \text{ hours/week}$$

Thus, the week is nicely divided into four 42-hour segments.

In the German and Scandinavian countries there is a clear preference for fast, forward-rotating shift schedules. The philosophy is that the number of consecutive night shifts should be as few as possible. Preferably, there should be only one consecutive night shift in a shift schedule. In the schedule in Table 5.5 several important principles have been incorporated:

- It takes 4 weeks to go through the cycle. The shorter the cycle, the easier it is for the worker to keep track of it.
- After each night shift there is at least 24 hours of rest.
- The long weekend at the end of the first week is much appreciated.
- The shift assignments rotate forward: from morning to afternoon to night.

Forward rotation is advantageous because the true diurnal cycle is closer to 25 than 24 hours. That is, people have a tendency of wanting to go to bed 1 hour later every night. This has been proven in investigations where people live in isolation for a long period of time without any time cues (as if they are living in a dark, isolated cave).

The main philosophy behind this shift-work pattern is that workers are supposed to remain adjusted to the daytime schedule. Usually it is possible to work a single night shift without being overly tired. Of course the one disadvantage of this shift-work pattern is the

Table 15.5 A rapid forward-rotating 8-hour shift system with four crews and a 4-week cycle for a 42-hour week: each crew will work 21 shifts of 8 hours each (total 168 hours)

Week	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Sun.
1	N	–	M	A	N	–	–
2	–	M	A	N	–	M	M
3	M	A	N	–	M	A	A
4	A	N	–	M	A	N	N

M, Morning shift; A, afternoon shift; N, night shift; –, rest.

sequence of three nights at the end of week 4 and beginning of week 1.

Labour unions in Germany and the Scandinavian countries have claimed that this type of schedule improves family life and social life (Rutenfranz *et al*., 1985). But the tradition elsewhere in the world is different. In the USA it is common to have a slowly rotating shift schedule with one week devoted to each shift. Monk and Folkard (1992) suggested that this might be the worst possible policy, since there is insufficient time for the body to adjust to the new work patterns (see Figure 15.1). A much slower speed of rotation with 3 weeks or more in one shift would allow circadian adjustment. The main controversy has been discussed in detail by Monk (1986) and revolves around the loss of nocturnal orientation during free weekends, which break down the adjustment to the night-time schedule.

Two alternative fast-rotating shift-work schedules, the so-called 'metropolitan rota', or '2–2–2 shift system', and the 'continental rota', or '2–2–3 shift system', are displayed in Table 15.6 (Knauth *et al*., 1979). The numbers refer to the number of days on each shift. We provide these examples to illustrate the endless number of combinations that exist for shift-work schedules. However, in the European tradition, the schedules illustrated in Tables 15.5 and 15.6 are among the better ones.

There are social advantages in starting the morning shift either at 7.00 am or 8.00 am instead of 6.00 am; the family can have breakfast together. The preferred starting hours would then be 7–15–23 or 8–16–24.

15.5.3 Selecting Individuals for Shift Work

Some individuals, although they volunteer to participate in shift work, may eventually have difficulties in coping. Usually they are at a disadvantage from the very beginning. There are several factors which can be used to predict if individuals can be expected to have difficulties with shift work (Tepas and Monk, 1986). Managers and workers should be informed about these factors, since they are linked to satisfaction and success on the job (Table 15.7).

Table 15.6 The metropolitan rota (2–2–2) and the continental rota (2–2–3) shift systems: both systems assume 4 crews and 42-hour weeks; The metropolitan rota has an 8-week cycle and the continental rota a 4-week cycle

Metropolitan rota Week No.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Sun.
1	M	M	A	A	N	N	–
2	–	M	M	A	A	N	N
3	–	–	M	M	A	A	N
4	N	–	–	M	M	A	A
5	A	N	N	–	–	M	M
6	A	N	N	–	–	M	M
7	A	A	N	N	–	–	M
8	M	A	A	N	N	–	–
Continental rota							
1	M	M	A	A	N	N	N
2	–	–	M	M	A	A	A
3	N	N	–	–	M	M	M
4	A	A	N	N	–	–	–

M, Morning shift; A, afternoon shift; N, night shift; –, rest.

Table 15.7 Individual factors that are likely to cause problems in adapting to shift work

- People living alone do not adjust as easily
- More difficult for people with gastric or digestive disorders
- People with inadequate sleeping facilities suffer more
- Over 50 years of age
- Morning-type individuals (larks)
- Second job or heavy domestic duties
- Epileptics

Family members usually support a shift worker and make concessions. A wife of a shift worker had bought a white-noise generator for her husband to diminish the impact of noise during the daytime; the bedroom had special curtains to make it completely dark; and meals were served at special times to help her husband to adjust to the shift-work schedule.

With increasing age it seems that individuals become more set in their circadian rhythm. There is also a change towards a pattern of 'morningness', indicating that individuals tend to go to bed earlier and wake up earlier. Morningness is indeed one of the greater obstacles to shift work. Öquist (1970) established differences between 'morning types' and 'evening types', and Horne and Östberg (1976) have published a questionnaire which can be used to distinguish between morning and evening types. This questionnaire can be used to help select 'evening types' who are more suitable for shift work.

Several medical conditions could disqualify an individual from shift work. People with gastrointestinal problems get worse. Epileptics have a higher rate of seizures during the night shift.

15.6 Recommended Reading

An excellent text on shift work is: *Making Shiftwork Tolerable* (Monk and Folkard, 1992).

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