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# Zagotavljanje večje konkurenčnosti s koordiniranjem procesa konstruiranja*
# Ensuring Competitive Advantage with Design Coordination

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*Prispevek opozarja, da je treba za zagotovitev večje konkurenčnosti posebno pozornost nameniti učinkoviti koordinaciji procesa konstruiranja (KPK), da bi lahko dosegli najboljši razvoj izdelkov in produktivnosti. Predstavljena je zamisel KPK kot temelj, na katerem je mogoče uresničiti dani cilj, s poudarkom določenih vidikov razvoja izdelka, in sicer: skladno inženirsko delo, podporo odločitev, upravljanje procesa konstruiranja, upravljanje izdelkov in skupinsko inženirsko delo. Orodja oz. postopke, npr. DC, je treba vrednotiti na podlagi danih pogojev, da bi zagotovili njihovo zmožnost zadovoljiti tako poslovne kakor tudi tehnične potrebe podjetja. Na podlagi takšne ocene pridemo do sklepa, da je mogoče s koordiniranim inženirskim delom, in še posebej s koordiniranjem procesa konstruiranja, zagotoviti učinkovit razvoj izdelkov.*

*This paper argues that to ensure competitive advantage considerable effort must be directed at effective Design Coordination (DC) in order to achieve optimal product development performance and productivity. The DC Framework is presented as the basis upon which to realise this aim by providing support to particular aspects of product development, namely: Concurrent Engineering, Decision Support, Design Management, Product Management, and Team Engineering. It is suggested that tools/means such as DC should be evaluated upon identified requirements to ensure that they are capable of meeting the business as well as technical needs of the enterprise. From such an evaluation, it is concluded that Coordinated Engineering, and in particular Design Coordination within engineering design, is the means to achieve effective product development.*

## 0 UVOD

Večjo konkurenčnost lahko dosežemo na veliko različnih načinov [1], [2]. Podjetja so se v današnjem tržnem okolju prisiljena hitro prilagajati spremembam in mnogovrstnim zahtevam odjemalcev, hkrati pa morajo znati izdelati in ponuditi svoje izdelke hitreje in po konkurenčnih cenah. Proizvodna podjetja morajo torej zagotoviti:

— krajši čas od zamisli do prihoda izdelka na tržišče,

— izboljšanje kakovosti in zadovoljstva odjemalca in

— konkurenčne cene.

Vpliv procesa konstruiranja na uspeh ali neuspeh izdelka na tržišču je velik. Vedno bolj očitno je, da je zelo pomembno doseči večjo učinkovitost procesa konstruiranja. D. Rimmer [3] je prišel do naslednjih spoznanj:

»Analiza nekega vprašalnika sredi 80. let je pokazala, da je skupna »učinkovitost« razvojne faze okoli 4 %. Podlaga za tak izračun je dejstvo, da inženirji v povprečju porabijo okoli tretjino svojega časa za »dejansko« konstruiranje. Le tretjina tega časa je porabljena za reševanje »dejanskih« problemov, pri tem pa je pravilen postopek uporabljen le v tretjini tega časa ($1/3 \times 1/3 \times 1/3 \approx 4\%$). Na podlagi tega lahko sklenemo, da se v fazi konstruiranja skriva velik potencial za izboljšanje sedanjega stanja, ob predpostavki, da poznamo mehanizme za njegovo izboljšanje.

## 0 INTRODUCTION

Competitive advantage can be achieved by a number of different means [1], [2]. Within the current market environment, enterprises are being required to become increasingly responsive to changing and diverse customer needs, while being able to introduce and deliver their products more efficiently and at competitive prices. That is, manufacturing enterprises need to ensure:

— shorter time to market,

— improved quality and customer satisfaction, and

— competitive cost.

The signficance of the design process in determining the success or failure of a product in the market place is becoming increasingly more articulated. It is becoming more apparent that there is considerable scope for substantial improvements and efficiency gains within design, as intimated by Mr. D. Rimmer [3]:

»A questionnaire study carried out in the mid-80s suggested that overall effectiveness of development engineering is around 4 %. The basis for this statistic is that, on average, engineers reported spending around one third of their time doing »real« design, of this only one third was spent solving the »right« problems, and of this management have the right competencies only one third of the time ( i.e. $1/3 \times 1/3 \times 1/3 \approx 4\%$). This leads to the conclusion that the potential for improvement in better productive use of the engineering designer resource is substantial - provided we have the mechanisms to realise it.

* Referat na drugi mednarodni konferenci »Od konstruiranja do proizvodnje v sodobni industriji«. Bled 29.–30.5.95
This paper has been presented at 2nd international conference »Design to Manufacture in Modern Industry – DMMI'95.

V splošnem lahko rečemo, da je veliko časa in napora izgubljenega zaradi neuspešnega osredotočenja na aplikacijo, kakor tudi neuspešnega upravljanja konstrukcijskega dela«.

Konstruiranje zahtevnih izdelkov obsega koordinirano organizacijo več področnih skupin ter aktivnosti in informacije, ki se nenehno razvijajo in spreminjajo med samim procesom konstruiranja. Zgodovinsko gledano so bile različne aktivnosti povezane s konstruiranjem ločene in je bila medsebojna povezava na neformalni in formalni ravni komunikacij zagotovljena prek papirja ali prenosa datotek, kar je zahtevalo veliko napora, medtem ko so bili rezultati nedosledni in konfliktni, konstruiranje pa povsem neusklajeno. Konstruiranje postaja vse bolj neločljivo povezano z računalniškimi orodji za konstruiranje in podatkovnimi modeli, ki se nenehno spreminjajo. Preden je mogoče tako večplastno in zahtevno delo, kakršno je konstruiranje, učinkovito organizirati in uskladiti v okviru takšnega računalniškega medija, je treba zagotoviti združitev vseh razpoložljivih podatkov z orodjem za konstruiranje, da bi s tem zagotovili učinkovito uporabo vseh razpoložljivih možnosti. Takšno okolje daje lahko, ne le temelj razvoju večpodročnega konstruiranja in dinamične projektne skupine, temveč tudi hkraten, koordiniran in učinkovit razvoj izdelka.

Kako zapleten je proces konstruiranja, je razvidno iz velikega števila opisov v literaturi, kjer poskušajo predstaviti bistvo konstruiranja [4]. Zanimiva je predvsem raznolikost teh opisov, kakor tudi dejstvo, da poudarjajo različne vidike, glede na različno interpretacijo in dognanja posameznih avtorjev. Večina se jih prav tako nagiba k opisu modeliranja, kot verigi aktivnosti, ne upoštevajo pa zapletenosti [5], vidika dobe trajanja [6] in poslovnih oz. podjetniških posledic [7], ki so bistvenega pomena za učinkovito konstruiranje. V zadnjih letih smo torej priče oddaljevanju od teh »tradicionalnih« modelov k »hkratnemu inženirskemu delu«.

Za skrajšanje faze konstruiranja, izboljšanje kakovosti konstruiranja ali zmanjšanje stroškov proizvodnje, so bili na področju raziskav skladnega inženirskega dela vloženi precejšnji napori, usmerjeni v iskanje primernih načinov hkratnega izpolnjevanja nalog, ki so bile tradicionalno reševane bolj ali manj zaporedno. Raziskovalni napori v Zahodni Evropi in na Japonskem so osredotočeni predvsem na vprašanje dobe trajanja, medtem ko v Združenih državah Amerike poudarjajo predvsem boljšo povezanost in komuniciranje človeških potencialov.

Razlog za uvedbo koordinacije konstrukcijskega procesa (KPK) je potreba po optimizaciji tega

In general a considerable amount of time and effort is wasted by the lack of focus on the application and management of design effort«.

The design of complex products involves the coordinated organisation of multi-disciplinary groups, activities and information which continually evolve and change during the design process. Historically, different activities in the design process have been kept separate and interact through informal and formal communications, via paper medium or file transfers, resulting in considerable effort going into the resolution of inconsistencies, conflicts, and uncoordinated design activities. The design process is becoming increasingly and inextricably linked to computational design tools and data models which invariably remain disparate. Before multi-design tasks can be effectively organised and coordinated within such a computer medium, there is a need to integrate the data of the product model and the design tools in order to make effective use of the resources available. Such an environment can provide not only a basis upon which to develop multi-disciplinary design and dynamic project team organisations but also consistent, coordinated and efficient product development.

An indication of the complexity of formalising the design process comes from the large number of descriptions which exist in the literature and which attempt to present the essence of design [4]. What is interesting about these descriptions is their variety, as well as the fact that they emphasise different aspects, according to the interpretation or findings of the author(s). They have also tended to model design as a chain of activities and have not taken into account the many complexities [5], life phase aspects [6] and business/enterprise issues [7] which are essential considerations for conducting effective design. Consequently, in recent years, we have seen a trend which moves away from these »traditional« models towards »Concurrent Engineering«.

To shorten the design cycle time, improve the design quality, or reduce product costs, considerable effort in Concurrent Engineering research has been directed at ways of performing tasks in parallel which have traditionally been carried out relatively sequentially. The research effort in Western Europe and Japan has tended to concentrate upon life cycle issues, while in the United States of America, the emphasis has primarily been upon enhancing integration and communications of human resources.

The argument for Design Coorditation (DC) is that, top optimise design, activities should not be necessarily carried out »concurrently« but should be structured in such a fashion as to procesa. »Hkratno« izvajanje aktivnosti ni nujno potrebno, vendar morajo biti aktivnosti strukturirane tako, da je mogoče doseči optimalen učinek (kakovost, stroški, časovni ciklusi, donosnost itn.). V ta namen je treba koordinacijo konstrukcijskega procesa usmeriti na probleme, ki so neposredno povezani z optimizacijo procesa konstruiranja, in tako doseči kolikostni preskok v učinkovitosti razvojne faze. Tako kakor je KPK način optimizacije konstrukcijskega procesa, vodi koordinacija inženirskega dela k optimizaciji celotnega procesa razvoja izdelkov.

Pričujoči prispevek podaja poglavitne razloge za uvajanje in osnove koordinacije procesa konstruiranja ter izpostavlja ogrodje KPK kot sredstvo za obvladovanje določenih vidikov razvoja izdelka, in sicer: skladno inženirsko delo, podporo odločitev, upravljanje procesa konstruiranja, upravljanje izdelkov in skupinsko inženirsko delo. Vsi ti vidiki so drug za drugim podrobneje opisani, osvetljena pa je tudi vloga, ki jo lahko ima ogrodje DC. Sledi ovrednotenje učinkovitosti teh vidikov za zagotovitev večje konkurenčnosti in na podlagi te analize tudi sklepi.

## 1 OZADJE

V zadnjem desetletju so gospodarstveniki in znanstveniki spoznali, kako pomemben je razvoj metod za povečanje konkurenčnosti proizvodnih podjetij. To je bilo še posebej očitno pri razvoju metodologij modeliranja podjetja (MP) in skladnega inženirskega dela (SID).

*Modeliranje podjetja* je osredotočeno predvsem na učinkovito izkoriščanje uporabljenega materiala in proizvodnega procesa znotraj poslovnega okolja podjetja ter na celotno integracijo podjetja [8], [9]. Vendar takšen način neposredno ne vpliva na probleme, ki prevladujejo na področju razvoja konstruiranja izdelkov, in zato ne predstavlja načina ali podlage za optimizacijo konstrukcijskega procesa. Postopek MP je imel torej za cilj izboljšanje globalnega delovanja podjetja, strategije in razvoj celotnega poslovanja ter je bil usmerjen k zagotavljanju mehanizmov na visoki ravni — direktor/vodstvo. Velika pomanjkljivost tega načina je, da se neposredno ne ukvarja s problemi, ki se pojavljajo pri konkretnem delu na zahtevnih in večdisciplinarnih projektih.

*Hkratno inženirsko delo* je bilo usmerjeno predvsem v hkratno izvajanje nalog, ki so se tradicionalno izvajale večinoma zaporedno. To je pripeljalo do razvoja številnih metod po predlogih Vasilasha [10], npr.: sočasno inženirsko delo, inženirsko delo v dobi trajanja, procesno vodeno konstruiranje, skupinsko delo in konstruiranje za proizvodnjo. V Zahodni Evropi so poudarjali dobo

achieve optimum performance (such as total life quality and costs, cycle timer, profitability, etc.). To achieve this, Design Coordination focuses upon issues directly relevant to the optimisation of the design process in order to achieve a quantum leap in the performance of the Product Development Process. It is postulated that, similar to DC being the means to optimise design, Coordinated Engineering is the means to optimise the whole Product Development Process.

This paper gives a brief background to the stimulus for and an overview of Design Coordination, and outlines the DC Framework as a means to support particular aspects of product development, namely: Concurrent Engineering, Decision Support, Design Management, Product Management and Team Engineering. Each of these aspects is discussed in turn and the support offered by the DC Framework highlighted. An evaluation of the effectiveness of these aspects to ensure competitive advantage and conclusions from this analysis are then presented.

## 1 BACKGROUND

Over the past decade, industrialists and academics have recognised the importance of developing approaches to enhance competitive advantage within manufacturing companies. This has been particularly apparent in the development of Enterprise Modelling (EM) and Concurrent Engineering (CE) methodologies.

*Enterprise Modelling* focuses upon the effective utilisation of the material use and manufacturing process within a companys' business environment and the total integration of the enterprise [8], [9]. However, these approaches do not directly address the issues prevalent within product design development and hence do not provide a means or foundation upon which to optimise the design process. That is, EM approaches have tended to concentrate upon global company functioning, strategy, overall business development and has tended to be directed at providing a high level director/managers' tool. A major weakness of these approaches is that they do not directly address the issues involved in the actual design activity of complex and multi-disciplinary design projects.

*Concurrent Engineering* has been primarily directed at ways of performing tasks in paralel which have traditionally been carried out relatively sequentially. This has resulted in a number of methods being developed as suggested by Vasilash [10], such as simultaneous engineering, life cycle engineering, process driven design, team approach, and design for manufacture. Within Western Europe, the emphasis has been upon approaches which consider the product's life cycle trajanja izdelka [11] do [14] in povezavo tržnih zakonitosti s konstruiranjem in proizvodnjo v poslovno celoto [15]. Tako se je zahodnoevropsko delo usmerilo predvsem na skrajšanje časa konstrukcijskega ciklusa z zgodnjim upoštevanjem problema dobe trajanja med konstruiranjem, da bi tako ublažili probleme in dosegli boljšo kakovost izdelka. V ZDA je bilo bolj poudarjeno kooperativno delo, kakor je bilo predstavljeno v programu DICE [16], [17], strokovnih delavnicah [18], knjigah [19] in raziskovalnih objavah [20] do [23]. Dodatno sta predmet raziskav na področju skladnega inženirskega dela v ZDA trenutno še dodeljevanje informacij [24], [25] in upravljanje procesa konstruiranja [26] do [31]. V ZDA so poudarjali predvsem boljšo povezanost in komuniciranje človeških potencialov. Vendar pa je bila skupna značilnost raziskovalnega dela na obeh kontinentih prizadevanje k hkratnemu in skladnemu izvajanju aktivnosti. Glavna pomanjkljivost takšnega videnja problema je spoznanje, da dejansko ni potrebe po hkratnem izvajanju aktivnosti, temveč po učinkoviti izrabi razpoložljivih potencialov, da bi lahko izvajali naloge po potrebi, ob pravem času in v skladu z zahtevami ter tako zagotovili ustrezne rezultate. Tako je: *ključ za dosego optimalne kakovosti konstruiranja in s tem tudi produktivnega konstruiranja učinkovita koordinacija procesa konstruiranja.*

Avtor je bil član delovne skupine raziskovalcev (CIMDEV), ki jo je septembra 1992 osnovala komisija Evropske skupnosti ESPRIT. Skupina je bila oblikovana z namenom pospeševati in razvijati povezave na osnovni stopnji raziskav (programska orodja) za računalniško integrirano proizvodnjo (RIP). Vse od začetka njenega delovanja je podskupina CIMDEV imela vodilno vlogo pri razvoju ključnega vprašanja na področju raziskav, povezanih s konstruiranjem — koordinacije konstrukcijskega procesa — ki ga je sedaj prevzela širša evropska skupina kot skupni osnutek več področij raziskav (vsaka preiskuje različne vidike te osrednje teme) [32].

## 2 KOORDINACIJA KONSTRUKCIJSKEGA PROCESA

Utemeljitev za uvedbo koordinacije konstrukcijskega procesa (KPK) je optimizacija konstruiranja, pri čemer ni nujno, da potekajo aktivnosti »skladno«, vendar pa morajo biti tako strukturirane, da je omogočen optimalen učinek. Glede na to je KPK definirana kot [33]: *vrhunski osnutek načrtovanja, predstavitve, odločitev in kontrole razvoja izdelka glede na čas, naloge, izkoriščenost potencialov in različne vidike konstruiranja.*

issues [11] to [14] and the integration of the market, design, and production into a business focused totality [15]. Thus, the Western European work has tended to concentrate upon shortening the design cycle time by introducing and addressing life cycle issues earlier in the design process, in order to alleviate problems and define a better quality of product. In the USA, more emphasis has been placed upon cooperative working as typified by the DICE (DARPA Initiative in Concurrent Engineering) program [16], [17] workshops [18], books such as that entitled Computer-Aided Cooperative Product Development [19] and research publications [20] to [23]. In addition, supporting information sharing [24], [25] and design management [26] to [31] are currently topical issues in American concurrent engineering research. The emphasis in the USA has primarily been upon enhancing integration and communications of human resources. In both continents, however, the ethos has been one of attempting to carry out activities in parallel/concurrently. A major shortcoming of this view is the recognition that what is truly required is not for activities to be carried out in parallel but for the effective utilisation of resources in order to carry out tasks for the right reasons, at the right time, to meet the right requirements and give the right results. That is: *the key to achieving optimum design performance and hence design productivity is the effective coordination of the design process.*

The author has been a member of a working group of researchers (CIMDEV) founded by the Commission of the European Communities ESPRIT initiative since September 1992. The group was formed in order to foster and develop collaborative links in basic research in DEVices (i.e. software tools) for Computer Integrated Manufacture (CIM). Since its inception, a sub-group of CIMDEV has played a leading role in the development of a key issue in design research - Design Coordination - which has now been adopted by the wider European group as a unifying concept for several areas of research (each examining different aspects of this central theme) [32].

## 2 DESIGN COORDINATION

The argument for Design Coordination (DC) is that, to optimise design, activities should not be necessarily carried out »concurrently« but rather they should be structured in such a fashion as to achieve optimum performance. With this objective in mind, DC has been defined as [33]: *a high level concept of the planning, scheduling, representation, decision, making and control of product development with respect to time tasks, resource utilisation and design aspects.*

Uskladitev konstrukcijskega procesa tako zaokroža rezultate, ki so neposredno povezani z rezultati skladnega inženirskega dela, podpore odločitev, upravljanja konstrukcijskega procesa, upravljanja izdelkov in skupinskega inženirskega dela in še veliko drugih. KPK je bila razvita kot temelj za podporo konstruiranju in pomeni most med integracijo podjetja, modeliranjem proizvodnje in konstrukcijsko razvojnim procesom. Žarišče je usmerjeno na učinkovito uporabo in integracijo sredstev, z namenom optimizirati konstrukcijske aktivnosti. Tako bodo, kjer bo to primerno, nekatere aktivnosti potekale hkrati, nekatere pa zaporedno. Nekatere bodo skupinsko zasnovane, nekatere pa posamezno. Nekatere bodo združene, medtem ko bodo nekatere ostale ločene. Tako imamo lahko koordinacijo konstrukcijskega procesa za sredstvo, s katerim je mogoče uresničiti skladno inženirsko delo. Ali drugače povedano, skladno inženirsko delo je rezultat hkratnega izvajanja aktivnosti, uskladitev konstrukcijskega procesa pa je način, kako to storiti.

V zadnjih sedmih, osmih letih so bili razviti številni računalniško podprti postopki, ki so neposredno povezani s podporo koordinaciji konstrukcijskega procesa. Glavno žarišče teh postopkov je povezava konstrukterjev, podatkovnih modelov in računalniških orodij [34], [35], obvladovanje protislovij in podpora odločitev [36] do [39] ter načrtovanje konstrukcijskih aktivnosti [40]. Vendar so bili le nekateri posebej usmerjeni k uskladitvi konstruiranja [41] do [46], nobeden pa ni bil utemeljen na popolnem poznavanju teorije uskladitve konstrukcijskega procesa. Čeprav pomenijo ti postopki pomembne elemente pri razvoju podpore KPK in podlago za njegovo izgradnjo, pa naslavljajo le majhen del ključnih problemov KPK. Potemtakem so še vedno potrebni precejšnji napori za razvoj glavne znanstvene podlage in temeljito poznavanje na podlagi česar bo mogoče izdelati orodja za učinkovito podporo KPK.

Primer, ki kaže, da je temu res tako, so integracijski problemi pri konstruiranju, npr. integracija računalniških orodij, podatkovnih modelov, informacij, znanja itn. Integracija je združevanje različnih, heterogenih enot, v pomenu, kako izvesti združitev, da bi lahko takšne enote delovale kot združena celota. Vendar tako ne rešujemo problema, kako bodo enote delovale kot celota, torej koordinacije. Ta razlika kaže, da integracija ne vsebuje koordinacije, ki je bistven pogoj za učinkovitost konstruiranja.

Tudi na podlagi rezultatov nedavnega projekta TC7: Gnosis, izvedenega od globalne iniciative za inteligentne proizvodne sisteme [47], je mogoče sklepati, da leži ključ za uspešno uporabo integriranih računalniških orodij za konstruiranje v njihovi učinkoviti koordinaciji v okviru konstrukcijskih aktivnosti.

To achieve this, Design Coordination encompasses issues directly relevant to concurrent engineering issues, decision support, design management, product management, and team engineering, as well as many other issues. Consequently, DC is being developed as the underlying theme for supporting the design process and offers a bridge between enterprise integration, manufacture modelling and the design development process. Its focus is directed at the effective utilisation and integration of resources in order to optimise the design activity. Consequently, where appropriate, some activities will be carried out concurrently while others sequentially, some will be team-based while some individual-based, some will be integratd and others may be kept disparate. In this way, Design Coordination can be considered as a vehicle for the realisation of Concurrent Engineering. That is, Concurrent Engineering is the result of carrying out activities in parallel and Design Coordination is the means by which to do so.

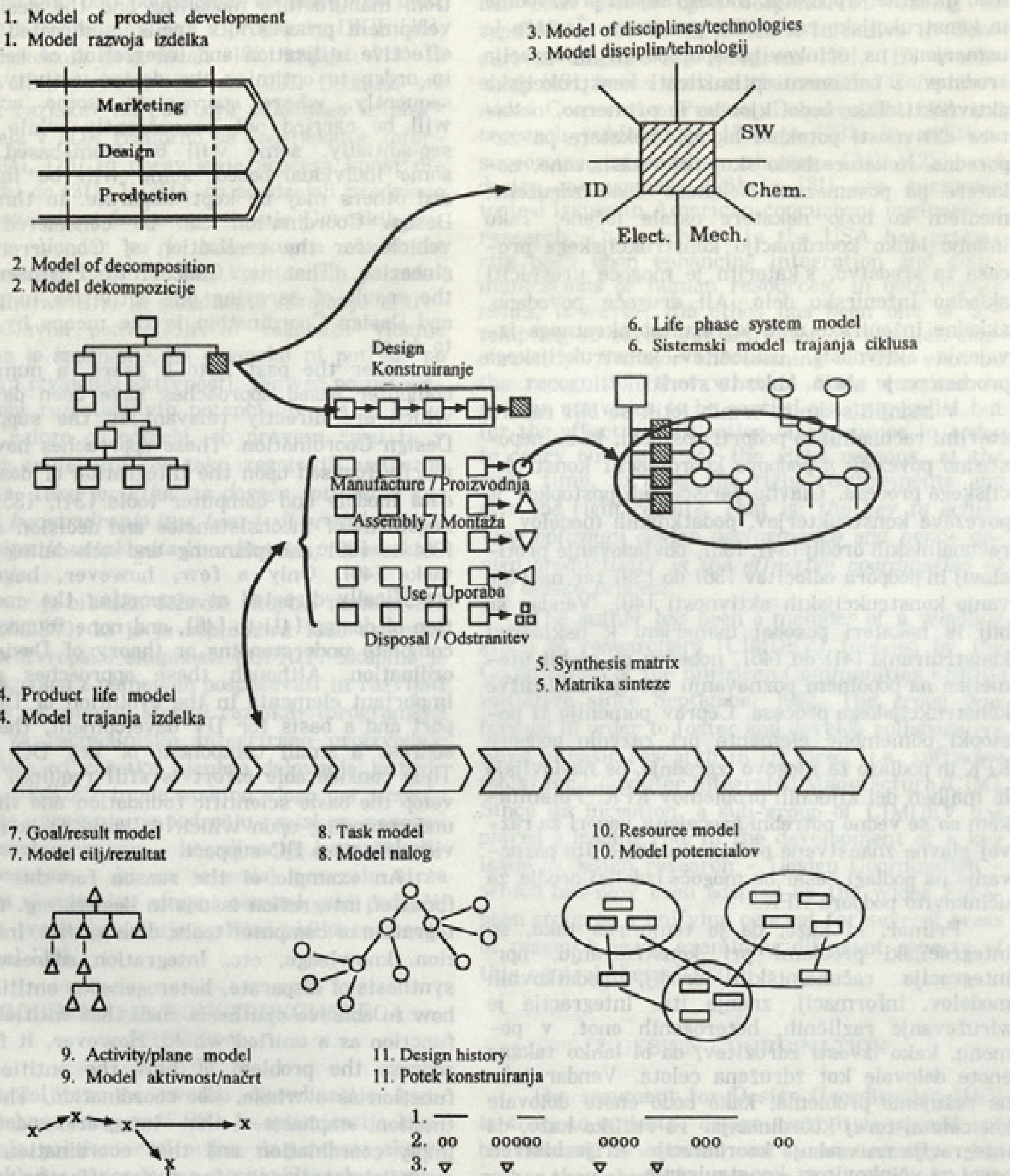
Over the past 7 to 8 years, a number of computer based approaches have been developed which are directly relevant to the support of Design Coordination. These approaches have primarily focused upon the integration of designers, data models and computer tools [34], [35], management of inconsistencies and decision support [36] to [39] and planning and scheduling design tasks [40]. Only a few, however, have been specifically directed at supporting the coordination of design [41] to [46], and none founded upon complete understanding or theory of Design Coordination. Although these approaches provide important elements in the evolution of DC support and a basis for DV development, they only address a small component of key DC issues. Thus considerable effort is still required to develop the basic scientific foundation and thorough understanding upon which to build tools to provide effective DC support.

An example of the reason for this is the focus of integration issues in design, e.g. the integration of computer tools, data models, information, knowledge, etc. Integration addresses the synthesis of disparate, heterogeneous entities, i.e. how to achieve synthesis such that entities could function as a unified whole. However, it fails to address the problem of how the entities will function as a whole, i.e. coordination. This distinction emphasises that integration does not imply coordination and that coordination is an essential prerequisite for design effectiveness.

In fact, results from a recent project, TC7: Gnosis, carried out under the global Intelligent Manufacturing Systems initiative [47] concluded that the successul utilisation of integrated design computer tools lay in their effective coordination within the design activity.

Pri poskusu oblikovanja koordinacije konstrukcijskega procesa je podskupina CIMDEV izpostavila razmere in probleme pri KPK [33], natančno določila sedanjo podporo znotraj podskupine [48] in definirala ogrodje kot osnovo za razvoj podpore KPK različnim zapletenim vidikom razvoja izdelka.

In attempting to formalise Design Coordination, the CIMDEV sub-group have outlined the issues and problems involved in DC [33], detailed its existing support within the sub-group [48] and defined a framework as a basis upon which to develop DC support of various complex aspects of product development [49].




Sl. 1. *Ogrodje koordinacije konstruiranja [49]*
Fig. 1. *Design coordination framework [49]*

Ogrodje KPK (sl. 1) sestoji iz serije ogrodij/modelov, ki predstavljajo informacijske elemente procesa razvoja izdelka in so lahko uporabljeni za vzpostavitev, nadzor in preverjanje konstrukcijskih aktivnosti. Doslej je bilo predlaganih in definiranih enajst modelov, in sicer:

— *Model razvoja izdelka*

To je model konstrukcijske aktivnosti, ki orisuje potek projekta razvoja izdelka, od zaznave potrebe po izdelku, do predstavitve izdelka na tržišču.

— *Model dekompozicije*

Model dekompozicije pomeni razbitje strukture izdelka, definirane s funkcionalnimi podsistemi in do neke mere kaže strukturo konstrukcijskih aktivnosti, nalog in poteka konstruiranja.

— *Model panog in tehnologij*

Vsak *izdelek* je izdelan na poseben način, z uporabo določenih inženirskih panog in tehnologij. Predlagani model panog in tehnologij je usmerjen v predstavljanje takšnih posebnosti za vsak podsistemski izdelek in tako modelira vsebino in porazdelitev potrebnih panog in tehnologij.

— *Model trajanja izdelka*

To je model, predlagan za predstavitev izdelka skozi različne faze nastajanja, na katere naletimo pri konstruiranju izdelka, tj. uporaba, vzpostavitev, vzdrževanje, odstranitev iz uporabe ter za upoštevanje ciklusa trajanja pri razvoju izdelka.

— *Matrika sinteze*

Izdelek in njemu pridruženi podsistemi in komponente se razvijajo skozi faze povečevanja dorečenosti, od osnovnih zamisli do popolnoma definirane specifikacije. Še več, med razvojem komponent je treba upoštevati tudi različne vidike sistema trajanja izdelka. Matrika sinteze modelira izdelek in njegove podsisteme in komponente skozi vse faze konstruiranja za vsak sistem nastajanja izdelka.

— *Sistemski model ciklusa trajanja*

Sistemski model ciklusa trajanja predstavlja sisteme, ki sodelujejo v fazah nastajanja izdelka: tj. proizvodnja, prodaja in transport med fazo vzpostavitve, servis med fazo vzdrževanja in recikliranje v fazi odstranitve izdelka iz uporabe.

— *Model ciljev in rezultatov*

V splošnem je razvoj izdelka nadzorovan z natančno določitvijo cilja, ki ga razbijemo na manjše, laže obvladljive, med seboj neodvisne cilje. Ta struktura ciljev se nanaša na dekompozicijo strukture, predstavljeno v modelu dekompozicije in podrobno določa zahteve izdelka.

— *Model nalog*

Model nalog je logična sestava nalog, ki morajo biti opravljene. Te naloge obsegajo navedbe, kaj je treba storiti, bodisi posamezno, v skupini ali v sklopu večjih organizacij.

The DC Framework (Figure 1) consists of a set of frames/models which represent informative elements of the product development process that may be used for establishing, monitoring and controlling the design activity. So far, eleven models have been proposed and defined as:

— *Model of product development*

This is a model of the design activity which carts a product development project's progress from the identification of a need for a product through to the introduction of that product in the market place.

— *Model of decomposition*

A decomposition model represents a product's breakdown structure, defined by functional sub-systems, and reflects to some extent a design activity structure, tasks and design progress.

— *Model of disciplines/technologies*

Each product has its own particular make-up of engineering disciplines and technologies. The proposed model of disciplines/technologies is directed at representing such peculiarities for each sub-system product and, thereby, model the content and distribution of required disciplines and technologies.

— *Product life model*

This is a model proposed to represent the product during various life phases which impinge on the design of a product, e.g. use establishment, maintenance, decommission, and life cycle concerned within the product development.

— *Synthesis matrix*

A product and its associated sub-systems/components evolve, through stages of increasing detail, from general concepts to fully defined specifications. In addition, various aspects of the product's life system should be considered during the components evolution. The synthesis matrix models a product and its sub-systems/components through each design stage for each product life system.

— *Life phase system model*

The life phase system model is one which represents the system which are involved during a product's life phases: e.g. the production, sales and transport systems during the establishment phase; the service system during the maintenance phase and the recycling system during the decommision phase. The design activity uses or alters those different life phase system models.

— *Goal/requirements model*

Generally, the product development activity is controlled by goal specifications which are broken down into smaller, more manageable self-contained goals. This goal structure is related to the decomposition structure represented in the decomposition model, and details the requirements of a product.

— *Task model*

The task model represents the logical breakdown of tasks required to be executed. These tasks represent statements about what is required to be done by individuals or groups or organisations.

— *Model aktivnost in načrtovanje*

Ta model vsebuje predstavitev časovne dimenzije glede na model nalog in določa, kdaj morajo biti naloge opravljene.

— *Model potencialov*

Pri konstruiranju so zmogljivosti lahko znanje, ljudje (posamezniki in skupine) in orodja (izdelana po tehnologiji in metodologiji), ki so na voljo za razvoj izdelka. Namen modela potencialov je takšno modeliranje različnih zmogljivosti, da lahko ustrezne razpoznamo in razporedimo ter hkrati nadzorujemo njihovo gibanje.

— *Model poteka konstruiranja*

Model poteka konstruiranja je posnetek razvojne aktivnosti izdelka. Vsebuje podatke, npr. konstrukcijske odločitve, njihove temelje, vse razvite konstrukcijske alternative, strategije, načrte, itn. Uporablja se za povečanje učinkovitosti KPK.

## 3 VIDIKI RAZVOJA IZDELKA

Ogrodje DC omogoča razumljivost pojavov in problemov povezanih s koordinacijo konstrukcijskega procesa, obravnava faze nastajanja sistema in probleme ciklusa trajanja, konstruiranje samo in njegovo upravljanje, primerno predstavitev in razvoj izdelka kakor tudi ljudi, zmožnosti in orodja, potrebne za izvedbo konstruiranja. Modeli znotraj ogrodja sami zase niso koordinacija konstrukcijskega procesa, temveč elementi, ki so vanj vključeni. Koordinacija konstrukcijskega procesa zadeva učinkovito integracijo, mreženje, nadzor in upravljanje teh elementov kot celovitega telesa. Tako so razmerja med elementi DC poseben vidik koordinacije konstrukcijskega procesa, ki ni nedvoumno predstavljen v ogrodju [49]. Kljub temu menimo, da ogrodje predstavlja nove in kritične pojave za prihodnji razvoj in zagotavlja podlago za podporo učinkovite koordinacije konstrukcijskega procesa in tako povečuje produktivnost konstruiranja in optimizacijo konstrukcijskega procesa ter pospešuje večjo konkurenčnost.

Vidiki razvoja izdelka, za katere ogrodje KPK daje osnovo, na podlagi katere je mogoče razviti podporo, so:

— hkratno inženirsko delo,
— podpora odločitev,
— upravljanje konstrukcijskega procesa,
— upravljanje izdelka,
— skupinsko inženirsko delo.

Da bi lahko bolj razumeli, kako lahko ogrodje KPK podpira te vidike, je vsak od njih natančno opisan v nadaljevanju.

— *Activity/plan model*

This model involves the introduction of the time dimension to the task model and explains when tasks are to be done.

— *Resource model*

In design, a resource can be the knowledge, skills, people (e.g. individuals, and teams) and tools (e.g. technology and methodology based) available to carry out product development. The resource model is aimed at modelling the various resources such that appropriate resources can be identified and allocated and the dynamics of resources can be monitored.

— *Design history model*

The design history model represents a recording of a product development activity. It includes items such as design decisions, their rationale, all developed design alternatives, design strategies and plans, etc. It is used to enhance the effectiveness of DC.

## 3 ASPECTS OF PRODUCT DEVELOPMENT

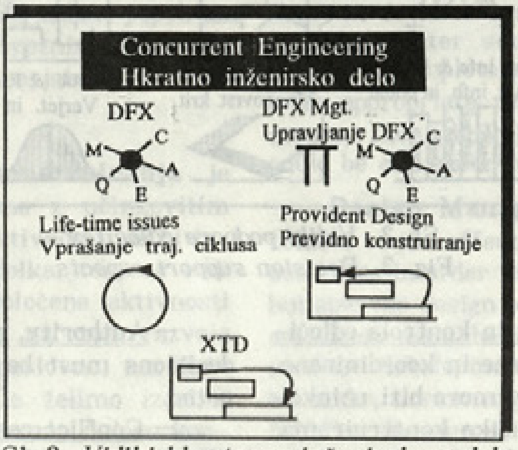
The DC Framework provides an understanding of the issues and problems involved in Design Coordination, and addresses life phase systems and life cycle issues, the design activity and its management, the appropriate representation and development of the product, and the people, skills and tools needed to carry out the design. The models within the framework are themselves not representative of Design Coordination but rather the elements that are involved. Design Coordination is concerned with the effective integration, networking, control and management of these elements as a holistic entity. Thus, an aspect of Design Coordination which is not explicitly represented within the framework (but presented in [49]) are the relations between the DC elements. It is considered, however, that the framework presents new and critical issues for future research and provides a basic means to support effective Design Coordination and thus enhance design productivity, optimisation of the design process and facilitate competitive advantage.

The aspects of product development which the DC Framework provides a foundation upon which to develop support are:

— Concurrent Engineering,
— Decision Support,
— Design Management,
— Product Management,
— Team Engineering.

In order more clearly to understand how the DC Framework can support these aspects, each are elaborated in turn.

**Hkratno inženirsko delo** je skupek vidikov razvoja izdelka, ki so usmerjeni k skladnemu vodenju inženirskih aktivnosti. Središče je torej v formulaciji, integraciji in upravljanju poprej ločenih inženirskih aktivnosti, panog in vidikov, ki jih je bolje izvajati hkarti, kakor pa zaporedno. V tem prispevku je torej skladno inženirsko delo povezano (sl. 2):




Sl. 2. *Vidiki hkratnega inženirskega dela*

Fig. 2. *Concurrent engineering aspects*

— S konstruiranjem za »X« (skr. angl. DFX), ki upošteva proizvodnjo (npr. izdelavo, montažo) in pomembne zadeve izdelka (npr. ceno, kakovost), ki morajo biti natančno določene in podprte za konstruiranje izdelka [6].

— Z upravljanjem konstruiranja za »X« (skr. angl. ΠDFX), ki upošteva vprašanja X-a ob pravem času in na podlagi pravih razlogov ter zagotavlja, da en vidik X ni konflikten ali da, kjer to ni zaželeno, ne postavi na glavo prejšnje odločitve v povezavi z nekim drugim X.

— Z vprašanjem dobe trajanja, ki upošteva vidike celotnega trajanja izdelka, npr. uporabo, uvajanje, vzdrževanje in izločitev iz uporabe. ki pokrivajo celotno trajanje izdelka, npr. uporaba, vzpostavitev, vzdrževanje in izločitev iz uporabe.

— S previdnim konstruiranjem, ki skuša predvidevati prihodnje razmere, usmeritve in probleme kakor tudi potrebe po izdelku [50].

— S t.i. X-em v odnosu do konstruiranja (skr. angl. XTD, ki zagotavlja, da je proizvodnja kos izdelku, tj. zagotavlja izdelavo in montažo v skladu z načrtom.

**Podpora odločitev** zadeva razvoj vse potrebne podpore za učinkovito odločanje. Med procesom konstruiranja je treba sprejeti veliko odločitev iz številnih razlogov ter vključevati različne udeležence, da bi pripeljali konstruiranje do uspešnega konca. Ne samo, da morajo biti te odločitve razpoznavne, temveč mora biti znana tudi njihova bistvenost, pomembnost in posledičnost. Za učinkovito podporo je potrebno upoštevati številne ključne teme, (sl. 3) in sicer:

**Concurrent Engineering** cosidered here to encompass aspects of product develoment which are directed at conducting engineering activities concurrently. That is, its focus is on the formalisation, integration and management of previously disparate engineering activities, disciplines and aspects which can be carried out concurently rather than sequentially. Thus, Concurrent Engineering, within this paper, is considered to address (Fig. 2):

— DFX (i.e. Design For »X«) takes into account life phase systems (e.g. manufacture, assembly) and product life concerns (e.g. cost, quality) which need to be formalised and supported for designing the product [6].

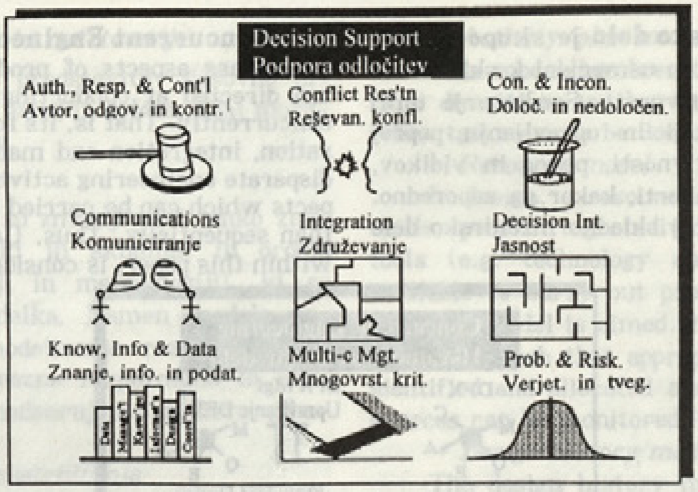
— DFX Management (i.e. ΠDFX) is directed at consideration of X issues at the correct time and for the correct reasons and ensures that one aspect of X does not conflict or overturn, where undesired, a previous decision in connection with another X.

— Life cycle issues address aspects covering the complete life of the product, such as use, establishment, maintenance, decommission.

— Provident design focuses upon being able to anticipate future issues, trends, problems, or aspects of the product requiring consideration [50].

— XTD (i.e. »X« to the Design) ensures that life phase systems correctly meet the product requirements, e.g. ensures the manufacturing or assembly process meets the design specification.

**Decision Support** is concerned with developing all the necessary support to make effective decisions. During the design process, multiple decisions need to be made, for numerous reasons and involving various participants, in order to progress the design to a successful conclusion. These decisions not only need to be identified but also their relevance, importance and consequence need to be known. To achieve effective support, a number of key issues must be addressed, such as (Figure 3):




Sl. 3. *Vidiki podpore odločitev*
Fig. 3. *Decision support aspects*

— Avtoriteta, odgovornost in kontrola odločitev morajo biti jasno razpoznavne in koordinirane.

— Razreševanje konfliktov mora biti učinkovito, posledice, glede na vse vidike konstruiranja, pa popolnoma uresničene in podprte.

— Upravljanje določenosti in nedoločenosti mora zagotoviti, da bodo lahko posamezne neznanke v okviru modela izdelka v določenih trenutkih njegovega razvoja nedoločene, sicer pa določene. Določenost in nedoločenost naj ne bi bila zagotovljena le pri individualnih modelih, temveč tudi pri drugih.

— Učinkovito komuniciranje bo vzpodbudilo prenašanje odločitev, pripomoglo k reševanju konfliktov ter k združevanju in skladnosti odločitev.

— Združevanje informacij je osnovni pogoj za učinkovito podporo odločitev. V uresničevanje tega pogoja je bilo usmerjenih precej naporov (gl. poglavje 1).

— Celovitost in skladnost odločitev in sprejemanja odločitev je potrebna za kar najbolj učinkovit napredek procesa razvoja izdelka. Odločitve so navadno sprejete posamezno brez zadostnega razumevanja učinka in pravih posledic takšne odločitve. Še več, pomembnost in prave posledice odločitve znotraj celotnega procesa konstruiranja pogosto niso popolnoma razumljive niti posamezniku, niti skupini, ki sprejme takšno odločitev.

— Upravljanje znanja, informacij in podatkov (UZIP) je ključna komponenta za podporo odločitev. UZIP ima vlogo vhodnega podatka za proces sprejemanja odločitev in se nenehno spreminja, zastara in je najbolj pomemben za določene odločitve. Zato mora upravljanje UZIP zagotoviti, da je tistim, ki odločitve sprejemajo, predstavljen pravilen in kar najbolj zanesljiv UZIP, ki je posnetek trenutnega stanja. Le tako so lahko sprejete pravilne odločitve.

— Authority, responsibility and control for/of decisions must be clearly identified and coordinated.

— Conflict resolution needs to be carried out effectively and the consequences upon all aspects of the design must be fully realised and supported.

— Consistency and inconsisteny management must ensure that particular variables within the product model will be required to be inconsistent at particular times of the product's development and at other times consistent. Consistency/inconsistency should not only be ensured withing individual models but also with other models.

Effective communications will enhance decision making, promote conflict resolution, integration and coherence of decisions.

Information integration is a basic requirement for effective decision support and one in which considerable effort has been directed (see Background section 1).

Integration and coherence of decisions and decision making is required in order to evolve the product development proces most effectively. Typically decisions are taken individually without sufficient understanding of the effect and true consequence of that decision. Further, the importance and true consequence of a decision within the overall design process is often not fully understood by the individual or group who is/are taking that decision.

Knowledge, Information and Data (KID) management is a key component for decision support. KID acts as input to the decision making process and continually changes, becomes outdated, and is most relevant for particular decisions. Thus, KID management must ensure that the correct, most relevant and up to date KID is presented to the correct decision makers for the correct decisions to be made.

— Upravljanje mnogovrstnih kriterijev je potrebno pri izdelkih, ki v splošnem zahtevajo zadovoljitev več in pogosto nasprotnih zahtev. To terja presojo med spreminjanjem in nastajanjem meril. Različni udeleženci ali skupine bodo poudarili različna merila.

— Ocenitev verjetnosti in tveganja je element sprejemanja odločitev, za katerega je treba razviti ustrezno računalniško podporo. Za podano popolnoma podprto ogrodje KPK, z ustreznimi razmerji med elementi, bi lahko ocenili verjetnost in tveganje na podlagi meritev.

**Upravljanje procesa konstruiranja** je usmerjeno v probleme, povezane z učinkovitim upravljanjem konstrukcijskih aktivnosti, da bi izpolnili zahteve, ne le glede izdelka, temveč tudi glede procesa konstruiranja. Določene aktivnosti morajo biti izvedene v skladu z načrtom razvoja izdelka ter hkrati izpolnjevati poslovne, naročnikove in zakonske omejitve. Če želimo izdelati primerno rešitev in doseči zahtevano nalogo konstruiranja v mejah omejitev, moramo čim bolje izkoristiti razpoložljive potenciale. Še več, pojavili se bodo raznovrstni konstrukcijski projekti, ki bodo zahtevali različne potenciale v različnih časovnih obdobjih in postavljali različne zahteve glede procesa razvoja izdelka. Nekatera pomembna vprašanja so (sl. 4):

Multi-criteria management is required for products which generally involve the satisfaction of multiple, and often conflicting, requirements. This requires consideration of trade offs between changing and evolving criteria. Further, different participants or teams will address different criteria.

Probability and risk assessment is an element in decision making and one in which adequate computer support needs to be developed. Given a completely supported DC Framework, with appropriate relationships between the elements, the probability and assessment of risk could be estimated on a sounder basis.

**Design Management** focuses upon issues related to the effective management of the design activities in order to fulfill not only the product's but also the design process' requirements. Specific activities must be carried out within an overall product development plan while ensuring that business, customer and regulatory constraints are fulfilled. Resources must be utilised to their full potential in order to produce appropriate solutions and achieve specified design tasks within the design constraints. Further, there will be multiple design projects all requiring different resources at different times and placing different demands upon the product development process. Some relevant issues are (Figure 4):


Sl. 4. *Vidiki upravljanja konstruiranja*
Fig. 4. *Design management aspects*

— Ponovna uporaba izkušenj s področja konstruiranja je podlaga, na kateri je mogoče razvijati in stopnjevati upravljanje konstruiranja. Izkušnje s področja upravljanja konstruiranja imajo odločilno vlogo pri zmanjšanju neučinkovitosti, razpoznavanju problemov in izvajanju kakovostnih postopkov.

— Upravljanje ugleda konstruiranja, tako znotraj podjetja, kakor tudi navzven, mora biti učinkovito vodeno, tako da se zunanji dobavitelji držijo najboljših navad podjetja.

— Načrtovanje in nadzor sta, tako kakor upravljanje projekta v splošnem, ključni prvini učinkovitega upravljanja konstruiranja in morata biti popolnoma integrirani in realizirani znotraj ogrodja KPK.

— Modeliranje procesa določa konstrukcijske aktivnosti podjetja in je zato podlaga za optimiranje konstrukcijskega procesa. Modeli procesov se razlikujejo po tipu (npr. predpisujoč ali opisen [4]) in po stopnji abstrakcije (npr. natančen do splošen). Različne stopnje opisnih modelov naj bi temeljile na dejanskih posebnih pojavih v sklopu konstrukcijskih aktivnosti in se v abstrakciji spreminjale navzgor do modela razvoja izdelka na ravni podjetja. Predpisujoče modele lahko uporabimo kot sredstvo za uvajanje novih tehnologij ali postopkov za izboljšanje konstrukcijskega procesa [51]. Podjetja brez jasnih in ustreznih modelov konstrukcijskega procesa v bistvu ne morejo popolnoma obvladovati svojih aktivnosti ali narave svoje organizacije.

— Upravljanje potencialov mora zagotoviti razpoložljivost ne le pravih ljudi, s potrebnim znanjem, spretnostmi, psihičnim ustrojem in izkušnjami, temveč tudi ustrezno UZIP, pripomočke, orodja in okolje za izpolnitev ustreznih nalog ob pravem času.

— Preverjanje časa prve prave rešitve, ponovnega dela in iteracij je lahko podlaga in način ocenjevanja učinkovitosti DC in procesa razvoja izdelka. Merjenje časa, potrebnega za prvo pravilno rešitev, ponovnega dela in iteracij je lahko napotilo za upravljanje konstrukcijskega procesa, za izvedbo nalog potrebnih potencialov in potrebnega časa za določene naloge in tudi za potrditev nivoja kriterijev kakovosti.

— Upravljanje nalog je osredotočeno na logično razdelitev dela, ki mora biti opravljeno, da bi bilo tako mogoče izpolniti konstrukcijske zahteve in omejitve. Tako je tudi preskrbljeno za določitev potrebnih potencialov, časa in aktivnosti za razvoj izdelka.

**Upravljanje izdelka** se nanaša na tiste vidike, ki so v povezavi z njegovim modeliranjem proizvoda in podporo v času njegovega razvoja.

— Reusing design process and design activity experience provides a basis upon which to evolve and enhance design management. Design management experience plays a crucial role in reducing inefficiencies, anticipating problems, and implementing good practice.

— Managing distributed design authority, both within and outwith the enterprise, needs to be effectively managed such the external suppliers adhere to the enterprise's best practice.

— Planning, scheduling and control, as with project management in general, are key elements to effective design management and must be fully integrated and realised within the DC Framework.

— Process modelling provides a formalisation of the enterprise's design activity and hence a basis upon which to optimise the design process. Process models vary in type (e.g. prescriptive or descriptive [4]) and in levels of abstraction (e.g. detailed to general). The different levels of descriptive models should be based upon the actual specific phenomena of the design activities and vary in abstraction up to the enterprise's product development model. Prescriptive models can be used as a means to introduce new techniques or approaches to enhance the design process [51]. Enterprises without explicit and appropriate design process models, essentially, cannot fully comprehend their activities or the nature of their organisation:

— Resource management must ensure the availability not only the right people, with the right expertise, skills, psychological nature and experience, but also the relevant KID, facilities, tools and environment to fulfill appropriate tasks at the right time.

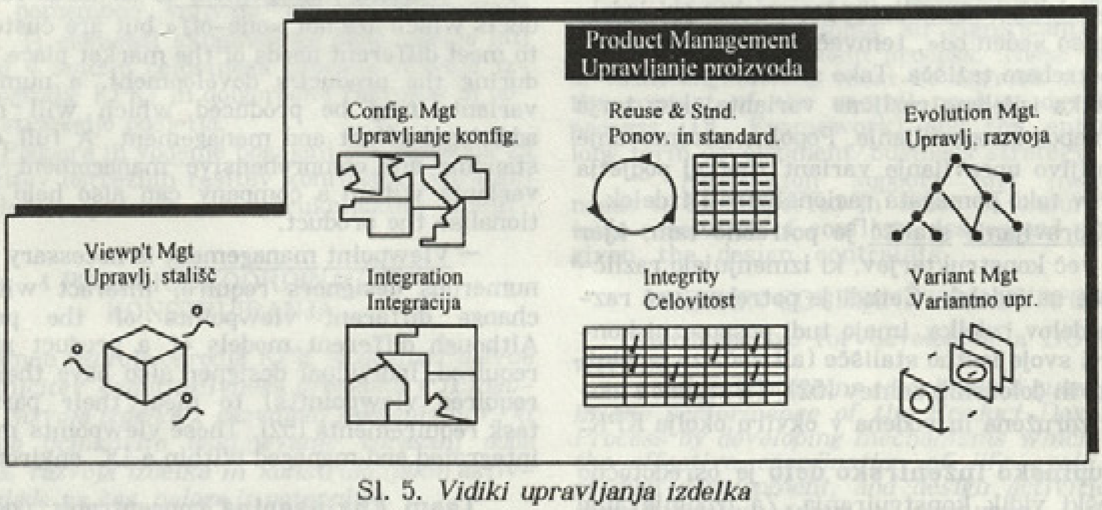
— Right-first-time, re-work and iteration control can be used as a base and means to evaluate the effectiveness of DC and the Product Development Process. Measuring right-first-time, re-work and iteration can provide a basis to manage the design process, the resources employed to carry out tasks, the time needed for particular tasks, or the acceptance level of the quality criteria.

— Task management centres upon the logical breakdown of the required work to be done in order to fulfill the design requirements and constraints. It also provides the basis for determining the required resources, times, and activities which are required to evolve the product's development.

**Product Management** adresses all aspects related to the product's modelling and support during its development.

V splošnem poteka razvoj izdelka od abstraktne zamisli do natančno določenega opisa. Med tem procesom potrebujejo različni konstrukterji različne modele izdelka za pomoč pri reševanju problemov, pri čemer je vsak model neomejeno notranje povezan s preostalimi modeli. Vidiki, ki morajo biti upoštevani, so (sl. 5):

The product generally evolves from an abstract solution to a defined specification. During this process, various designers require different models of the product to help solve their problems, where each model is inextricably inter-related with other models. Aspects which need to be considered are, for example (Fig. 5):




Sl. 5. *Vidiki upravljanja izdelka*
Fig. 5. *Product management aspects*

— Upravljanje konfiguracije ima ključno vlogo pri koordinaciji razvoja izdelka. Zadeve, ki morajo biti učinkovito obravnavane, so: ureditev in sinteza modelov, upravljanje različnih tipov modelov (npr.: prostorski, geometrijski, shematični) in različnih modelov, uporabljenih v sklopu različnih panog (npr. strojništvo, elektrotehnika, kemija) ter učinki spremembe ene komponente ali dela na konfiguracijo preostalih elementov in modele izdelka v celoti.

— Ponovljeno konstruiranje in standardizacija lahko zagotavljata začetno točko pri reševanju mnogih problemov konstruiranja. Da bi spoznali vlogo ponovnega konstruiranja in standardizacije pri procesu razvoja izdelka, ju je treba podrobneje razumeti in formalizirati.

— Upravljanje razvoja je potrebno za zagotovitev stalnega prehoda modela izdelka k sprejemljivi rešitvi. Med razvojem izdelka se bo pripadajoč model spreminjal v celoti, ali pa se bodo spreminjali posamezni (pod)modeli in bodo tako nastale različice. Vse spremembe modela izdelka morajo biti vodene, da učinki privedejo do razvoja rešitve, glede na konstrukcijske omejitve in v skladu z zahtevami.

— Celovitost in nadzor sta trenutno zanimiva tema, saj je veliko modelov izdelka povsem različnih. Vendar pa je treba opozoriti, da celovitost in nadzor poprej različnih modelov ne zagotavljata nujno tudi povečanja produktivnosti konstruiranja. Njihovo vodenje je temelj učinkovitega upravljanja izdelka.

— Configuration management plays a key role in the coordination of the product's development. Issues which need to be sufficiently addressed are the formation/synthesis of models and the management of different types of models (such as, spatial, geometric, schematic), different models used within different disciplines (e.g. mechanical, electrical, chemical), and the effects of one component/part change upon the other configuration elements and product models as a whole.

— Design reuse and standardisation can provide a good starting point or basis for helping to solve many design problems. The role of design reuse and standardisation needs to be more fully understood and formalised in order to clearly identify its role within the Product Development Process.

— Evolution management is necessary to ensure that the product model continually evolves to an acceptable solution. During a product's evolution, its associated model will change either as a whole or individual sub-parts will be altered and different versions created. All the changes to the product model must be managed to ensure that the overall effect is one of evolving the solution, within the given design constraints, to meet the requirements.

— Integration and control is presently a topical issue as many models of the product are disparate. However, it should be noted that the integration and control of previously disparate models does not ensure that they will necessarily enhance design productivity. Rather, it is their management as a holistic entity which will provide the basis for effective Product Management.

— Celovitost mora biti zagotovljena v različnih fazah razvoja izdelka, še posebej na mejnikih in pred končno specifikacijo izdelka. Različni deli izdelka bodo morali v različnih trenutkih izpolnjevati različne zahteve po celovitosti. Upravljanje s problemi in učinki zagotavljanja celovitosti izdelka mora biti jasno.

— Variantno upravljanje je potrebno pri izdelkih, ki niso »eden od«, temveč so prilagojeni različnim potrebam tržišča. Tako so lahko v fazi razvoja izdelka izdelane različne variante, kar terja dodaten napor in upravljanje. Popolno razumevanje in razumljivo upravljanje variant znotraj podjetja lahko prav tako pomagata racionalizirati izdelek.

— Upravljanje stališč je potrebno tam, kjer sodeluje več konstrukterjev, ki izmenjujejo različne poglede na izdelek. Četudi je potrebno več različnih modelov izdelka, imajo tudi posamezni konstrukterji svoje lastno stališče (ali več) za izpolnitev njihovih določenih zahtev [52]. Ta stališča morajo biti združena in vodena v okviru okolja KPK.

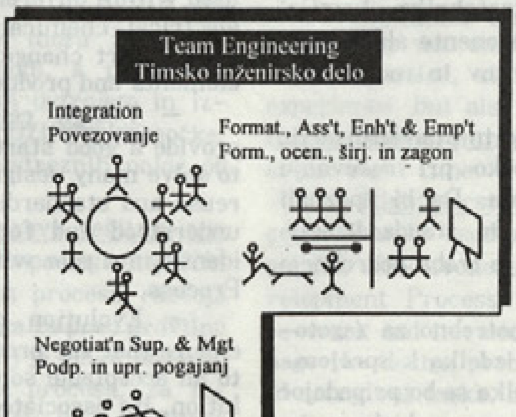
**Skupinsko inženirsko delo** je osredotočno na človeški vidik konstruiranja. Za izpolnjevanje vedno znova spreminjajočih se potreb razvojnih faz izdelka in predstavljanje novih izdelkov, morajo biti oblikovane, razpuščene in reorganizirane večdisciplinarne skupine konstrukterjev, v katerih vsak posameznik pokriva svoje strokovno področje in ima svojstven način dela. Vprašanja, ki morajo biti še posebej obdelana, so (sl. 6):

— Integrity needs to be ensured at various stages of the product's development, particularly at milestones and for the final product specification. Different parts of the product at various times will need to meet different integrity requirements. The issues and effects of ensuring the product's integrity needs to be explicitly managed.

— Variant management is an issue for products which are not »one-off« but are customised to meet different needs of the market place. Thus, during the product's development, a number of variants may be produced which will require additional effort and management. A full understanding and comprehensive management of the variants within a company can also help to rationalise the product.

— Viewpoint management is necessary where numerous designers require, interact with and change different viewpoints of the product. Although different models of a product may be required, individual designer also have their own required viewpoint(s) to meet their particular task requirements [52]. These viewpoints must be integrated and managed within a DC environment.

**Team Engineering** concentrates upon the human aspects of the design process. Multidisciplinary design teams, each with their own particular areas of expertise and way of working, need to be formed, disbanded and re-organised in order to meet the ever changing needs of the product development process and new product introduction. In particular, issues which need to be addressed are (Fig. 6)




Sl. 6. *Vidiki skupinskega inženirskega dela*

Fig. 6. *Team engineering aspects*

— Medsebojno povezovanje skupin je potrebno, da lahko posamezne skupine spoznavajo kakovost, zmožnost ter odgovornost in kakšna je njihova povezava z drugimi skupinami v okviru procesa razvoja izdelka in širše v podjetju. V izboljšanje komunikacije med skupinami so bili usmerjeni precejšnji raziskovalni napori ob pomoči okolja za

— Inter/intra integration of teams is necessary in order for teams to know their qualities, capabilities and responsibilities and how they relate to other teams within the Product Development Process and the enterprise in general. Considerable research effort has been directed at računalniško podprto kooperativno delo (RPKD). V bistvu je to poskus povezati različne skupine [19], [53], [54]. Vendar je, kakor je bilo že omenjeno, potrebno povezovanje podpreti z učinkovito koordinacijo (tako formalno, kakor tudi neformalno), kar je prvi pogoj za izvedbo popolne funkcionalnosti skupine.

— Oblikovanje, ocenjevanje, širjenje in zagon skupin pomembno vplivajo na proces razvoja izdelka. Ti elementi skupinskega dela morajo biti izvedeni v smislu celostnega procesa razvoja izdelka (ogrodje KPK) in dolgoročne razvojne in poslovne strategije podjetja.

— Podpora in vodenje pogajanj sta potrebna za zagotovitev ustreznih rešitev konfliktov, vprašanj in problemov, podanih s konstrukcijskimi omejitvami.

## 4 PODPORA KOORDINACIJE KONSTRUIRANJA

Namen razvoja ogrodja KPK je *dognati načine za uresničitev kvantitativnega preskoka v učinkovitosti razvoja izdelka z razvojem mehanizmov, ki podpirajo učinkovito usklajevanje vprašanj dobe trajanja, razvoja izdelka in konstrukcijskih aktivnosti, glede na čas, naloge in potenciale.*

Uskladitev konstruiranja je potemtakem videna kakor način podpore integracije in optimizacije določenih vidikov razvoja izdelka (sl. 7).

enhancing team communications through Computer Suported Cooperative Working (CSCW) environments and in essence attempting to integrate disparate teams [19], [53], [54]. However, as stated earlier in this paper, integration must be supported with effective coordination (both formal and informal) which is considered here as a prerequisite for the full functionality of the team to be realised.

— Team formation, assessment, enhancement and empowerment all significantly affect the product development process. These elements of team engineering must be carried out within the context of the overall product development process (DC Framework) and the enterprise·s long term development/business strategy.

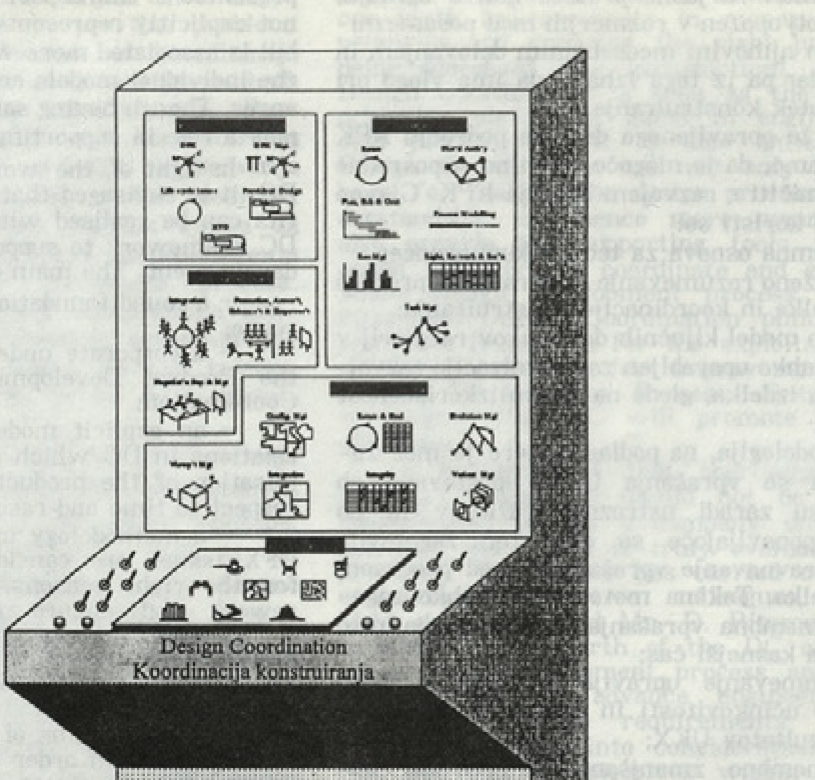
— Negotiation support and management needs to be supported in order to ensure acceptable resolution of conflicts, issues and problems, given the design contraints.

## 4 DESIGN COORDINATION SUPPORT

The objective for developing a DC Framework is:

*to provide a means to achieve a quantum leap in the performance of the Product Development Process by developing mechanisms which support the effective coordination of life cycle issues, product development, and design activities with respect to time, tasks and resources.*

Thus, design coordination is seen as the means to support the integration and optimisation of the particular aspects of product development (Fig. 7):




Sl. 7. *Vidiki razvoja izdelka, podprtega z usklajevanjem konstruiranja*
Fi. 7. *Aspects of product development supported by design coordination*

Preglednica 1: *DC podpora vidikov razvoja izdelka*
Table 1: *DC support for aspects of product development*

| | Aspects of Product Development / Vidiki razvoja izdelka | | | |
|---|---|---|---|---|
| *DC Framework models*<br>*Modeli ogrodja DC* | Concurrent Engineering<br>Skladno inženirsko delo | Design Management<br>Upravljanje konstruiranja | Product Management<br>Upravljanje izdelka | Team Engineering<br>Skupinsko inženirsko delo |
| 1. Product development<br>Razvoj izdelka | ✓ | ✓ | | |
| 2. Decomposition<br>Dekompozicija | | | ✓ | |
| 3. Disciplines/technologies<br>Discipline/tehnologije | ✓ | ✓ | | ✓ |
| 4. Product life<br>Trajanje izdelka | ✓ | | | |
| 5. Synthesis matrix<br>Matrika sinteze | ✓ | ✓ | ✓ | |
| 6. Life phase systems<br>Faze nastajanja | ✓ | | | |
| 7. Goal/result<br>Cilj/rezultat | | ✓ | ✓ | |
| 8. Task<br>Naloga | | ✓ | | |
| 9. Activity/plan<br>Aktivnost/načrt | | ✓ | | |
| 10. Resources<br>Potenciali | | ✓ | | ✓ |
| 11. Design history<br>Potek konstruiranja | | ✓ | | |

Modeli znotraj ogrodja so razviti posebej zato, da je poskrbljeno za glavno podporo točno določenih vidikov, kakor je razvidno v preglednici 1. V preglednici ni prikazana podpora odločitev, saj ta vidik razvoja izdelkov ni jasno predstavljen v ogrodju, temveč je bolj opazen v razmerjih med posameznimi modeli in njihovim medsebojnim delovanjem in vplivi. Vendar pa iz tega izhaja, da ima vlogo pri odločanju potek konstruiranja.

V luči že opravljenega dela na področju KPK lahko sklepamo, da je mogoče številne neposredne koristi uresničiti z razvojem ogrodja KPK. Glavne pričakovane koristi so:

– razumna osnova za teorijo konkurence;

– združeno razumevanje in strategija procesa razvoja izdelka in koordinacije konstruiranja;

– jasen model ključnih dejavnikov razmerij v KPK, ki je lahko uporabljen za optimizacijo razvojnega ciklusa izdelka, glede na čas in izkoriščenost potencialov;

– metodologija, na podlagi katere je moč zagotoviti, da so vprašanja UKX upoštevana ob pravem času zaradi ustreznih razlogov in bo zmanjšala ponavljajoče se delo ter zagotovila ustrezno obravnavanje vprašanj X med procesom razvoja izdelka. Takšna metodologija lahko zagotovi, da pomembna vprašanja konstruiranja niso preložena na kasnejši čas;

– razumevanje upravljanja UKX, v duhu optimizacije učinkovitosti in načina za »uravnoteženje« rezultatov UKX;

– pomembno zmanjšanje potrebe po ponavljanju opravil z nadzorom časa prve pravilne rešitve in iteracij, podprto z učinkovito uporabo metodologije KPK;

– zmanjšanje nepovratnih inženirskih stroškov;

– učinkovitejša izraba potencialov in skrajšanje časovnega ciklusa razvoja izdelka;

In particular, the models within the framework are being developed to provide the main support for the specified aspects as indicated in Table 1. Within this table, Decision Support is not presented as this aspect of product development is not explicitly represented within the Framework but is associated more with the relations between the individual models and their interaction/influences. Though having said this, design history can play a role in supporting decision making.

In light of the work already carried out in DC, it is envisaged that a number of direct benefits can be realised with the development of the DC Framework to support the aspects of product development. The main expected benefits are:

– a sound foundation for a theory of concurrence;

– a corporate understanding and strategy of the Product Development Process and Design Coordination;

– an explicit model of the key factors and relations in DC which can be used for the optimisation of the product development cycle with respect to time and resource utilisation;

– a methodology upon which to ensure that DFX issues are considered at the right time for the right reasons, and which will reduce rework and ensure appropriate consideration of X issues during the product development process. Such a methodology can ensure that important design issues are not oveturned at a later date;

– understanding of the management of DFX considerations in order to optimise their effectiveness and a means to »balance« DFX issues;

– a significant reduction in re-work through right-first-time practice and iteration control supported by effective use of DC methodology;

– a reduction in non-recurring engineering costs;

– more effective utilisation of resources and reduced product development cycle time;

— vpogled v človeške kakor tudi računalniške vidike glede KPK. Ta vpogled da koristno usmeritev k upravljanju, ki bo izboljšalo tako produktivnost kakor tudi zadovoljstvo pri delu;

— seznanjanje konstrukterjev in skupin glede njihove vloge, merjenje njihove učinkovitosti pri konstruiranju (npr. stopnja ponavljanja) in predstavitev diagramov in trendov učinka. Največja pričakovana korist metodologije KPK je motivacija inženirjev, ki se tako zavedajo pomembnosti in učinka svojega prispevka k uspehu procesa razvoja izdelka;

— poglavitno razumevanje vprašanj, povezanih s KPK in njihova vloga pri procesu razvoja izdelka bo v pomoč pri zvišanju tehnične in znanstvene ravni inženirjev in vodstva v podjetju.

Obstaja prepričanje, da je lahko ogrodje KPK s podporo spoznanih vidikov razvoja izdelka, način zagotavljanja večje konkurenčnosti. Toda, kako lahko zagotovimo, da bo temu res tako?

## 5 VREDNOTENJE KORISTNOSTI USKLAJEVANJA KONSTRUIRANJA

Če upoštevamo, da se mehanizmi DC spoprijemajo neposredno z vprašanji učinkovitega razvoja izdelka, je mogoče doseči podvojeno »učinkovitost« razvojnega inženiringa s samo za šestino izboljšanim upravljanjem in z zagotovitvijo, da se obravnavajo pravilni problemi (glej uvod). V bistvu gledamo na koordinacijo konstruiranja kot na način za dosego pomembnih koristi pri produktivnosti konstruiranja. Prav tako pričakujemo, da usklajevanje konstruiranja ne bo le zagotovilo podlage za boljše razumevanje procesa konstruiranja in zato večje možnosti za upravljanje, temveč tudi dodatna orodja za pomoč vodstvu pri usklajevanju in vrednotenju celotnega konstrukcijsko razvojnega procesa. Tako bo integrirana filozofija usklajevanja konstruiranja podlaga za izkoriščanje ogromnih potencialov za izboljšanje procesa razvoja izdelka. Toda, kako naj zagotovimo, da bo KPK zvišala konkurenčnost?

Koordinacijo konstruiranja naj ne bi privzeli ali uporabili v podjetju, dokler ni ovrednoten in ocenjen skupni potencial in koristnost uporabe. Avtor je skupaj z dvema kolegoma, prof. M. M. Andreasenom in D. Rimmerjem, izvedel takšno evalvacijo, da bi ovrednotil koristnost vidikov KPK, glede na proces razvoja izdelka ter razpoznal pogoje. Za izboljšanje produktivnosti konstruiranja so bili ti pogoji definirani ob upoštevanju časa, stroškov in kakovosti v okviru poslovnih potreb in strategije podjetja ter narave izdelka in tržišča. S podajanjem jasnih pogojev in ciljev, po katerih je treba ovrednotiti predlagano orodje (npr. KPK), lahko hitreje ovrednotimo »koristnost« orodja. Rezultati so prikazani v nadaljevanju kot primer ovrednotenja potencialne koristnosti KPK za zagotovitev večje konkurenčnosti.

— an insight into the human aspects of DC as well as those which are computational. This insight will give valuable direction to the development of a management approach that will optimise both productivity and job satisfaction;

— a basis upon which to inform designers and teams of their role, measuring their effectiveness within the design process (e.g. degree of re-work) and presenting performance graphs/trends. Consequently, motivating engineers and ensuring that they know the importance and effect of their contribution to he success of the product development process is a major expected gain from the DC methodology;

— a basic understanding of DC issues and their role in the Product Development process will help to advance the technical and scientific level of the engineers and managers within the enterprise.

By supporting the identified product development aspects it is believed that the DC Framework provides the means to enhance competitive advantage. However, how can we ensure this?

## 5 EVALUATING THE WORTH OF DESIGN COORDINATION

Given that DC mechanisms are directly tackling the issues of effective product development, double the »effectiveness« of development engineering can be achieved with only one sixth improvements in management competencies and ensuring the right problems are being addressed (see Introduction). In essence, Design Coordination is seen as the means for achieving significant gains in engineering design productivity. It is also anticipated that Design Coordination will not only provide the basis for making the design process more understandable, and hence more manageable, but also provide the supporting tools which will assist managers to coordinate and evaluate the whole design development process. Thus, the integrated Design Coordination philosophy will provide a foundation for the exploitation of the enormous potential for improvements in the product Development Process. But, how can we ensure that DC will promote competitive advantage?

It is suggested that approaches such as Design Coordination should not be adopted or implemented within a company until its full potential and worth is truly evaluated and appreciated. The author has carried out such an evaluation with two colleagues, Professor M.M. Andreasen and Mr. D. Rimmer, in order to quantify the worth of the DC aspects upon the product development process and identified requirements. To advance engineering design productivity, these requirements have been defined by taking into consideration the time, cost and quality objectives within the enterprise's own business needs and strategy, and the nature of the product/market. Given clear requirements and targets upon which to base the evaluation of the proposed tool (e.g. DC), the »worth« of the tool can then be more readily evaluated. Results are presented below as an example of evaluating DC's potential worth to ensure competitive advantage.

Za dosego krajšega časa do predstavitve izdelka na tržišču, izboljšanja kakovosti in zadovoljstva naročnika ter konkurenčnih cen, so bili identificirani naslednji pogoji:

**Pogoji**

– zmožnost hitrega prilagajanja konstrukcij,
– zmožnost obvladovanja izredno zapletenih izdelkov,
– zmanjšanje nepovratnih tehničnih stroškov,
– povečana kakovost izdelkov,
– boljše ujemanje z željami naročnika,
– uporaba novih izdelkov in procesnih tehnologij,
– krajši čas razvojnega ciklusa izdelka.

Očitno je, da se ti pogoji spreminjajo in imajo različne prednosti glede na določeno podjetje. Analiziranje in vrednotenje vidikov razvoja izdelka v primerjavi s temi pogoji podjetja dajeta jasnejšo sliko področij, za katera je KPK najprimernejša in lahko da največje produktivne koristi (pregl. 2, 3).

Na podlagi te analize se zdi, da lahko potegnemo naslednje sklepe:

– *Največje pridobitve*

Največje pridobitve koordinacije konstruiranja lahko z zagotavljanjem vseh možnih sredstev dosežemo pri skrajšanju izdelavnega časa izdelka (42%), upravljanju konstruiranja (29%), podpori odločitev (26 %) in hkratnem inženirskem delu (23 %).

– *Pomembne pridobitve*

S koordiniranjem konstruiranja lahko dosežemo pomembne pridobitve tudi pri upravljanju prilagajanja (19 %), doseganju boljše kakovosti izdelka (15 %) in zmanjšanju nepovratnih inženirskih stroškov (12 %).

To achieve a shorter time to market, improved quality and customer satisfaction, and competitive costs, the following requirements were identified:

**Requirements**

– ability to support rapid design change,
– ability to deal with increasingly complex products,
– reduced non-recurring engineering costs,
– improved product quality,
– better match to the customer's requirements,
– exploitation of new product and process technologies,
– shorter product development cycle times.

Obviously, these requirements will vary and carry different priorities depending upon the particular enterprise. Analysing and evaluating the aspects of product development against these enterprise requirements gives a clearer indication for the areas that DC most aptly supports and can give the greatest productivity gains (Tables 2 and 3).

From this analysis it would seem that the following conclusions can be reached:

– *Greatest impact*

Design Coordination can make the greatest impact on reducing the product cycle time (42 %), with Design Management (29 %), Decision Support (26 %) and Concurrent Engineering (23 %) providing the greatest means for meeting that requirement.

– *Significant impact*

Design Coordination also makes a significant impact on the management of change (19 %), achieving a better quality of product (15 %), and reducing non-recurring engineering costs (12 %).

Preglednica 3: *Povzetek analize matrike*
Table 3: *Matrix analysis summary*

<table>
<tr><th rowspan="2">Aspects of Product Development<br>Vidiki razvoja proizvoda</th><th colspan="14">Enterprise's requirements / Pogoji podjetja</th><th colspan="2">Totals / Skupaj</th></tr>
<tr><th colspan="2">Change</th><th colspan="2">Comp</th><th colspan="2">N Costs</th><th colspan="2">Qual</th><th colspan="2">Req'ts</th><th colspan="2">Tech</th><th colspan="2">Time</th><th>Points / Točk</th><th>%</th></tr>
<tr><td rowspan="2">Concurrent Engineering<br>Skladno inženirsko delo</td><td colspan="2">63</td><td colspan="2">3</td><td colspan="2">10</td><td colspan="2">51</td><td colspan="2">90</td><td colspan="2">3</td><td colspan="2">225</td><td rowspan="2">445</td><td rowspan="2">19</td></tr>
<tr><td>14</td><td>14</td><td>3</td><td>1</td><td>4</td><td>2</td><td>15</td><td>11</td><td>60</td><td>20</td><td>17</td><td>1</td><td>23</td><td>51</td></tr>
<tr><td rowspan="2">Decision Support<br>Podpora odločitev</td><td colspan="2">153</td><td colspan="2">25</td><td colspan="2">60</td><td colspan="2">102</td><td colspan="2">45</td><td colspan="2">3</td><td colspan="2">250</td><td rowspan="2">638</td><td rowspan="2">28</td></tr>
<tr><td>35</td><td>24</td><td>27</td><td>4</td><td>21</td><td>9</td><td>30</td><td>16</td><td>30</td><td>7</td><td>17</td><td>1</td><td>26</td><td>39</td></tr>
<tr><td rowspan="2">Design Management<br>Upravljanje konstruiranja</td><td colspan="2">54</td><td colspan="2">22</td><td colspan="2">120</td><td colspan="2">66</td><td colspan="2">15</td><td colspan="2">12</td><td colspan="2">285</td><td rowspan="2">574</td><td rowspan="2">25</td></tr>
<tr><td>12</td><td>9</td><td>24</td><td>4</td><td>43</td><td>21</td><td>20</td><td>11</td><td>10</td><td>3</td><td>66</td><td>2</td><td>29</td><td>50</td></tr>
<tr><td rowspan="2">Product Management<br>Upravljanje izdelka</td><td colspan="2">93</td><td colspan="2">15</td><td colspan="2">45</td><td colspan="2">63</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">75</td><td rowspan="2">291</td><td rowspan="2">13</td></tr>
<tr><td>21</td><td>32</td><td>16</td><td>5</td><td>16</td><td>15</td><td>19</td><td>22</td><td>-</td><td>-</td><td>-</td><td>-</td><td>8</td><td>26</td></tr>
<tr><td rowspan="2">Team Engineering<br>Timsko inženirsko delo</td><td colspan="2">81</td><td colspan="2">27</td><td colspan="2">45</td><td colspan="2">54</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">135</td><td rowspan="2">342</td><td rowspan="2">15</td></tr>
<tr><td>18</td><td>24</td><td>30</td><td>8</td><td>16</td><td>13</td><td>16</td><td>16</td><td>-</td><td>-</td><td>-</td><td>-</td><td>14</td><td>39</td></tr>
<tr><td>Total points / Skupaj točk</td><td colspan="2">444</td><td colspan="2">92</td><td colspan="2">280</td><td colspan="2">336</td><td colspan="2">150</td><td colspan="2">18</td><td colspan="2">970</td><td>2290</td><td>100</td></tr>
<tr><td>% of Total points / % od skupnih točk</td><td colspan="2">19</td><td colspan="2">4</td><td colspan="2">12</td><td colspan="2">15</td><td colspan="2">7</td><td colspan="2">1</td><td colspan="2">42</td><td>100</td><td></td></tr>
</table>

Key:
Legenda:

<table>
<tr><td colspan="2">Points / Točke</td></tr>
<tr><td>% of column total<br>% v stolpcu</td><td>% of row total<br>% v vrstici</td></tr>
</table>

| DC means (methodologies/tools) / Načini DC (metode/orodja) | Change | Comp | N Costs | Qual | Req'ts | Tech | Time | Totals Skupaj |
|---|---|---|---|---|---|---|---|---|
| *Enterprise's requirements / Pogoji podjetja* — Priority / Prioriteta | 3 | 1 | 5 | 3 | 5 | 3 | 5 | |
| **Concurrent Engineering / Skladno inženirsko delo** | | | | | | | | |
| DFX | ● | | Δ | Δ | | | ● | 80 |
| DFX Management / Upravljanje DFX | ● | | Δ | Δ | | | ● | 80 |
| Life cycle issues / Vprašanja življenjskega ciklusa | | | | ○ | ● | | ● | 99 |
| Providence / Previdno konstruiranje | | ○ | | ○ | ● | Δ | ● | 105 |
| XTD | ○ | | | ● | | | ● | 81 |
| **Decision Support / Podpora odločitev** | | | | | | | | |
| Authority, responsibility and control / Avtoriteta, odgovornost in kontrola | ● | | | | | | ○ | 42 |
| Conflict resolution / Reševanje konfliktov | ● | ○ | | ● | | | ● | 102 |
| Consistency management / Upravljanje določenosti | Δ | Δ | | Δ | | | Δ | 12 |
| Effective communications / Učinkovito komuniciranje | ● | | | Δ | | | ● | 75 |
| Information integration / Združevanje informacij | ● | | ○ | Δ | | | ● | 90 |
| Integration and coherence / Integracija in jasnost | ● | | | ○ | | | ● | 81 |
| Knowledge management / Upravljanje znanja | Δ | ○ | | ● | | Δ | Δ | 41 |
| Multy-criteria management / Upravljanje mnogovrstnih kriterijev | Δ | ● | | ● | ● | | | 84 |
| Probability and risk assesment / Ocenitev verjetnosti in rizika | ○ | ● | ● | Δ | | | ● | 111 |
| **Design Management / Upravljanje konstruiranja** | | | | | | | | |
| Design experience re-use / Ponovna uporaba izkušenj s področja konstruiranja | | | ○ | ○ | | | ● | 69 |
| Distributed design authority / Upravljanje ugleda konstruiranja | ● | ● | ● | ● | | ○ | ● | 162 |
| Planning, scheduling and control / Planiranje, načrtovanje in kontrola | Δ | ○ | Δ | | | | ● | 56 |
| Process modelling / Modeliranje procesa | Δ | ● | Δ | ○ | | Δ | ○ | 44 |
| Resource management / Upravljanje potencialov | ○ | | | Δ | | | ● | 57 |
| Right-first-time, rework & iter. cont. / Kontrola časa 1. prave reš., ponavlj. in iterac | ○ | | ● | ○ | | | ● | 108 |
| Task management / Upravljanje nalog | Δ | Δ | Δ | ○ | ○ | | ● | 78 |
| **Product Management / Upravljanje izdelka** | | | | | | | | |
| Configuration management / Upravljanje konfiguracije | ○ | ● | | | | | | 18 |
| Design re-use and standardisation / Ponovljeno konstruiranje in standardizacija | | | ● | ○ | | | ● | 99 |
| Evolution management / Upravljanje razvoja | ● | ○ | | ● | | | | 57 |
| Integration in control / Integracija in kontrola | ● | | | | | | ○ | 42 |
| Integrity / Celovitost | | | | ● | | | | 27 |
| Variant management / Variantno upravljanje | ● | | | | | | ○ | 42 |
| Viewpoint management / Upravljanje stališč | Δ | ○ | | | | | | 6 |
| **Team Engineering / Timsko inženirsko delo** | | | | | | | | |
| Inter/Intra Integration / Medsebojno povezovanje timov | ● | ● | | | | | ● | 81 |
| Form., assess't, enhance't & empower't / Formiranje, ocenj., širjenje in zagon | ● | ● | | ● | | | ● | 108 |
| Negotiation support & management / Podpora in upravljanje pogajanj | ● | ● | ● | ● | | | ● | 153 |
| Totals / Skupaj | 444 | 92 | 280 | 336 | 150 | 18 | 970 | 2290 |

Key:

Legenda:

- Change - Cope with rapid design change / Sposobnost hitrega prilagajanja konstrukcij
- Comp - Ability to deal with increasingly complex products / Sposobnost obvladovanja izredno zapletenih izdelkov
- N Costs - Reduce non-recurring engineering costs / Zmanjšanje nepovratnih inženirskih stroškov
- Qual - Achive a better quality product / Povečana kvaliteta izdelkov
- Req'ts - Meet the customer requirements / Boljše ujemanje z željami naročnika
- Tech - Exploit new product technology / Izkoriščanje novih proizvodov in procesnih tehnologij
- Time - Shorten product cycle time / Krajši čas razvojnega ciklusa izdelka

- ● - High effect (9 points) / Velik učinek (9 točk)
- ○ - Medium effect (3 points) / Srednji učinek (3 točke)
- Δ - Low effect (1 point) / Slab učinek (1 točka)

- DFX - Design to X (fit product to life phase system) / Konstruiranje za X (prilagajanje izdelka)
- XTD - X to the Design (fit life faze systems to the product) / X proti konstruiranju (prilagajanje življenjske faze)

Preglednica 2: *Matrična analiza načinov KPK v odvisnosti od lastnosti podjetja [3]*

Table 2: *DC means against enterprise requirements matrix analysis [3]*

— *Najpomembnejše metode*

Najpomembnejši metodi za izpolnjevanje zahtev sta očitno podpora odločitev (28 %) in upravljanje konstruiranja (25 %), medtem ko je delež hkratnega inženirskega dela tik pod povprečjem (19 %).

— *Najpomembnejši prispevki*

Hkratno inženirsko delo (51 %), upravljanje konstruiranja (50 %), podpora odločitev (39 %) in skupinsko inženirsko delo (39 %) najpomembneje prispevajo k skrajšanju časa ciklusa izdelka. Upravljanje izdelka na drugi strani najpomembneje prispeva k splošnemu obvladovanju hitrih sprememb pri konstruiranju (32 %).

— *Najboljše metode za določene pogoje*

Hkratno inženirsko delo zagotavlja najboljše načine (60 %) za izpolnjevanje zahtev naročnika.

Podpora odločitev je najboljša metoda za obvladovanje hitrih sprememb pri konstruiranju (35 %) in dosego večje kakovosti izdelka (30 %).

Upravljanje konstruiranja je najboljša metoda, ki omogoča izrabo novih tehnologij izdelka (66 %), zmanjšanje nepovratnih inženirskih stroškov (43 %) in skrajšanje časa ciklusa izdelka (29 %).

Skupinsko inženirsko delo daje največje možnosti (30 %) za obvladovanje izredno zapletenih izdelkov.

Ne moremo pričakovati ali zares želeti, da bi bila zgornja analiza in sklepi merilo za vsa podjetja. Spisek pogojev, dodelitev prednosti in vrednosti se bodo spreminjali glede na naravo podjetja in stopnjo razumevanja in izkušnje ocenjevalcev. Tukajšnja analiza je bila torej uporabljena za osvetlitev potrebe po vrednotenju preudarne rabe predvidenih orodij in metod. Tako vrednosti v določenih točkah niso absolutne, vendar lahko kažejo napačno vodena prizadevanja ali najboljše poti za dosego povečanja konkurenčnosti.

## 6 SKLEP

Ta prispevek skuša dati vpogled in pregled problemov, povezanih z izboljšanjem procesa razvoja izdelka, da bi zagotovili večjo konkurenčnost. Tako opozarja, da je treba, če želimo proces razvoja izdelka narediti resnično bolj produktiven, poudariti učinkovito uskladitev konstruiranja in ne »hkratno inženirsko delo«. Podlaga za takšno razmišljanje je prepričanje, da vse aktivnosti ne morejo biti izvedene hkrati. Za napredek učinkovitega konstruiranja, bi moral biti proces razvoja izdelka tako integriran in strukturiran, da bi omogočal dosego najboljše kakovosti in produktivnosti. Vidiki hkratnega inženirskega dela bodo torej rezultat učinkovite usklajenosti konstruiranja.

— *Most significant means*

It is apparent that the most significant means to meeting the requirements are Decision Support (28 %) and Design Management (25 %), with Concurrent Engineering making a just below average contribution (19 %).

— *Most significant contributions*

Concurrent Engineering (51 %), Design Management (50 %), Decision Support (39 %) and Team Engineering (39 %) make their most significant contributions to reducing the product cycle time. Product Management, on the other hand, makes its most significant contribution to coping with rapid design change (32 %).

— *The best means for particular requirements*

Concurrent Engineering provides the best means (60 %) to ensure meeting the customer requirements.

Decision Support is the best means to cope with rapid design change (35 %) and achieving a better quality of product (30 %).

Design Management is the best means for being able to exploit new product technology (66 %), reducing non-recurring engineering costs (43 %) and shortening the product cycle time (29 %).

Team Engineering provides the greatest opportunity (30 %) to deal with increasingly complex products.

The above analysis and conclusions are not expected or indeed intended to be indicative of all manufacturing enterprises and the list of requirements, allocation of priorities, and values will vary depending upon the nature of the enterprise and the level of understanding and experience of the evaluators. Having said this, it is used here to highlight the need to evaluate the envisaged worth of potential tools/means. Thus, the point values are not absolute but may accentuate misguided effort or the best avenues to explore for enhancing competitive advantage.

## 6 CONCLUSION

This paper has attempted to give an insight and overview of the problems involved in enhancing the product development process in order to ensure competitive advantage. It argues that in order to make the product development process truly more productive then the emphasis should be placed upon effective Design Coordination and not »Concurrent Engineering«. The basis for this argument is the view that not all activities can be carried out concurrently, and that to promote efficient design, the product development process should be integrated and structured in such a fashion as to achieve optimum performance and productivity. Having said this, aspects of concurrent engineering will be a result of effective Design Coordination.

Ogrodje koordinacije konstrukcijskega procesa (KPK) je predstavljeno kot način podpore ključnih vidikov razvoja izdelka: hkratnega inženirskega dela, podpore odločitev, upravljanja procesa konstruiranja, upravljanje izdelka in skupinskega inženirskega dela. Vsak od teh vidikov je temeljito predstavljen z osvetlitvijo podpore, ki jo lahko ponudi ogrodje KPK.

Za zagotovitev večje konkurenčnosti je predlagano ovrednotenje orodij in metod, kakršna je usklajevanje procesa konstruiranja, glede na pogoje posameznega podjetja. Prikazan je primer takšne analize kakor tudi rezultati, in sicer:

— usklajevanje konstruiranja lahko največ prispeva k skrajšanju časa izdelave izdelka in zato tudi časa prihoda na tržišče; in

— podpora odločitev in upravljanje konstruiranja sta najboljši metodi za uspešno obvladovanje pogojev, ki bodo drug za drugim prispevali k skrajšanju časa prihoda na tržišče, izboljšanju kakovosti, zadovoljstvu naročnika in konkurenčnim cenam. Prispevek hkratnega inženirskega dela je pri tem le podpovprečen.

Tako lahko sklenemo, da je hkratno inženirsko delo sicer občudovanja vreden cilj, vendar pa sta koordinacija inženirskega dela in koordinacija konstruiranja tista, ki bosta temelj za produktiven in optimalen razvoj izdelka.

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*Zamisli, predstavljene v tem prispevku, so bile spodbujene v mnogih zanimivih in koristnih razpravah s člani podskupine CIMDEV za koordinacijo konstruiranja (prof. M. M. Andreasen, Technical University of Denmark, prof. J. Bowen, University College Cork, prof. K. J. MacCallum, University of Strathclyde ter prof. N. Reijers in dr. T. Storm, Delft University of Technology) in udeleženci iz industrije (M. L. Boerstra, Stork Demtec B. V., J. Bryden, Philips BCS UK, P. Carr, Digital Equipment Scotland Ltd., G.Y. Jacobsen, Bang & Olufsen A/S, D. Rimmer, Pilkington Optronics Ltd., A. Travers, Centre of Integrated Product Development Scottish Design Council in M. Vaag, Danfoss A/S). Odveč je govoriti, da zamisli posameznih udeležencev ne bi zaživele brez financiranja, CIMDEV Esprita. V članku izražena mišljenja so avtorjeva in niso predmet odgovornosti podskupine KPK. Avtor bi se želel še posebej zahvaliti prof. M. M. Andreasenu in D. Rimmerju za njun neposredni prispevek in trud pri izvedbi matrične analize ter za Rimmerjevo spodbudo za takšen postopek. Hvaležnost gre tudi dr. S. M. Duffyju in prof. Andreasenu za njun prispevek in bistvene pripombe.*

The Design Coordination (DC) Framework has been presented as the means to support key aspects of product development: Concurrent Engineering, Decision Support, Design Management, Product Management, and Team Engineering. Each of these aspects has been elaborated with a view the highlighting the support provided by the DC Framework.

To ensure competitive advantage, it has been suggested that tools/means such as Design Coordination should be evaluated against the requirements of the respective enterprise. An example of such an evaluation has been presented and a number of conclusions reached, namely:

— Design Coordination can make the greatest impact on reducing the product cycle time and hence the time tho market; and

— Decision Support and Design management are the best means to meet the identified requirements, which will in turn contribute to shorter time to market, improved quality and customer satisfaction, and competitive costs. Whereas Concurrent Engineering provides a just below average contribution.

It is concluded that, while Concurrent Engineering is an admirable goal, it is Coordinated Engineering, and Design Coordination within the context of engineering design, that will be the foundation for productive and optimal product development.

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## 7 LITERATURA
## 7 REFERENCES

[1] Institute of Mechanical Engineers. Design for Competetive Advantage - Making the Most of Design. International Conference on Design for Competitie Advantage, Coventry, UK, March 1994

[2] Manufacturing Breakthrough-Managing Product Development. Information For Success (IFS) Ltd Publishers, Bedford, UK. International Journal.

[3] Andreasen, M.M.-Duffy, A.H.B.-Hein, L.-Rimmer, D.: Design Coordination for Concurrent Product Development. March 1995. Research Proposal Submitted to the Industrial & Technologies Initative (IMT) of the Commision of the European Communities (CEC).

[4] Finger, S.-Dixon, J.R.: A Review of Research in Mechanical Engineering Design. Part 1: Descriptive, Prescriptive, and Computer Based Model Design Processes. Research in Engineering Design, 1:51-67, 1989.

[5] Duffy, S.M.: The Design Coordination Framework and the Design Complexity Map. In Paper Presented Integrated Production Systems (IPS) Research Seminar, Fuglsocentret, Fuglso, Denmark, April 1995.

[6] Olesen, J.: Concurrent Development in Manufacturing - Based on Dispositional Mechaniss. PhD Thesis, Institute for Engineering Design, Technical University of Denmark, 1992.

[7] Polito, J.-Jones, A.-Grant, H.: Enterprise Integration: A Tool's Perspective. In S.Y. Nof, editor, Information and Collaboration models of Integration, NATO ASI Series E: Applied Sciences, Vol. 259, pages 149-167. Kluwer Academic Publishers, Dordrecht, The Netherlands, 1994. Based on the NATO Advanced Research Workshop on Integration: Information and Collaboration Models, Italy, June 6-11, 1993.

[8] Douneingts, G.: GRAI: Methode de Conception des Systemes Productique. University of Bordeaux I, France.

[9] Kosanke, K.: The European Approach for an Open System Architecture for CIM (CIM-OSA)- ESPRIT Project 528 AMICE. Computing & Control Engineering Journal, pages 103-108, May 1991.

[10] Vasilash, G.S.: Simultaneous Engineering: Managament's New Competitiveness Tool. Production, 99 (7): 36-41, July 1987.

[11] Andreasen, M.M.-Kahler, S.-Lund, T.-Swift, K.: Design for Assembly. IPS Publications/Springer-Verlag, London, 1987.

[12] Tichem, M.-Design for Manufacturing and Assembly: A Closed Loop Approach. In International Conference on Engineering Design, ICED 93, August 1993.

[13] Design for Manufacture (DFM) Guide for Improving the Manufacturability of Industrial Products. Institute for Product Development, Building 423, DTU, Lyngby, DK., 1994,

[14] Miles, B.L. and Swift, K.G. Working together. Manufacturing Breakthrough, 1 (2), 1992.

[15] Andreasen, M.M., Hein, L.: Integrated Product Development. IFS Publications Ltd., Springer-Verlag, London, 1987.

[16] Sprague, R.A.-Singh, K.J.-Wood, R.T.: Concurrent Engineering in Product Development. IEEE Design and Test of Computers, 8(1):6-13, March 1991.

[17] Ashley, S.: DARPA Initiative in Concurrent Engineering. Mechanical Engineering, pages 54-57, April 92.

[18] Sriram, D.-Logcher, R.-Fukuda, S.: Proceedings of the MIT-JSME Workshop on Cooperative Product Development. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA, 1989.

[19] Sriram, D.-Logcher, R.: Computer-Aided Cooperative Product Development. Springer-Verlag, New York, USA, 1991.

[20] Klein, M.-Lu, S.C.Y.: Insights Into Cooperative Group Design: Experience with the LAN Design System. In G. Rzevski and R.A. Adey, editors, AIENG' 91, pages 143-162, UK, 1991. Proceedings of the Sixth International Conference on Applications of Artificial Intelligence in Engineering, University of Oxford, 1991.

[21] Sriram, D.-Logcher, R.D.-Groleau, N.-Chernoff J., Dice: An Object-oriented Programming Environment for Cooperative Engineering Design. In T. Christopher and D. Sriram, editors, Artificial Intelligence in Engineerign Design: Knowledge Acquisition, Commercial Systems, and Integrated Environments, volume 3, pages 303-366. Academic Press Inc., 1992.

[22] Visser, W.: Collective Design: A Cognitive Analysis of Cooperation in Practice. In Rozenburgh, Proceedings of ICED 93, volume 1, pages 385-392, Heurista, Switzerland, 1993.

[23] Anupam, V.-Bajaj, C.L. Shasra: Multimedia Collaborative Design Environment. IEEE Multimedia, pages 39-49, Summer 1994.

[24] McGuire, J.G.-Kuokka, D.R.-Weber, J.C.-Tenenbaum, J.M.: Technology for Knowledgebased Collaborative Engineering. Journal of Concurrent Engineering: Applications and Research (CERC), 1(3):137-146, 1993.

[25] Toye, G.-Cutkosky, M.R.-Leifen, L.J.-Tenenbaum, J.M.-Clicksman, J. Share: A Methodology and Environment for Collaborative Product Development. In Proceedings of the 2nd Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises, pages 22-47. IEEE Computer Press, 1993.

[26] Kusiak, A.-Park, K.: Concurrent Engineering: Decomposition and Scheduling of Design Activities. International Journal of Production Research, 28(10): 1883-1900, 1990.

[27] Eppinger, S.D.: Model-Based Approaches to Managing Concurrent Engineering. Journal of Engineering Design, 2(3), 1991.

[28] Kusiak, A.-Wang, J.: Decomposition of the Design of the Design Process. Journal of Mechanical Design, 115:687-695, December 1993.

[29] Kusiak, A.-Belhe, U.: Scheduling Design Activities. In S.Y. Nof, editor, Information and Collaboration Models of Integration, NATO ASI Series E: Applied Science, vol. 259, pages 43-60. Kluwer Academic Publishers, Dordrecht, The Netherlands, 1994. Based on the NATO Advanced Research Workshop on Integration: Information and Collaboration Models, Italy, June 6-11, 1993.

[30] Pourbabai, B.-Pecht, M.: Management of Design Activities in a Concurrent Engineering Environment. International Journal of Production Research, 32(4):821-832, 1994.

[31] Eppinger, S.D.-Whitney, D.E.-Smith, R.P.-Gebala, D.A.: A Model-Based Method for Organising Task in Product Design, 6(1):1-13, 1994.

[32] Cimdev Progress Report - Prototyping of CIM Models. http://www.newcastle.research.ec.org/espritbr/synopses/740.html, August, 1994.

[33] Duffy, A.H.B.-Andreasen, M.M.-MacCallum, K.J.-Reijers, L.N.: Design Coordination for Concurrent Engineering. Int. Jrnl of Engineering Design, 4(4):251-265, December 1993.

[34] Konda, S.-Monarch, I.-Sargent, P.-Subrahmanian, E.: Shared Memory in Design: A Unifying Theme for Research and Practice. Technical Report EDRC, 05-56-91, EDRC, Carnegie Mellon University, 1991.

[35] Nii, H.P.: Blackboard Systems: The Blackboard Model of Problem Solving and the Evolution of Blackboard Architectures. AI Magazine, 7(2&3), 1986.

[36] Klein, M.: Conflict Resolution in Cooperative Design Systems. IEEE Systems Man and Cybernetics, 21(6), December 1991.

[37] Bowen, J.-Bahler, D.: Supporting Cooperation Between Multiple Perspectives in a Constraint-Based Approach to Concurrent Engineering. Design and Manufacturing, 1:89-105, 1991.

[38] Bowen, J.-Bahler, D.: Frames, Quantification, Perspectives and Negotitation in Constraint Networks for Life-Cycle Engineering. Artificial Intelligence in Engineering, 7:199-226, 1992.

[39] Chakrabarti, A.-Bligh, T.P.-Holden, T.: Towards a Decision-Support Framework for the Embodiment Phase of Mechanical Design. Artificial Intelligence in Engineering, 7:21-36, 1992.

[40] Knapp, D.-Parker, A.: The ADAM Design Planning Engine. In IEEE Transactions on the Computer-Aided of Integrated Circuits and Systems, Volume 10(7), 1991.

[41] MacCallum, K.J.-Carter, I.M.: A Software Architecture for Design-Coordination. In J.S. Gero, editor, 1st Int. Conf. Artificial Intelligence in Design (AID'91), pages 859-883, Edinburgh, UK, June 1991. Butterworth-Heinmann.

[42] MacCallum, K.J.-Carterm I.M.: Opportunistic Software Architecture for Support of Design Coordination. Knowledge-Based Systems, 5(1):55-65, March 1992.

[43] Guo, W.-Cha, J.-Xue, Q.-Si, L.-Rao, M.: Integrated Intelligent Design Environment for Design Management and Cooperation. In D.L. Taylor and L.A. Stauffer, editors, Design Theory and Methodology, DE-Vol. 42, pages 157-166. Presented at The 1992 ASME Design Technical Conference - 4th International Conference on Design Theory and Methodology, Scottsdale, Arizona, Sept 13-16, 1992, ASME, 1992.

[44] Cha, J.-Guo, W.: The Methodology and Environment for Modelling and Implementation in Concurrent Engineering. In B.J. Gilmore, D.A. Hoeltzel, S. Azarm, H.A.Eschenauer, editors, DE-Vol. 65-1, Advances in Design Automation - Volume 1, pages 51-56. Presented at The 1993 ASME Design Technical Conference - 19th Design Automation Conference, Albuquerque, New Mexico, Sept. 19-22, 1993.

[45] Kannapan, S.M.-Bell, D.G.-Taylor, D.L.: Structuring Information and Coordinating Teams in Product Development. In T.K. Hight and L.A. Stauffer, editors, DE-Vol. 53, Design Theory and Methodology, pages 233-242, New York, NY, USA, 1993. The 1993 ASME Design Technical Conferences - 5th International Conference on Design Theory and Methodology, Sept 19-22, 1993, Albuquerque, New Mexico, The American Society of Mechanical Engineers.

[46] Klein, M.: Integrated Support for Cooperative Design Coordination: Managing Processes, Conflicts and Memories. In S.Y. Nof, editor, Information and Collaboration Models of Integration, NATO ASI Series E: Applied Sciences, Vol. 259, pages 435-459, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1994. Based on the NATO Advanced Research Workshop on Integration: Information and Collaboration Models, Italy, June, 6-11, 1993.

[47] Intelligent Manufacturing Systems - A Program for International Cooperation in Advanced Manufacturing. January 1994. Final Report of the International Steering Committee adopted at ISC6.

[48] Duffy, A.H.B.-Andreasen, M.M.-Bowen, J.-MacCallum, K.J.-Reijers, L.N.: Design Coordination Support. In Esprit Basic Research Working Group 7401 - CIMDEV/CIMMOD Workshop, pages 1-34, Bordeaux, France, May 1994.

[49] Andreasen, M.M.-Bowen, J.-MacCallum, K.J., Duffy, A.H.B.-Storm, T.: Design Coordination Framework. In Esprit Basic Research CIMMOD/CIMDEV Workshop, pages 1-21, Torino, Italy, September 1994.

[50] Andreasen, M.M.-Olesen, J.: The Concept of Dispositions. Engineering Design, 1(1), 1990.

[51] Duffy, A.H.B.-Andreasen, M.M.: Enhancing the Evolution of Design Science. International Conference on Engineering Design (ICED 95), Prague, August 1995.

[52] Duffy, A.H.B.-Kerr, S.M.: Customised Perspectives of Designes from Automated Group Rationalisations. Artificial Intelligence in Engineering, Special Issue in Machine Learning in Design, 8:183-200, 1993.

[53] Bodker, S.-Knudsen, J.L., Kyng, M.-Ehn, P.-Madsen.: Computer Support for Cooperative Design. In Proceedings of ACM CSCW 88 Conference on Computer-Supported Cooperative Work, pages 377-394, 1988.

[54] Fotta, M.E. and Daley, R.A.: Improving Interpersonal Communications in Multifunctional Teams. In H.R. Parsaei and W.G. Sullivan, editors, Concurrent Engineering: Contemporary Issues and Modern Design Tools, chapter 5, pages 75-92. Chapman and Hall, London, UK, 1993.

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