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APPLICATION OF ICDM FOR THE CONCEPTUAL DESIGN OF A NEW PRODUCT

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1. Introduction

ICDM is an Integrated, Customer Driven, Conceptual Design Method for the entire conceptual design process starting from the definition of a need, through creation of alternative solutions until the selection of the optimal concept. ICDM is demonstrated, in this paper, with a case study.
The objectives of this study are the following:

(1) To bridge the gap between the theory of ICDM and the industrial practice of a high-tech company.
(2) To evaluate the applicability of ICDM for an industrial product development of a system.

The goals of the study were:

- Demonstration of the application of ICDM in the conceptual design of an industrial, high-tech, system and methodological application of ICDM in a “real” industrial case study.
- Introduction of ICDM to industry.
- Action learning of ICDM for project teams in a graduate System Engineering course.
- Use of the Design Quality Measurement system (DQM) for evaluation of concepts and for evaluation of the value of ICDM for the product development team.
- Creation of a concept for a new product with a good chance of success in the market.

2. ICDM – Integrated, Customer Driven, Conceptual Design Method

A few conceptual design methods have been developed recently, each emphasizing a different aspect of the process, and each possessing certain qualities. The best known method was presented in [Pahl & Beitz, 1984], incorporating abstraction, functional analysis, creation of solution principles, combination of sub-functions to form alternative concepts for system design, evaluation and selection of the preferred concept. ICDM, the Integrated Conceptual Design Method, as presented in [Hari & Weiss, 1996], is more suitable for concurrent engineering environment and can prevent some of the risks imposed by team work and managerial constraints [Hari & al., 1996]. The 10 steps of ICDM are:

1. Identification of the customers and their needs.
2. Translation of the Voice of the Customer into the product definition and specification.
3. Abstraction and functional analysis, definition of the “basic problems”.
4. Creation of solution principles for the “basic problems”.
5. Selection of evaluation criteria.
6. Synthesis of primary concepts.
7. Evaluation of the primary concepts and selection of a few main concepts for further development.
8. Design, architecture, analysis and improvement of the main concepts.

9. Final concept selection.
10. Project launch.

ICDM is flexible, has an open architecture, and can be tailored to the unique needs of each case, to an organization's requirements or to personal preferences. The method considers the human aspects of the conceptual design and provides the means to improve motivation and creativity during the product development teamwork. ICDM includes the means for on-line Design Quality Measurement (DQM) and control during the design process. This paper describes a case study using ICDM methods in a New – Product Development process, prior to project launch and Full Scale Development (FSD).

3. The case study of LF 100 conceptual design

A multi disciplinary team of six senior engineers, with 15 – 20 years of experience each, was nominated to perform the case study. The team included engineers with knowledge and experience in Computer Engineering, Software Engineering, Electronic Engineering, Communication Engineering, Mechanical Engineering, Packaging, Assembly and Production Engineering. The team members participated in the graduate program for M.S. in System Engineering in the Technion, Haifa, Israel.
The team members were instructed to apply ICDM methodology step by step in their industrial location and environment. The quality of the design was measured at several points during the process using DQM- the Design Quality Measurement system of ICDM [Hari & al, 2001].
The case study describes the stages of the product definition and the conceptual design for a "Lost Kid Finding System - LF100". The problem behind the need was defined as: "Kids get lost or kidnapped in public areas, like playgrounds or shopping centers, without parents attention and it is difficult to notice that in real time". The task of the team was to define the customers needs and translate them into requirement specification, to create alternative concepts that satisfy the need, to evaluate the alternative concept and to select the optimal concept for further development.

Step 1: Identification of the customers and their needs.

In order to produce a system that the customer needs and is willing to buy, one must carefully identify the customer, the user and the whole spectrum of needs this system is intended to fulfil. In this step, we learn and analyze the customer requirements. A close connection with the customer and knowledge of his needs is essential. A team effort is best suited for this step, in which a multi-disciplinary view will expose all required information. The tools serving this activity are market researches, customer / user interviews, Customer Value Management (CVM) [Gale, 1994] and focus groups. The LF100 team gathered the customers' needs by interviewing field users. The main users are children up to 9 years old and the accompanying adults. Purchasing decision-makers are parents, location owners and kids equipment networks. A hierarchical tree of the customer needs is shown in Figure 1.

Step 2: Translation of the Voice of the Customer into the product definition and specification

Quality Function Deployment (QFD) translates the Voice of Customer into the system specification. Customers needs and benefits which emerged in step 1, are the input to this step. The QFD outputs are the target values for the system characteristics. QFD also position the new system relative to the competing ones, showing its strength and weaknesses. Customer Satisfaction Rating (CSR) functions expresses the metrics value of each target value fulfillment [Hari & al., 2001]. The QFD process of the LF100 produced the house of quality shown in Figure 2. In addition, the system initial specification was prepared, using the results of the house of quality. The initial specs, shown in the decision table in Table1 were derived directly from the customer preference, which was in turn derived from the house of quality. Finally, CSR functions, as demonstrated in Figure 3, formed, to quantify customer satisfaction of target values. CSR functions measure the compliance of the conceptual design to customer needs.

Step 3: Abstraction and functional analysis, definition of the basic problems

In this step, the tools of abstraction enable a deeper and more thorough understanding of the nature of the problem. The common tools are functional analysis, flow charts or block diagrams. In addition,

basic quantitative analyses, modeling and logical evaluations are performed during this step.
A "basic problems" list is produced. These problems are to be solved by the new system. The LF100 team performed the abstraction using the FAST (Functional Analysis System Technique) chart for the reference scenarios. The "basic problems" of LF100 produced by the team are:

1. How to detect the distance from a child to the gates?
2. How to find the direction to the child?
3. How to display the direction to the child?
4. How to check a communication signal from a child in panic?
5. How to transfer the signal from the child to his/her parent (What type of communication media?)
6. How to produce an alarm?

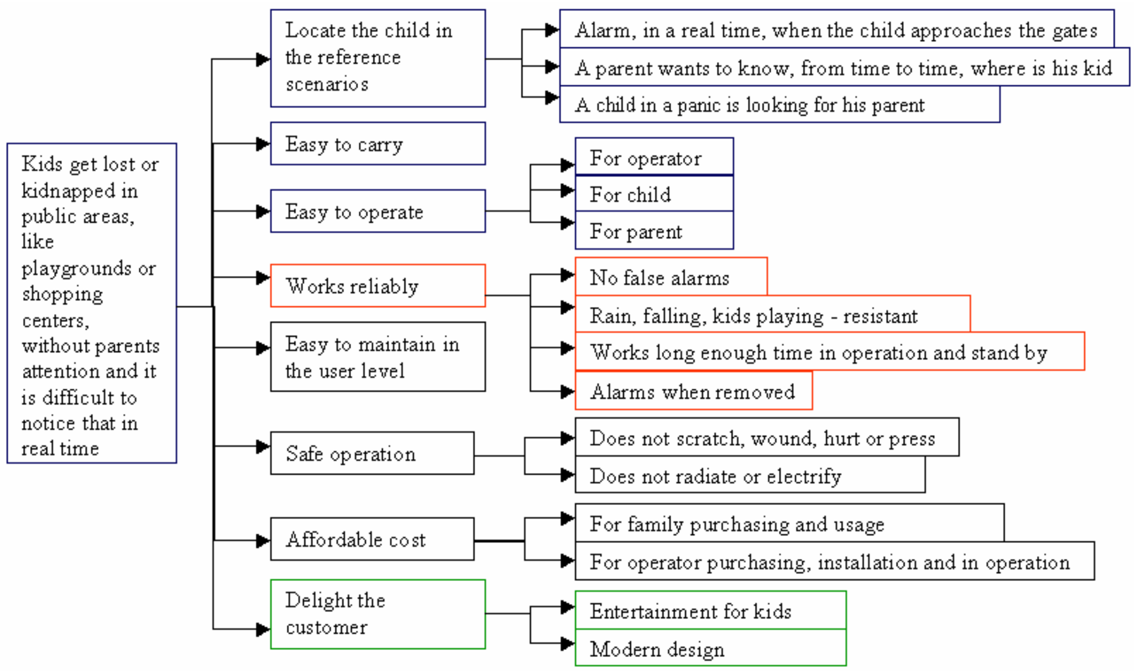

Figure 1. Hierarchical tree for the customer needs of LF100

LF100 House of Quality	Weight	Volume	Design Level	Continuous operation Time	Purchasing Price	Operation Costs	Mission Reliability	Radiation	Alarm Volume	Range	Importance
Alarm, in a real time, when the child approaches the gates	▲	▲		▲	○		●	○	●	●	5
The parent wants to know, from time to time, where is his kid	▲	▲	▲	▲	○	▲	○	○	○	●	4
A child in a panic is looking for his parent	▲	▲	▲	▲	○		●	○	●	●	5
Easy to carry	●	●	▲	○	▲			○	▲	▲	4
Easy to operate	○	○	●	○	▲	○			○	▲	3
Works reliably				●	○	○	●		▲	▲	5
Easy to maintain in the user level			●		▲		○				1
Safe operation			○		○		▲	●		○	4
Affordable cost				○	●	●	○				4
Delight the customer		▲	●	○	○	○	▲				2
Total Importance	59	61	79	98	119	70	169	90	120	150	1015
Relative Importance	6	6	8	10	12	7	17	9	12	15	100
RANK	10	9	7	5	4	8	1	6	3	2	

Figure 2. The House of Quality of LF100

Table 1. Specification Decision Table for LF100

#	Product Characteristics	W	Trade offs	Reference Products	Target Values	Implications		
		%	Charac.	Cell. phone		Diff.	Cost	Concept
A	Mission Reliability	17		50%/50%	**95%/95%**			No
B	Range	15	A	Very Large	**120 M**			Forces
C	Alarm Volume	12		20 dB	**60 dB**			No
D	Purchasing Price	12	A,B	100$	**110$**			No
E	Continuous Operation Time	10	D	48 hrs	**40hrs**			No
F	Radiation	9	A,B	0.25 W/cm^2	**0.2 W/cm^2**			Forces
G	Design Level	8	D,F	High (8)	**High (8)**			No
H	Operation Costs	7	D,E	100$/month	**50$/month**			No
I	Volume	6	E,G	70 cc	**50/150cc**			No
J	Weight	6	E,G,I	200g	**85/250g**			No

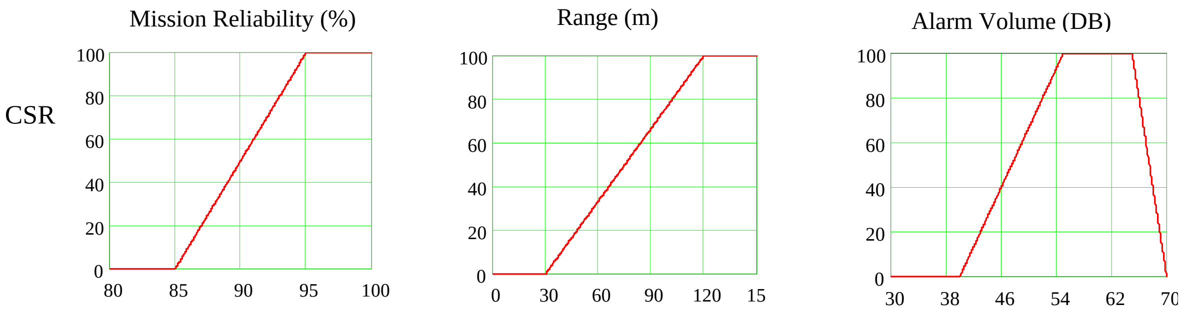

Figure 3. Sample of system CSR functions: Mission Reliability, Range, Alarm Volume

Step 4: Creation of principal solutions to the basic problems

In this step, the team uses creative tools to generate solution principles to each "basic problem". Brainstorming, TRIZ or design manuals are used to create verbal or visual solution. This step is summarized using a morphological table [Zwicky, 1976] that contains a row of solution principles to each basic problem. The solution principles for the LF100 basic problems are organized in the morphological table in figure 4.

Step 5: Selection of evaluation criteria

The main concepts are evaluated by criteria produced in this step. Evaluation criteria are most likely the important system characteristics and their target values, stated in the QFD step. Criteria are organized into two groups: Group A is used for the first evaluation phase (Step 7) and includes relatively few (but important) criteria that can be used without any further analysis. This criteria group must cover at least 70% of the customer satisfaction according to their rating. Group B includes more criteria and covers at least 95% of the customer satisfaction. These criteria are used for the final concept selection phase (Step 9). These criteria may require further analysis of the alternative concepts. Evaluation criteria for the LF100 were organized into the table in Figure 5.

Step 6: Synthesis of primary concepts

This step produces whole concepts out of single solutions. This step is performed using a morphological table. A concept is a combination of one solution principle from each row of the morphological table. Many solutions can be combined, but only a few actually form a feasible set. Among those, the one with the best potential must be selected. The synthesis of solutions for the LF100 system was made using the morphological table in Figure 4. Each row contains solution

principles for each basic problem stated in the right-hand column. On the lower-right corner of each cell is a pair of numbers, denoting lack of development risks and proportional performance of the respective solution principle.
The feasible solution concepts are the combination of particular principles from each row, marked with a line over the table. In this step, the team marked 13 feasible solution concepts. Since detailed descriptions of each concept is out of the scope of this paper, we will demonstrate only two primary concepts, VTCF and Two- way transmission on the morphological table in Figure 4.

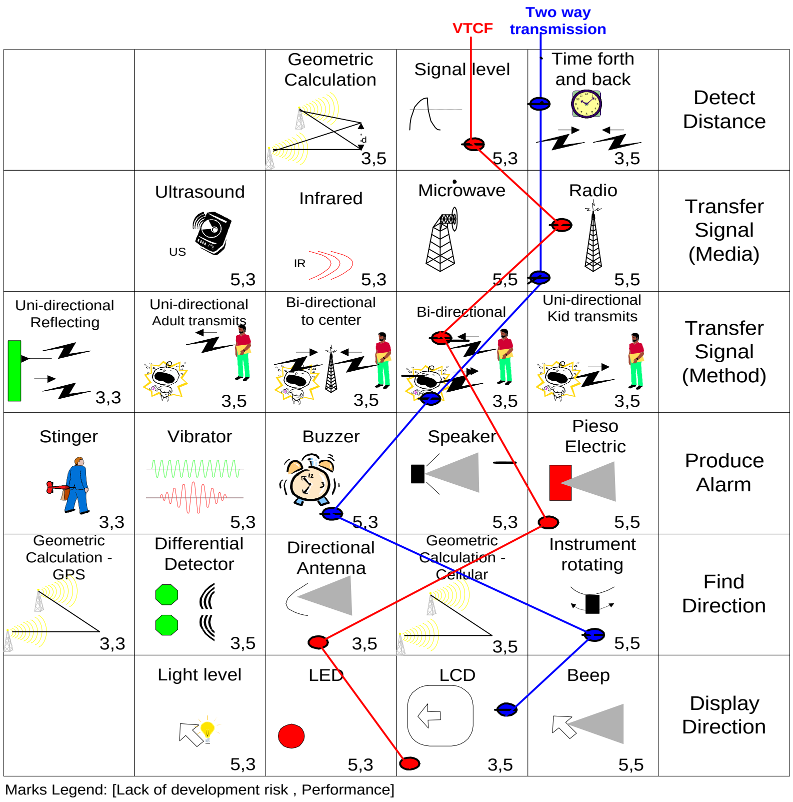

Figure 4. Morphologic table for LF100

No	Criterion	A	B	QFD Target Value
1	Technological knowledge gaps	+	+	
2	Mission Reliability	+	+	95%/95%
3	Range	+	+	120 M
4	Alarm Volume	+	+	60 dB
5	Purchasing Price	+	+	450$
6	Continuous Operation Time		+	40hrs
7	Radiation	+	+	0.2 W/cm^2
8	Design Level		+	High (8)
9	Operation Costs		+	50$/month
10	Volume		+	50/150cc
11	Weight		+	85/250g
12	Manufacturability		+	
13	Ease of installation and operation		+	
14	Originality and attractiveness to the customer		+	
15	Maintainability		+	

Figure 5. Evaluation criteria for the LF100

Step 7: Evaluation of the primary concepts and selection of main concepts

The selected concepts from step 6 are evaluated according to the criteria of group A (from step 5). A common tool for evaluation is the Pugh table [Pugh, 1981]. The evaluation process yields a few main concepts for further development. In addition, new improved concepts can be generated at this step by merging and synthesizing ideas from other concepts or by improving some disadvantages of the most promising concepts.

The LF100 team evaluated the primary concepts using Pugh method, as the datum, they choose the Bi-directional local concept. Out of the 13 primary concepts, 6 where selected as main concepts, for further development. One team member worked each concept separately in the next step, managing a sub-team or on his own. Figure 6 demonstrates a part of the LF100 evaluation table.

Criterion \ Concept	Bi-directional local	Unidirectional, Pure Passive kid System Radio Trans.	Unidirectional, Pure Passive kid System Cellular Trans.	Adult unit transmits, kid unit compares	Two-way transmission	VTCF	LACLS Local Area Cellular
Technological knowledge gap	**D**	S	-	S	S	S	-
Mission reliability	**A**	S	-	S	+	+	-
Range	**T**	-	-	S	+	+	+
Alarm Volume	**U**	S	S	S	S	S	S
Purchasing Price	**M**	+	S	+	+	+	S
Radiation		+	+	+	-	-	-
Σ+	0	2	1	2	3	3	1
Σ-	0	1	3	0	1	1	3
Total	**0**	**1**	**-2**	**2**	**2**	**2**	**-2**

Figure 6. Evaluation of the LF100 primary concepts using Pugh method

Step 8: Design, architecture, analysis and improvement of the main concepts.

In this step the team members further developed the main concepts for the final selection. The first draft system design is prepared, together with basic form and architecture. Conceptual decisions are made concerning production, materials, technologies, storage, handling, logistic support, etc. Examples of some conceptual design aspects of the proposed systems are shown in Figure 7.

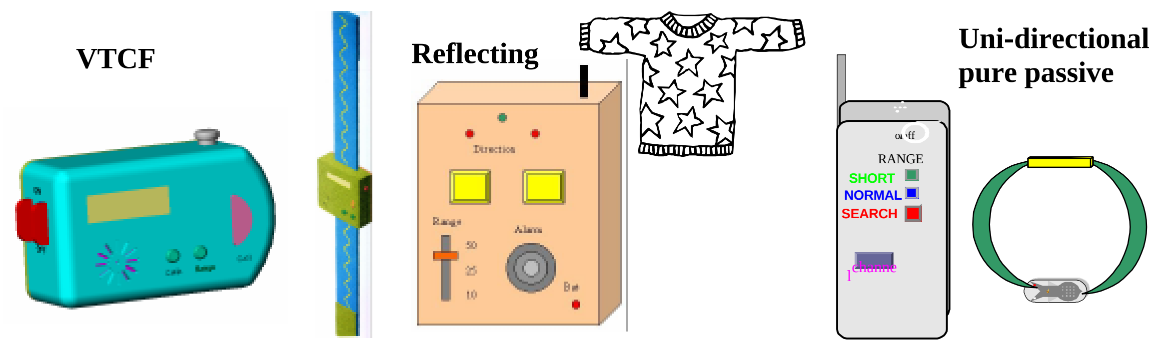

Figure 7. Examples of some conceptual design aspects of the proposed systems

In addition, some analyses are performed, upon consulting group B of the evaluation criteria (step 5). For each criterion, a quantitative or semi-quantitative evaluation is required. ICDM provides some generic analysis tools like **CFMA** - Conceptual Failures Modes Analysis, **CDTC** - Conceptual Design To Cost, **R&TTMA** – Risk and Time To Market Analysis.

CFMA is based on functions and specific organizational experience rather than on components and detailed design. The purpose of this tool is to prevent failures from reaching the customer. The analysis detects the earliest step in the design process when countermeasures can be taken to prevent the failure [Hari & Weiss, 1999]. Three parameters were defined: S (Severity), F (Frequency of occurrence) and D (Detection capability). For each function, some significant failure modes and their results were quantified. A partial table of CFMA for LF100 is shown in Figure 8, in this example the process yielded 10 design changes. The original score is shown in the SFD column. Entries with values higher than 100 were treated to reduce their effect. The "New SFD" column shows the new values of each failure mode. After applying the action listed in the "Correction action" column, the maximum SFD figure was reduced from 320 to 60, which means that the criticality of the concept was reduced by 81%.

Conceptual Failure Mode Analysis - CFMA				**System:** Lost Child Finder – LF100						**Organizer:** Technion
Team members: M.T, J. H ,A. B, R.K. A. Z, Y. M										
Function	**Failure mode**	**Failure Result**	**S**	**Failure causes**	**F**	**Ways to detect**	**D**	**SFD**	**Corrective action**	**New SFD**
Alert the escort	Low/No signal	Inconvenience	5	Obstacles	3	Simulations and experiments	3	45	None	
			5	Adult PCB circuits failure	1	Detailed design reliability analysis	3	15	None	
			5	Child PCB circuits failure	1	Detailed design reliability analysis	3	15	None	
			5	Mutual Coexisting Failure	3	Analysis and simulations	1	15	None	
			5	Mechanical Break – STRAP tearing	5	Prototype tests – strap mechanical stress.	5	125	Improve strap strength design. F→1	25
	Low/No alarm	Kid loosing	5	Low Battery	5	Design PDR	1	25	None	
			10	Buzzer alarm failure	1	Prototype components test	4	40	Change Circuit design. Include power on BIT to circuit S → 5	20
			10	Noisy place	5	Analysis after detailed design	1	50	Increase volume. S→1	5
	No removal alarm	Kid loosing	10	Shorted strap contact	1	Environmental tests on first prototypes	7	70	Change design to test on power-on. BIT S→5	35

Figure 8. CFMA table for "Alert the escort" function (partial)

CDTC - Conceptual Design To Cost **-** The tool is based on the principles of the Design to Cost (DTC) theory, on the Pareto principle and on organization experience, rather than on detailed product and process design. The tool helps the team to quickly evaluate the major costs of the alternative concepts and to reduce cost, when information is still very limited at this very early stage of the design process.

R&TTMA – Risk and Time To Market Analysis - is based on the “Knowledge Gap” principle [Bonen, 1964] and on the organization experience. It considers the product development as a process of closing the Knowledge Gap - The gap between the current state of the art in the company and the additional knowledge in areas like technology or marketing that has to be developed or acquired for the product development. The analysis identifies the main events of the development process and can forecast the number of design cycles. It also provides a prediction of the risks involved in each candidate concept.

Step 9: Final concept selection

Each team member presents the work performed in step 8. The concepts are evaluated according to criteria group B (step 5). The "winning" concept is selected together with a list of improvements and further design activities to follow. The concept is analyzed in accordance with Customer Satisfaction Rating (CSR). The CSR analysis for the final concept is shown in Figure 9. According to the target values, their relative weight, derived from the QFD process and listed in the decision table (Figure 2), the final customer satisfaction was compiled - using the respective CSR functions (Figure 3). The total Customer Satisfaction Rating according to the above was 89 %.

Step 10: Project launch

In this step the team prepares presentations for the System Design Review (SDR) and for the management to approve the project. This is a crucial step in the process. Additional system engineering and project planning activities are planned and documented.

No	Product Characteristics	W %	Target Values	Value Achieved	CSR %	W*CSR
A	Mission Reliability	17	95%/95%	95%/95%	100	17
B	Range	15	120M	120M	100	15
C	Alarm Volume	12	60dB	60dB	100	12
D	Purchasing Price	12	110$	97*2=195$	10	1.2
E	Continuous Operation Time	10	40h	40h	100	10
F	Radiation	9	0.2 W/cm^2	2*e-6	100	9
G	Design Level	8	High (8)	High (8)	100	8
H	Operation Cost	7	50 $/month	0.5 $/month	100	7
I	Volume (Adult/Kid)	6	150/50 cc	85/14 cc	100	6
J	Weight (Adult/Kid)	6	250/85 g	149/25 g	100	6
	Total	**100**				**89**

Figure 9. Customer Satisfaction Rating (CSR) analysis for the final concept

4. Results and Conclusions

The case study showed that ICDM can considerably help product development teams to create and agree upon an optimal concept for a new product that satisfies the needs of the customers. The Customer Satisfaction Rating (CSR) that was achieved was 89% with a significant improvement in the product reliability and cost and with a relatively low development risk. But above all the case study exposed system engineers from high tech industry to the methodology and demonstrated its applicability for development of high tech system products.

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